8

FROM FLOOD PREVENTION AND FLOOD MANAGEMENT TO ABC WATERS

Today this (drainage and reservoir) system helps us collect water, store water, and control floods. So we have taken care of the basics well. But moving on, there is further potential — if we think creatively and work together. With some planning and enhancement, the water bodies and waterways can be changed into vibrant areas for everyone in the community to enjoy. There can be more lifestyle activities and people will have more recreational choices. This in essence is the spirit of the ABC Waters Programme.

Minister for the Environment and Water Resources,
Dr Yaacob Ibrahim, at the Kallang River Fiesta "Fun & Joy"
cum Launch of PUB's ABC Waters Programme demonstration
project at Kallang River/Kolam Ayer,
16 April 2006

In the 1960s and 1970s, floods were common and widespread in Singapore, especially in the city centre, which was built on relatively low-lying land. As the ground levels of developments in these

areas were usually barely above high tide level, they would flood almost every time heavy rain coincided with high tide. Floods like these not only caused great inconvenience and disruption to people's lives but also damage to property.

SEVERE FLOODS IN SINGAPORE

Flood of 1969

In December 1969, Singapore experienced 467 millimetres of rain within a 17-hour period, the second highest rainfall ever recorded in Singapore in a single day. The heavy rain, coupled with a high tide of 3.1 metres, resulted in extensive floods across the island. The most severely affected areas were Bukit Timah Valley and Potong Pasir, where several stretches of road were submerged under 2 metres of flood waters. The floods claimed the lives of five people, and more than 3,000 people were evacuated. The city transport system was paralyzed, and all roads and rail links between Singapore and West Malaysia were severed. Total damages were estimated at S$4.3 million (based on 1969 prices).

Flood of 1978

In December 1978,[1] Singapore experienced its most severe flood ever. A total of 512.4 millimetres of rain was recorded over a 24-hour period — the highest in a single day and almost a quarter of Singapore's average annual rainfall. To compound matters, the rain coincided with a very high tide of 3.2 metres (the average high tide level is about 2.8 metres). Roads were submerged under more than a metre of water, resulting in massive traffic jams as hundreds of vehicles were abandoned. The worst hit areas were the farm belts of Woodlands, Braddell Road, Potong Pasir, and Changi, where more than 2,000 pigs and poultry perished in the swollen waters. In some areas, the flood levels reached the roofs of squatter huts.

Seven people died in the 1978 flood. Altogether, more than 1,000 people were evacuated from their homes by army and police boats, with the more serious casualties transported via helicopters. Total damages were estimated at S$5.75 million (based on 1978 prices).

Causes of Floods

Many believe that flooding depends on the volume of rainfall and the size of canals and drains, that is, the capacity to convey storm waters away quickly. To some extent, this is true, but there are other factors as well.

One such factor is the intensity of rainfall, which is the volume of rainfall within a period of time, usually expressed in millimetres of rainfall per hour. Due to Singapore's location in the equatorial belt, it receives about 2,400 millimetres of rainfall each year on average, which is characteristic of a tropical rainforest climate. The rainfall occurs throughout the year, but with higher rainfall in the northeast monsoon season from December to early March, when there are frequent afternoon showers, and intense spells of widespread moderate to heavy rain, lasting from one to three days. In some cases, a huge volume of rain can fall within a relatively short period of time, such as during the flood of 1978, in which almost a quarter of Singapore's average annual rainfall fell within a single day.

With such abundant rainfall, it is not surprising for floods to occur if the storm water drainage infrastructure is inadequate. Fortunately for Singapore, careful planning and judicious implementation of an efficient drainage network has helped spare the island from major floods for more than two decades. Nevertheless, floods could still occur in Singapore during an intense storm, such as that occasionally experienced during the northeast monsoon season, when heavy or localized rains coincide with a very high tide, causing flash floods.

Besides hydrological factors, the relief and contour of the land may also increase the risk of flooding. Although Singapore is relatively flat, there are land undulations, with the lowest-lying lands located along the southern and eastern coastal fronts. These areas, which include Singapore's Central Business District, are subject to a higher risk of flooding. Some pockets of low-lying land can also be found further inland.

Furthermore, floods are not always caused by geographical elements. Blocked drains, for example, can reduce the conveying capacity of drains, compromising their conveyance function. At times, some developers may also overlook the fact that their new concrete-based structures reduce the amount of rain that can infiltrate into the ground, resulting in increased surface run-off. This is typical of areas that undergo urbanization or land development, where drains ought to be enlarged in tandem to cater to the excess surface flow. To ensure there are no chokepoints, the drains downstream will also need to have the capacity to handle the excess flow.

FLOOD MANAGEMENT STRATEGY

From close to 7,000 hectares of flood-prone areas in the 1960s, there were only about 130 hectares at the end of 2007. Furthermore, unlike the extensive floods in the past, today's floods are localized flash floods, that is, floods that occur in a small locality, which often subside quickly, within thirty minutes to an hour. How were such improvements achieved?

Because of the potential damage floods could cause, Singapore's leaders had recognized from early on that if not tackled, floods could disrupt lives and become a major impediment to economic growth. Thus, various measures were taken to tackle the flood problem along two key thrusts:

a. Flood alleviation projects were implemented to tackle and reduce the size of flood-prone areas, by improving the drainage in these areas.

b. Flood prevention measures were put in place in low-lying areas, even those that had escaped serious flooding previously. Flood prevention was also important in areas undergoing major development, as increased urbanization would reduce natural infiltration into the ground, thereby leading to increased surface run-off and a higher risk of flooding during storms.

