出國報告(出國類別：開會)

參加國際水環境工程與研究協會(IAHR)舉辦第 41 屆世界大會出國報告

服務機關：國家發展委員會
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摘要

國際水利與環境工程學會 (IAHR) 第 41 屆世界大會以「創新水工程助力可持續發展」為主題，旨在匯聚全球專家，共同探討如何以創新技術應對日益嚴峻的水資源與氣候變遷挑戰。本次大會目標是促進知識交流與建立夥伴關係，以產生實質影響。本次會議聚焦氣候變遷下城市防洪韌性、永續水資源管理、數位轉型、融資挑戰、跨部門合作及水力發電的永續發展等六大核心議題。

氣候變遷帶來的極端天氣事件日益頻繁且劇烈，因水所造成的災害佔所有受災害影響人數的 90%，經濟損失高達 5500 億美元，水相關災害頻發、水資源短缺及水生態環境污染已成為全球性挑戰。在城市防洪韌性與調適策略方面，傳統工程與創新方案並行。新加坡透過建設廣泛的排水網絡，將易澇面積大幅減少，基礎設施設計必須考量土地限制和氣候變異性。自然解方（Nature-Based Solutions, NBS），如雨水花園、濕地等「藍綠系統」或「海綿城市」概念，被各國專家學者視為提升城市韌性的關鍵，尤其對日常「惱人洪災」效果顯著。有學者也建議將 NBS 與傳統工程結合，以達到最佳韌性。數位轉型與人工智慧（AI）超本地化降雨監測與預測，這對數據稀缺的發展中國家尤為重要。中國則大力推動「數位孿生水利建設」，丹江口水庫的數位孿生模型已在水質防控、藻類智慧監控及生態補水方面取得顯著成果。然而，部分專家學者提醒，AI 工具的使用，不能完全取代人類決策。水資源領域的融資挑戰與跨部門合作是實現永續發展的關鍵瓶頸。資金流向氣候變遷調適的私人資金僅佔氣候變遷調適總私人投資的 9%，遠低於需求，僅靠政府資金則嚴重不足，需動員私人資本，應將水的經濟效益轉化為可持續的收入流，例如透過徵稅並發行「藍色債券」來吸引資金。水力發電在能源轉型中扮演關鍵角色，提供基載電力並平衡間歇性再生能源。抽蓄式水力發電 (PSH) 則提供長時間儲能，對實現淨零排放至關重要。

應對全球水資源與氣候變遷挑戰，需要跳脫舊思維，以整體、創新和協作的方式，整合多元融資機制、強化跨部門治理、廣泛推動公眾參與和能力建設，並將自然解方與數位創新技術充分結合。

關鍵字：**氣候變遷** (Climate Change)、**水資源管理** (Water Resource Management)、**防洪韌性** (Flood Resilience)、**數位轉型** (Digital Transformation)、**融資挑戰** (Financing Challenges)、**跨部門合作** (Cross-Sectoral Cooperation)、**水力發電** (Hydropower)、**自然解方** (Nature-Based Solutions, NBS)、**數位孿生** (Digital Twins)

壹、目的

一、會議背景說明

國際水利與環境工程學會(IAHR，International Association for Hydro-Environment Engineering and Research)成立於 1935 年，隨著全球水利科學和工程領域的迅猛發展，迫切需要一個能夠促進國際間水利專家、工程師和學者交流合作的平台。IAHR 的成立緣起源於早期歐洲與美國水工、河川與海岸工程領域的專業發展，科學家與工程師紛紛意識到，水環境問題往往跨越地區需國際協作，因而共同發起組建一個具全球影響力的專業學會。其宗旨是推動水利、河川、海岸、環境工程等相關領域的基礎理論與實務技術創新，建立國際交流合作網絡，促進人類社會及自然環境的永續發展。

IAHR 自創立至今歷經多次重大轉型與發展。1950 年代之後，學會開始拓展涵蓋水工、流體力學、海岸工程、河川整治、環境水工程等多元化領域，並設立多個專業委員會，同時積極發展世界大會、洲際會議與地區性研討會。歷任主席如 Pierre Danel、Arthur T. Ippen、Nobuyuki Tamai 等，皆為水利流體科學、河川與海岸工程等分支領域的先驅學者，推動了學會在基礎水理學、數值模擬、環境工程等面向的持續進步。自 1970 年代起，IAHR 進一步開放參與國家範疇，吸納來自亞洲、拉美、非洲及世界各國的會員，形成更廣泛且具影響力的全球性組織。

迄今，IAHR 會員涵蓋全球近百個國家，定期舉辦世界大會及各主題型國際會議，並推出多項國際重要研究獎項，如 M. Selim Yalin 終身成就獎、Arthur Thomas Ippen 傑出貢獻獎等，用以表彰對水利科學領域做出重大貢獻的科學家與工程師。學會持續推動創新水資源管理、智慧水工程、氣候變遷調適和水、能源、糧食安全等跨領域挑戰，促進聯合國永續發展目標的落實。IAHR 不僅是全球水利與環境領域專業人士的學術核心，更是國際合作、智識交流及技術創新的重要推手，多年來穩健推進人類社會水資源與生態系統的永續治理。

二、參與會議目的

第 41 屆 IAHR 世界大會的研討會以「創新水工程助力可持續發展」為主題，核心目的在於回應全球水資源管理、氣候變遷適應，以及水、能源、糧食安全和自然環境間複雜關係所帶來的多重挑戰。本次世界大會聚集來自全球各地的專家、研究人員及實務工作者，平台設立目標在於推動跨領域對話，分享最新研究成果、技術創新及解決方案，進而強化水利工程領域在解決全球重要議題上的影響力，促進知識交流與合作。

本次世界大會暨研討會重點關注如何以創新水利工程技術應對氣候變遷下的水環境變化，並探索緩解水、能源、糧食等三大資源整合管理的系統性方法。此外，大會強調以水利創新推動聯合國可持續發展目標(SDGs)，涵蓋水資源短缺、水質、衛生設施及生態系統保護等全球性目標。藉由匯聚世界領袖與專業人士，研討會致力於推動更具韌性的社會環境建設，造福現代與未來世代，確立水利工程師在永續發展進程中的關鍵角色。

