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Mr Robin Frith

Tamar Lake Inc.
31 Lanoma Street
East Launceston
TASMANIA 7250

14 March 2012

Project No: B12671.001

Dear Sir

RE: Tamar Lake Barrage Cost Estimate

Further to our discussions, E3 Consulting Australia Pty Ltd (E3) is pleased to provide you with a fee proposal to prepare an order-of-magnitude cost estimate for the proposed Tamar Lake Barrage. E3 is wholly owned CDM Smith and is the Australian operating entity for CDM Smith. In Australia, we have offices in Brisbane, Sydney and Melbourne.

Background

E3 understands that Tamar Lake Inc is developing a strategic plan to find a solution to the accumulation of silt in the upper reaches of the Tamar River. The optimal solution appears to be a tidal barrage located near the Point Rapid area of the river, between Moriartys Reach and Long Reach. This solution offers many other significant benefits to the whole of the Tamar Valley in addition to improved silt management.

To move the proposal forward and to facilitate discussions with key stakeholders such as the State government a cost estimate for the project is required. We offer our services in this regard as follows.

Scope of Services

It is proposed to develop an order-of-magnitude cost estimate for the barrage using the recently completed Marina Barrage in Singapore as the conceptual model as follows:

- A kick off meeting via teleconference between E3 and Tamar Lake Inc will be held to confirm project objectives and gain a better understanding of the key stakeholders and their needs;
- Review of available information including:
 - Geological mapping;
 - Navigation charts;



- Marina Barrage design drawings, construction methodology and bill of quantities that will be sourced from CDM Smith office in Singapore; and
- Any other information that can be provided by Tamar Lake Inc.
- A Bill of Quantities for the proposed Tamar Barrage will be estimated using the Marina Barrage as the conceptual model and an initial cost estimate developed.
- At this stage of the project there is significant uncertainty around a number of project inputs, particularly the unknown geotechnical and geological conditions at the proposed location which can significantly impact on the costs. An initial high level risk assessment will be undertaken to determine the likely cost range;
- The cost estimate will be reviewed by CDM Smith staff who were involved in the design and construction supervision of the Marina Barrage, and if Tamar Lake Inc are agreeable an Australian contractor experienced in marine works; and
- An estimate of costs for the next logical phase of the project - a feasibility study – would be prepared including an estimate for concept design, high-level geotechnical investigations, delivery strategy, an approvals strategy, identification of environmental constraints and a community engagement strategy.
- A 3D model of the concept will be developed as a 3D sketch-up in Google Earth using images from Marina Barrage and nominal dimensions

Key Personnel

The study will lead by David Murray who has over 35 years' experience in the delivery of bulk water infrastructure. During that time he has developed comprehensive skills in the planning, design and construction phases of major water infrastructure projects including dams, weirs, off stream storages and pipelines.

David started his career as a design engineer and worked on a number of major projects including the hydraulic design and physical modelling of the Burdekin Falls Dam; Queensland's largest dam. In 1985 he was appointed Site Engineer at the dam providing the unique opportunity to build designs he had developed. In 1987 David was appointed Resident Engineer and oversaw the completion of the construction of the main dam and saddle dams.

Since that time David has undertaken the roles of design manager, construction manager and project manager on major water infrastructure projects in Queensland. His more recent projects include:

- Paradise Dam (\$200M) – Technical Advisor
- Traveston Crossing Dam (\$600M)– Project Manager
- Cedar Grove Weir (\$20M)– Expert Review Panel
- Bromelton Offstream Storage (\$40M)– Expert Review Panel
- Wyaralong Dam (\$140M) - Chairman of the Expert Review Panel and Verification Manager

A review of the cost estimate will be undertaken by Robert Hurdle who served as the Project Director and Design Manager for the design phase of the Marina Barrage project in Singapore. The design



was based on CDM's Study Report completed in mid-2003 which defined the major project elements required to separate a river system from the ocean to create a fresh water reservoir. Impounding fresh water would increase the potable water supply for Singapore, greatly reduce flooding and enhance opportunities for commercial development around the periphery of the newly created Marina Reservoir. Design work commenced in Aug-2003 and, in his role as the Project Director, Mr. Hurdle was the single point of contact between the CDM Smith design team and the client, the Singapore Public Utilities Board (PUB); he also managed the CDM Smith design team and design teams from other subconsultants. As the Design Manager he coordinated the efforts of all technical design discipline teams to assure their work was coordinated. Key aspects of the project include:

- A 350m long concrete barrage filled with nine 28m wide steel crest gates that open during significant storm events when the ocean tide is low;
- A massive drainage pumping station, with seven pumps that each have a capacity of 40m³/s, that are used during storm events when the crest gates are closed and ocean tide is high;
- A boat hoist that allows 70-tonne, 20m long boats to traverse the barrage and gain access to either the ocean or reservoir;
- A back-up power supply consisting of three 4.3MW diesel engines that allow the facility to operate independent from utility power; and,
- A control system that provides comprehensive control of all equipment with remote monitoring to integrate facility operations with other PUB operations.

Robert was responsible for the team's preparation of the detailed design documents including technical specifications, drawings, bills of quantities, technical schedules and cost estimates. The contract documents were issued to tenderers in mid-2004 and he was responsible for evaluation of tenderer proposals in late-2004 and initiation of contractor construction activities in Jan-2005. He continued to provide technical support to the project through construction which resulted in official commissioning of the facility in Oct-2008.

For your information we attach:

- CDM Smith's project description of the Marina Barrage project
- A copy of an article on the Marina Barrage in the June 2009 edition of "The Singapore Engineer".

Deliverables

E3 will provide a brief report detailing the anticipated construction methodology and the order-of-magnitude estimate of the likely cost range. In addition a 3D Google earth model built using 2D images of Marina Barrage or other relevant barrages will be provided.



Fee

The work described above will be undertaken for a lump sum fee of 19,750.00 (excl GST).

Should a site inspection be required, this would be undertaken by David Murray ex our Brisbane office. Allowing for two nights and two working days of travel and site time, our estimate for a site inspection would be \$5,100 (comprising \$4,000 for labour plus \$1,100 for flights, accommodation and rental car).

Should other additional work be required beyond the scope of services proposed, the additional costs shall be discussed with Tamar Lake Inc. prior to proceeding. Similarly, should the scope of works be reduced or a more cost-effective option be taken, the savings will be passed on to you. Any variation will be at time and expense according to the attached E3 Schedule of Rates and Charges (GST exclusive) subject to prior approval.

This quotation is confidential and valid for 60 days and is based on the above scope and programme. the cost estimate is quoted exclusive of any Goods and Services Tax (GST). Invoices will be issued monthly passed on progress.

Assumptions

This Proposal is based on good faith and E3 understanding of the scope at this point in time and takes into account the assumptions:

- This is a desktop study only and no allowance has been made for E3 staff to undertake a site inspection or field investigations unless specifically directed by scope change; and
- Allowance has been made for submission of one draft report and receipt of a single coordinated response prior to issue of a final report.

