Sustainability assessment of the impact of the Marina Bay development on Singapore: application of the index of sustainable functionality

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Abstract: The index of sustainable functionality (ISF) was applied to assess the impact of the Marina Bay development project on the sustainability of Singapore. The development project has three aims: water supply, flood control and lifestyle attraction; construction for the various stages began in 2005, with scheduled completion end of 2009. The period of study was 2001–2007, before and during construction. The ISF increased from 2001 to 2004, then decreased slightly and stabilised from 2005 onwards, staying below the 2004 ISF value, showing that the development has not increased sustainability. A quick forecasting exercise, for the case that the three aims above were achieved and all other indicator values the same as those in 2007, increased the ISF value by 5.1%. Continued ISF construction would indicate if the functionality, and thus sustainability, of Singapore would increase after the Marina Bay development is completed and the benefits can be realised.

Keywords: ISF; index of sustainable functionality; sustainability; indicator; Marina Bay; Marina Barrage; Singapore; water management; water supply; resilience; environmental management.

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1 Introduction

1.1 Sustainability and indices, and the index of sustainable functionality

Many definitions and differing concepts of sustainability have been advanced, and they are not necessarily opposing ideas, but ways of understanding and applying the concept from different viewpoints. These have also evolved to include quantitative measures of sustainability, in the efforts to apply the concept: to translate the concept of sustainability into practical application in order to improve practices and increase sustainability. However, all these attempts have been somewhat limited because the definition of sustainability, underpinning all this work, rested on the qualitative definition first advanced by Brundtland (1987), in which sustainable development 'seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future'. As Imberger et al. (2007) discussed, the assessment of 'need' is problematic, as it is not a fact, but an interpretation.

Imberger et al. (2007) presented a formal systems definition of sustainability and used it to advance the methodology of the index of sustainable functionality (ISF), an adaptive, multi-criteria measurement of sustainability. They began with a quantitative concept of sustainability that brought together the idea of resilience and the functionality of underlying processes within the systems under consideration. They state that a system's level of functioning must be adequately high for it to be robust and resilient, and therefore has longevity and sustainability. In defining sustainability, Imberger et al. (2007, p.5) advanced the following definition of sustainability:

> "An action by one system on another system, within a particular domain or across adjacent domains, is adaptively weakly sustainable provided the rate of loss to the system's functions, brought about by the action, is slower than the rate at which the recipient system can mitigate for the loss of function as measured by particular indicators."

Unlike other sustainability concepts (Pope et al., 2004, etc.), the above definition does not purport or focus on the idea that sustainability is a state or a future point of reality, rather it is related to the present characteristics or level of functioning of the system(s) under considerations.

The ISF also takes into account the interaction and integration of all components of society within its definition of sustainability and, most importantly, separates the objective assessment of functionality, from the adaptive and changing priority or weightings of each function. It also goes further than the triple-bottom line approach by recognising that certain domains can be described by, and are better assessed through, unique systems, which may be more than social, environmental and economic systems. Indeed, the number of systems can be very large in order to gain process resolution, but then the data requirements increase correspondingly.

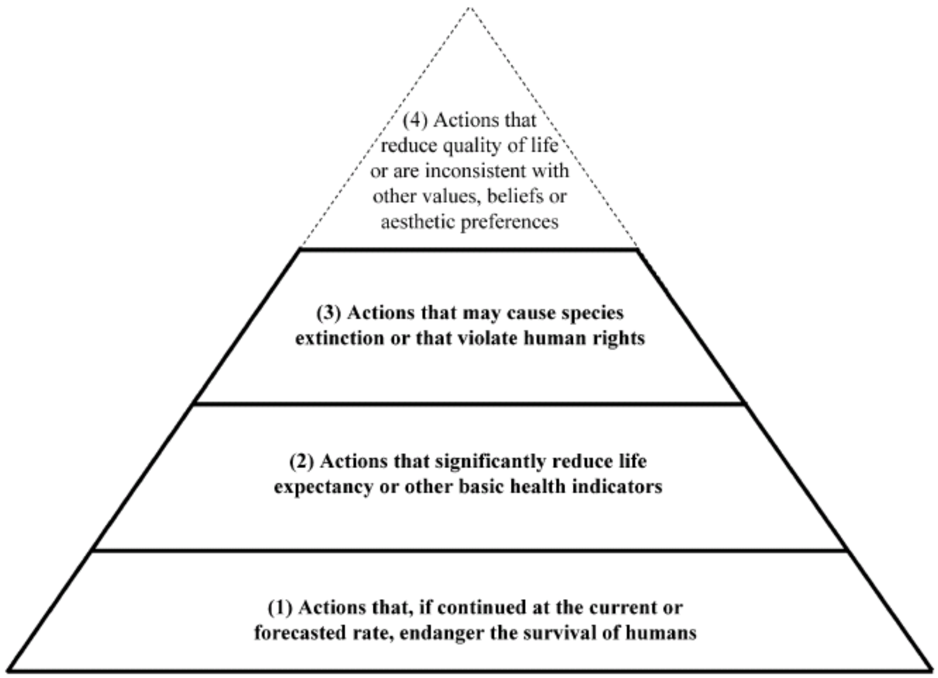
Since the ISF was first developed in 2005, there have not been many new methods of sustainability assessment or indices (Krajnc and Glavic, 2005; van Dijk and Mingshun, 2006; Wiek and Binder, 2005); however, there have been many articles which discussed the merits of existing approaches to sustainability assessments and the notion and concept of sustainability, itself (Gasparatos et al., 2008; Hacking and Guthrie, 2008; Hopwood et al., 2005; Kidd and Fischer, 2007; Schultz et al., 2008; Wallis et al., 2007, etc.).

Krajnc and Glavic (2005) developed the 'composite sustainable development index' (I_{CSD}), a model to assess sustainability performance of companies, and it is discussed here in context of its similarity to the ISF. As with the ISF, the index involves selection of indicators, normalisation, weighting and aggregation to a single value or index, I_{CSD}. The ISF, however, allows for more than the three 'groups' of economic, social and environmental indicators in I_{CSD}, to create an assessment unique/tailor-made to the particular domain being assessed. Weighting in I_{CSD} is determined through analytic hierarchy process (AHP), whereas the ISF uses a participatory method involving stakeholders, which has been established to be important in sustainability initiatives (Bebbington et al., 2007; Fraser et al., 2006; Gasparatos et al., 2008; Giampietro et al., 2006; Grosskurth and Rotmans, 2005; Hacking and Guthrie, 2008; Hedelin, 2007; Hjorth and Bagheri, 2006; Middlemiss, 2008; Wallis, 2006). Furthermore, the I_{CSD} produces an index value which is not referenced, meaningful only when compared to other values in a time series. In comparison, the ISF begins with the concept of what is sustainable or functional and the index value indicates how far from functional the domain is. The I_{CSD} is what Pope et al. (2004) refer to as showing 'direction to target', where, increasingly, assessment showing 'distance to target' is deemed a more useful tool.

Both the ISF and the I_{CSD} are categorised by Gasparatos et al. (2008) as 'composite indices' (CI) in their review of reductionist sustainability evaluation tools. They reviewed three types of tools: monetary tools (e.g. cost benefit analysis, contingent valuation method), biophysical models (e.g. energy, ecological footprints) and sustainability indicators and CI (e.g. human development index). Despite delivering some criticisms, CI were considered the most flexible and, depending on the specific method used, can fulfil the criteria of holism: integrated, predictive, precautionary, participatory and equity considerations (Gasparatos et al., 2008).

The United Nations (UN) also endorses the use of indicators and developed a guideline for the use of their suggested 'indicators of sustainable development' (ISD) (United Nations Department of Economic and Social Affairs, 2001, 2007). Within this framework is a list of selected indicators placed under themes and subthemes of sustainable development. Their latest work on thematic linkages shows that the UN is increasingly acknowledging and accounting for the multi-dimensional and integrated nature of sustainable development. Although the framework does not aggregate the indicators, they noted that aggregated indicators (such as the ISF, I_{CSD} and the ecological footprint) are valuable tools to achieve the goal of influencing decision-makers and communities towards more sustainable practices (United Nations Department of Economic and Social Affairs, 2007).

Figure 1 Sustainability hierarchy, with the most basic needs at the bottom



Source: Marshall and Toffel (2005).

In terms of the concept of sustainability, Marshall and Toffel (2005) attempted to bring together the many different existing concepts into their sustainability hierarchy (Figure 1). They argued that while level 4 issues are important, they should not be considered 'within the rubric of sustainability' (Marshall and Toffel, 2005). They are also an advocate for the concept (and quantification of) ecosystem functions as relating to sustainability, seeing an instructive parallel between perturbations to ecosystem function and toxic effects on human health. Marshall and Toffel (2005) called for more research to predict how potential ecosystem perturbations may affect short- and long-term ecosystem functionality. The ISF contributes to this research as it looks at how the (indicators of) functionality of all the systems within a domain (including the environmental system) changes through time as a result of perturbations and changes.

1.2 ISF past applications

Imberger et al. (2007) applied the ISF framework to the state of Western Australia. The ISF has also been applied in other (different) contexts and geographical domains, including at a regional level (Cirella, 2007), a local application to the City of Subiaco (Centre for Water Research, 2005) as well as a coastal city of Gold Coast (Cirella et al., 2007). These studies successfully applied the ISF framework, and by analysing the results of different components of the ISF matrix they were able to assess the management of the domain and make practical and specific recommendations to improve the sustainable functionality of the whole domain.

The ISF methodology was also investigated as a potential sustainability assessment for World Bank projects and used to assess one of its projects: Cartagena Water Supply, Sewerage and Environmental Management project (Brown and Imberger, 2006). It was concluded that the ISF has advantages and benefits over the currently-used methodology, benefits such as: it aggregates all indicators and visually represents the trend, it may be used over the entire project cycle, and it is not economically based, as project evaluation methods often are only concerned with economic indicators (Brown and Imberger, 2006). Most importantly, the ISF methodology clearly separates the objective measure of sustainability, the indicators for functionality, from the subjective value that is given by the function weightings; this makes the ISF an adaptive measure.

In the ISF application to the World Bank project, a focused matrix was used, which essentially assessed the project from different perspectives. This paper, using the case study of the Marina Bay development project in Singapore, investigates and assesses the sustainability of the domain, with its complete/comprehensive set of systems, over the entire cycle of a relatively large-scale development project. It explores how the introduction of completely new functions as a result of infrastructure development impacts the overall sustainability of the domain. This is the aim of the study: to assess the impact of the project on the sustainability of the domain.