Flood Alleviation

The earliest drainage network in Singapore began as a public health measure. In the early 1900s, malaria was very rampant as the malaria vector — the *Anopheles* mosquito — thrived in warm weather and bred easily in pools of stagnant water. To combat this, an anti-malarial drainage system was introduced in 1914 to convey seepage water and prevent formation of stagnant pools. The network comprised naturally formed earth streams, subsoil pipes, and concrete drains. With the growth and urbanization of Singapore, the anti-malarial drains also served the purpose of flood alleviation. However, as seen by the extent and severity of the floods experienced, the drainage system was inadequate to meet the needs of a rapidly growing Singapore. The immediate task then was to reduce the size of the flood-prone areas.

Early Flood Alleviation Schemes

In 1951, a Joint Committee on Flood Alleviation was formed under the Public Works Department (PWD), which was charged with improving the drainage system. As a single department was responsible for flood alleviation, from drawing up plans to carrying them out, coordination and implementation were easier and faster. A number of flood alleviation projects were carried out in the 1950s and 1960s, mainly in flood-prone areas such as Queenstown, Geylang, Bedok, Potong Pasir, Whampoa, Jurong, Tampines, and Seletar. It was important to alleviate flooding in these areas, as they were densely built up and flooding would affect a large number of residents (this was before the development of public housing estates

in new towns and many Singaporeans were still living in dense squatter colonies). To improve their capacities to convey flood water to the sea, the drains serving these areas were widened, deepened, and concrete-lined.

At the same time, a tide-gate system was also designed for the Central Business District and other areas in central Singapore that were below the high tide level and faced frequent flooding during high tides. To protect these low-lying areas from tidal inundation, eighteen tide-gates were installed in the vicinity of the Singapore River, Rochor, and Katong. Nevertheless, the tide gates would have to be open when there was heavy rain, and if this coincided with high tides, the low-lying areas would still be flooded.

Bukit Timah Flood Alleviation Scheme

One of the most important and complex flood alleviation schemes was the Bukit Timah Flood Alleviation Scheme (BTFAS). The Bukit Timah Catchment had a history of flooding from as far back as the 1930s, due to the undersized Bukit Timah Canal and Rochor Canal which were the main outlets for the catchment. In particular, areas surrounding the Bukit Timah Canal experienced frequent flooding as a result of being on relatively lower ground. The problem came to a head in the 1960s when rapid development of the Bukit Timah Catchment resulted in regular overflowing of the canal.

Unfortunately, the Bukit Timah and Rochor areas had been densely built up all the way to the edge of the canals. This made it impossible to widen the canals without a highly disruptive and costly exercise to resettle and compensate those developments. To reduce flooding upstream, the PWD, therefore, decided to divert storm water by channelling it to the sea via a different route.

The BTFAS was conceived at a time when Singapore had just become independent and there were other pressing issues that had to be addressed urgently, such as education and national defence. Nevertheless, the government provided S$7 million for the scheme,

but because this was insufficient to carry out the entire project, it was divided into two phases.

Phase 1 of BTFAS: Phase 1 of the scheme was implemented over six years (1966–72). Under this project, part of the storm water from 700 hectares of the Upper Bukit Timah Catchment was diverted to Sungei Ulu Pandan via a new canal. This was a huge undertaking even by today's standards, and although the budget of S$7 million was a stretch, with dim prospects of further government funding, the PWD engineers came up with innovative engineering methods to deliver the project within the approved budget.

Phase 2 of BTFAS: By the 1980s, further developments in the central part of the catchment made it necessary to implement Phase 2 of the scheme. By then, the success of Phase 1 had convinced the government of the importance of good drainage and the need for Phase 2. The speedy approval for Phase 2 was also in part due to the economic downturn in the early 1980s. The government had given the green light for many large projects in the hope that these would boost the economy and help it get back on its feet.

As the Bukit Timah Canal was flanked by major roads and services on both sides, the maximum expansion that could be achieved was limited, even for the most efficient of canal designs. Besides deepening and widening the Bukit Timah Canal, a second diversion canal (4.4-kilometre long, including 2 kilometres of tunnel) diverting water from the Bukit Timah Canal to Kallang River was constructed — from Swiss Cottage Estate to Sir Arthur's Bridge at Kallang River. A section of Kallang River was also improved to increase its drainage capacity to handle the diverted flows from Bukit Timah. Downstream of the Bukit Timah Canal, two major subsidiary drains, the Thomson Road Outlet Drain and the Pelton Canal, and several other smaller subsidiary drains, were constructed to allow for more efficient drainage of storm water.

Phase 2 of the BTFAS was hailed as ENV's largest civil engineering project then — it was a complicated affair that cut across an expressway and involved major works close to the intersection of Singapore's two major expressways. Comprising seven separate contracts awarded to four different consultants and seven contractors, Phase 2 was rolled out in 1986 and completed in five years at a cost of S$240 million.