近年來，氣候變遷所帶來的衝擊與日劇增，勢必得從多方面汲取國際經驗並應用於臺灣水利建設政策規劃，透過國際學術研究單位深入探討現代水資源管理、氣候變遷調適及水、能源、糧食安全和自然環境間的複雜關聯，學習國外在水資源規劃、極端氣候應對、都市防洪、自然解方(Nature-base Solution, NbS)與智慧水利系統等領域的最新技術和管理方法，強化臺灣在面對天災與水環境挑戰方面的政策設計，提升韌性與永續發展的實際作為，並藉由大會交流，搜集其他國家在永續城市、智慧水務、地下水保護、生態河川復育等公共治理策略，並評估如何納入台灣現行政策，促使政府部門間資源協同分配、強化橫向溝通，將最新全球治水理念、政策工具與技術標準等前瞻性解決方案，納入臺灣水利工程政策規劃，促使臺灣面臨未來挑戰時能及早佈局。

貳、過程

一、議程

本次 IAHR 第 41 屆世界大會安排 3 場主題演講，特別邀請新加坡公共事業局(PUB, Singapore's National Water Agency) Bernard Koh Eng Wah 助理首席執行官、澳洲昆士蘭科技大學 Ana Deletic 教授、英國 ARUP 工程顧問公司 Mark Fletcher 總監，各別分享「新加坡水資源管理—歷史上的挑戰與創新」、「以自然為本的解決方案：由自然驅動的智慧水管理 」、「永續水資源管理 」等主題；另規劃 4 場 High-Level Panel 高層論壇，邀請西班牙、新加坡、荷蘭王國、丹麥、中國、美國、巴西等國家政府人員及研究機構，以及亞洲開發銀行、世界銀行、聯合國教育、科學及文化組織(UNESCO)等國際組織等計畫執行專案管理人員，說明各國在水資源議題上的研究或推動成果。

另 IAHR 安排多場技術和特別議程(Technical & Special Sessions)會議，以及學術研討會議，並圍繞「水利工程與技術創新」、「水利工程與社會經濟考量」等 2 子主題展開討論，並舉辦 5 場工作坊及 4 場大師課，供各國參與人員學習交流。IAHR 第 41 屆世界大會過程及簡報詳如附件。

由於本次研討會各別主題會議場次眾多，本章節將以本人參與會議內容，分別歸類為「氣候變遷下城市防洪韌性與調適策略」、「永續水資源管理與創新技術應用」、「水利工程中的數位轉型與智慧化管理」、「氣候變遷下水資源領域的融資挑戰與跨部門合作」、「水力發電與能源轉型中的永續發展挑戰」等 5 項主題，進行會議內容摘要說明。

二、會議重點

(一)氣候變遷下城市防洪韌性與調適策略

在全球水與氣候危機的背景下，城市正以前所未有的速度經歷著極端天氣事件的衝擊，這對其防洪韌性與調適策略提出了嚴峻的挑戰。聯合國秘書長水事務特使 Retno Marsudi 女士指出，氣候變遷的影響已不再是預測，而是日常現實，其中最具破壞性和影響的之一就是城市洪災。她強調，因水所造成的災害佔所有受災害影響人數的 90%，這凸顯了水在氣候變遷影響中的核心地位。

圖一、聯合國秘書長水事務特使 Retno Marsudi 女士開幕致詞

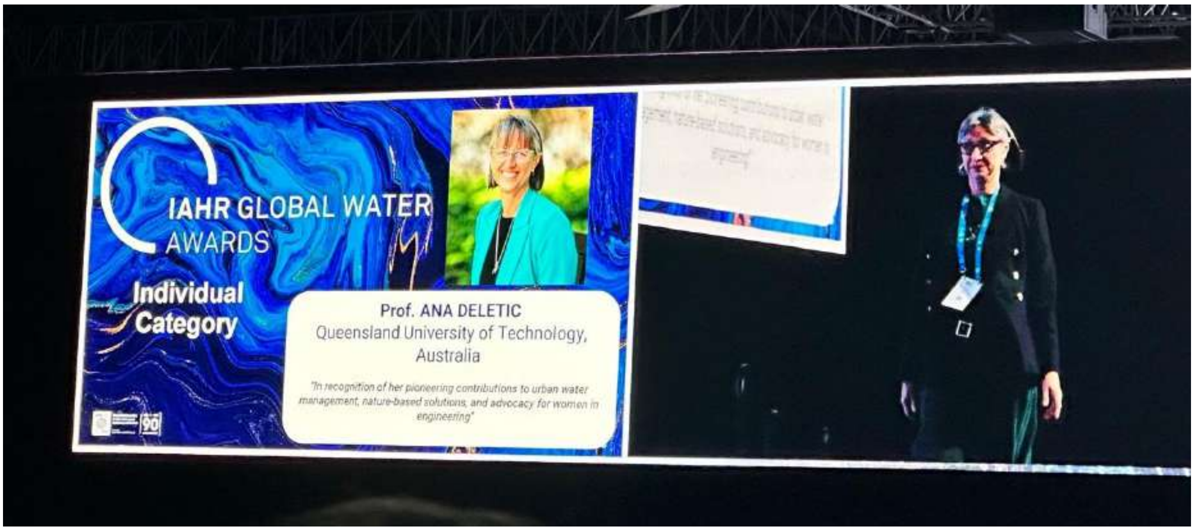
近年來，全球範圍內的極端天氣事件，尤其是洪水和乾旱，正變得越來越頻繁和劇烈。自 2000 年以來，與洪水相關的災害增加了 134%。氣候模型甚至預測，過去百年一遇的洪水，現在可能每 10 到 20 年就會發生一次。新加坡永續發展與環境部長 Grace Fu 指出，洪水、乾旱和極端天氣將持續考驗我們的系統和決心。

圖二、新加坡可持續發展和環境部長 Grace Fu 女士開幕致詞影片

這些極端事件不僅造成巨大的經濟損失(2024 年水相關災害已導致高達 5500 億美元的經濟損失)，更威脅著生命安全與基礎設施的穩定。中國水利部副部長陳敏也提到，在全球氣候變遷和人類活動日益加劇的影響下，水災害頻發，水資源短缺和水生態環境污染等水安全問題日益成為全球性挑戰。