E3's Terms and Conditions of Business

We accept this engagement on the basis that our Terms and Conditions of Business, as attached, will apply to this work and shall govern our relationship with you. Should you wish to propose different Terms and Conditions, we would be pleased to discuss this with you.

This letter is the 'Engagement Letter' mentioned in our Terms and Conditions of Business. Please read the terms carefully.

You can accept this offer simply by continuing to instruct us or by signing and returning a copy of this letter. It is preferable if we each hold a signed copy of this letter and we suggest that you accept in this way.

Tamar Lake Inc.
Tamar Lake Barrage Cost Estimate
14 March 2012



If you require any further information, do not hesitate to contact me on 07 3828 6951 or 0400 949 335.

Regards,

Marco van Winden

Principal Engineer

Enclosures: E3 Terms & Conditions, E3 Schedule of Rates, CDM Smith Project Description, The Singapore Engineer article

CC:

TERMS AND CONDITIONS OF BUSINESS

1 INTRODUCTION

1.1 We have set out in this document Our basic terms and conditions of business (the 'Terms'), which together with Our Engagement Letter form the Agreement, which will apply to all work We will undertake for You in respect of this engagement. 1.2 If there is any discrepancy or conflict between these Terms and Our Engagement Letter, then the Engagement Letter shall prevail.

2 OUR SERVICES

2.1 We will provide the services set out in Our Engagement Letter (the 'Services') and will use all reasonable efforts to provide the Services in an efficient and timely manner, using the necessary skill and expertise to an appropriate professional standard.

3 YOUR OBLIGATIONS

3.1 You agree to pay for the Services in accordance with this Agreement. 3.2 You will provide Us promptly with such information as may reasonably be required for the proper performance of the Services. 3.3 We will be entitled to rely upon the accuracy of all information provided by You, or others on Your behalf, without independently verifying it. 3.4 You shall retain responsibility for the use of or reliance on advice or recommendations supplied by Us in the delivery of the Services

4 INTELLECTUAL PROPERTY

4.1 We own the Intellectual Property Rights in everything We create in connection with Your matter. Unless We agree otherwise, what We create may be used by You only for the matter for which We create it. 4.2 If You provide anything to Us (for example drawings, specifications) You warrant that Our use of it in performing the Services will not infringe any third party's Intellectual Property Rights.

5 CONFIDENTIALITY

5.1 Both parties acknowledge that they may, in the course of the engagement be exposed to or acquire information that is proprietary or confidential to the other party. Both parties agree to hold such information in strict confidence and not to divulge such information, save for (a) in accordance with a court order, law or stock exchange rule; or (b) with the consent of the relevant party.

6 RELIANCE

6.1 Unless otherwise specifically stated in the Engagement Letter any advice or opinion relating to the Services is provided solely for Your benefit and may not be disclosed in any way, including any publication on any electronic media, to any other party and is not to be relied upon by any other party. 6.2 During the supply of Our Services, We may supply oral, draft or interim advice or reports but in such circumstances Our written advice or final written report shall take precedence. No reliance should be placed by You on any oral, draft or interim advice or reports. Where You wish to rely on oral advice You shall inform Us and We will provide documentary con-

firmation of the advice. 6.3 We shall not be under any obligation in any circumstances to update any advice or report, oral or written for events occurring after the advice or report has been issued in final form.

7 FEES, EXPENSES AND PAYMENT TERMS

7.1 The time based fees, if any, quoted in the Engagement Letter or as separately quoted in a fee letter will remain in force until 30 April and We may increase fees for work continuing past that date. 7.2 Out of pocket expenses incurred in connection with the engagement will be charged to You. 7.3 Any fees, costs, estimates quoted exclude GST unless otherwise stated. 7.4 We will raise a monthly invoice which will be issued to You. Our invoices are payable within 14 days after the date of issuance and are payable in full without any set off, deduction or withholding. 7.5 If the invoice is not paid pursuant to clause 7.4 above We may charge you an additional amount for the Services equal to interest on the unpaid balances at the rate set out in the Engagement Letter.

8 VARIATION

8.1 You may only alter, amend, omit, add to or otherwise vary the Service by issuing a 'Variation Notice' directly to Us. We shall then within 14 days of receipt of the Variation Notice provide You with a breakdown of the increase or the decrease in Our fee resulting from such variation. 8.2 The increase or decrease will be raised by Us within the next monthly invoice to You following provision of the break down.

9 ASSIGNMENT

9.1 You may not assign, novate or subcontract Your rights under this Agreement without Our prior written consent, which We may grant or withhold in Our absolute discretion. 9.2 We may at any time assign, novate or subcontract Our rights, obligations and benefits under this Agreement.

10 SUSPENSION

10.1 In the event of a dispute or where fees remain unpaid beyond the due date, We reserve the right to suspend provision of the Services until such time as the dispute is resolved or the fees are paid. Suspension of the Services will not affect Your obligation to pay Us for Services rendered to the date of suspension.

11 TERMINATION

11.1 Either party may terminate this Agreement by way of written notice served on the other, if:- (a) the other becomes insolvent; or (b) the Services are suspended under clause 10.1 for more than 10 working days; or (c) the other party commits any material or persistent breach of its obligations under this Agreement (which, in the case of a breach capable of remedy, shall not have been remedied within 14 days of receipt by the party in breach of a notice identifying the breach and requiring its remedy). 11.2 We may terminate this Agreement by way of written notice served on You, if You have not made a payment due to Us more than 42 days after its due date and We remind You of that payment and the amount remains unpaid 8 days after the issuance of that reminder. 11.3 Clause 11 shall be without prejudice to any rights that may have accrued for either of us before termination and all sums due to us shall become payable in full when termination takes effect.

12 LIMITATION OF LIABILITY

12.1 In this section, We set out, and You accept, the limitations which apply to Our liability to You should You have reason to make a claim against Us. The limitations and exclusions are accepted by both of us to be fair and reasonable, given the duties We are undertaking, the sums to which We are entitled and the availability (and cost) of insurance. 12.2 Nothing in these Terms excludes, restricts or modifies the application or provisions of any statute where to do so would contravene the statute or cause any part of these Terms to be void. 12.3 These Terms, and the Engagement Letter, are the only communications governing our relationship. Subject to clause 12.2 We expressly exclude and will have no liability for any statements, representations, guarantees, conditions or warranties including any which may be implied by statute, common law or custom or which arise from oral or written communications with You, which are not expressly contained in this Agreement. If any representations are of importance to You, You should ensure that they are expressly set out in the Engagement Letter before signature. 12.4 Subject to clause 12.2 and 12.6, You agree that Our liability for any loss or damage suffered by You (whether direct, indirect or consequential) in connection with Our engagement, including (without limitation) liability for any negligent act or omission or misrepresentation by Us, shall be limited to the amount of professional fees paid to Us in respect of the Services. 12.5 To the extent permitted by law, You agree that to the extent that any loss or damage suffered by You is attributable to negligence, fault or lack of care on Your part or on the part of any person for whom You are responsible, We are not liable (in contract, tort or otherwise) for that loss or damage. 12.6 You acknowledge and agree that any advice, recommendations, information, reports or work product provided to You by Us in connection with this engagement is for Your sole use. You agree that if You make such advice, recommendation, information, reports or work product available to any third party You will notify such third party, in writing, that Our advice, recommendations, information, reports or work product is for Your sole benefit based on the specific facts and circumstances and the scope of Our engagement with You and is not intended to be relied upon by any other person. In the event of a claim by a third party relating to Our Services under this engagement that arises out of a breach by You or any other personnel of this clause 12.6, You agree to indemnify and hold Us harmless and Our personnel from all such claims, liabilities, costs and expenses (including legal fees and disbursements).