To achieve these objectives, the paper begins with exploring Singapore and its current social and political climate as the context of the Marina Bay development, and then it describes the development itself; before the ISF methodology, results and discussion are presented.

1.3 Singapore: Marina Bay in context

The development of Marina Bay is a set against the backdrop of Singapore, the island nation. To better understand or construct the sustainability concept for Marina Bay, we must first explore Singapore and its cultures and norms with an emphasis on Singapore's identity and its place in the world and how these are shaped through its history.

Information can be found on Singapore's history before the British colonial rule, dating back to the trading empire of Srivijaya (from 7th century) and the first mention of 'Temasek' (the name before it was called Singapore) and the sultanate of Malacca. However, the form of the modern city is mainly derived from European, British in particular, colonial influence. This began in 1819 when Stamford Raffles landed on the island and established a British trading post. Due to Singapore's geostrategic location on the main Europe-Far East shipping route, the island port thrived, giving great maritime and commercial power to its British ruler (King, 2006; Perry et al., 1997; Regnier, 1991).

Besides its pivotal importance in the region, it is important to note the city planning policy. Raffles strived to separate the populations of Indian, Chinese and Malay origins (as well as European) into different parts of the island to minimise conflicts and avoid uprisings. This segregation later proved to be significant in shaping the present Singapore. Of these dominant races, Chinese residents increased steadily and accounted for more than 70% of the population at the turn of the 19th century (Perry et al., 1997).

In 1942, during World War II, the Japanese army drove the British army and most European residents out of Singapore, and thus began a three-year period of Japanese occupation. When the British reoccupied Singapore at the end of the war, "the myth of British superiority and invincibility which had long prevailed in the colonial era was undermined and Britain's right to re-impose colonial rule was called into question" (Perry et al., 1997, p.46). Consequently, self-government under the British Empire was eventually granted to Singapore.

At this point, the place of Singapore in the world is one of the aspiring island nations, small and relatively vulnerable amongst its much larger neighbouring 'nations.' Aware of this, Singapore's political leaders thus saw the future of Singapore was in a merger with its northern neighbour of Malaysia. The Federation of Malaysia, which included Singapore, and the current Malaysia and East Malaysia, became a reality in 1963. However, the small island's largely Chinese population became marginalised when the Federation introduced a major policy giving privileges to those of Malay origins. Racial tension increased and many riots broke out before Singapore finally left the Federation and declared independence as a republic in 1965.

With the background of riots and unrest, the government of the new Republic of Singapore put in place policies and legislations, which were able to quickly eliminate these, as the leaders set their sights on their nation's survival through economic growth. In the same vein, Perry et al. (1997) observed that the political style of Singapore's leadership was (and is) to cultivate a continual sense of crises and urgency amongst the population to unite and focus their attention on survival.

Singapore's colonial legacy provided a strong foundation and starting block for growth, through its impact in developing efficient systems of government administration, establishing trade networks and building industrial capacity and infrastructure (Perry et al., 1997). King (2006) summarised the four basic (economic) strategies Singapore adopted for its survival, which led to open-door policies for foreign capital: rapid industrialisation, export-based development, the state to operate strategic industries and establish enterprises that foreign capital or the private sector could or would not start, and the development of financial reserves and assets to weather adverse times. As a result, Singapore experienced rapid growth, low inflation and a healthy balance of payments in the 30 years following its independence (Bercuson, 1995).

Also a legacy is long-term agreements with Malaysia on water supply, which were signed in 1961 and 1962 (Lee, 2003; Ministry of Information Communication and the Arts, 2007; Tortajada, 2006a), since Singapore was a self-governing British colony. These agreements were confirmed and guaranteed in the 1965 Separation Agreement, a document that was lodged with the UN, to ensure its binding nature (Lee, 2003; Long, 2001). Under these agreements, Singapore can transfer water from the neighbouring Malaysia's state of Johor for a price of 0.7 cent per 1,000 gallons (~4,500 l) until the years 2011 and 2061, respectively (Kolesnikov, 2002; Tortajada, 2006b). Singapore buys and imports 350 million gallons (~1,600 ml) of raw water per day from Johor and resell 37 million gallons (~170 ml) of the treated water back to Johor (Kolesnikov, 2002; Said, 2002). The water that Singapore imports represents about 40% of its water supply/needs, and as a water-scarce city state, its water security has been largely dependent on Malaysia (Long, 2001; Nathan, 2002; Tortajada, 2006b).

Singapore and Malaysia have been negotiating the possible extension of the water agreements. However, they have not been able to agree on the terms of the new agreements. As a result of this continuing stalemate/deadlock in water negotiations, Singapore has developed new strategies to increase water security and self-sufficiency with concurrent emphasis on supply and demand management, wastewater management, institutional effectiveness, and public education and awareness (Lee, 2005; Nathan, 2002; Tortajada, 2006b). Within the supply management, Singapore has adopted the

Four National Taps Strategies, in which water is supplied from four ‘taps’: local catchment areas, imported water (Malaysia), reclaimed water (NEWater) and desalinated water (Public Utility Board (PUB), 2008a; The World Bank, 2006).

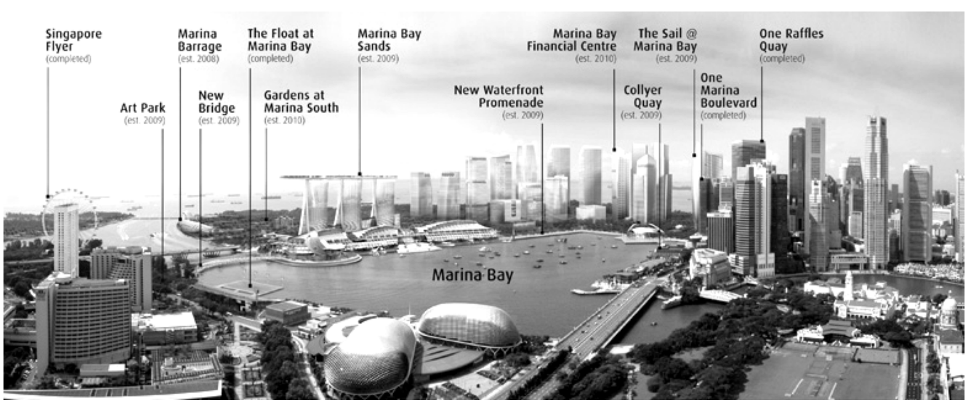
To maximise water yield from its local catchment, Singapore decided to utilise its largest catchment, the Marina catchment, as a water supply catchment. With the enlargement of catchment area, Singapore’s effective catchment area will be increased to approximately 50% with the inclusion of Marina Reservoir (and to about two-thirds with Punggol-Serangoon Reservoirs). The Marina Reservoir will increase water supply by about 10% of current water needs. To create this new reservoir, a 350m-wide barrage or tidal barrier was constructed across Marina Channel or Marina Bay, effectively damming the bay. Through natural flushing over time, the Marina Reservoir will turn into a body of freshwater (Public Utility Board (PUB), 2008a; The World Bank, 2006).

It is this Barrage and the developments surrounding it that is the subject of sustainability assessment in this paper.

1.4 Marina Bay, Singapore

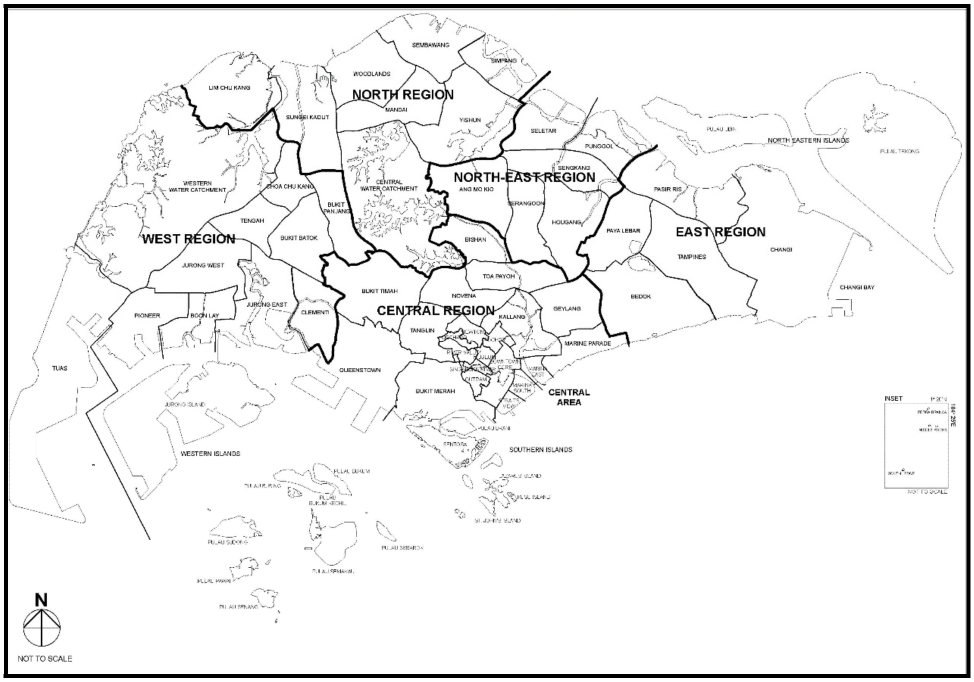
Marina Bay is a bay located in the southern part of Singapore, and it is within the central business district/area of Singapore (Figure 2). The water from Singapore River and Kalang Basin flows into this bay before reaching the sea. The Marina catchment covers a land area of approximately 10,000 ha or 100 km^2, almost 15% of the land area of Singapore (707 km^2) (Ministry of Trade and Industry, 2008; Public Utility Board (PUB), 2008b). It coincides with most of Singapore’s Central Region (which includes the Central Area – see Figure 3), one of the most densely populated and urbanised planning regions in Singapore (The World Bank, 2006; Urban Redevelopment Authority (URA), 2008a). Calculations based on the 2000 census of population revealed that more than 20% of the Singapore population lived in this catchment area; in 2008, this translates to a population of almost 1 million people (Leow, 2001; Ministry of Trade and Industry, 2008).

Figure 2 Marina Bay, Singapore



Source: Urban Redevelopment Authority (URA) (2008b).

Figure 3 Map of Singapore's planning areas



Source: URA (2008a).

Within this catchment are the prime office districts of the Central Business District (CBD), Marina Centre and Marina Bay, as well as the main shopping corridor along Orchard Road. Four major hospitals are among the healthcare facilities in Marina catchment. Most of the hotels and accommodation for visitors and tourists are also in this area, along with most tourism draw cards, such as the Singapore Botanic Garden, Mt Faber Park, and the heritage areas of Little India, Chinatown, Kampong Glam and Civic Districts. Thus, the Marina catchment is a highly urbanised area, central to Singapore as a city-state (Urban Redevelopment Authority (URA), 2008a).