Given the dense build-up within the Bukit Timah Catchment, the improvements in Phase 2 would have been impossible if not for the fact that British engineers had foreseen the need for this diversion canal decades before. Although the British had not found it necessary then to implement the flood alleviation measures in the Bukit Timah Catchment, they had identified possible solutions to potential flood problems before the 1960s. In one particular report prepared by the Chief Drainage Engineer F. Pelton of the Public Works Department in the 1950s, plans for the Bukit Timah Diversion and for alterations to the Bukit Timah Canal were laid out. Having identified the solution, the British had the foresight to earmark the land for the diversion route (from Bukit Timah Canal to Kallang River) as a drainage reserve for the implementation of such a solution. If this had not been done, there would have been no cost-effective solution to the flooding problem in the Bukit Timah Catchment. It is perhaps fitting, therefore, that the Pelton Canal was named after this Chief Drainage Engineer.

The BTFAS experience offers a valuable lesson. It illustrates the importance of taking a long-term approach to planning, a key principle that continues to underpin the master planning that is done today. Anticipating challenges early provides for more options available downstream as provisions can be made upfront to cater for the solutions. This is particularly true in flood management, where drainage needs tend to grow over time with urbanization, whilst the flexibility for solutions decreases as more and more land is developed. Hence, foreseeing problems and finding ways to tackle them early is critical.

Flood Prevention

In the 1970s, as drainage infrastructure could not keep pace with new developments, flood incidents occurred across the island, even in areas that had not experienced flooding before. Rapid urbanization would lead to increased storm water flows that required corresponding expansions of the drainage system, but this was limited by the budget set aside for drainage infrastructure amidst other competing needs for government funds.

The situation would become particularly acute in the 1970s and 1980s, as it was a period of rapid expansion, spreading even to the suburban areas. New towns were being built as the Housing and Development Board (HDB) expanded its public housing programme. The Jurong Town Corporation (JTC) had also embarked on an ambitious plan to develop industries in the western part of Singapore.

Drainage Master Plan and Development Control

To cope with these challenges, the Drainage Department in ENV was designated the drainage authority responsible for spearheading and implementing drainage planning and control strategies. ENV was formed in 1972 to look into providing Singaporeans with a quality living environment and a high standard of public health. The decision was made to move the Drainage Department to ENV in recognition of the fact that besides physical infrastructure, drainage issues were linked with public health considerations (for example, stagnant water could cause water-borne diseases).

In close consultation with the Urban Redevelopment Authority (URA), HDB, JTC, and other development agencies, the Department drew up a comprehensive drainage master plan in the mid-1970s. Taking into consideration the drainage requirements based on current and projected land uses, the master plan guided the provision of drainage systems and set aside drainage reserves for future requirements. The master plan also targeted known flood-

prone areas, laying out the plans to tackle them through flood alleviation projects.

In line with the administrative procedures for planning and building control, the Drainage Department would have to be consulted on drainage technical requirements at every stage of any development proposal, be it at the land reclamation phase, planning consultation, or building plan stage. With this, the Department would scrutinize all new land development proposals and impose drainage requirements[2] which were in line with the drainage master plan for effective flood control. The requirements also applied to public projects by agencies such as HDB, JTC, and the Land Transport Authority (LTA).

Road Drainage Improvement Task Force

Even today, the most commonly reported floods are those that occur on public roads, due to the extent of disruption they cause. In 1984, a Road Drainage Improvement Task Force was set up to minimize disruption to traffic during rainstorms, by alleviating ponding and localized flooding on roads. The need for integrated planning had been recognized back then, with the Task Force comprising representatives from the Drainage Department and the Environmental Health Department in ENV, and the Roads Division of the PWD.

The Task Force was structured to maximize efficiency and benefits from specialization. Different departments were made responsible for different aspects, from the design of roads, to the sweeping, cleansing, and even structural maintenance of the drainage outlets, scuppers, and roadside drains. This set-up clearly identified the parties responsible for finding solutions to the different parts of the problem, and hence there was ownership of the issue.

The Task Force met regularly and established an approach to tackle cases of localized flash floods as soon as they occurred. First, they would identify roads that were prone to ponding or localized

flooding, and investigate all potential causes. They would then seek practical (engineering) solutions to the problems, and formulate implementation plans for the improvement works that would generally fall into one of five key strategies:

1. *Raising of low-lying roads:* For roads that were below or marginally above high tide levels, improving the drainage outlet facilities would not solve the flooding problems, especially when heavy rains coincided with high tides. Such roads had to be raised.
2. *Patching up of localized depressions in roads:* Sometimes, only isolated stretches of road were low-lying and simple patching up of the localized depressions would suffice.
3. *Improvement of road drainage facilities:* Even if the roads were well above the high tide level, if high intensity rainfall occurred, this could pose problems. The rapid accumulation of the run-off from the roads could cause ponding if the road drainage facilities were inadequate, in which case the drainage facilities would be improved to allow rainwater to drain away more quickly.
4. *Improvement of outlet drains:* In cases where the downstream outlet drains could be overloaded, they would be enlarged to the required capacity.
5. *Cleansing of road drainage facilities:* One common cause of ponding and localized flooding was the blockage of scuppers, roadside drains, and other road drainage facilities by leaves, litter, or debris from structural damages. Such problems could easily be overcome by increasing the frequency of inspection, cleansing, and maintenance of the drainage facilities.

Another example of close cooperation within the task force was the sharing of information. The Roads Division, for example, would send images from its extensive network of traffic cameras and highlight cases of ponding on roads to ENV in real time. ENV would then send officers to investigate and clear any blocked drainage outlets.