13 INDEMNITIES

13.1 You agree to indemnify and hold Us harmless against any and all losses, claims, costs, expenses, actions, demands, damages, liabilities or any other proceedings, whatsoever incurred by Us in respect of any claim by a third party arising from or connected to any breach by You of Your obligations under this Agreement. 13.2 We shall not be liable for any losses, claims, expenses, actions, demands, damages, liabilities or any other proceedings arising out of reliance on any information provided by You or any of Your representatives, which is false, misleading or incomplete. You agree to indemnify and hold Us harmless from any such liabilities We may have to You or any third party as a result of reliance by Us on any information provided by You or any of Your representatives, which is false, misleading or incomplete.

14 FORCE MAJEURE

14.1 If the performance of this Agreement by a party is prevented or restricted by reason of fire, storm, flood, earthquake, war, labour dispute, transportation embargo, law, order or directive of any government in matters relating to this Agreement, or any other act or condition beyond the reasonable control of that party then the party is excused from such performance to the extent of the same, but will use their best efforts to avoid or remove the causes of non-performance and to cure and complete the performance.

15 NOTICE

15.1 Any notice, approval, consent, document submission, direction or other communication under or in relation to this Agreement must be: (a) in writing; (b) marked to the attention of the relevant party; and (c) at the sender's election: (i) sent to the relevant party's email address or; (ii) left at the relevant party's address; or (iii) sent by ordinary post to the relevant party's address. 15.2 A notice, approval, consent, document submission or other communication takes effect from the time it is received unless a later time is specified in it. 15.3 A letter or facsimile is deemed to be received: (a) in the case of a posted letter, on the fifth day after posting; or (b) in the case of an email, four hours after it is sent (as recorded on the device from which the sender sent the email) unless the sender receives an automated message that the email has not been delivered. 15.4 Email may not be used to give notice of termination or suspension.

16 OTHER MATTERS

16.1 No variation of this Agreement will be valid unless confirmed in writing by authorised signatories of both parties on or after the date of signature of the Engagement Letter. 16.2 Any waiver of a party's rights, powers or remedies under this Agreement must be dated and signed by an authorised representative of the party granting that waiver and must specify the right that is being waived and to what extent. 16.3 Our rights and remedies under this Agreement are in addition to any other rights or remedies We have at law.

17 GOVERNING LAW AND JURISDICTION

17.1 This Agreement and all aspects of Our engagement and Our performance of the Services are governed by and construed in accordance with, the laws of applicable in the state of Queensland. The parties agree to submit to the non-exclusive jurisdiction of the courts of that jurisdiction.

18 DEFINITIONS AND INTERPRETATIONS

18.1 In this Agreement unless the contrary intention appears:

GST means the tax payable on Taxable Supplies under the GST legislation. GST legislation means the A New Tax System (Goods and Services Tax) Act 1999 (Cth) and any related Act imposing such tax or legislation that is enacted to validate, recapture or recoup such tax.

Intellectual Property Rights means copyright, all rights conferred under statute, common law or equity in relation to inventions (including patents), moral rights, registered and unregistered trademarks, registered and unregistered designs, circuit layouts, confidential information and all other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields. **Services** means those services set out in the Engagement Letter.

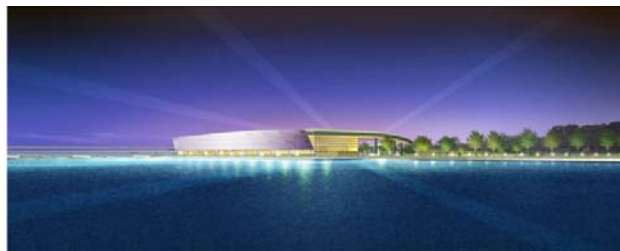
E3 Consult Schedule of Rates and Charges - Effective from 1 October 2011		
Professional and Technical Services	Site Auditor	\$410
	Consultant Director	\$300-380
	(Senior)/Principal Engineer and Scientist	\$220-\$300/hr
	(Senior)/Associate Engineer and Scientist	\$190-\$220/hr
	Senior Engineer and Scientist	\$150-\$190/hr
	Project Engineer and Scientist	\$135-\$150/hr
	Staff Engineer and Scientist	\$110-\$135/hr
	Technician	\$85-\$110/hr
	Drafter/CAD Operator	\$115/hr
Clerical	\$60 - \$90/hr	
Contract Labour	From time to time, E3 Consulting Australia Pty Ltd retains outside professional and technical labour on a temporary basis to meet peak workload demands. Such contract labour will be charged at regular Schedule of Charges rates	
Litigation Support	Expert testimony in depositions, hearings, mediation and trials will be charged at 200 per cent of above rates.	
Travel Time	Travel time will be charged at regular hourly rates, for actual time involved	
Equipment	Field test equipment	As specified for item
Motor vehicle usage	Motor vehicle daily rate (kilometre restrictions apply)	\$0.75/km or
		\$120/day
Outside Services (sub-contracted mark up)	Rental of equipment not ordinarily furnished by E3 Consulting Australia Pty Ltd, and all other costs such as laboratory analysis, special printing, photographic work, freight, subsistence, subcontractors, etc.	Cost + 10-15%
Communication and Report Production	In-house costs for telephone and computing support, facsimile, postage and printing.	5% of total Project labour cost (hourly rate x5%)
Goods and Services Tax (GST)	Prices in this schedule are exclusive of GST. Where GST is applicable, the prices will be adjusted to account for the GST arising. Any quoted lump sum prices are assumed to be exclusive of GST unless expressly included.	GST is 10% as per GST legislation
Terms	Payment is due 14 days after date of invoice. A finance charge of 1.5% per month may be charged on past due accounts. E3 Consulting Australia Pty Ltd makes no warranty, either expressed or implied, as to its findings, recommendations, specifications, or professional advice except that they are prepared and issued in accordance with generally accepted professional practice.	