In recent years, the Marina Bay area has been the site around which the Marina Bay developments took place, with the large development claimed to be 'Singapore's most exciting and ambitious urban project' (Public Utility Board (PUB), 2005). The Marina Bay development will see the construction of large-scale projects, including Gardens by the Bay and Marina Promenade, as well as the Marina Bay Sands, an Integrated Resort offering world-class hotel, convention, leisure and entertainment facilities and a casino (Public Utility Board (PUB), 2008b). It is a 360 ha (3.6 km^2) development in Singapore's downtown district, "designed to seamlessly extend (the district) and further support the city-state's continuing growth as a major business and financial hub in Asia" (Public Utility Board (PUB), 2008b). The major development is expected to, among other things, bring tourists and revenue to Singapore, as well as create more employment opportunities for Singapore residents.

Central to this development is the construction of the Marina Barrage, across the Marina Channel that will transform the Marina Bay into a reservoir and a source of water supply for Singapore. The Barrage will also function as a flood control measure, through stable or constant water level. This will be achieved through the use of the crest gates, which release excess storm water (low tide), and through the use of giant pumps, capable of pumping 2.5 ml min^{-1}, to drain excess water into the sea (high tide). This new flood control measure was instrumental in securing Singapore the Formula 1 (F1) Night Race, as well as enabling the development of the new Financial Centre along the Marina Reservoir. The stable water level will also mean that a variety of recreational activities can (then) be carried out in the reservoir. The Kallang Sports Complex development, focusing on water sports, greatly benefited from this stable water level, and it was a significant factor in bringing the 2012 Youth Olympics to Singapore. Thus, the developments surrounding the Marina Bay or reservoir also support the last function or purpose of the Marina Bay development, namely, lifestyle attraction. Although the area of development is less than 4% of the whole Marina catchment (for the future reservoir), it is expected to have (and already has) a considerable impact on the whole catchment, as well as on Singapore as a whole.

The construction of the Marina Barrage commenced in early 2005, and it was completed in 2008 (Public Utility Board (PUB), 2008b). Of the Marina Barrage, it is claimed to be "a showcase of environmentally sustainable development" (Public Utility Board (PUB), 2005). To ascertain the impact of the Marina Bay development, as well as the (long term) sustainability of the associated catchment and Singapore, a method of measurement or indication, as well as regular monitoring, is needed. The ISF offers a quantitative and robust index of sustainability, with opportunities to dissect and identify areas of unsustainable practices/processes.

2 ISF methodology

The methods for the calculation and formulation of the ISF here adhered largely to what is defined in Imberger et al. (2007). Figure 4 shows the steps for calculating the ISF.

The aggregate ISF is defined as follows:

$$\mathrm{ISF} = \sum_{j=1}^{J^i} \sum_{k=1}^{K^i} \left[\frac{W_{jk}^i}{L_{jk}^i} \left\{ \sum_{l=1}^{L_{jk}^i} \frac{1}{M_{jkl}^i} \sum_{m=1}^{M_{jkl}^i} \left(I_{jklm}^i \right) \right\} \right] \tag{1}$$

where i = subdomain 1, 2, 3, …

j = perspective 1, 2, 3, …

k = system 1, 2, 3, …

l = function 1, 2, 3, …

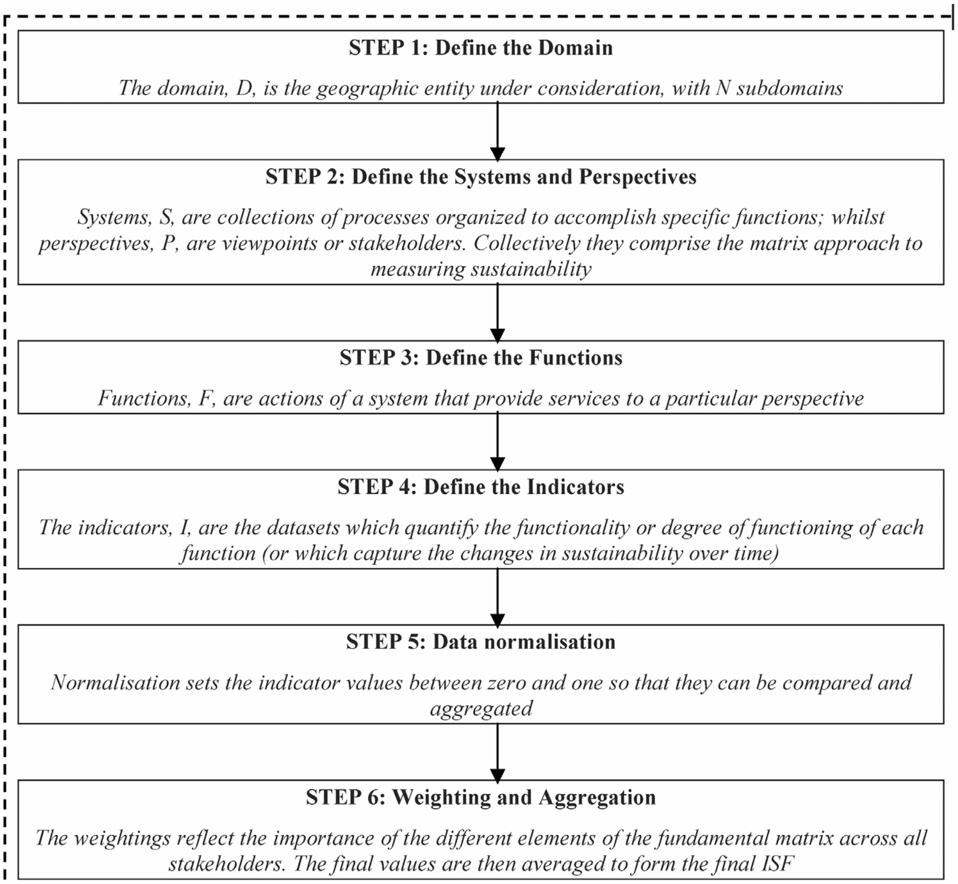
L = number of functions in the matrix element (j, k)

I = indicator 1, 2, 3, …

M = normalised indicator 1, 2, 3, …

W = weightings (Imberger et al., 2007).

Figure 4 The methodology for calculating the ISF



Source: Imberger et al. (2007) and Brown and Imberger (2006).

3 Marina Bay ISF

3.1 Domain

As the Marina Bay development is a large-scale development and has been promoted as a national-scale infrastructure development, we define the domain in this study as Singapore. There are no subdomains included in this study.

Singapore is a small nation in the Southeast Asian region comprising of one main island (617 km^2) and some 63 offshore islands, the larger ones being Pulau Tekong, Pulau Ubin and Sentosa. It is an intensely urbanised city-state, and the economy depends heavily on exports, particularly in electronic and information technology products, as well as petroleum refining, chemicals and pharmaceutical products (National Environment Agency, 2005; Singapore Department of Statistics, 2008). Singapore is the 5th wealthiest nation in terms of GDP per capita (International Monetary Fund, 2008).

Singapore is also the second-most densely populated country in the world, with a population of almost 4.6 million people occupying a total land area of 707 km^2 in 2007 (Singapore Department of Statistics, 2008). The population of Singapore has steadily increased, with the latest annual population growth rate being 4.3%. In response to the small size of the country, Singapore government has on-going land reclamation projects to increase its land area. As a result, Singapore's land area has increased by more than 20% since the 1960s, with plans to further continue the projects.

Singapore has an equatorial, tropical climate, characterised by uniform temperature and pressure, high humidity and abundant rainfall that falls throughout the year. Its total rainfall in 2007 was 2,886 mm, well above the global annual average of 1,050 mm (Lee, 2005; Singapore Department of Statistics, 2008). Thus, Singapore is not short of rainfall; however, capturing and storing the rainfall is problematic due to its limited land area.

3.2 Systems

Within the defined geographic area, there are a number of systems, which are collections of processes organised to accomplish specific functions. The systems identified within Singapore were:

- The environmental system (Env): includes waterways and gardens, both terrestrial and aquatic.
- The social system (Soc): includes the community, both residents and tourists.
- The economic system (Eco): all the economic activities in Singapore.
- The system of administration (Adm): a collection of processes and the system of administration within organisations, such as the Public Utility Board (PUB) and other government organisations.
- The built system (Bui): includes buildings and hard infrastructure, such as transport, water, energy and telecommunication services that are the supporting system of the area. The built system both accommodates and facilitates the transfer of people, goods, utilities and information within its boundary. This also includes the Marina Barrage as well as pumps, treatment plants and pipes.

3.3 Perspectives

The functions of the above systems will differ from different perspectives and/or stakeholders. The perspectives included in this case were:

- Environmental (Env): considerations for the conservation and perpetuation of natural ecosystems and biodiversity.
- Social (Soc): community perspective.

- Economic (Eco): considers economic growth and wealth creation for the nation.
- Public Utility Board (PUB): perspective of the water utility as custodian of the Marina Barrage, which is the initial or central development in the Marina Bay development project. PUB has tasks and targets set by the government and for its revenue generating operations.

A government agency, the PUB, was included as a stakeholder. The PUB is Singapore's water agency. The PUB was included to represent the main administrative body in developing the Marina Barrage project and the supply of water from the new Marina Reservoir. Although another government agency, the Urban Redevelopment Authority (URA) play a significant role as the key government administrator in the development of the Marina Bay area as a whole, and strive for the prosperity (and popularity) of the area, it was not included as a perspective or stakeholder, as many of its interests duplicate that of the economic perspective.

3.4 Functions and indicators

The functions of the five defined systems above, indicators to quantify their degree of functioning and their normalisation boundaries, were determined from a literature review. The three phases of selection were followed (Imberger et al., 2007): conceptual relevance was examined; then feasibility of implementation and response variability of the indicators were considered; finally, interpretation and utility to ensure the indicators could be normalised between zero and one.

Functions of each system from different perspectives and normalisation method for each indicator can be found in Appendix A and B, respectively, and summaries of the indicator trends between 2000 and 2007 are shown in Table 1. Most of the indicators were obtained from the Singapore Department of Statistics (SDS).

Refer to Appendix B for further explanation.

3.5 Weightings

No survey was conducted, so the weighting of each function was assumed equal.