The Task Force proved to be so effective that it still exists today. Although the Ministry of the Environment and Water Resources, as ENV is now known, has since passed on its drainage functions to PUB, and its environmental health functions to the National Environment Agency (NEA), and the Roads Division has been restructured under LTA, the various agencies continue to work together with a common objective — to ensure minimal disruption to traffic during heavy rains. Since its inception, the task force, headed by the Drainage Department of then ENV (now known as the Catchment and Waterways Department of PUB), has tackled about 800 cases of flash floods over the past twenty-four years. The number of cases has dwindled in the past few years due to PUB's ongoing efforts both in preventing and alleviating floods. Nevertheless, the task force continues to meet every one or two months to coordinate activities, and resolve flash flood occurrences. This remains relevant today as flash floods can still occur for a number of reasons, including the blockage of drainage outlets by errant contractors, inadequate road drainage facilities, and wear and tear with the ageing of Singapore's drainage and road infrastructure.

Platform Levels and Requirements

Apart from specifying drainage requirements, the Drainage Department also stipulated the platform levels required for new buildings and infrastructural facilities for flood protection purposes. Vulnerable underground facilities such as rail and road tunnels had to comply with more stringent requirements. For example, all ground openings (including ventilation ducts) and accesses of subterranean facilities, such as Mass Rapid Transit (MRT) tunnels and stations, underground roads, and building basements, would have to be at least one metre above the highest recorded flood level. The effectiveness of these measures was put to the test in May 1988, when heavy rains caused flooding in various parts of Singapore. Although the floods resulted in traffic jams and disrupted bus

services, the MRT trains continued to run smoothly as the stations and tunnels were well protected.

High sea levels also pose a challenge for drainage to the sea. Higher tide levels can aggravate inland flooding during rainstorms or storm surges, where the seawater is pushed to the shore by the force of the wind. In view of this, since 1991, all reclamation projects had to be built at least 125 centimetres above the highest recorded tide level. This was deemed by experienced drainage engineers to be a prudent measure, given the tendency for reclaimed land to settle over time. With hindsight, this requirement has put Singapore in a stronger position to deal with any future increases in sea levels arising from climate change as the requirement exceeds the Intergovernmental Panel on Climate Change's projection of the highest sea level rise in the region — 59 centimetres — by the end of the twenty-first century.

Dealing with Land Constraints: Opera Estate Outlet Drain Project

In land-scarce Singapore, drainage engineers often found themselves having to find creative solutions to drainage problems so as to minimize the use of land or develop conjunctive uses for the land. One example of the innovative use of land was the Opera Estate Drainage Improvement Scheme.

Houses lined the banks of the Opera Estate Outlet Drain and used to be hit by frequent floods. During flood events, residents were greatly inconvenienced and roads were made impassable to traffic. The conventional approach was to widen the drain, but this would require expensive and disruptive land acquisitions. Instead, in 1996, the Drainage Department's engineers came up with the solution of a Pump Drainage System, which comprised a two-tier drain (an upper tier and lower tier), a storage pond, and a pumping station.

During normal rainfall, rainwater would be channelled (by gravity) via the upper tier of the outlet drain to the sea. In a heavy storm, excess rainwater would overflow into the lower tier and be

stored in an underground pond next to the outlet drain. After the storm, the rainwater would then be pumped back into the outlet drain. This two-tier system ensured minimal electricity consumption as the pump was only operated during heavy storms.

To maximize land use, the engineers designed a storage pond underneath a school field, with the pumping station sited above it in a small corner beside the field. The old outlet drain was replaced with a new covered drain which enabled a landscaped park connector with benches, and jogging and cycling tracks to be built on it for community enjoyment, and provided improved connectivity between both banks of the drain as well. Hence, besides a flood-free estate, residents of Opera Estate can now enjoy a picturesque stroll or ride to East Coast Park on top of the covered drain.

FLOOD CONTROL TODAY

Since 1973, more than S$2 billion[3] has been spent on the construction of new drains and canals in Singapore. These have helped to reduce flood-prone areas significantly by more than 95 per cent over the last few decades, even as urbanized areas have increased over the same period. By the early 1990s, basic drainage infrastructure had been provided almost all over Singapore, and by 2000, widespread flooding had become virtually unheard of.

On 19 December 2006, Singapore experienced its third heaviest storm recorded. A total of 366 millimetres of rain fell over a 24-hour period. Despite the intense rainfall, there were no major floods and only a few isolated spots (totalling 15 hectares) were affected. This is a strong testimony of the effectiveness of the drainage system.

Nevertheless, flash floods and pondings still occur in isolated locations around Singapore, and some low-lying areas experience localized flooding during heavy rains. PUB is now targeting its flood alleviation projects in these areas. As some of the older canals, drains, and outlet drains approach the end of their useful lifespan, PUB will also improve and upgrade them, as well as others that

may still be functioning well, but will become inadequate when new developments take place in the near future.

Integration of Storm Water Management with the Water Loop

With the transfer of the Drainage and Sewerage Departments in ENV to PUB in 2001, the drainage functions are now integrated with the water supply catchment functions. Reservoirs such as Kranji, Pandan, Bedok, and Lower Seletar had been constructed within urban catchments and received urban run-off from the drainage network. This close relationship between drainage networks and water catchments was further enhanced in June 2006, when the planning, development, and management of reservoirs and waterways for water supply and flood control were integrated under one department in PUB — the Catchment and Waterways Department. This underscores the important role that storm water management plays in the water loop.