E3 Consulting Australia Pty Ltd reserves the right to revise its Schedule of Charges with changes in its practice.

Creating Marina Reservoir – the Marina Barrage and Pump Station

Singapore

The Marina Barrage was first conceptualized by CDM Smith while performing a 1983 study for a flood alleviation scheme in Bukit Timah, and was further developed in a 1986 study to determine the feasibility of situating the barrage across the Marina Channel. In 2002, the Public Utilities Board (PUB) of Singapore retained CDM Smith to perform a detailed engineering study which included a conceptual design. In mid-2003 CDM Smith was commissioned to prepare detailed design documents and this was followed in early 2005 with the provision of services during construction. CDM Smith was PUB's representative and construction manager during the implementation of the facilities.



CDM's services to PUB have included concept development (including system yield and water quality analyses), feasibility study, detailed design, owner's representative during procurement and tendering, and construction management.

The facility was commissioned in 2008. The principal Barrage facilities include a 305m-long barrage with nine 5m-tall steel crest gates each 26.8m long and a massive 280 m³/sec pumping station facility with a 13 megawatt power station.

The completed Barrage creates an urban water body having multiple and important benefits to Singapore including flood protection, stable water levels for recreational activities and aesthetic interest in the heart of the nation's downtown centre, and impoundment of an additional 132,500-m³/day (35 mgd) of fresh water as a source of drinking water from urban runoff.

Under normal conditions, the crest gates will remain closed to isolate the reservoir from the ocean. During extreme storm events and when the tide is low, they will



operate in harmony to release excess flows from the marina. When the tide is high, the pump station – housing seven vertical-shaft, axial-flow pumps, each of 40 m³/sec capacity – will operate, to pump excess stormwater to the sea. Regardless of storm flows and tide levels, the barrage and pumping station will alternate to provide stable water levels

Key Project Features

- 305m channel barrage and 280 m³/sec pumping station
- Multiple-benefit project for flood control, aesthetic / recreational interest, and new water supply
- Visitor Centre with interpretive and interactive exhibits on environmental sustainability and urban water management

Client:
Public Utilities Board

Project Dates:
2002 – 2008

Construction Cost:
US\$170,000,000

CDM fees:
US\$10,900,000

in the reservoir. Pump and gate operations will be managed from central control facilities having real-time data links to national weather stations and catchment monitoring points to ensure early and proactive measures when flood conditions are threatening.



To accommodate the occasional movement of boat traffic between Marina Reservoir and the sea, the east abutment of the Barrage includes a 70-tonne boat hoist.

The Marina Barrage is located in land that is being developed as urban parkland - “Gardens by the Bay” - surrounding the newly created reservoir. The facility’s architecture and landscaping soften the structure’s shape and integrate it into the park by carefully melding textures and colors into the surroundings. The public will be encouraged to visit the site for leisure. Due to the project’s natural setting and emphasis on user-friendliness, the design team sought a careful balance between form and function. The roof of the pumping station, visitor center, and power station is covered with turf grass and accessible to the public via two concentric helical ramps. Visitors can walk from the park, around the facility, and up the ramps to take in dramatic sea and city views from the roof, and then walk across the barrage itself.

The state-of-the-art visitor center will showcase Singapore’s significant environmental accomplishments, offering films, exhibits, and refreshments.

Marina Barrage and Pump Station
Singapore



The **SINGAPORE ENGINEER**

Jun 2009
MICA (P) 262/09/2008

Civil & Structural • Infrastructural • Environmental Edition

COVER STORY: Marina Barrage



Marina Barrage

Officially opened in October 2008, the multiple-award winning Marina Barrage spans the mouth of the 350 m wide Marina Channel, located in the southern part of Singapore. The large and complex engineering project was implemented at a cost of S\$ 226 million, over a period of three years. The many challenges in its execution were overcome through an innovative and integrated approach involving strong partnerships across multiple disciplines.

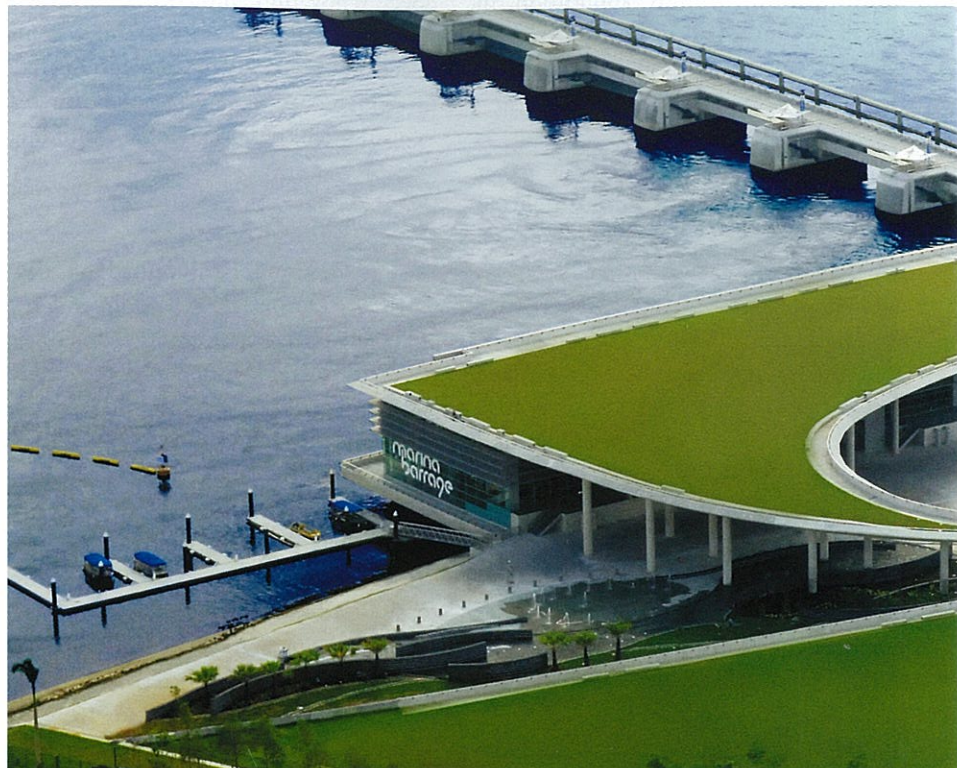
INTRODUCTION

Marina Barrage is a cost-effective engineering solution to meet Singapore's need for water, whilst providing flood control, and offering water-based recreational activities, at the same time.

Freshwater reservoir

By keeping the seawater out, Marina Barrage has created the Marina Reservoir, Singapore's 15th freshwater reservoir, and the first in the heart of the city.