3.6 Results

The ISF was then calculated according to Equation (1) and the results are shown in Figures 2 and 3, separated at system and perspective levels, respectively. Figure 4 shows the comparison of ISF with GDP and population growth in Singapore.

This study focused on ISF construction from 2001 to 2007 to closely observe the sustainability of the domain around the time period of the project (Marina Barrage construction began in 2005).

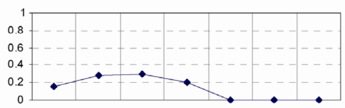
Table 1 Indicators in the ISF matrix and normalised values in 2001–2007 (*x*-axes) (see online version for colours)

ENVIRONMENTAL SYSTEM

Env/Env (System/Perspective)

F: Provide diversity which reinforces nature (synergy)

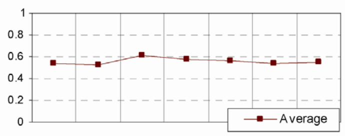
1. Opportunity for or level of natural synergy (1-expenditure on maintenance per ha per 1,000 people/5)



F: Conducive to physical health & recreation

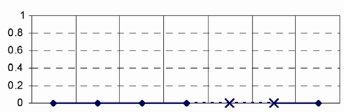
Env/Soc

2. Air quality based on levels of atmospheric SO_2, NO_2, PM10, CO, and O_3 (1-amount in the atmosphere/threshold)



Env/Soc

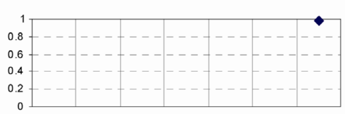
3 Recreational water quality based on pathogen concentration in reservoir (1-(concentrations-40)/460))



F: Conducive to physical health and recreational use; Support water supply operation; Reduce chlorophyll a concentrations

Env/Soc; Env/PUB; Bui/Env

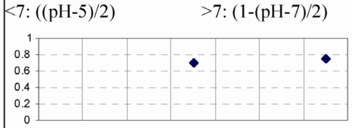
4. Recreational water quality based on algae and cyanobacteria (1-(chlorophyll a concentrations-10)/40)



F: Conducive to physical health & recreation

Env/Soc

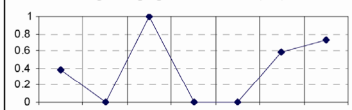
5. pH and buffering capacity
<7: ((pH-5)/2) >7: (1-(pH-7)/2)



F: Mental wellbeing

Env/Soc

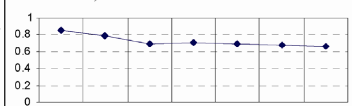
6. Mental wellbeing based on admissions to mental institutions (1-(change in admission versus change in population-0.25)/2)



F: Enhance tourism; Enhance tourism

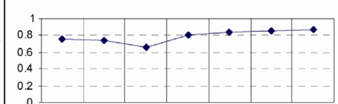
Env/Eco; Bui/Eco

7. Annual income from accommodation (Percentage of income from accommodation of GDP/2.5)



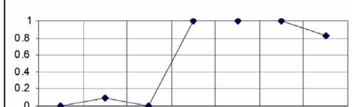
Env/Eco; Bui/Eco

8. Occupancy rate of accommodation



Env/Eco; Bui/Eco

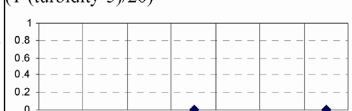
9. Annual visitor arrivals (Growth rate/0.065)



F: Support water supply operation; Increase sedimentation

Env/PUB; Bui/Env

10. Sedimentation ability of the reservoir (1-(turbidity-5)/20)



SOCIAL SYSTEM

F: Minimise pollutants

Soc/Env

11. Household waste
1- (Household waste per capita per year/500)

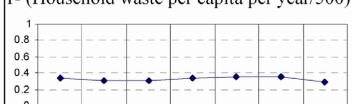
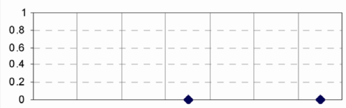
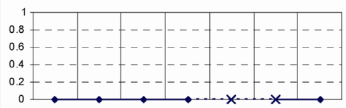
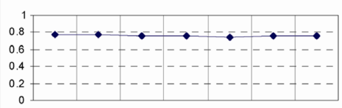
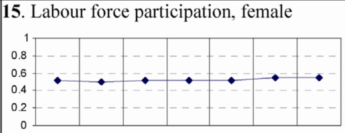
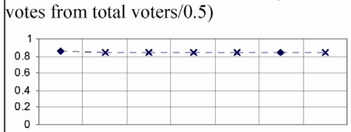
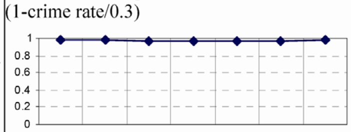
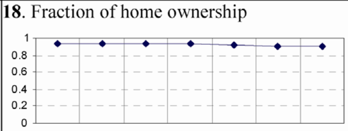


Table 1 Indicators in the ISF matrix and normalised values in 2001–2007 (*x*-axes) (see online version for colours) (continued)

Soc/Env	**12**. Minimising sediment load to reservoir (1-(turbidity-5)/20) 
Soc/Env	**13**. Water quality based on pathogen load to reservoir (in catchment) (1-(concentrations-40)/460)) 
	F: Social cohesion
Soc/Soc	**14**. Labour force participation, male 
Soc/Soc	**15**. Labour force participation, female 
	F: Positive social capital
Soc/Soc	**16**. Fraction of voting population who does not distrust the government (1-fraction of absent voters and illegitimate votes from total voters/0.5) 
	F: Compliance with laws; Stable environment for economic growth
Soc/Soc; Soc/Eco	**17**. Level of compliance with the laws (1-crime rate/0.3) 
	F: Stable environment for economic growth
Soc/Eco	**18**. Fraction of home ownership 

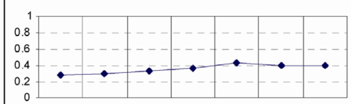
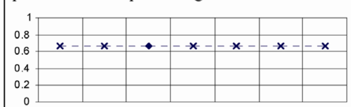
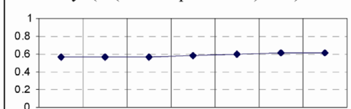
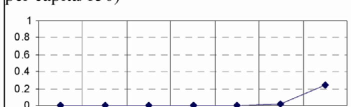
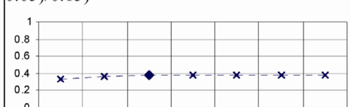
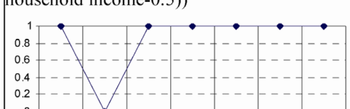
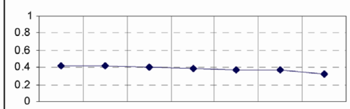
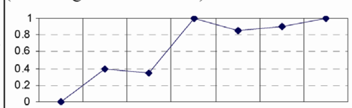
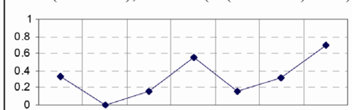
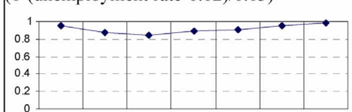
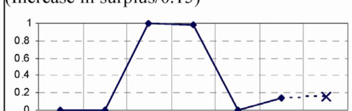
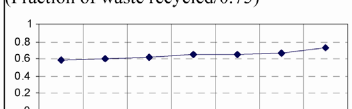
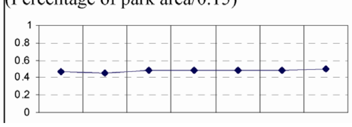
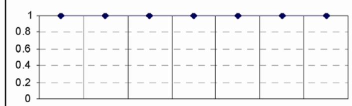
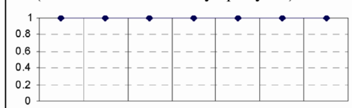
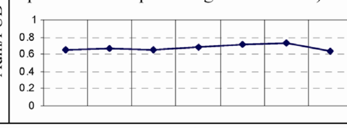
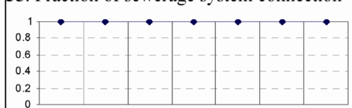
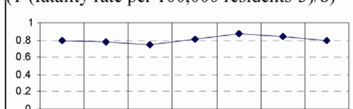
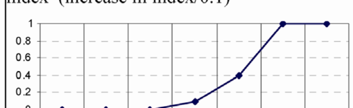
	F: Skills to society
Soc/Eco	**19**. Labour force qualification (1-(fraction of work force with non-school qualification-20)/70) 
	F: Capacity for consumption
Soc/Eco	**20**. Fraction of average household income spent in consumption of goods and services 
	F: Support PUB operations
Soc/PUB	**21**. Improvement in domestic water use efficiency (1-(consumption-100)/150) 
	ECONOMIC SYSTEM
	F: Management of industries' and businesses' environmental impacts
Eco/Env	**22**. Minimising waste from commercial sources (1-waste from non-domestic sources per capita/150) 
	F: Essential services
Eco/Soc	**23**. Food spending compared to household income (1-(fraction of income spent on food-0.05)/0.15) 
Eco/Soc	**24**. Change in housing cost compared to change in household income (1-(percentage change in housing price index versus percentage change in average household income-0.5)) 

Table 1 Indicators in the ISF matrix and normalised values in 2001–2007 (*x*-axes) (see online version for colours) (continued)

	F: Opportunities for human development
Eco/Soc	**25**. Income equity (1-(Gini coefficient-0.25)/0.35) 
	F: Stability and economic growth; Fair regulations conducive to profit generation
Eco/Eco; Adm/Eco	**26**. Growth rate of GDP per capita (Annual growth rate/0.05) 
	F: Stability and economic growth
Eco/Eco	**27**. Average annual rate of change of CPI ≤3%: (rate/0.03); >3%: (1-(rate-0.03)/0.07) 
Eco/Eco	**28**. Unemployment rate (1-(unemployment rate-0.02)/0.13) 
	F: Economic growth conducive to profit generation
Eco/PUB	**29**. Increase in PUB's surplus after tax (Increase in surplus/0.15) 
	SYSTEM OF ADMINISTRATION
	F: Minimise environmental impacts through legislation and public awareness
Adm/Env	**30**. Recycling rate (Fraction of waste recycled/0.75) 
	F: Promote nature tours
Soc/Env	**31**. Land set aside as gardens or parks (Percentage of park area/0.15) 
	F: Fair and working system
Adm/Soc	**32**. Affordability of water (1-(fraction of income spent on water-0.025)/0.05) 
	F: Security of supply and fair allocation of resource
Adm/Soc	**33**. (1-water restriction days per year) 
	F: Working system for efficient operation
Adm/PUB	**34**. Risk in the face of climate change ((R&D expenditure as a percentage of GDP-0.5)/2.5) 
	BUILT SYSTEM
	F: Allow for ecosystem health
Bui/Env	**35**. Fraction of sewerage system connection 
	F: Provide serviced land for societal activities
Bui/Soc	**36**. Minimising traffic accidents per year (1-(fatality rate per 100,000 residents-3)/8) 
	F: Provide a network of tangible assets
Bui/Eco	**37**. Increase in private residential property index (increase in index/0.1) 
Bui/Eco	**38**. Increase in rental index (increase in index/0.1) 

Note: All graphs show the data from 2001 to 2007. Dashed/broken lines correspond to interpolation in the datasets.