圖三、中國水利部陳敏副部長開幕致詞

城市，作為全球人口和經濟活動的中心，尤其脆弱。馬來西亞和韓國的案例突顯了強降雨事件造成的嚴重洪災和人命財產損失。中國鄭州在 2021 年經歷的極端暴雨，24 小時內降下全年降雨量，導致城市排水系統「超乎設計容量」而癱瘓，交通受阻，人員被困，資訊與預警系統失效，最終導致大規模人員傷亡。昆士蘭科技大學的 Ana Deletic 教授提到，許多城市，特別是高度發展的城市，都對氣候變遷的準備不足。

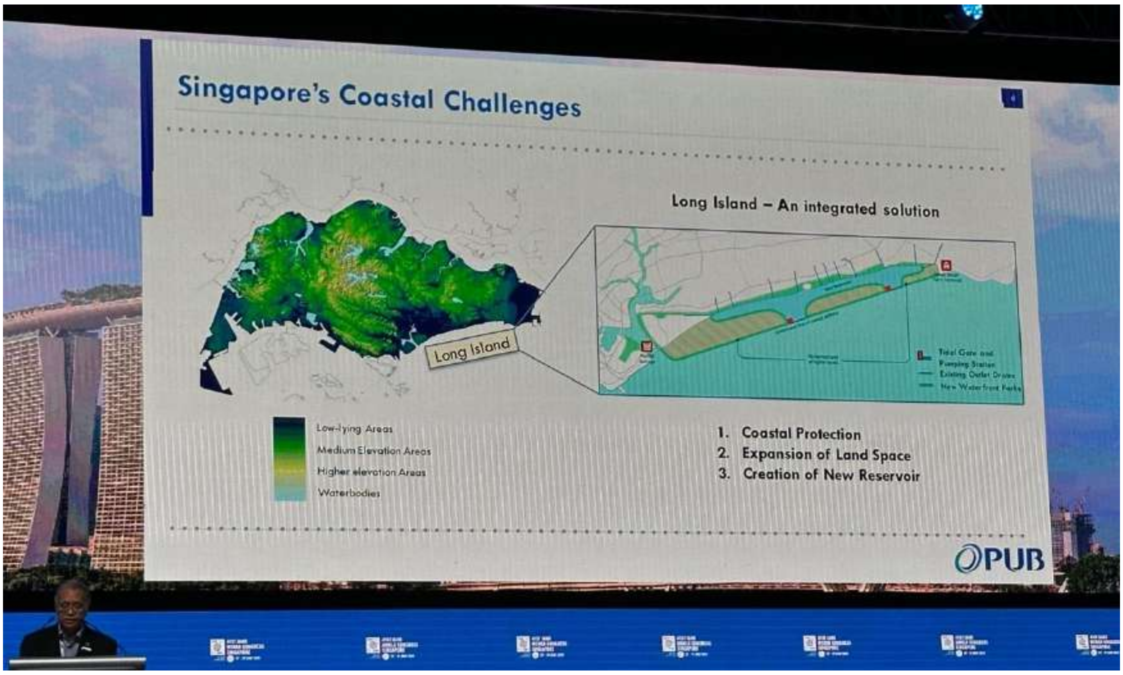


圖四、澳洲昆士蘭科技大學 Ana Deletic 教授上台領獎

圖五、IAHR 主席 Philippe Gourbesville 先生與澳洲昆士蘭科技大學 Ana Deletic 教授領獎合影

面對這些挑戰，各國和國際組織都強調需要一個整合、創新且多面向的城市防洪韌性與調適策略，以增強城市防洪韌性。

1.**基礎設施與工程創新**：傳統的「灰色基礎設施」仍然是城市防洪的重要組成部分。新加坡在過去 50 年中，透過建設廣泛的排水網絡，將易澇面積從 3200 公頃減少到 25 公頃。他們也開發了如「Long Island[1]」這類多功能項目，透過填海造地形成連續防禦線以應對海平面上升，同時創造淡水水庫並提供住房和娛樂空間。中國也積極推進水利基礎設施建設，並透過南水北調等重大跨流域調水工程，優化水資源配置，提升國家水安全保障能力。



圖六、新加坡長島(Long Island)計畫介紹

2.新加坡公共事業局(PUB)助理執行長 Bernard Koh 先生強調，僅依賴傳統工程是不夠的，基礎設施的設計必須**考慮土地限制和氣候變異性**。另 IAHR 水利結構技術委員會主席 Stefan Felder 先生提到，水力結構的設計需要最高的技術專業知識來確保安全，但也必須考慮其對周圍環境、社會和經濟的影響。

[1]「Long Island」(長島)是新加坡政府於 2023 年底宣布的大型國土開發計劃，目的是結合填海造陸、住宅、休閒、工業園區以及水資源管理，提升新加坡的水資源自主能力。長島(Long Island)位於新加坡東部沿海，計畫興建於濱海堤壩外側的填海新區。計劃將規劃住宅區、休憩設施與工業用地，同時建設大型內陸蓄水池，未來成為新加坡第 18 座水庫，大幅提升水資源管理能力與都市防洪韌性。預期不僅能集雨蓄水，更能作為新加坡重要的水資源調度與供給設施，強化本地自給自足能力，減少對外來水源依賴。

3.**自然為本解決方案 (Nature-Based Solutions, NBS)**：自然為本解決方案(NBS)被廣泛視為提升城市韌性的關鍵。Ana Deletic 教授將其稱為「藍綠系統」或「海綿城市」(中國)的概念，旨在透過模仿自然過程(如雨水入滲、滯留、儲存和淨化)來管理徑流。這些解決方案包括雨水花園、生物過濾器、濕地、綠化屋頂和紅樹林恢復等。

4.NBS 不僅能管理逕流、改善水質，還能增強生物多樣性、提供城市降溫，並提升物業價值。例如，雪梨的一項研究顯示，居住在美麗的雨水花園 50 公尺內，房屋價格可增加 6%。英國 ARUP 工程顧問公司 Mark Fletcher 提到，將 NBS 與傳統工程措施(「灰色基礎設施」)結合，形成**混合解決方案**，可以達到最佳的韌性效果。

5.針對 NBS 對防洪的貢獻， Ana Deletic 教授指出，雖然在大型洪災中作用有限，但對於日常的「惱人洪災」(nuisance flooding)有顯著效果，甚至能為城市每年節省高達 30%的損失。 Stefan Suavowski 則認為，NBS 可以讓社區不斷接觸低水平的風險，從而提高其適應能力，而非像大型基礎設施那樣，讓社區在面對「超乎設計容量」的洪災時完全措手不及。