Marina Reservoir has the most urbanised catchment which is also the largest (with an area of 10,000 hectares). Rainwater collected in the drains and canals from one-sixth of Singapore's land area flows into Marina Reservoir, from places as far away as Ang Mo Kio, Bishan, Orchard Road, Alexandra, and Paya Lebar, via the Singapore River, Geylang River, and Kallang River, as well



Marina Barrage fulfils three objectives - the creation of a freshwater reservoir, achievement of flood control,

as Stamford Canal and Rochor Canal.

Together with two other new reservoirs, in Punggol and Serangoon, Marina Reservoir will increase Singapore's water catchment from half to two-thirds of the country's land area, by 2011.

Tidal barrier

Marina Barrage acts as a tidal barrier separating the reservoir from the sea. When high tide coincides with heavy

rainfall, the barrage prevents sea water from flooding low-lying parts of the city such as Chinatown, Boat Quay, Jalan Besar, and Geylang.

During heavy rain, at low tide, steel gates are lowered to allow excess stormwater to be discharged into the sea. When heavy rain coincides with high tide, giant drainage pumps are activated to pump the excess stormwater out to sea.



The Sustainable Singapore Gallery.

Recreation venue

With the barrage in place, water levels in the reservoir will be kept relatively constant all year round, creating further opportunities for the surrounding areas of Singapore's new downtown to be developed into a lifestyle attraction, bustling with water- and land- based activities.

Besides recreational boating, kayaking and dragon-boating, there will be colourful water-based performances, thrilling water-sports competitions, and the plying of river taxis between the waterfront attractions.

Education on environment

Marina Barrage also aims to educate the community on important environmental and water issues.

The Sustainable Singapore Gallery features the country's achievements in the areas of environment and water resources management, and promotes environmental awareness through interactive multi-media displays, exhibits



Opening of a new venue for recreation.



Location of Marina Barrage relative to downtown developments in Singapore. Image credit: URA.

and games.

At the central courtyard and community water playground with water features and play areas, visitors will develop a stronger bond with water and will better appreciate and cherish its importance.

As part of the overall design concept to make it a beautiful and relaxing place, Marina Barrage also houses an Arts Trail where visitors can admire a series of iconic sculptures.

Maintenance

To keep the waters in Marina Reservoir clean and free-flowing, PUB, Singapore's national water agency, has put in place measures including silt control and sewer rehabilitation programmes. For instance, to tackle the problem of silty discharges from construction sites, PUB has collaborated with the construction industry, resulting in a concerted effort to educate and engage, as well as upgrade technology and enforce good earth control measures.

The community also has an important role to play in keeping the waters clean.

While technology has made it possible to treat the water so that its quality reaches the high standards for drinking water, the public can help to keep the drains and canals free from pollution and litter, as these are part of the catchments that collect and channel rainwater to the reservoirs for treatment and subsequent supply as drinking water.

DESIGN

The Marina Barrage project was first conceived in the mid-1980s, as part of a comprehensive scheme to address the significant flooding that Singapore had been experiencing in its core urban area. Annual rainfall in Singapore exceeds 2500 mm, and daily rainfall upwards of 200 mm is not uncommon.

The design of the Marina Barrage scheme had to address various major challenges.

- The system has to be capable of handling large storm discharges of up to 2,800 m³/s from rapidly responding urban catchments, with the peak flows experienced in less than 30 minutes from

the occurrence of the storms.

- The scheme has to operate with storms, for up to 100 years, without flooding in the downtown areas.
- The system has to maximise fresh water supply, within flood control constraints, and fulfil recreational needs.
- The facilities have to be aesthetically attractive to the public, given their location in the heart of the new downtown Singapore.

The area around Marina Reservoir has been slated by the urban redevelopment planning process in Singapore, as the location for many high value projects, in particular, the multi-billion dollar Integrated Resort, the second financial hub in Singapore, Gardens by the Bay, and the Sports Hub.

These shoreline developments will benefit from the pool level in Marina Reservoir being maintained at a fairly static level, instead of the 3 m daily variation caused by sea tides experienced before the barrage was constructed. An operating range of less than 1 m was selected as a design goal.



Recreational activity at Marina Reservoir.

Awards for engineering achievements

Marina Barrage was an Award Winner at the IES Prestigious Engineering Achievement Awards 2007, as well as an Award Winner at the ASEAN Outstanding Engineering Achievement Awards 2007.

In 2009, the project received the Superior Achievement Award at the AAEE Annual Awards, as well as the inaugural BCA Green Mark for Infrastructure Award under the highest Platinum category.

IES Prestigious Engineering Achievement Awards, presented by the Institution of Engineers, Singapore (IES), give recognition to organisations or persons responsible for engineering projects in Singapore, that significantly contribute to the quality of life.

The ASEAN Outstanding Engineering Achievement Awards, presented by the ASEAN Federation of Engineering Organizations (AFEO), give recognition to organisations or persons responsible for engineering projects

in the ASEAN region, that significantly contribute to the quality of life. One project within each ASEAN country is nominated for an award. The awards are presented during the Conference of the ASEAN Federation of Engineering Organizations (CAFEO), held in a different member country, each year.

The criteria for both awards are contribution to the well being of people and communities; resourcefulness in planning and in the solution of design problems; pioneering the use of materials and methods; innovations in planning, design and construction; and unusual aspects and aesthetic values.

The Superior Achievement Award is the highest honour bestowed by the American Academy of Environmental Engineers (AAEE), at the AAEE Annual Awards. Marina Barrage is only the second project outside the US to win the award, in the last decade.

Focused exclusively on the environmental engineering field, the

award defines the best in environmental engineering practice - a holistic environmental perspective, innovation, proven performance and customer satisfaction, and contribution to an improved quality of life and economic efficiency.

The BCA Green Mark for Infrastructure Award is an initiative to promote sustainable development in project planning and conceptualisation, design and specification, and construction of infrastructure projects. It promotes an integrated approach towards project delivery and recognises good standards of performance that go beyond the legal requirements and industry norms.

Projects are evaluated based on six criteria - landscape, ecology and land efficiency; energy efficiency and renewable energy; water efficiency; project management; waste management and environmental protection; and innovation.



Utilisation of renewable energy at Marina Barrage.

KEY FEATURES

Marina Barrage includes the following:

- A barrage with nine 'fish-belly' crest gates spanning the Marina Channel and a 6 m wide pedestrian bridge, on top of the barrage, connecting Marina East and Marina South. Eight sheltered look-out points along the bridge enable people to rest and enjoy a panoramic view of the city.
- A drainage pumping station, housing seven drainage pumps (six main and one standby) with a total pumping capacity of 280 m³/s.
- A boat hoist facility on the eastern side of the barrage.
- An electrical building with three 4.3 MW diesel engine generators to supplement the utility supply when more than two pumps are operated, and which will provide back-up power.
- Solar panels on the roof, which provide supplemental power for use in the facility.
- An exhibition gallery which showcases Singapore's achievements in the areas of environment and water resources management.
- A turfed green roof accessible to the public throughout the day.