4 Discussion

4.1 Sustainability of Singapore

4.1.1 The aggregate index

As shown in Figures 5–7, the ISF increased from 2001 to 2004, albeit slightly, from a value of 48–64. Then, it decreased (and stabilised) from 2005 onwards, and stayed low below the 2004 ISF value. In contrast, the GDP per capita shows a stable increasing trend during this period (Figure 7). This indicates that the increased flux in money did not translate to improved functioning or functionality of the processes within the domain for a sustainable future. Furthermore, the large-scale development of the Marina Bay area, including the construction of Marina Barrage, which created (or will create) more services to the community, has not increased the sustainability of the domain. It appears that since the construction began the ISF has declined; this decline could potentially be attributed to the development. This is explored further in the next section, investigating the reason for the decline in the ISF by looking at indicators for each system and perspective in more details, as well as correlating these trends with various events occurring in Singapore during the period of study.

Figure 5 ISF and systems functionality

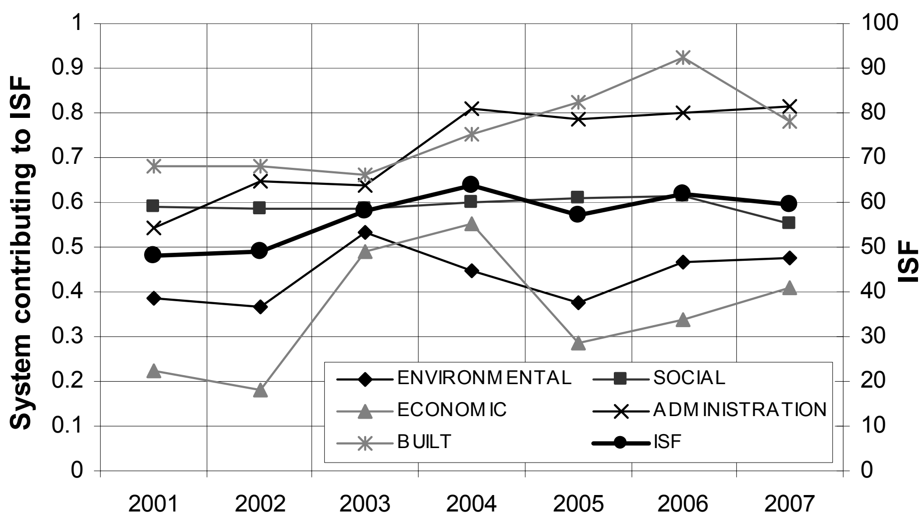


Figure 6 ISF and perspectives functionality

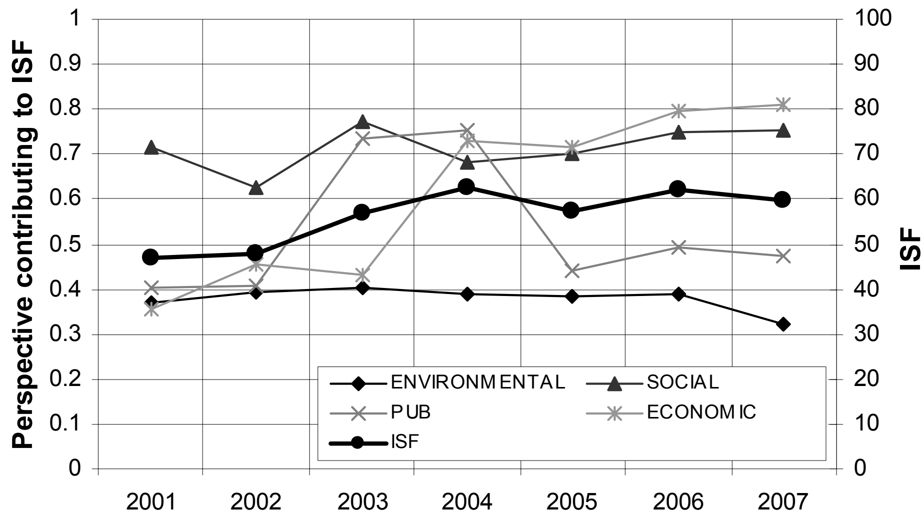
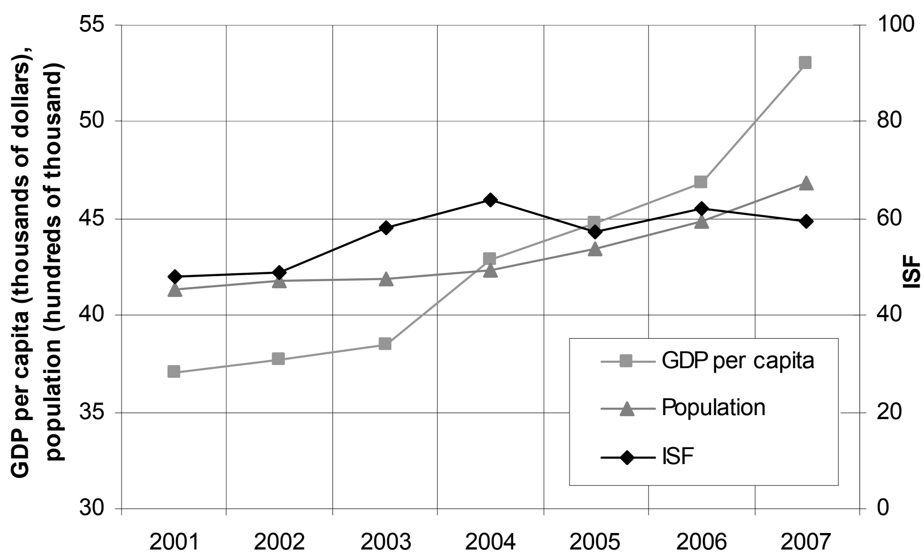


Figure 7 Singapore ISF, GDP and population growth



4.1.2 Events in Singapore

It is important to have a synopsis of the major events and trends in Singapore during the study period to inform the analyses of the ISF results: we can see these events being reflected in the ISF trends. Significant occurrences observed were the severe acute respiratory syndrome (SARS) epidemic, the recession and the two general elections. Below is an overview of each of these.

4.1.2.1 Severe acute respiratory syndrome: in terms of extraordinary events in Singapore during the period of study, the most significant of these was the outbreak of SARS, detected in Singapore in March 2003 (Gopalakrishna et al., 2004). The discovery and spread of this infectious disease created a reduction in tourism not only in Singapore, but also in other parts of Asia in 2003 (Henderson, 2004). Visitors arrivals into Singapore decreased by 1.4 million (19%) from the previous year (Singapore Department of Statistics, 2007). The government was forced to act quickly and drastic measures were, at times, taken to halt the spread, such as imprisonment for breaking Home Quarantine Orders (BBC News, 2003; Chua, 2004).

4.1.2.2 Recession: in 2001, Singapore experienced its worst recession since Independence in 1965, and this did not end until 2003 (Huxley, 2002; McRae, 2001; SPRING Singapore, 2002; etc.). The two key factors determining the trend/fate of Singapore's economy were the US economy and global electronics demand, thus the slowdown in the former and the sharp downswing in the latter in 2001 caused this recession (Abeysinghe and Choy, 2001; SPRING Singapore, 2002).

4.1.2.3 General elections: the 9th Singapore's general election (GE) was, by law, required by August 2002. However, the September 11 attacks in the US persuaded the Prime Minister to bring forward the election date such that the nation could focus on bigger issues in the economic and security sectors without distraction (Huxley, 2002). The ruling People's Action Party (PAP), which has governed Singapore since its independence, was confident of its win. However, the scale of PAP's landslide victory far exceeded its own expectations, securing 75.3% of the valid votes (Huxley, 2002; Singapore Elections, 2008a). This shows that PAP still had the confidence of the people of Singapore despite the deepening recession, proving effective its efforts in increasing social cohesion, including cutting the pay of government ministers, members of parliament, senior civil servants and judges by 17–20% (Huxley, 2002).

Another GE was held within the study period on 6 May 2006. At the time of the election, Singapore's economy was growing at around 7% per annum, hence maintaining this economic success was a significant incentive for the nation to vote for the ruling PAP (Chin, 2007). Although the number of contested seats increased from 29 in 2001 to 47 in 2006, requiring PAP to win only six of these contested seats to be the next government, the results confirmed the *status quo*, with PAP winning 82 out of 84 seats as per the previous election (Singapore Elections, 2008b). Their share of the valid votes was 66.6% (Chin, 2007; Singapore Elections, 2008b).

4.1.3 Systems and perspectives level of analysis

One of the major advantages of the ISF framework is the ability for it to be dissected into the smallest element. In Figures 5 and 6, the ISF of the perspectives and systems which contributed to the overall, aggregated ISF are shown, respectively. In the study of Singapore, the built system (Figure 5) showed values which are continually higher than other systems throughout the chosen time period (except for the year 2004 where the system administration has a higher value); it also shows an increasing trend. The system of administration and the economic and environmental systems also showed an overall increasing trend, although the system of administration appeared to be stabilising after 2004 (Figure 5). Both the social and the built environment decreased in performance in 2007 after the slight increasing trend from 2001 (Figure 5). The ISF also gained confidence in 2007 through the addition of newly-available indicators from recent monitoring practices, indicators such as turbidity measurement and chlorophyll a concentration. The ISF calculation showed these new indicators are significant to the aggregate value of the ISF; therefore, they should be included in future construction of the ISF.

4.1.3.1 Perspectives: the following discussions at the perspective level of the ISF refer to Figure 6, as well as Table 1 for specific indicator(s) trends. Observing ISF at the perspective level, the functions of the systems from the PUB perspective did not show a clear trend; from the social perspective, a slight increasing trend from 2004 onwards was evident, after fluctuating inconsistently since 2001; from the economic perspective, the positive trend was more marked; while from the environmental perspective, the trend was somewhat negative.