Marina Reservoir

Not long after the cleaning up of the Singapore River in the 1980s, the government began to seriously consider the Marina and Kallang Basin as a potential reservoir. Parts of the Marina Catchment, particularly those within the city centre, were notoriously low-lying, and a reservoir with a controlled water level could help to alleviate flooding.

Touted as a three-in-one project that would provide water storage, flood control, and lifestyle attractions, the Marina Reservoir would be formed by the building of a dam across the Marina Channel. This dam, known as the Marina Barrage, would act as a tidal barrier so that high tides would not be able to advance further inland, preventing the flooding of low-lying city areas in the Marina Catchment. At the same time, a 240-hectare freshwater reservoir

would be created behind the dam, Singapore's fifteenth reservoir. In addition, the Marina Reservoir would have the potential to become an integrated water sports hub and premier tourist attraction with its constant water level all year round, making it conducive for recreational activities such as sailing, canoeing, dragon boating, fishing, and river cruises. Its location and synergies with other key attractions and developments such as the Gardens-by-the-Bay, Marina Sands Integrated Resort, and the Downtown Marina would also reinvent the city centre, creating a unique and vibrant Singapore.

The Marina Barrage, comprising nine steel crest gates and seven pumps, would isolate the urban rivers and canals from the sea and its tidal influence. To serve a flood control purpose, the barrage would be operated based on rainfall and tidal conditions. Under normal conditions, the crest gates will remain upright so a constant water level is maintained throughout the reservoir and the inland rivers of the Marina Catchment, regardless of the tide level. If a heavy rain coincides with a low tide, the crest gates can be lowered. As the water level of the Marina Reservoir is above the tide level, the water will flow out to the sea. When a heavy rain coincides with a high tide, the crest gates will be kept upright to keep the high tide out. Pumps will be activated to remove the excess water from the reservoir, keeping the water level in the reservoir and its upstream catchment fairly constant.

When fully operational, the barrage will alleviate flooding in the low-lying areas in the city centre, and is expected to reduce the size of flood-prone areas in Singapore to less than 100 hectares.

The Remaining Areas

Despite these efforts, it is impossible to eradicate floods in Singapore completely. The drainage system is built to a design norm of one-in-five year storms, a widely adopted standard. Should there be storms that are more intense than this, the drainage system may have difficulty coping. It would be costly (in monetary terms as

well as opportunity cost in land-scarce Singapore) to upsize drains to cater to the most intense storms, nor is it possible to predict when the heaviest storms would occur and their maximum intensities, given the vagaries of the weather.

There are also low-lying flood-prone areas in Singapore where raising the ground level is the only way to alleviate flooding. Since tearing down buildings just to raise the ground level is extremely expensive, highly inconvenient, and a waste of resources, the only cost-effective option is to raise the ground in conjunction with redevelopment plans. In such cases, the drainage master plan earmarks such areas, so that when developers submit their development plans for approval, the requirements to raise the ground can be made known to them at an early stage and incorporated prior to development.

PUB has set up a database to track these areas. It shows, for example, the remaining depressed roads to be raised in conjunction with future road or drainage improvement works. A similar database is maintained on public buildings with a history of flooding.

Flood Response

Where flood alleviation projects have not been put in place, PUB will issue advisories to all building occupants in the flood-prone areas in October, prior to the wet season. These advisories will remind the residents of the high tide periods, the radio flood warning system, and the flood prevention measures they can take.

To cope with flood situations, PUB also has teams on standby to tackle them. A flood response room has been set aside as a command centre. When intense rain is forecasted, NEA's meteorological services will alert PUB via fax and mobile text messages, and the mobile teams are then deployed immediately to designated "hot spots" before the rain begins. Any drain obstructions observed at the sites are cleared immediately to prevent flooding, and if need be, the maintenance contractors are mobilized. If flooding does

occur, flood investigation officers will be deployed to the site to ascertain the cause of flooding. Should the situation escalate, PUB will activate a "Combined Operations Room" to monitor the flood situation, ensure a suitable distribution of resources, and mobilize additional manpower where necessary to address the floods.

After heavy rain, PUB will review any floods that have occurred and look into how a repeat flood in the same location can be prevented. Where the cause of the flood is insufficient drainage outlets, local constrictions, or damaged drains, PUB will plan and carry out the improvements or repairs within two weeks where possible. If the works are more substantial and outside the scope of its regular maintenance contracts, the drain will be included in PUB's ongoing drainage improvement plans.

Maintenance Regime

PUB maintains an extensive network of some 990 kilometres of drains and canals and 7,000 kilometres of public roadside drains. To keep them free-flowing and without silt or debris, PUB engages private contractors to carry out physical cleansing, maintenance, and minor structural repairs of drains and canals. It spends about S$10 million a year to keep drains and waterways clean and in good functioning condition. Nevertheless, cleaning contractors can only do so much, and a lot more depends on the public playing their part to keep Singapore litter-free. For example, litter thrown from cars along roads and expressways find their way into roadside drains and the chokage can pose flooding risks. As such, PUB works closely with NEA and non-governmental organizations such as the Waterways Watch Society to raise public awareness and educate Singaporeans on the importance of keeping Singapore clean.

While the waterways are clean most of the time, they turn brown during and after rain. This is due to sediments that are washed into the rivers by the rainwater. They can remain suspended in water for a long time, resulting in murky-coloured water. These

sediments are not only unsightly, but also increase the risk of floods as the build-up of silt reduces the conveyance capacity of the drains. Silt sediments also increase the cost of water treatment. To prevent the discharge of silty water and to keep storm water in the drainage system clean, a Best Management Practice (BMP) approach is adopted.