CONSTRUCTION

The structure for Marina Barrage was constructed in two phases. During Phase 1 construction of the barrage, a 100 m wide channel was maintained at the deepest portion of the Marina

Channel for navigation and flood control requirements. To ensure the safety of boat users navigating through the narrowed channel during the day as well as at night, current velocity meters showing real time readings and warning lights, were installed at strategic locations of a temporary marine cofferdam.

Under Phase 2 of the barrage construction, all four crest gates installed under Phase 1, had to be kept in the open position, with the marine cofferdam removed, to allow for storm flows out to the sea.

A boat hoist was installed at the eastern side of the barrage, to facilitate the transfer of boats entering the reservoir from the sea side and vice versa.

The boat hoist is capable of hoisting boats up to 20 m long and 6 m wide, and weighing 70 tonnes, into and out of the Marina Reservoir. The main users of the boat hoist are river taxis, the Singapore Navy, the Police Coast Guard, and leisure yacht owners. The time taken to hoist each boat is about 15 minutes.

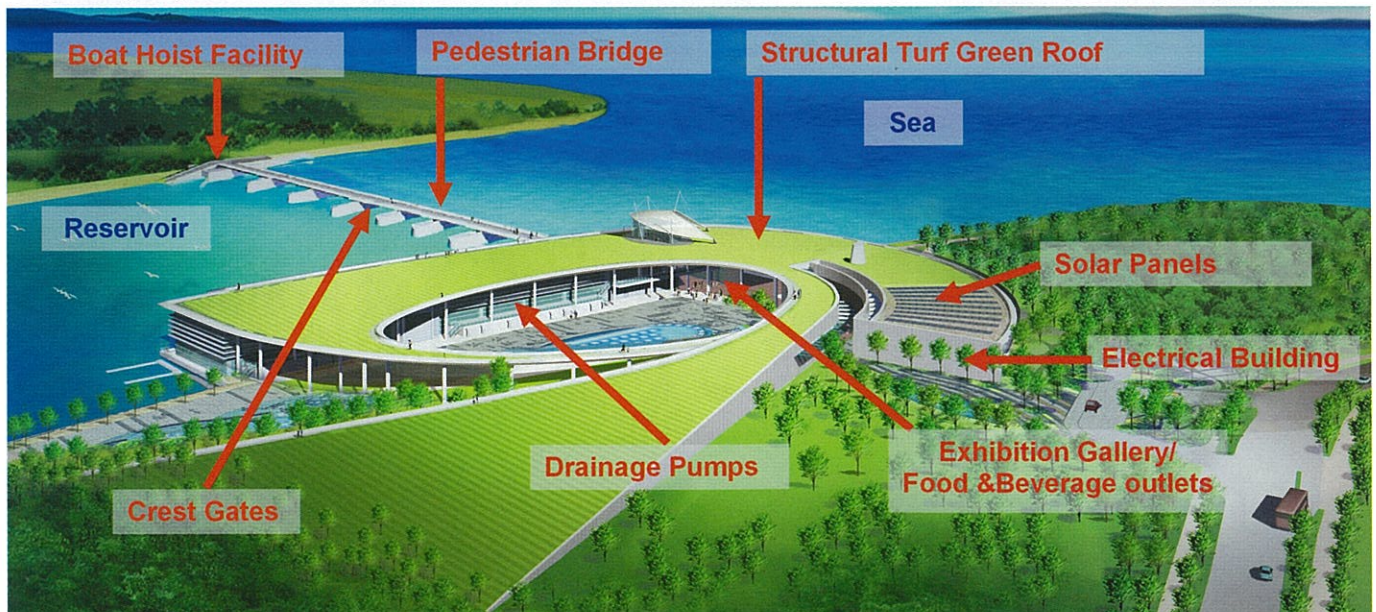
The design of the temporary cofferdam for the Marina Barrage project was specified by PUB in the contract. The detailed design of the cofferdam was carried out by the Contractor's Professional Engineer, and checked by the specialist checker engaged by the Contractor, PUB's Consultant, as well as by the Accredited Checker engaged by PUB.

The temporary works consisted of the marine cofferdam with 12 m wide double

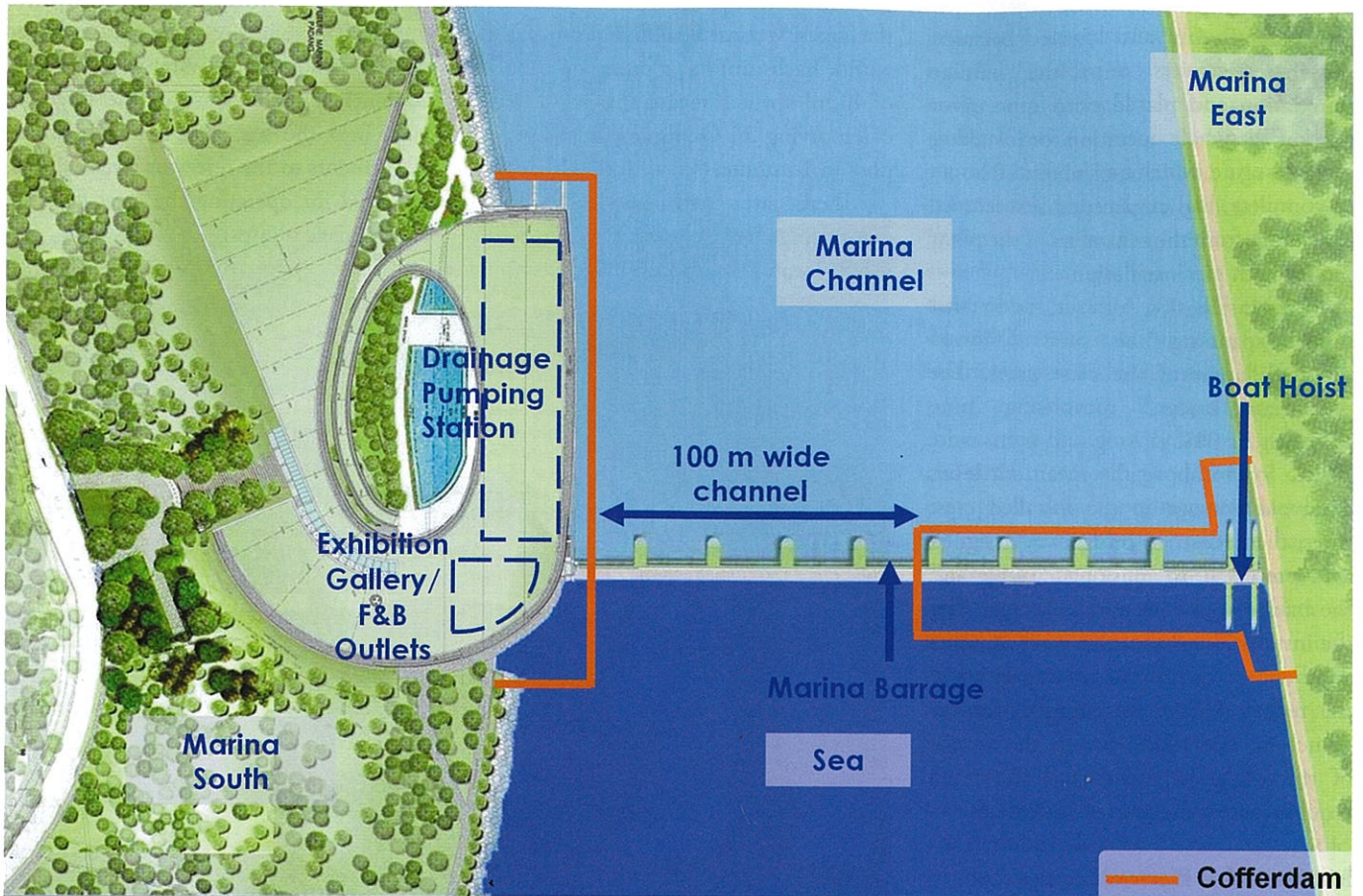
sheet pile wall of 42 m length, and filled with sand, joined by a cut off wall on the land side, and a transition wall made up of sheet piles and raker piles. Sheet piles with a length of 18 m served as the cut-off wall to prevent water infiltration into the excavation site. The double wall marine cofferdam was situated at the existing sand key area with two rows of tie rods. An earth berm was provided at the landward side, and the water level in the cofferdam was controlled by pumping wells. Prior to the construction of the marine cofferdam for the barrage across the 350 m wide Marina Channel, the seabed of the channel at this location, was dredged to a depth of about 12 m and filled with 144,000 m³ of sand to form sand keys. Sheet piles for the marine cofferdam were driven to a depth of 31 m into the sand keys which provided the required passive resistance in the design of the cofferdam.