6.**數位轉型與人工智慧 (AI)**： 數位科技和人工智慧(AI)在提升城市防洪韌性方面展現出巨大潛力。新加坡公共事業局資訊長 Kim Chye Lim 強調，數位轉型是應對氣候變遷、需求增長和人力短缺的關鍵。

7.AI 和數位工具可用於即時監測、早期預警和預測模型。香港排水服務部主管 Ringo Mok 提到，香港利用 AI 和超過 300 個感測器，結合 Rule-Based 水力模型，構建數位孿生系統，提供兩小時內的精確天氣預報和洪水預警。 Vladan Babic 教授也指出，AI 能利用無處不在的感測器數據(如手機、CCTV 攝像頭、甚至汽車雨刷速度)來實現超本地化的降雨監測和預測，這對於缺乏基礎水文監測網絡的發展中國家尤為重要。

8.數位孿生系統能模擬城市水循環，幫助決策者預測洪水範圍，指導應急計畫調整。AI 還能在水質管理、污染控制和優化水流控制策略方面發揮作用。然而，來自 KTH 皇家理工學院的 Ricardo Vinuesa 提醒，AI 雖然能帶來許多益處，但也可能加劇不平等，並且不能完全取代人類的決策和責任。 Oratio Giustolisi 教授也強調，數位轉型是人類控制過程的修正，而非機器取代人類，教育和人類的批判性思維至關重要。

9.**治理、政策與融資**：強有力的治理框架和跨部門合作對於應對水挑戰至關重要。聯合國水事務特使 Retno Marsudi 呼籲建立強大的治理框架，培養備災文化，並在所有發展部門中採取響應性方法。中國的「河長制」系統，將地方政府官員納入流域管理和污染防治責任，是一個創新的例子，目前已覆蓋全國 120 萬名河長。

10.融資是實施適應策略的關鍵瓶頸。世界銀行 Julia Fraser 強調，僅靠公共資金不足以應對巨大的投資需求，需要動員私人資本。荷蘭水務特使 Meike van Ginneken 建議，應將水的經濟效益轉化為可持續的收入流，例如透過徵收水費和稅收，並發行綠色債券和藍色債券來吸引資金。西班牙馬德里市議會的 Jan Askarate 提到，他們正在探索將再生水用於家庭用途，並透過公眾參與和宣傳提高民眾的接受度。

11.能力建設對於確保水管理領域具備足夠的專業人才至關重要。丹麥南丹麥大學的 Nikolaos Dolling 教授指出，即使在歐洲，也存在缺乏具備系統性思維和多學科知識的工程師和管理者的問題。

12.**社區參與與社會韌性**： 社區的韌性是城市防洪的基石。新加坡永續發展與環境部長 Grace Fu 強調，僅擴大排水系統並不可行，社區必須了解並減輕洪水風險。新加坡透過「Get Floodwise in a Flash」等活動，提升公眾對洪災風險的意識和應對能力。

13.世界銀行 Julia Fraser 強調，賦予當地社區，特別是婦女和弱勢群體權力，共同設計防洪解決方案，確保干預措施符合當地實際情況。紐西蘭奧克蘭大學的 Asaad Samad 教授提到，應整合原住民知識，因為這些知識蘊含著數百年來面對水挑戰的智慧。在孟加拉，聯合國秘書長水事務特使 Retno Marsudi 建議，早期預警系統結合社區參與，能有效減少災害損失。

(二)永續水資源管理與創新技術應用

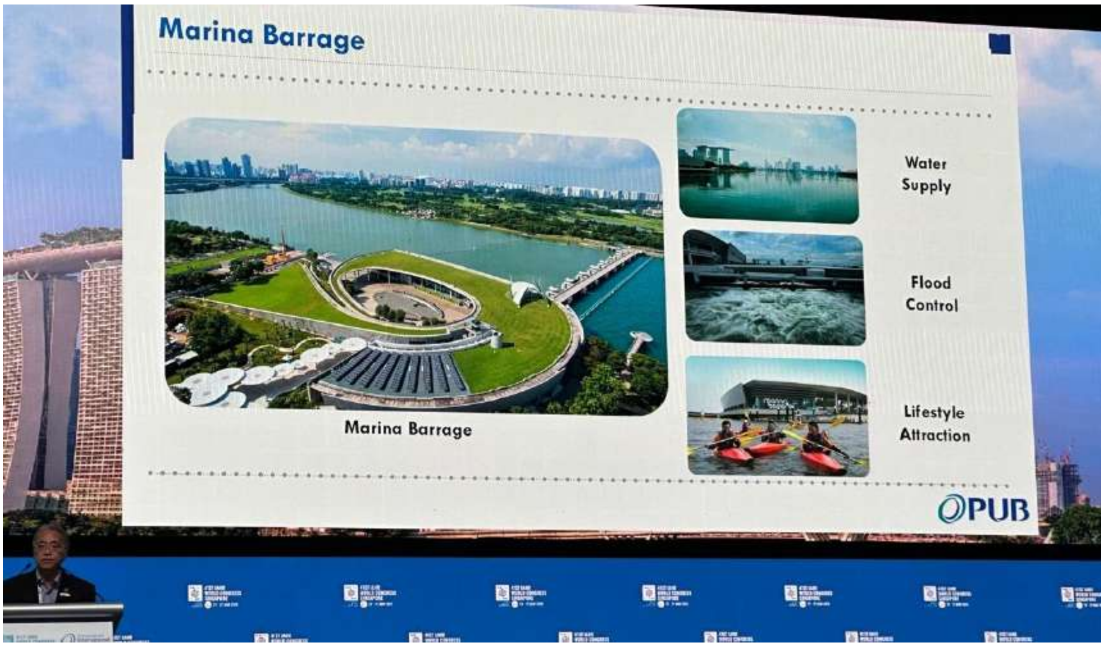
永續水資源管理與創新技術應用是應對全球水與氣候危機的關鍵。從新加坡的「四個國家水龍頭」和「ABC Waters」計畫，到中國的國家水網和「河湖長制」，再到全球推動的自然解方、數位轉型和 AI 應用，各國和地區都在積極探索適合自身背景的解決方案。然而，這些努力需要更強的跨部門、跨地域和多層次合作，有效的融資機制，以及廣泛的社區參與和能力建設。正如講者們所強調，我們不能再固守舊思維，必須以整體、創新和協作的方式，共同為子孫後代建設一個更安全、更永續的水未來。 IAHR 執行董事 Tom Soo 提到，這個大會的目標是促進知識交流，建立新的合作夥伴關係，以產生實質影響。IAHR 將繼續推動此方向的努力，鼓勵研究、實踐和政策的整合。以下就新加坡及中國在永續水資源管理創新技術應用，分述如下：