A major source of sediments is construction sites as construction activities tend to expose bare surfaces which are easily eroded and washed into the waterways during rain. In view of this, the construction industry is actively engaged in the sharing of BMPs and implementation of earth control measures at construction sites. To drive home the importance of earth control measures, PUB has instituted the need for all construction projects to employ a Qualified Earth Control Professional (QECP). The QECP designs a detailed earth control management plan for all stages of the project and supervises the implementation of the plan. Enforcement actions are taken against construction sites that do not abide by their earth control management plans and cause silty water to enter the waterways.

Integration of Drainage with Other Uses

Given the extensiveness of the drainage system and limited land in Singapore, PUB constantly explores the potential integration of drainage with other land uses. To a large extent, the integrated use of the drainage system for flood alleviation and water catchment purposes has been done. Another way to optimize land use lies in the design of covered drains, so that the top of the drains can be used as pedestrian walkways. Land developers are also encouraged to integrate the drainage infrastructure within their developments to optimize land use. The Stamford Canal serving the Orchard Road area, for example, was built as a series of covered drains and integrated within adjacent commercial developments to provide a wide and continuous pedestrian mall, which serves as an important

public space in the shopping district. PUB also worked in tandem with NParks and URA to create "park connectors" (jogging or cycling tracks) from drainage reserves on either side of canals or monsoon drains. Going forward, PUB has also embarked on the Active, Beautiful and Clean (ABC) Waters Programme to tap the potential of waterways and reservoirs to develop more social and recreational opportunities, and community spaces.

CREATING NEW VALUE

In most parts of the world, waterways are designed primarily for storm water conveyance purposes. Nevertheless, as early as the 1970s, Singapore realized that there is much value that can be created from clean flowing waterways. In 1977, then Prime Minister Lee Kuan Yew put forth an ambitious goal to clean up the Singapore River and Kallang Basin. Both were badly polluted from heavy traffic along the river, and the disposal of garbage, sewage, and other by-products of industries located along the river's banks. Cleaning up the rivers involved reviewing land-use planning for the area and re-siting pollutive industries, workshops, and street hawkers, amongst others, from the banks of the rivers. Ten years on, in 1987, the rivers were transformed into pleasant and flowing waterways that were even able to attract marine life back (see Chapter 3 for more details of this river clean-up). The success of the river clean-up together with URA's rejuvenation efforts led to pubs, restaurants, and shops sprouting up along the river banks, showing Singaporeans the value of clean and flowing rivers, and the potential for the development of waterfront activities.

In the 1970s and 1980s, the government made a concerted effort to develop new housing estates in previously undeveloped parts of Singapore, which required a corresponding expansion in the drainage system to deal with the increased surface run-offs. These canals were large and often empty during dry weather, which was not a pretty sight. Following the success of the Singapore River

clean-up, MND decided to set up a multi-agency Waterbodies Design Panel (WDP) in 1989, involving a multi-agency taskforce led by URA and comprising representatives from HDB, NParks, Maritime and Port Authority (MPA, then known as the Port of Singapore Authority), then PWD, PUB (then ENV's Drainage Department), as well as the private sector to evaluate and advise on improvements to the designs and aesthetics of all major waterways so as to integrate them into the urban landscape.

ENV worked closely with the WDP to identify key waterways which could be aesthetically developed in a manner that would enhance the natural charm and beauty of their surroundings while retaining their core functions. These waterways included Sungei Punggol, Sungei Api Api, and Alexandra Canal. For example, at Sungei Punggol and Sungei Api Api, mangrove saplings were replanted along the banks to restore part of the natural greenery and ecosystem. The rivers were also deepened to increase their conveyance capacity and to maintain a minimum water level in the rivers for the mangroves to thrive.

Ten years after its inception, the WDP was dissolved to encourage more innovative ideas from the private sector. Unfortunately, this did not take off with the private sector, in part due to the economic downturn of the late 1990s and early 2000s. Without the WDP, aesthetic improvements to waterways would lie dormant for several years.

PARKS AND WATERBODIES PLAN

In 2002, URA, working in collaboration with NParks, introduced a new Parks and Waterbodies Plan under the Singapore Master Plan. The Parks and Waterbodies Plan aims to transform Singapore beyond a "Garden City" into a "City in a Garden" with the vision to evolve Singapore into a bustling metropolis, nestled in a lush mantle of tropical greenery. Provisions have been made for an islandwide network of green spaces and to create more

opportunities for people to gain better access to its waterways and waterbodies for recreation. The intent is to make greenery, nature, and the waters more accessible to all, and to provide a variety of recreational choices.

With limited land area for recreation, enabling people to make use of water "spaces" was an important strategy to meet recreational needs. PUB worked with URA and NParks to open up selected waterways and waterbodies such as the Kallang River, Lower Seletar, Pandan, MacRitchie, and Bedok Reservoirs, for water-based activities such as rowing, kayaking, wakeboarding, or just for people to sit and picnic by the waters in the parkland fringing the reservoirs. At the same time, working with the Singapore Sports Council (SSC) and National Sports Associations (NSAs) such as the Singapore Canoe Federation, Singapore Dragon Boat Association, and Singapore Sailing Federation, PUB introduced new activities such as sailing, dragon boating, and canoeing in Singapore's reservoirs in 2004. Today, a myriad of activities are carried out in and around nine of fourteen reservoirs.