The negative trend in the functionalities of the systems from the *environmental perspective* was mainly attributed to the trend in the environmental system (indicator 1, Table 1): there have been increasing efforts to tend the gardens, and observed was the increasing tendency to engineer the 'natural' environment, such that the ability or functionality of nature to sustain itself may be diminished. Furthermore, the systems from this perspective were consistently the lowest among all the perspectives throughout the period. The normalised values for all the systems were 0.6 and below, except for the built system, which was fully functional for most of the study period (main indicator: fraction of sewerage system connection). This further indicate that the concern and integrity of nature had been somewhat neglected, except in the case where it can be engineered to appear otherwise.

From the *economic perspective*, the decrease in ISF value from 2002 to 2003 was due to the effects of the SARS outbreak, as tourism is one of Singapore's major industries. Almost 90% of the normalised indicators (indicators 7–9, 17–20, 26–28, 37–38) were dysfunctional or decreased in values, showing not only that all the systems were affected by the outbreak, but also showing the effect of the recession which began in 2001.

Following the decline, a sharp increase from 2003 to 2004 in the functionality of the systems from the *economic perspective* was evident. This was the result of an increase in each system's functionality, with the greatest increase within the system of administration (indicator 26) and the built system (indicators 7, 37, 38). In terms of indicators, the greatest increase in functionality was observed in the increase in the number of visitors per year (built and environmental system); the normalised indicator was 0 and 1 for 2003 and 2004, respectively (indicator 9). The slight decrease from the *economic perspective* that directly followed this increase was due to a slight decrease in each of the system, except for the social (indicators 17–20) and the built systems (indicators 7–9, 37, 38). The largest decrease was observed in the system of administration, from 1 to 0.85; this system has only one indicator for the function 'fair regulations conducive to profit generation', the indicator being the growth rate of GDP per capita (indicator 26).

The above sharp increase from 2003 to 2004 of functionality from the *economic perspective* was likely due to Singapore's climb out of recession (2001–2003) as well as the fast recovery in 2004, resulting from Singapore's government drastic measures, from the SARS epidemic which hit the country in 2003. The stabilising trend from 2004 onwards reflected the stabilising trends for most of the indicators in these years.

The trend in systems functionality from the *social perspective* appeared to be (uniquely) out of sync in comparison. Upon further examination, the main indicators contributing to the decrease from 2001 to 2002 were 'the change in admission to mental institution compared to the change in population' (environmental system, indicator 6) and 'the change in housing cost compared to the change in household income' (economic system, indicator 24). The former indicator was also the main contributing factor in the decrease of the ISF value from 2003 to 2004. This inconsistency with the general/prevalent trend observed for other perspectives is attributed to the time lag in the response (of one year) of the systems from the social perspective (i.e. the society).

There was no clear trend observed from the *PUB perspective*; the functions of all the systems have low values with a range of 0.4–0.5 throughout the study period, with the exceptions of the years 2003 and 2004, where the values were 0.74 and 0.75, respectively (Figure 6). These higher values were attributed to the economic system, with the indicator being the increase in PUB's surplus after tax (indicator 29). After being dysfunctional in 2001 and 2002 (decreasing surplus), it was fully functional in 2003 and 2004 (21 and 15% increase, respectively), before it decreased and stabilised until 2007. These values reflected the economic situation during those years (recovery from recession), with PUB perhaps recovering a little earlier. The decrease in this indicator value in 2005 and the subsequent, more stabilised period could be due to the commencement of the Marina Barrage construction, which would have increased their expenses (capital costs, etc.) in the following years.

PUB's interest in the Marina Barrage as water supply source (as well as for flood control and to provide stable water level) has not been fulfilled throughout the period of the study; indicators for these were not included in the ISF calculation. It will be of great interest and value to continue to measure the ISF of the domain as this service is provided by the Barrage (built system), by adding relevant indicator(s), and to observe how this new function affects, not only sustainability from a PUB perspective, but also the sustainability of the whole domain (especially as this function is of interest to the community (social perspective) and the economy).

4.1.3.2 Systems: interestingly, based on ISF analysis, the sustainable functionality of the *economic system* as a whole showed a positive trend. The trend for the economic system ISF showed some evidence of Singapore's economic recession that began in 2001 (Huxley, 2002; McRae, 2001). The country climbed back out of recession in 2004, with more than a 12% increase in GDP over the previous year. Without quick actions from the government to address the 2003 SARS outbreak, this improvement in the economy of the country would likely not have been achieved. This, in turn, indicates the efficiency of the *system of administration* of (government) agencies, which supports the high ISF values of the system of administration (compared to other systems in Singapore). The high values in 2003 and 2004 were, again, due to the functionality from the PUB perspective, which was previously discussed.

The slight decrease in the functionality of the *system of administration* in 2005 was due, mainly, to a slight decrease of functionality from the economic perspective (function: fair regulations conducive to profit generation, indicator 26). A high economic growth in 2004 was observed; and it appeared that this growth rate could not be maintained, thus stabilising in 2005 (4.3% increase in GDP per capita).

The jump in values within the *built system* from 2003 to 2004, again, reflected the recovery in the tourism industry, and thus Singapore's economy. The system also showed consistently higher values than most of the other systems during the study period. This indicated that the built system is well designed and constructed such that it is close to fully functional in almost a holistic sense: from the perspectives of the economy (increasing property price index, increasing tourism, etc.), the society and even contributed to minimising impacts on the environment.

The most stable of all the systems were the *social system*, with the range of functionality from 2001 to 2007 of 0.06 (0.55–0.61). This is consistent with political and social setting during this period, with little or no unrest or extraordinary events, politically and socially, occurring between 2001 and 2007.

4.1.4 Marina Bay development

Considering the Marina Bay development project specifically and its effects on the study domain, the ISF values show that during the construction of the project (2004–2007), it had little impact on the overall sustainability of the domain. The (slight) decline in the overall ISF from 2004 to 2005 is due to the decrease in the system of administration and the environmental and economic systems (Figure 5); and in terms of perspectives, the decline is evident from all the perspectives, except the social perspective (Figure 6). However, from 2005, the ISF stabilised somewhat, and most of the systems as a whole increased in functionality, albeit slightly (Figure 5).

It is important to continue the assessment of sustainability and ISF calculation when the main three objectives of the Marina development can be directly achieved, at the completion of the Marina Barrage construction. While the barrage construction was completed in 2008, the freshwater reservoir is predicted to be fully functional by the end of 2009.

Continued sustainability assessment would involve the addition of new functions (which are also the three objectives): water supply, flood control and lifestyle attraction. Both water supply and flood control would be the function of the built system from the social, economic and PUB perspectives; while the latter would be the function of the built system from the PUB perspective. The corresponding indicators would be: amount of water supplied from the Marina reservoir *(39)*; the number of times per year the water level in the reservoir exceeds a set maximum level *(40)* and the number of times per year the water level in the reservoir exceeds a set range *(41)*. Both (proposed) indicators 40 and 41 would also indicate how the giant pumps and crest gates at the barrage function.

A quick analysis of the field data, comparing the years 2007 and 2008 (until end of March), shows improvements in the functionality of flood control and stable water level (lifestyle attraction). From normalised values of 0 in 2007 (before the Barrage is completed), the functionality increased to 0.63 and 0.24, respectively (refer to Appendix B for normalisation methods). Therefore continued analysis and assessment of these indicators would be a valuable tool to indicate the success of the Barrage construction in achieving these initial objectives. This is especially important in 2010 (and onwards), as the Marina Reservoir is at its transitional period until this time. During this transitional period, the reservoir water level is artificially fluctuated (by 70 cm) to maintain a salinity range high enough to discourage mosquito breeding, as well as to get the recirculation scheme in place prior to turning the reservoir into a fresh water supply source.

It can also be seen from the above preliminary analysis that the increasing values would affect the overall ISF. To have more insight on the effects of the three proposed indicators above on the sustainability of the whole domain, one can construct the ISF for the case that these three objectives were achieved. Taking the year 2007 as an example, if these functions were fully functional (indicator values = 1) and all other indicator values remain the same, the ISF value for this year would increase by 5.1% from 59.6 to 62.6. The (three) indicators could, however, affect the values of other indicators; for example, if the water level is stable and supports the aim of lifestyle attraction, it could lead to an increase in tourism, thus increase the values of indicators 7–9. Continued ISF construction would indicate if the sustainability of the whole domain would increase after the Marina Bay development is completed and the benefits can be realised.

In terms of the suitability of the ISF methodology, its application to Singapore prior to and during the large development of the Marina Bay area has shown to be a (potential) valuable tool for decision and policy makers. It provided a holistic picture of sustainability of Singapore as a whole, taking into account the different functioning and processes occurring within the domain, and illuminating those with low functionality and in need of attention and intervention from policy makers.

5 Conclusions

The ISF methodology allowed the quantitative sustainability assessment of the Marina Bay development project within the domain of Singapore. Its underlying concept and features provided the ability to investigate which of the processes cause the low level of functionality of the system. It is very specific, allowing focused actions to be taken for improvement. However, careful choice of indicators is essential, and intensive data collections to increase resolution are preferred.

Overall, the result of applying the ISF shows that the Marina Bay development project and the new functions or services it provides did not increase the sustainability of Singapore during 2004 to 2007 (construction period). This increase may, indeed, occur following the completion of the project, when the new functions or services can be enjoyed by all the stakeholders. Continued ISF application and analysis would be very useful and necessary to ascertain this and the success of the development project in contributing to a better, more sustainable Singapore.

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Appendix A

The ISF matrix, showing functions of each system from different perspectives, and indicators (#) corresponding to each function

Perspectives	*Systems*: *Environmental*	*Social*	*Economic*	*Administration*	*Built*
Environmental	1 Provide diversity which reinforces nature (synergy) (1)	1 Minimise pollutants (11–13)	1 Management of industry's and business's environmental impacts (22)	1 Minimise environmental impact through legislation and public awareness (30) 2 Promote nature tours (31)	1 Increase sedimentation (10) 2 Reduce chlorophyll a concentrations (4) 3 Allow for ecosystem health (35)
Social	1 Conducive to physical health and recreational use(2–5) 2 Mental wellbeing (6)	1 Social cohesion (14–15) 2 Positive social capital (16) 3 Compliance with laws (17)	1 Essential services (23–24) 2 Opportunities for human development (25)	1 Fair and working system (32) 2 Security of supplies and fair allocation of resources (33)	1 Provide serviced land for societal activities (36) 2 Water supply (39)* 3 Flood control (40)*
Economic	1 Enhance tourism (7–9)	1 Stable environment for economic growth (17–18) 2 Skills to society (19) 3 Capacity for consumption (20)	1 Stability and economic growth (26–28)	1 Fair regulations conducive to profit generation (26)	1 Enhance tourism (7–8) 2 Provide a network of tangible assets (37–38) 3 Water supply (39)* 4 Flood control (40)*
PUB	1 Support water supply operation (4, 10)	1 Support PUB operations (21)	1Economic growth conducive to profit/surplus generation (29)	1 Working system for efficient operation (34)	1 Water supply (39)* 2 Flood control (40)* 3 Stable water level (41)*

*Proposed indicators.