1.新加坡：新加坡是一個小型島嶼城市國家，自然水資源有限，儘管降雨充沛，卻沒有足夠的土地來收集和儲存雨水。水資源與氣候危機對新加坡構成威脅，水安全對其生存至關重要。新加坡的水需求預計到 2065 年將翻倍。

(1)**「四個國家水龍頭」**策略：

A.在地水源(Local Catchment Water)：新加坡政府透過國土規劃和工程設計，將城市內大部分降雨收集並儲存在水庫，集為全國最重要的天然水資源之一。過去新加坡天然水資源有限，加上海島地勢低平且缺乏大河和湖泊，因此政府自 1960 年代起積極推展集水區工程，打造完善的城市雨水收集體系。目前已規劃 17 座主要水庫和大量集水區，集水面積約佔國土的三分之二。這些水庫多位於河口和地勢低窪地帶，其中濱海堤壩和濱海水庫是都市集水與防洪的代表設施。中央集水區(Central Water Catchment)是規模最大者，涵蓋多座蓄水池，包括麥里芝、貝雅士和實里達水庫，同時也是島內最大自然保護區所在地。水經由城市規劃的運河、溝渠和管網導流至水庫，儲存並經過淨化處理後，供給全國飲用與工業用水。現階段，本地集水區所供應的水量約佔新加坡每日用水量的 20%，

部分水庫如濱海水庫甚至結合防洪、休憩與景觀環境，體現水資源與城市發展相結合的理念。



圖七、新加坡 Marina Bay 濱海堤壩

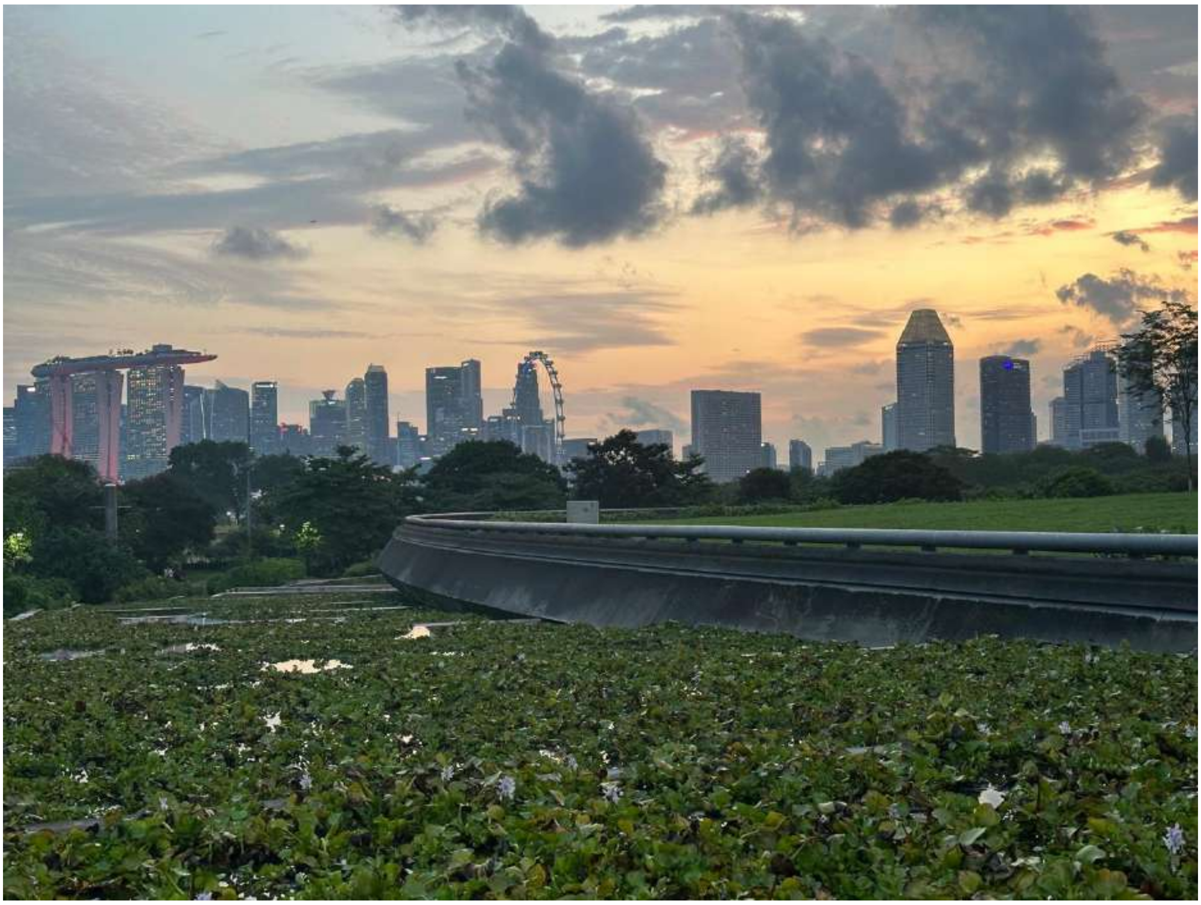
B.進口水源(Imported Water)：新加坡進口水主要來自馬來西亞柔佛州，是該國四大水資源來源之一。由於新加坡國土面積狹小，天然水源不足，長期依賴馬來西亞輸水以滿足日常用水需求。新加坡與馬來西亞自 1961 年及 1962 年分別簽訂長期供水協議，根據 1962 年協議，馬來西亞柔佛州每日可供新加坡 2.5 億加侖原水，協議效期長達 99 年，直至 2061 年。在此期間，新加坡可依約定以極低價格(每 1000 加侖 0.03 馬幣)購買原水，同時必須回售經過淨化的飲用水給柔佛，回售價約為原水的 17 倍。新加坡為保障穩定供水，不僅負擔管線與設施建設，也協助柔佛地區擴建蓄水池與水處理設備，確保雙方用水安全。新加坡政府充分認知進口水的地緣政治風險，據規劃，將在 2061 年合約到期前，國內再生水和淡化水產能將持續擴充，目標最終實現供水自主。