To enhance the accessibility between the green spaces, park connectors — green, landscaped jogging and cycling paths that connect people from park to park — were developed along the many waterways and drainage reserves around the island. The target is to build a total of 300 kilometres of park connectors by 2015, covering seven closed loops for recreational activities. To date (2008), about 100 kilometres have been built, including the first complete loop of 42 kilometres, known as the Eastern Coastal Park Connector Network.[4]

In addition to park connectors, the Parks and Waterbodies Plan provides for a hierarchy of parks distributed throughout Singapore. Founded in 1859, the Singapore Botanic Gardens is one of the icons of Singapore's green network. Now spread over 63 hectares close to the centre of the city, it offers some of the most luxuriant landscaped grounds in Singapore, welcoming about 3 million visitors annually. More than just a public park for recreation, the Botanic Gardens is

internationally recognized as a leading institution of tropical botany and horticulture with its Library and Herbarium collections of over 600,000 preserved specimens.[5]

The latest major addition to Singapore's green spaces is the Gardens-by-the-Bay, which will feature three world-class gardens on 101 hectares of prime land around the Marina Bay waterfront. This is truly an expression of the vision for a City in a Garden, and will anchor Singapore's new downtown. The first phase of the project involves the development of a 52-hectare garden at Marina South and is due to be completed by 2011. The Gardens-by-the-Bay will be a "green" garden in every sense of the word. To this end, the planners and designers have looked at the latest technologies available and are designing a system that will be as energy and water efficient as possible.

CONCEPTUALIZING THE ABC WATERS PROGRAMME

In 2004, seeing the untapped potential of reservoirs and waterways, the Ministry of the Environment and Water Resources spearheaded the opening up of these waterbodies both for their aesthetic value and for community activities on the water. As the waterways are often located close to, and run through, residential heartlands, they could potentially be developed as focal points for community activities, enhancing the value of surrounding properties. The use of the waterways for community activities will be further enhanced by the park connectors, which will increase accessibility to these sites, and invite even more residents to visit and participate in activities.

There is also great potential in utilizing the pervasive "blue network" of reservoirs and waterways (as shown in Map 5) for experiential-based public education on the need to keep the waters clean. Prior to this, PUB had conducted with mixed success several public campaigns over the years to get Singaporeans to value and

conserve water. Adopting a bold mindset, PUB felt that the best way to get people to internalize these values was for them to enjoy and appreciate waterbodies and waterways, and in so doing, bond with water. At a national level, Singapore could be transformed into a unique "City of Gardens and Water".

The Active, Beautiful and Clean Waters Programme (or ABC Waters) is the umbrella programme that embodies this vision of unlocking the hidden potential and opportunities in waterbodies and waterways. The ABC acronym encapsulates the fundamental objectives of the programme:

Active: Providing new community spaces and bringing people closer to water through recreational activities. With more opportunities for interaction, it is hoped that people will connect with the water, developing a sense of ownership and valuing it better.

Beautiful: Developing reservoirs and waterways into vibrant and aesthetically pleasing lifestyle attractions that integrate with parks, estates, and even commercial developments.

Clean: Improving water quality by incorporating features such as aquatic plants, retention ponds, fountains, and recirculation to help remove nutrients. The aim is also to minimize pollution in the waterways through public education and by building closer people-water relationships.

Developing the ABC Waters Master Plan

To kickstart the programme, PUB initiated demonstration projects at three of the most popular waterbodies — MacRitchie Reservoir, Bedok Reservoir, and a stretch of Kallang River. These projects would be showpieces of what could be achieved through ABC Waters.

With experience gained from implementing the demonstration projects, PUB began to develop a master plan to identify potential projects across the island, for systematic implementation over the

next ten to fifteen years. The map of Singapore was divided into three "watersheds", each with its own themes and projects. For each watershed, a consultant team known as the watershed manager (Black & Veatch, CH2M Hill, and CPG Consultants for the Western, Central and Eastern Catchments respectively) was appointed to develop the plans together with other planning agencies such as URA, HDB, JTC, and NParks. Such an integrated approach allowed various agencies to pool ideas and resources and to synergize the planning of infrastructure. For example, PUB's plans to redevelop the stretch of Kallang River running adjacent to Bishan Park were tied in with NParks' plans to overhaul the park. Concurrently, PUB consulted non-governmental organizations and interest groups that had specialist knowledge in particular areas. For example, the Nature Society was invited to share its expertise on plant and animal life.

The ABC Waters Programme will be implemented in phases, starting with the first five-year plan (2007–2011) comprising twenty-eight projects at an estimated cost of S$300 million. Subsequent projects will be further evaluated based on the evolving needs and aspirations of the community.

Engaging the 3P Partners

From the outset, PUB recognized the importance of actively engaging the public, private, and people sector (3P) partners in all aspects of the ABC Waters programme. On its own, PUB lacked the expertise in master planning and landscape design, the knowledge of what residents wanted, and the ability to maintain the projects in the long run. Working closely with the 3P sectors was the best solution to plugging these gaps.