Appendix B

Details of data source and normalisation methods

All the data obtained for the construction of the ISF were obtained from the SDS, unless otherwise specified below.

1 Data were obtained from the National Parks Annual Reports (2002/03–2006/07) and the SDS. The functional bound was defined to be 0, when the environmental system and its biodiversity are able to maintain itself without human effort being expended on it. The dysfunctional bound was defined as $1/ha/1,000 person.

2 The air quality data used for the indicators were an average of the measurement types (industrial, urban and suburban). The functional bounds that were applied for the normalisation were 0. The dysfunctional bounds were 80 μm m^{-3} SO_2, 100 μg m^{-3} NO_2, 10 mg m^{-3} CO and 157 μg m^{-3} O_3, adhering to the United States Environmental Protection Agency (USEPA) Standards for Air Quality.

3 Data (2001–2004, 2007) were obtained from the results of monitoring by PUB and NEA Geometric mean of pathogen (faecal coliform) concentration (mpn 100ml^{-1}) was used in the calculation. Data for the first four years were sampling results from Singapore River, Stamford Canal and Geylang River, while for the last year, sampling points MC 02, MC 03, MC 04, MC 09 and MC 15 were used (details of each sampling locations can be found in Appendix C). These were chosen as they were the closest sampling points to the Marina Reservoir. PUB has adopted a recreational standard of 1,000 counts per 100ml of faecal coliforms, and this was used as the dysfunctional bound in the normalisation. The functional bound was set as 0.

4 Data were obtained from field data from LDS and gauging stations in Marina Bay reservoir and catchment. Monitoring began in mid-2007 until current time; there are no data prior to this date. Annual average of chlorophyll-a concentrations as measured by different stations was calculated. Values used for normalisation were the average value from different stations in Marina Reservoir. The normalisation was based on WHO's safe recreational water guideline (WHO, 2003). The functional bound was defined to be when there is relatively low (or less) probability of adverse health effects: 20,000 cyanobacterial cells ml^{-1} or 10 μg chlorophyll-a $litre^{-1}$ (with dominance of cyanobacteria). The dysfunctional bound was 100,000 cyanobacterial cells ml^{-1} or 50 μg chlorophyll-a $litre^{-1}$ (with dominance of cyanobacteria), which represent moderate (or higher) probability of adverse health effects.

5 Data for the year 2004 were from the results in a PUB report of water quality assessment carried out prior to the Marina Barrage construction. (Average) values are from sampling points in Singapore River, Stamford Canal and Geylang River. Data for 2007 were obtained from field data from gauging stations in Marina catchment, where pH measurements were taken from sampling points MC 02, MC 05, MC 09, MC 11 and MC 15 (locations details in Appendix C). For the ISF calculation, average values from MC 02 and MC 15 were used, due to their close proximity to the Marina Reservoir. Normalisation was based on guideline used by the Canadian government (CCME, 2007) for the protection of recreational activities,

where a pH range of 5.0 to 9.0 is acceptable. The dysfunctional bounds were thus set at pH 5.0 and pH 9, and the functional bound at pH 7.

6 The functional bound was defined as the point where the change in admission into Woodbridge Hospital divided by the change in Singapore population is equal to 0.25. This is the equivalent of the change in hospital admission changing 75% slower than the change in population. The dysfunctional bound was defined when this ratio is equal to 1.75, which is the point where the change in hospital admission change 75% faster than the change in population. When there is a negative change in hospital admission and a positive change in population, then the indicator receives a normalised score of one.

7 The fraction used is the fraction of GDP from 'hotels and restaurants'. The functional level was determined based on the 1998 world ratio of tourism revenues vs. GDP (1.15%). Revenues from hotels and restaurants in Singapore would include spending by Singapore residents as well as tourists. Therefore, the functional bound was determined as 2.5%, and the dysfunctional level as 0% (Imberger et al., 2007).

8 The values used to determine the indicator value are the standard average occupancy rate of gazetted hotels. The functional bound was defined to be 100% occupancy rate, when demand reached supply and the dysfunctional bound 0.

9 Data were acquired from the SDS and Singapore Tourism Board. The values were calculated from the percentage change in visitor arrivals. Normalisation was based on (comparison with) world tourism, and statistics obtained from the United Nations' World Tourism Organisation (UNWTO). The number of international arrivals shows an average annual growth rate of 6.5% for the years 1950 to 2007. This percentage is used as the functional bound in the normalisation process, with the dysfunctional bound being 0 (no increase in visitor arrivals into Singapore).

10 Data for the year 2004 were from the results in a PUB report of water quality assessment carried out prior to the Marina Barrage construction. (Average) values are from sampling points in Singapore River, Stamford Canal and Geylang River. Data for 2007 were obtained from field data from three LDS stations in the Marina Reservoir (monitoring began in 2007 until present time). Guideline values (Canada, USA) for turbidity in recreational waters have upper limit ranging from 25 to 50 NTU (CCME, 2007; Singleton, 2001; Water Resources Panel, 2008). The Australian drinking water guidelines have turbidity standard of 5 NTU. As the water will eventually be used as drinking water, the functional bound was defined as 5 NTU and dysfunctional bound 25 NTU.

11 For the year 2007, indicator value was calculated using data of waste statistics for 2007 obtained from Singapore's National Environment Agency (2008). Food waste, paper/cardboard and plastics were regarded as domestic waste, while remaining waste types (construction debris, horticultural waste, ferrous metal, etc) were considered as commercial waste. OECD (2007) reported annual household waste generation of USA, UK, Australia and Netherlands in 2000 as 460, 510, 400 and 540 kg per capita, respectively. Based on this, the dysfunctional bound was set at 500 kg per capita. Zero waste to landfill is ultimately the upper limit of sustainable waste management, and is the functional bound in this case.

12 Data source for the year 2004 were the same as that for indicator 10; however, data used were all the sampling points in the catchment. Data for 2007 were obtained from field data from gauging stations in Marina catchment, where turbidity measurements were taken from sampling points MC 02, MC 05, MC 09, MC 11 and MC 15 (locations details in Appendix C). The normalisation method and the bounds were the same as those used for indicator 10.

13 Data source were the same as that for indicator 3; however, data used were all the sampling points in the catchment.
A benchmark value of 10,000 counts per 100 ml of faecal coliforms was used based on recommendation in a PUB report on urban runoff. This value was set as the dysfunctional bound, and a value of 1,000 counts per 100 ml, the functional bound.

14 The percentage of labour force participation was used as the normalised values, with 100% as the functional bounds and 0 as dysfunctional. The data were separated by gender, as a differing trend was observed between them.

15 The normalisation method was the same as that used for indicator 14.

16 General elections results were obtained from the Elections Department, Singapore and Singapore Elections (Singapore Elections, 2008a; Singapore Elections, 2008b). In Singapore, where voting is compulsory, the percentage of non-voters and informal voters can be used as a measure of the population's level of distrust or apathy towards their governance. The functional bound is defined as 0% of people distrusting the government: everyone eligible votes and all votes cast are legitimate. The dysfunctional bound, when there is so little generic trust within the society that Social Capital begins to lose its functionality, is set at 50% of non-voters or illegitimate votes. At this point, the majority of people within the society do not display generic trust in the country's political systems. As elections do not happen annually, the indicator values in non-election years were calculated using linear interpolation between two adjacent available data, as the level of trust in the government is not expected to fluctuate widely (and historical data support this).

17 Data were obtained from the SDS and the Singapore Police Force. The most functional bound for the crime rate from the perspective of providing a stable social environment for the economic system in the community would be a crime rate equal to zero. This would mean that the risk of social instability from crime would not affect any economic decisions; therefore, allowing purely economic factors to motivate decisions for spending and investment. Crime rates among different countries cannot be directly compared. Despite this fact and in order to define a dysfunctional boundary for the normalisation, international values were researched. England and Wales have been reported to have the highest crime rate among the world's leading economies, according to a report by the United Nations. The highest crime rate in UK over the past 15 years was reported in 1995, when the number of incidents reported exceeded 19 million. The rate of offences per population calculated to be close to 33%. Based on this figure, the dysfunctional bound was set equal to 30% (Imberger et al., 2007).

18 The percentage of home ownership was used as the normalised values (100% ownership was considered optimal or functional value).

19 Labour force qualification data of upper secondary and higher levels were summed to produce the indicator data. Comparisons with other OECD member countries show the highest proportion of population with educational attainment equal to and above secondary graduation as being upwards of 85%. The upper levels of educational attainment peak at around 90% for OECD countries for 25-64 year age group. Based on the above, the functional bound was set up to 90%. The lowest bound among the OECD countries is ~20%. This leads to a selection of 20% as a dysfunctional bound.

20 Data were based on the household expenditure surveys carried out every five years in 1988, 1993, 1998 and 2003. The values of dysfunctional and functional bounds were selected to be 0 and 1, respectively. For ISF calculation, data between the five-year surveys were linearly interpolated from the normalised value of available data.

21 Data were acquired from the PUB Annual Reports. The minimum amount of water recommended by the United Nations is 20 l person day^{-1} (United Nations Development Programme, 2006), and Gleick (1996) suggested basic water requirements for domestic activities are 50 l person day^{-1}. Average water use in Europe ranged from 200 to 300 l person day^{-1} and 575 l person day^{-1} in USA in 1998–2002 (United Nations Development Programme, 2006); in Australia, average water use in 2004 was 296 l person day^{-1} (Water Corporation, 2008). Based on these values, the functional bound was set as 100 l person day^{-1} and dysfunctional bound 250 l person day^{-1}.

22 For the year 2007, indicator value was calculated using data of waste statistics for 2007 obtained from Singapore's National Environment Agency. Food waste, paper/cardboard and plastics were regarded as domestic waste, while remaining waste type (construction debris, horticultural waste, ferrous metal, etc.) were considered as commercial waste, and was used to calculate indicator value. OECD (2007) reported annual municipal and household waste generation of OECD countries. The difference in municipal waste and household waste was considered as the non-domestic component of the waste generated. This value for USA, UK, Australia and Japan in 2000 was 300, 70, 290 and 140 kg per capita, respectively. Based on this, the dysfunctional bound was set at 250 kg per capita. Zero waste to landfill is ultimately the upper limit of sustainable waste management, and is the functional bound in this case.