C.新生水(NEWater)：新加坡新生水(NEWater)是世界知名的高科技再生水方案，由公用事業局(PUB)主導開發，其核心目標是將城市污水高度淨化，成為可供飲用和工業使用的「超純水」，徹底打破過去天然水資源受限

的困境。NEWater 的製程分為三大步驟。首先，污水經深隧道排放系統送至回收廠進行傳統初級和生物二級處理，再進一步以微過濾(MF)或超過濾(UF)技術，濾除懸浮固體、膠體顆粒、細菌和部分病毒。第二步是逆滲透(RO)，透過半透膜徹底去除剩餘溶解性鹽分、重金屬、細菌、病毒與有害化學物質。最後，經紫外線消毒，確保水中任何殘留的微生物和有機物質完全不活化。製程的高標準與多層次管控，使 NEWater 品質達到或超越世界飲用水基準，甚至能直接瓶裝販售或釀製啤酒，充分展現其純淨與安全形象。NEWater 自 2003 年正式投產，四座主要工廠分別位於 Bedok、Kranji、Seletar 和 Ulu Pandan，總每日產能超過 21 萬立方米，目前已佔新加坡 40%的供水量。其主要用途包括電子業、高科技製造業冷卻水、發電廠，以及部分直接補充水庫的飲用水源。一般家庭飲用則仍以天然水為主，NEWater 僅約 1%直接進入家戶，惟工業使用及公共水庫補充則高達三成以上。

D.海水淡化(Desalinated Water)：新加坡首座海水淡化廠於 2005 年啟用，隨著用水需求不斷成長，新加坡已興建五座海水淡化廠，分布在樟宜、裕廊島、大泉、海濱東區等地，每日總產能可達約 1.3 億加侖水，佔據全國用水約 30%的比例。這些海水淡化廠常與再生水廠、電力設施整合，提高運營效率並降低能源消耗，如裕廊島海水淡化廠採用鄰近多聯產設施供電，降低約 5%的耗電量。新加坡吉寶濱海東海水淡化廠(Keppel Marina East Desalination Plant)是新加坡第四座海水淡化廠，也是本次技術參訪的行程地點之一，該廠於 2020 年動工，並於 2021 年 2 月正式投入運作。該廠是全世界首座大型雙模式海水淡化廠，能夠根據水源情況靈活切換處理海水和來自濱海蓄水池的淡水，保障供水穩定且不受天氣影響。吉寶濱海東海水廠的日產能約為 3000 萬加侖(約 13.7 萬立方公尺)，利用先進的逆滲透(RO)技術配合混凝膠凝、浮除和超過濾(UF)等多重過濾技術，確保淡化水質達到高標準飲用水要求。為提升能源效率，該廠採用了直接耦合、能量回收裝置等創新技術，淡水處理耗能較海水淡化低，因此在雨季優先處理蓄水池淡水，旱季切換至海水淡化。


圖八、吉寶濱海東(Keppel Marina East Desalination Plant)海水淡化廠外觀


圖九、吉寶濱海東(Keppel Marina East Desalination Plant)海水淡化廠屋頂

(2)**ABC Waters 計畫**：全名是 **Active, Beautiful, Clean Waters Program**，是一項新加坡政府於 2006 年啟動的永續水資源管理策略，主要係透過生態化設計與公共參與，改造城市水體環境，使水資源管理更具活力、美觀與潔淨。ABC 三字母分別代表 Active(活化)、Beautiful(美化)與 Clean(淨化)。計畫的核心在於打造親水環境，讓人們能更親近河道與水庫，並將傳統的混凝土水渠轉變為蜿蜒自然的河道和濕地，形成多功能的生態空間，同時具備排

洪和水質淨化功能。透過引入雨水花園、生態草溝、人工濕地等生態工法，提升水體的自淨能力，並在設計上結合了社區綠地、休閒空間與生物多樣性保護。此外，該計畫配備完善的感測與警報系統，能在暴雨前通知民眾安全撤離，保障生活安全，另外也涵蓋水環境教育與公共參與等措施，提升全民珍惜水資源的意識，目前新加坡已實施超過 55 個 ABC Waters 地點，以下就 ABC 核心觀念及案例，介紹如下：

- Active(活化)：主要強調活化水體的使用與功能，並將水體納入城市公共生活，讓居民能直接親近和使用水岸空間。新加坡透過設計親水步道、休憩區以及水上活動設施，鼓勵民眾參與水資源的保護與維護，提升水資源的社會價值。活化不僅促進社區互動，也讓水資源管理變得更有人情味和實用性，建立生態與人文的共生共榮。

- Beautiful(美化)：強調將水資源管理與景觀設計結合，使水體及其邊緣環境更具美感和生態功能。新加坡在河道與水庫普遍採用自然化整治方法，透過綠化帶、雨水花園、植被濾池等生態設計，使水環境成為城市綠地系統的一部分。這不僅提升城市美觀，還幫助控制水流、減少污染和提升生物多樣性，創造公平且宜人的環境品質。

- Clean(淨化)：主要是聚焦於水質保護與治理技術，確保集水區及水體水質良好，使水資源能有效且安全地被回收和再利用。新加坡利用生態濕地、沉澱池和過濾系統降低污染，加強雨水及廢水的處理能力，防止污染源破壞水生生態。乾淨的水環境同時支持新生水和海水淡化的水質要求，是整體都市供水安全的技術基礎。

- 案例：碧山宏茂橋公園是 ABC Waters 計畫的經典代表案例。該處原為混凝土渠道且排洪能力有限，經過改造後，加冷河(Kallang River)的河道被拓寬且自然化，蓄水能力提升約 40%，生物多樣性也增加約 30%，同時增加居民的休憩空間，讓城市河流從單純的排水系統轉型為集生態、休閒和防洪為一體的綠色水岸。

圖十、新加坡碧山宏茂橋公園及加冷河(Kallang River)(圖片來源：C40 CITIES[2])