The foundation for the various structures in Marina Barrage, including the drainage pumping station, east abutment, barrage, exhibition gallery, and electrical building, consists of base slabs supported by bored piles down to a maximum depth of 74 m. Owing to the magnitude of the pile length, specially-made kelly bars were fabricated in Italy and delivered to site for the boring operation.

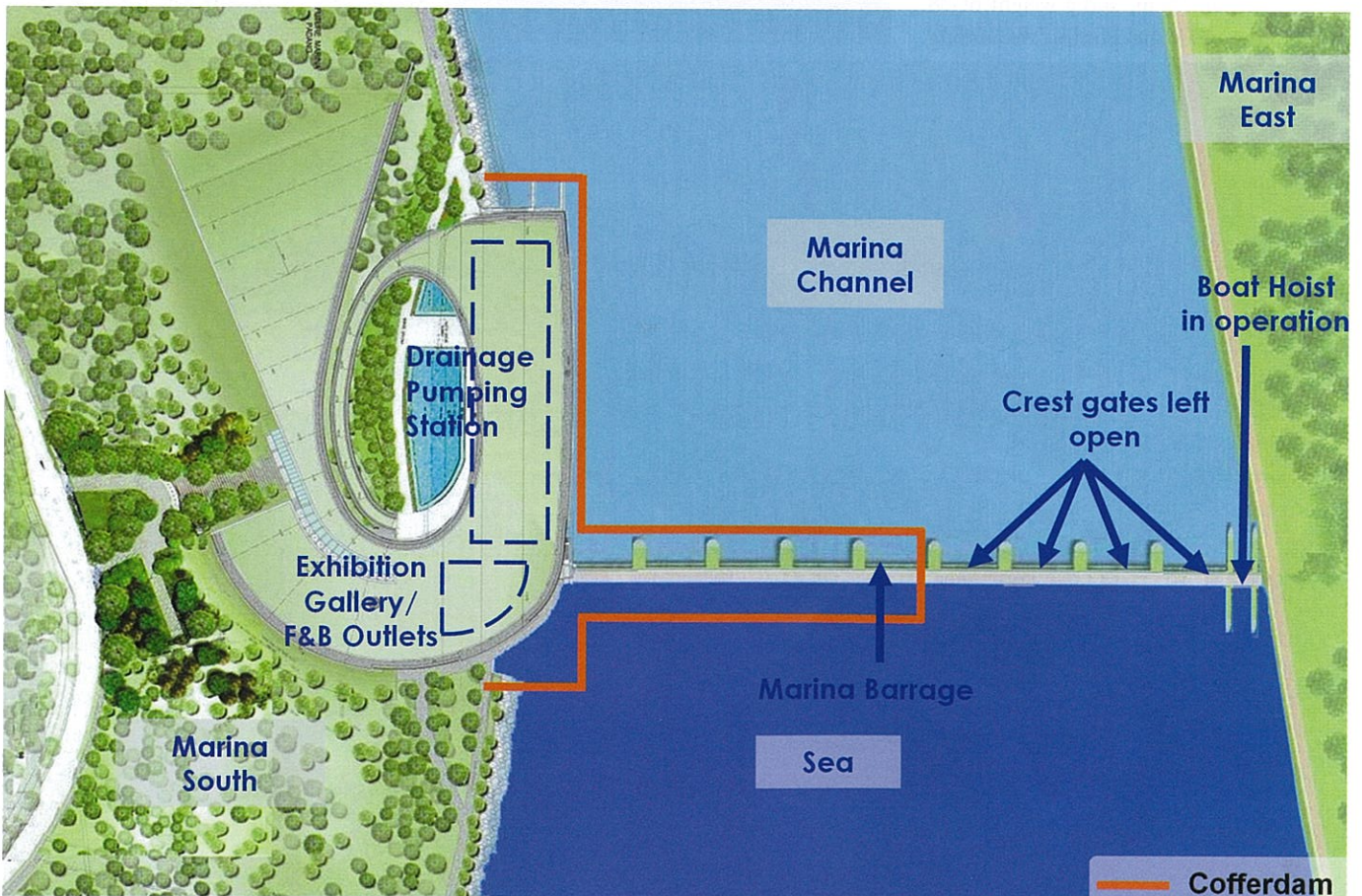
The nine 'fish-belly' steel crest gates of the barrage are designed to be self-floating. Each gate, which is 29.75 m wide and 5 m high, and weighs 70 tonnes, had to be lifted from a crane barge outside the



Key features of Marina Barrage.



Phase 1 construction of Marina Barrage.



Phase 2 construction of Marina Barrage.

Cover Story

barrage cofferdam and lowered between the barrage piers onto the barrage foundation and placed onto nine pivot blocks. The whole operation for installing each crest gate, which took about 10 hours to complete, had an acceptable tolerance of + 2 mm from the centreline of the pivot pin for each pin installation.