23 Data were obtained from the results of the Household Expenditure Surveys of 1988, 1993, 1998 and 2003 by the SDS. Normalisation method follows that in Imberger et al. (2007): the functional bound was determined as a value of 0.05 for the ratio of food expenditure to income. In the USA, 6.2% of household income is spent on food at home, and 4.0% is spent away from home. As Singapore is an economically developed country unlike the USA, it can be expected to spend as little as 5% of the income on food. The dysfunctional bound was set to 0.20. Japan is a net food importer, and a typical level of spending on food is around 16% of the gross disposable household income. Mediterranean countries including Italy and Greece spend 15.2% and 19%, respectively. Thus, 20% would be an unacceptable level of spending.

24 Data of the cost of housing were a component of the consumer price index (CPI). The functional bound was defined as the point where the change in housing costs divided by the change in household income is equal to 0.5. This is the equivalent of the change in housing costs changing 50% slower than the change of income. The dysfunctional bound was defined when this ratio is equal to 1.5, which is the point where the change in housing costs change 50% faster than the change in income. In the rare case that there is a negative change in household income and a positive change in housing costs, the indicator receives a normalised score of zero.

25 The Gini coefficient is a measurement of income equity. The normalisation method for this indicator follows the line of thought that is in Imberger et al. (2007): the ideal state of the indicator is not when the true income distribution is the same as the completely equal distribution (when the Gini coefficient equals 1). This would only be the case when all people within the society were placing the same effort and had the same talents and abilities. To construct bounds for the normalisation of the indicator, the best technique is to adopt a world's best/world's worst approach. The Pan American Health Organisation found that Finland, Norway and Sweden have the most equitable distribution of income, with Gini coefficient values ranging between 0.25 and 0.3. The countries of the world with the highest levels of inequity in terms of income distribution have a Gini coefficient in the order of 0.60 and the world's average Gini coefficient is 0.40. Based on the above, the functional bound was set to 0.25 and the dysfunctional 0.60.

26 The functional bound of 5% growth rate of GDP per capita per annum was set. Static or even negative growth rate of GDP per capita would indicate a significant stagnation of the economy, and most probably recession. Recession indicates a shrinking of the economy and so is not sustainable, given that it is assumed that the population base is always increasing. The dysfunctional bound was therefore set to 0 growth rate.

27 The CPI gives a measurement of the worth of capital. Normalisation was based on the recommended rate of increase of CPI by the Reserve Bank of Australia of 3% per annum (functional bound). High rates of CPI increase indicate unsustainable growth; while low or negative rates of CPI indicate slow or negative growth, which may result in job losses and unemployment. Thus, a lower and higher dysfunctional bounds of 0 and 10%, respectively, were applied.

28 Normalisation followed that in Imberger et al. (2007), where they noted that historical evidence suggests 2% is as low as unemployment can go before an upturn in unemployment levels is initiated by the associated rise in inflation. Thus, the functional bound is set at 2%. There are no measures of the level at which unemployment causes this aspect of the functionality, namely, stability, to cease. By examining unemployment in OECD countries, it was observed that the highest five year averages are between 11% and 15%, with a few exceptions that reach up to 19%. The above figures refer to the years from 1983 to 1984. Based on the above, the dysfunctional limit of 15% was set.

29 Annual growth data of PUB's surplus after tax were obtained from PUB Annual Report 2006/2007. Normalisation was based on optimal growth rate, with dysfunctional and functional bounds defined as 0 and 15%, respectively.

30 Recycling rate was calculated as the percentage of recycled waste of the total waste output (sum of waste disposed and waste recycled). Data for the year 2007 were obtained from the National Environment Agency. Normalisation was based on one of the highest recycling rate of a nation (Norway) of 75% (Hass, 2001). This percentage was set as the functional bound and 0 as the dysfunctional bound.

31 Data were obtained from National Parks Annual Reports (2002/03–2006/07). The area set aside as nature reserves, parks and park connectors in Singapore were compared to the total land area, and these percentage values were normalised. The Australian Department of Conservation and Land Management defines a value of 15% of land to be set aside for conservation. Based on this, the functional bound was set to be 15% of Singapore's land area and the dysfunctional bound 0.

32 Water affordability was calculated using income data and household water expenditure. Data of household expenditure of water were extracted from the Report on the Household Expenditure Survey 2002/03 (Singapore Department of Statistics, 2003) as well as from Tortajada (2006b). Data were found for the years 1988, 1993, 1995, 1998, 2000, 2003 and 2004. Two types of data were available: average monthly water consumption per household (1995, 2000, 2004) (Tortajada, 2006b) and average monthly household expenditure of (combined) water, electricity and gas (2003) (Singapore Department of Statistics, 2003). For the years 1988, 1993 and 1998, the monthly expenditure of water, electricity and gas were calculated as 17.1% (2003 percentage) of housing costs, and housing costs were obtained from Singapore Department of Statistics (2003).
Normalisation was based on affordability benchmarks (found in Fankhauser and Tepic (2007)). For the first type of data (water consumption only), the functional bound was set to be 2.5% of household income, a benchmark used by the US government, and the dysfunctional bound as 5% of household income, an Asian Development Bank benchmark.
For the second type of data (combined expense of water, electricity and gas), the functional bound was set to be 12.5% of household income (sum of US benchmark for water and World Bank lower benchmark for electricity); while the dysfunctional bound was defined as 17.5% of household income (sum of US benchmark for water and World Bank upper benchmark for electricity). Heating was excluded in Singapore case, considering its minimal use in the country's tropical climate.

33 Data were obtained from the Public Utility Board. There has been no case of water restrictions in Singapore. As the functional bound was defined as no water restrictions, the normalised score is one.

34 Within the United Nation's Indicators of Sustainable Development, research and development (R&D) expenditure was used as an indicator for institutional capacity, not dissimilar to the system of administration in this study, thus this indicator was used. Value for the year 2007 was extrapolated from the available data. OECD reported that the average R&D expenditures as a percentage of GDP were 2% in EU countries and 2.4% in OECD countries, in 2007 (OECD, 2007), with a range in OECD countries of 0.5–3.7%. As Singapore prides itself on education and research and development, a (higher) value of 3% was used as the functional bound. The dysfunctional bound was determined based on the target for African countries to

allocate at least 0.4–0.5% of its GDP to research by 2000 (United Nations Department of Economic and Social Affairs, 2001). The dysfunctional bound was set as 0.5%.

35 Data on the coverage of sewerage connection in Singapore were obtained from WHO and UNICEF (2006). Data were available for the years 1980, 1983, 1985, 1988, 1990 and 1999; and the report also included estimates for the years 1998, 2000 and 2004. For ISF calculation, linear interpolation was carried out to determine annual values that were not obtained. Beyond 2004, it was expected that Singapore maintained its 100% sewerage connection. The functional bound for the normalisation was set at 100% coverage and dysfunctional bound at 0%.

36 Data of fatalities *per capita* (number of deaths per 100,000 population) were obtained from the Singapore Police Force. Fatality rates around the world in 2003 reported by DSA (2003a) range from 3.29 in Brunei to 26.75 in Malaysia, Singapore's close(st) neighbour. The range for the 30 OECD countries in 2002 is from 6.0 in Sweden to 19.3 in Greece, with an average of about 11 road deaths *per capita* (DSA, 2003b). Based on these values, the bounds for normalisation were set at 3 for functional and 11 for dysfunctional.

37 Data of private residential property price index (PPI) were obtained from the URA. As economic assets to Singapore, the decrease in PPI indicates a dysfunction. Thus, 0 was defined as the dysfunctional bound, and an annual increase of 10% or more was deemed as functional and set as the functional bound.

38 Data of rental index annual growth were obtained from the URA. The bounds for the increase in rental index were defined as 0 and 10% for dysfunctional and functional bounds, respectively.

39 (*Proposed indicator*) One of the aims of the construction of Marina Barrage was to create a freshwater dam, as another water supply for Singapore. Therefore, the function of this built dam could not be fulfilled before and during the construction stage. The commencement target for utilising the water in the reservoir is 2009.

40 (*Proposed indicator*) Data on water level of the Marina Reservoir were obtained from an LDS station. The number of days the water level exceeds a set maximum level of 2 m (above sea level) were associated with the success of flood control measures. The functional bound was defined as 90% of the time below this maximum level (~36 days above 2 m, or flooding) and the dysfunctional bound 75% (~91 days of high flood risk).

41 (*Proposed indicator*) Source of data is the same as that for indicator 40. The tidal range in Singapore waters can be up to 3 m. The Barrage was designed such that tides will not affect water level and the recreational activities in the reservoir; furthermore, slightly fluctuating water level of 0.7 m is considered by the PUB as necessary to maintain a minimum salinity at the beginning of the barrage operation. Therefore, stable water level was defined as having a water level range of less than 1.5 m in one day. Thus, the bounds were similarly defined as indicator 40: 90% and 75% of the time below this range for functional and dysfunctional bounds, respectively.

Appendix C

Location details of hydrologgers

Site	*Site description*	*Longitude*	*Latitude*
MC01	Geylang River Upstream	103°53'33.85"E	1°19'16.12"N
MC02	Geylang River Downstream	103°53'10.14"E	1°18'20.97"N
MC03	Kallang River (Upper Boon Keng)	103°52'16.18"E	1°18'58.42"N
MC04	Sungei Whampoa	103°51'56.08"E	1°19'11.76"N
MC05	Kallang River (CTE)	103°51'25.35"E	1°20'48.17"N
MC06	Kallang River (Lor Chuan)	103°51'41.42"E	1°21'00.28"N
MC07	Kallang River (Toa Payoh Ave 8)	103°51'24.88"E	1°20'30.77"N
MC08	Bukit Timah Canal	103°49'11.18"E	1°19'21.35"N
MC09	Rochor Canal	103°51'07.23"E	1°18'14.88"N
MC10	Stamford Upstream	103°49'37.57"E	1°18'23.27"N
MC11	Stamford Downstream	103°50'18.41"E	1°18'03.25"N
MC12	Alexandra Canal (Strathmore)	103°48'44.43"E	1°17'37.47"N
MC13	Alexandra Canal (Viking)	103°49'09.97"E	1°17'30.18"N
MC14	Alexandra Canal (Prince Charles)	103°49'09.15"E	1°17'32.91"N
MC15	Singapore River Tributary	103°50'43.87"E	1°17'08.80"N