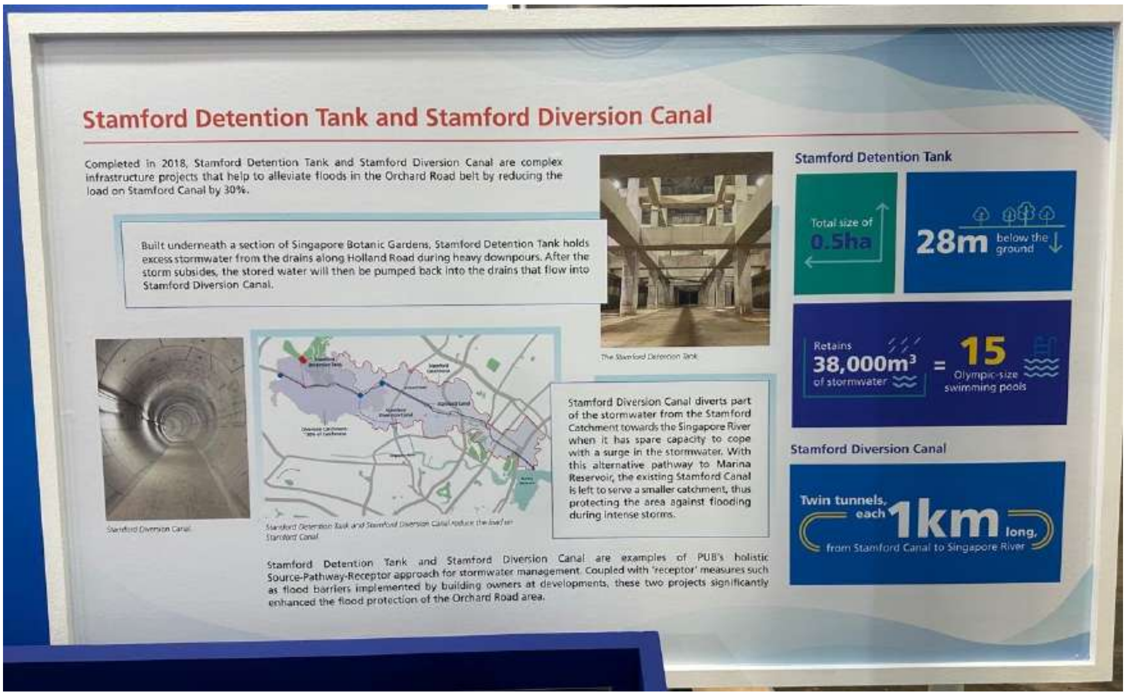
(3)斯坦福拘留池及分洪隧道(Stamford Detention Tank and Stamford Diversion Canel, 簡稱 SDT 和 SDC)：該設施係新加坡政府 PUB 審慎規劃的關鍵防洪設施，採用的整體「源-路徑-受體」方法的一個很好的例子。主要係在降低風險並更好地保護烏節路(Orchard Road)免受洪水侵襲。

- **斯坦福拘留池(SDT)**：總面積為 0.5 公頃，地下 28 米。位於植物園的泰爾索爾學習森林(Tyersall Learning Forest)和國家蘭花苗圃(National

[2] https://www.c40.org/zh-CN/case-studies/singapore-bio-engineering-works-at-bishan-ang-mo-kio-park-to-prevent-urban-flooding/

Orchid Nursery)的馬車公園下方。當大雨來臨時，荷蘭路(Holland Road)沿線排水管的多餘雨水將流入 SDT，預計可以暫時容納 38,000 立方米的雨水，相當於 15 個奧林匹克運動會大小的游泳池。俟暴雨或洪水消退後，儲存的水將被泵回流向斯坦福分流運河(SDC)的排水管中。

- **斯坦福分洪隧道(SDC)**：SDC 主要係 2 條各 1 公里的箱涵組成，當 SDT 有足夠的容量可以應對激增的暴雨水量時，管道能將部分雨水從斯坦福集水區轉移到新加坡河(Singapore River)。



圖十一、斯坦福拘留池及分洪隧道介紹海報

(4)**賽義德·阿爾維抽水站(Syed Alwi Pumping Station)**

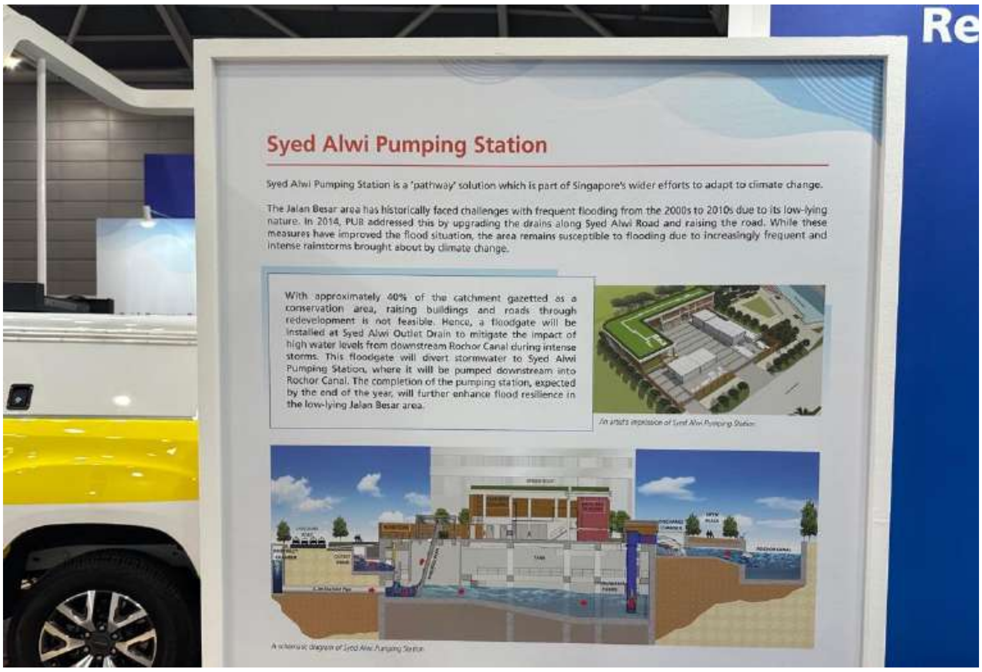
新加坡的賽義德·阿爾維抽水站(Syed Alwi Pumping Station)是一座位於惹蘭勿剎(Jalan Besar)地區、靠近 Rochor 運河的地下抽水設施，於 2025 年完工，主要目標係提升該區防洪能力，特別是應對氣候變遷帶來更頻繁和強烈的暴雨。