The installation of the pedestrian bridge spanning the piers followed the installation of the crest gates. The pedestrian bridge, comprising nine segments, is 310 m long and 6 m wide, and is 5.5 m above the mean sea level. To avoid damage to the installed crest gates, the pedestrian bridge was designed as a pre-cast post tensioned bridge and the bridge segments were launched after the installation of the crest gates. A crane with one of the largest lift capacities in the region, had to be engaged, for the launching operation, due to the weight of the bridge segments and the reach required across the marine cofferdam.

Mechanical & Electrical equipment

Seven pumps are located in the drainage pumping station. With a diameter of 3.2 m, a height of 7.5 m, and a weight of 28 tonnes, the drainage pumps are among

the largest vertical axial flow pumps in the world. Each unit has a pumping capacity of 40 m³/s which means that it is capable of emptying an Olympic-size swimming pool in 1 minute.

There are two low-level sluices comprising bypass pipes and butterfly valves located in the drainage pumping

station. The sluices serve to release denser reservoir water (saline water with high salt content) at the bottom of the reservoir back into the sea, and to make minor adjustments to the reservoir level without the need for operating the crest gates or the drainage pumps.

Three 4.3 MW diesel engine-



Boat hoist for transferring boats in and out of Marina Reservoir.



Aerial view of the double wall marine cofferdam.



Installation of a 70 tonne crest gate.



Launching of pedestrian bridge segment.

generators are installed in the electrical building. Besides serving as a back up for utility supply, they also help to supplement power if more than two drainage pumps are required for operation. The cooling system for the engine-generators uses freshwater from the reservoir, which circulates through the heat exchangers mounted on them. A 500 kVA emergency standby generator set provides power for building services during utility failures.

A Supervisory Control And Data Acquisition system (SCADA) provides real-time monitoring and control of the crest gates, drainage pumps, and low level sluices. There is also a Predictive Barrage Operating System that will process the hydrological and meteorological data in real time, and forecast rainfall and runoff. This useful information is used to aid the operation of the crest gates and drainage pumps.

CONCLUSION

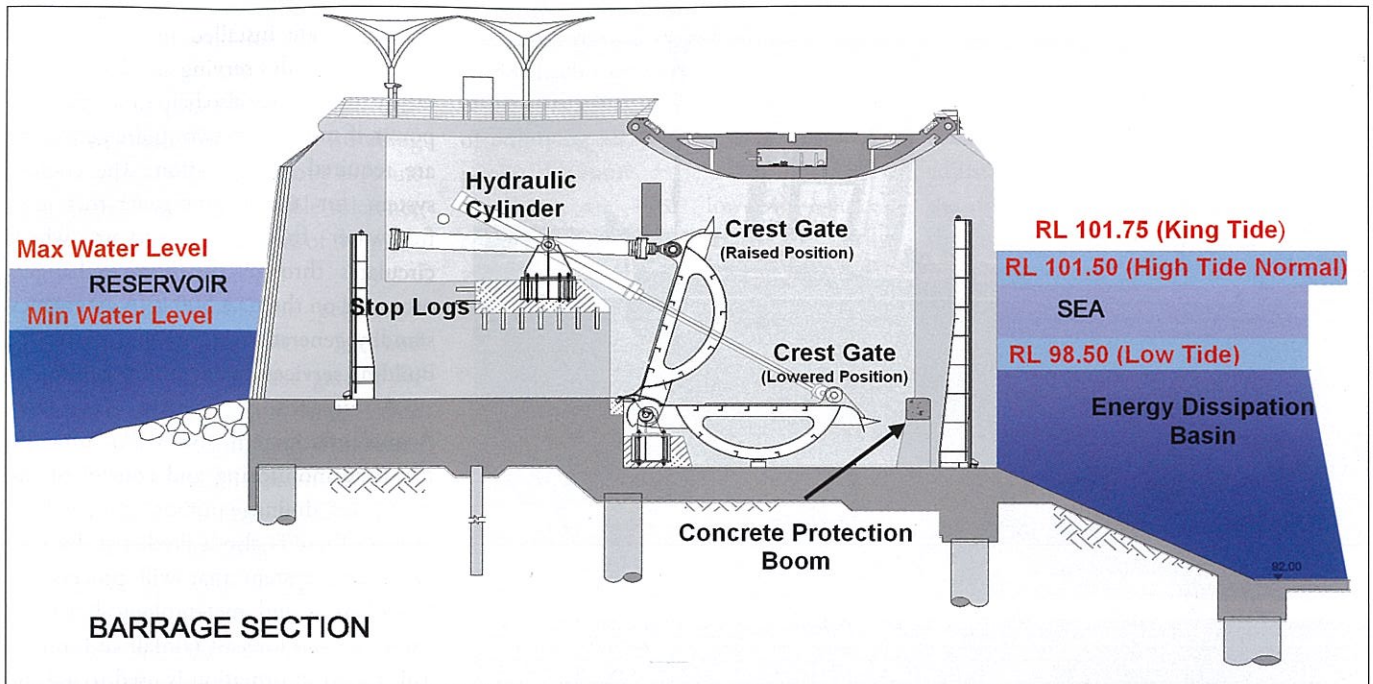
The creation of Marina Barrage as an iconic waterfront attraction and a showcase for environmentally sustainable development, is an engineering achievement.

ACKNOWLEDGEMENTS

Information for the article was obtained from the following sources:

- Press Releases and fact sheets issued by PUB, Singapore's national water agency.
- The paper 'Marina Barrage: A Unique 3-in-1 Project In Singapore', presented by Mr Moh Wung Hee, Director, and Ms Su Pei Lin, Senior Project Manager, Best Sourcing, PUB Singapore, at the Conference on 'ICONIC STRUCTURES IN SINGAPORE AND ASIA', held on 25 and 26 July 2008 in Singapore. The conference was jointly organised by IES (Institution of Engineers, Singapore) and IStructE (Institution of Structural Engineers) Singapore Division, to celebrate IStructE's '100 Years of Excellence in Structural Engineering'.
- Fact Sheets from IES, on the IES Prestigious Engineering Achievement Awards, and on the ASEAN Outstanding Engineering Achievement Awards.

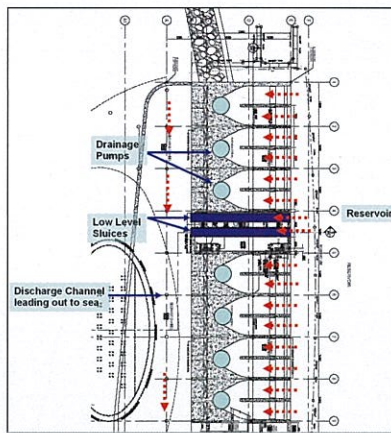
All images courtesy of PUB, Singapore's national water agency, unless otherwise stated.



Section across the barrage: the installation of the pedestrian bridge segments followed the installation of the crest gates.



Drainage pump at Marina Barrage.



Layout of drainage pumping station.



Diesel engine-generators in the electrical building.



Aerial view of Marina Barrage during the construction stage.