The Public Sector

An inter-agency working committee (IAWC) was set up to coordinate the planning of projects among planning agencies such as PUB, HDB, and NParks. The agencies were also invited

to review some of their existing projects to incorporate ABC Waters elements. HDB has done this for some of its estate redevelopments, for instance, at Whampoa Estate along Kallang River. Meanwhile, NParks is working with PUB on several projects, such as the Gardens-by-the-Bay, to integrate adjacent waterways with their parks and park connectors.

Aside from providing technical input, the IAWC has also served as a very useful source of feedback. The agencies involved have had plenty of experience in public consultation, and were aware of what the community wanted. NParks and HDB, for example, had knowledge of the common complaints and requests, as well as the profile of residents who live in various neighbourhoods. These in turn affected the concepts for each project, the facilities proposed, and the way the public education messages were presented to the community.

The Private Sector

To woo the private sector, multiple workshops and seminars were organized to introduce the concept of ABC Waters and to present successful overseas examples of waterfront transformation. Meanwhile, PUB continues to persuade developers to consider installing ABC Waters features. Additional incentives come in the form of "Green Mark"[6] points — that is developers could gain Green Mark points for incorporating ABC Waters elements. Private sector projects have started to come in, mainly from businesses that see the benefits of integrating water elements into their developments.

From a technical standpoint, PUB's Code of Practice on Surface Water Drainage was modified to encourage ABC Waters elements such as water-sensitive landscaping. PUB also developed a set of ABC Waters Design Guidelines, which include design ideas and considerations for the treatment of water edges, and technical guidelines for water sensitive landscaping.

Besides persuading professional engineers and architects on the ground, PUB has also been tapping the experience of renowned

experts in the design field. Together with URA and other government agencies, PUB has formed an ABC Waters Review Panel, comprising top local architects, engineers, and developers. In a set-up not unlike the WDP, the panel meets on an *ad hoc* basis to review the ABC Waters Master Plan and the design of strategic ABC Waters projects, providing valuable insights and advice on the ABC Waters Programme.

The People Sector

The most critical group of stakeholders for the ABC Waters programme is the community itself. A week-long public exhibition was held in 2007 featuring the ABC Waters Master Plan. The opening ceremony was officiated by Prime Minister Lee Hsien Loong. In a show of support for the programme at the highest levels, he declared that Singapore would strive to become "a City of Gardens and Water", a significant acknowledgement of the waterways becoming part of the new image of Singapore.

PUB engages the community by encouraging them to develop sustainable projects around the enhanced water features in their neighbourhood. For instance, a community workshop was conducted prior to the launch of the Kolam Ayer project, with participants from grassroots organizations, schools, and interest groups taking part. At the workshop, participants selected the best ideas and were excited about developing them into sustainable projects that would be run by the community itself.

For people to participate enthusiastically in water activities, they have to feel comfortable and safe with water. Hence, all ABC Waters projects are designed with safety as a top priority. PUB has developed an alternative of bringing water closer to people in a safe manner, such as the carving of rivulets and water playgrounds away from the main canal channels, where people can interact safely with water, out of harm's way. Metal railings are replaced by earth mounds, boulders, or shrubs to form a natural barrier along the river bank.

Developing New Dimensions and Capabilities

To unlock the opportunities of the "blue network", a change in mindset was needed from all stakeholders to see drains, canals, and reservoirs not only as utilitarian facilities, but as potential areas for fun-filled community activities and aesthetic appreciation. For PUB, this meant that the water activities had to be managed in a way that safeguards the water quality standards. In addition, drainage engineers were also charged with the task of ensuring that with the introduction of new aesthetic designs for drains and canals, the waterways would still be capable of fulfilling their core functions of flood alleviation and speedy conveyance of surface run-offs. The scale of the ABC Waters Programme also added a more challenging dimension to the project.

In developing the ABC Waters programme, PUB engineers had to utilize new skill sets such as urban planning, environmental engineering, and landscape design. To address this, PUB leveraged both the public and private sectors through the engagement of the Watershed Managers, who worked in consultation with other planning agencies such as URA, HDB, JTC, and NParks. PUB engineers were also able to learn quickly from an NParks senior landscape architect, who was attached to PUB in an advisory capacity for six months.

CONCLUSION

Singapore has done much to turn floods into a thing of the past. The success of its flood management strategy stems from the long-term approach adopted. This is exemplified in the Bukit Timah Flood Alleviation Scheme, where the foresight of the British to earmark land for drainage reserve safeguarded the option to construct a diversion route. Long-term planning continues to underpin the work that is done today. To ensure that new flood areas do not occur with more urbanization, PUB proactively plans for and puts in place early drainage schemes for new developments.

In addition, some of the safeguards and measures that were instituted previously have stood Singapore in good stead to address emerging issues such as rising tide levels due to climate change. Scientists predict that climate change will bring with it more intense rain in Singapore. PUB is taking part in a vulnerability study to understand the impact and implications of climate change on the drainage system and to develop ways to ensure the robustness and efficiency of the system.

Even as PUB enhances drainage efficiency and flood response, it is moving beyond just flood control and flood management to transform utilitarian reservoirs and waterways into Active, Beautiful and Clean Waters. Developing this Programme and realizing its full potential may take a few decades, and the journey promises to be an uncertain but exciting one. Some regard it as a risky and expensive gamble, as allowing people to come close to canals and reservoirs could dirty them. However, PUB is prepared to challenge this mindset, so instead of keeping people away, it is now encouraging them to come closer to water so that they will learn to keep the waters clean. This stems from the strong belief that long-term sustainability for Singapore can only be achieved if the people become stewards of the environment.