該抽水站占地約 1190 平方米(約為一個足球場的六分之一)，設計有三個進水口和兩道防洪閘門，能在暴雨期間將雨水從上游的 Rochor 運河引入地

下水槽，最大容量可容納 4 個奧林匹克運動會大小的泳池(約 9300 立方公尺)的雨水，用以暫時儲存並防止積水回流。當水位高度達到 4.5 公尺時，抽水站會自動啟動抽水泵，將雨水泵回 Rochor 運河的下游，減少惹蘭勿刹(Jalan Besar)及其鄰近地區的淹水風險。

由於惹蘭勿刹(Jalan Besar)地勢較低，過去曾在 2000 年和 2010 年間頻繁發生淹水，儘管先前已進行排水系統升級、道路加高及運河擴寬等措施，但因地形限制，導致改善程度有限。為徹底解決惹蘭勿刹(Jalan Besar)淹水問題，新加坡政府 PUB 規劃賽義德·阿爾維抽水站(Syed Alwi Pumping Station)，特別是在該區有許多歷史建築需要保存的前提下，該抽水站以地下式設施進行規劃，在不影響地面用地和城市美觀，且無需大規模土地重新開發，成為最佳可行的解決方案。

此外，該抽水站設計著重環保與社區融合，設有綠色屋頂和綠牆等環保設施，並規劃開放空間供社區使用，與鄰近正在興建的 King George’s Heights 住宅項目整合，兼顧城市韌性與生活品質。



圖十二、賽義德·阿爾維抽水站(Syed Alwi Pumping Station)介紹海報

2.中國：目前中國推動「節水優先、空間均衡、系統治理、兩手發力」的治水策略，推行「河湖長制」，堅持「山水林田湖草沙一體化」治理理念，並加速推動南水北調工程等「國家水網建設」，有效緩解了北方水資源短缺。同時，建立基於氣象衛星、雷達雨量站和水溫站的水情監測預報體系，強化預報預警聯動措施。

(1)**海綿城市與藍綠基礎設施**：

- **海綿城市(Sponge City)**：

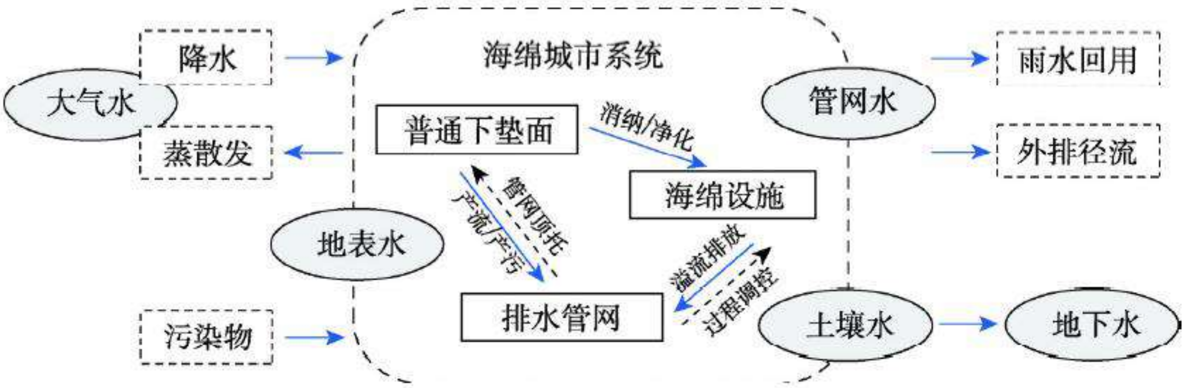
  此概念由中國學者俞孔堅教授提出，現為北京大學建築與景觀學院院長，也是中國最傑出的城市設計思想家之一。他所提出的「海綿城市」概念，主要是透過滲透、滯留、儲存、淨化、利用和排放等措施，將城市轉變為像是能夠吸收和利用雨水的海綿。

  海綿城市的核心理念包括六大措施：滲(雨水滲透到地下)、滯(暫時延緩雨水逕流)、蓄(雨水暫存利用)、淨(自然處理污染物)、用(合理利用雨水資源)、排(適當排放多餘雨水)。這些措施融合了生態修復、低影響開發(LID)、綠色基礎設施等技術和方法，強調保護和恢復城市自然生態系統和水循環系統。

  中國推動海綿城市建設的背景，是因快速城市化導致大量不透水面積擴大，傳統排水系統無法有效應對頻繁的暴雨和城市內澇問題，加劇水資源短缺、水污染和生態退化。由政府主導的海綿城市試點示範項目，從 2015 年正式啟動，通過增建雨水花園、透水鋪裝、綠屋頂、人工濕地等設施，提升城市雨水管理能力。

  海綿城市推廣還強調制度保障和政策引導，各地方政府須制訂專項規劃，整合城市規劃與水利設施建設，並促進公眾參與和多部門合作，打造低環境影響的城市發展模式。其長遠目標是實現城市面積中有 20%至 80%達到海綿城市標準，提升城市綠色韌性和可持續發展水

準，加強城市對雨水的吸納和調節功能，提升水資源利用效率，兼顧生態美化與環境改善，助力建設綠色、智慧和韌性的現代城市。



圖十三、海綿城市系統及輸入與輸出示意圖(圖片來源：中國地理學報[3])

➢ 藍綠基礎設施概念(Blue-Green Infrastructure， BGI)：

香港排水服務部總監 Ringo Mok 先生於本次大會分享此概念，香港的藍綠基礎設施(BGI)是一種融合「藍色」水體和「綠色」自然空間的綜合城市基礎設施概念，目標是通過自然系統的整合與模仿來提升城市的可持續發展能力和韌性。具體來說，藍綠基礎設施包括城市中的河流、湖泊、濕地(藍色元素)與公園、綠化屋頂、綠化牆面和森林等綠色空間，這些設施共同作用於調節氣候、管理雨水、提高生物多樣性和改善生活質量。

作為一座高度密集和擁擠的國際都市，香港歷來面臨土地資源有限、排水系統壓力大及氣候變化導致極端天氣增多等挑戰。藍綠基礎設施有助於減輕城市熱島效應，通過綠植物和水體的蒸散作用降低空氣溫度，改善空氣質素，同時促進雨水自然下滲，減少洪水風險。自然濾水效果改善水質，增強城市生態系統服務功能。

[3] https://www.geog.com.cn/CN/10.11821/dlxb202009002

此外，藍綠基礎設施不僅有環境效益，還提供豐富的社會與經濟價值。綠地和水域提供休憩空間和康樂設施，提高居民幸福感和健康水平，促進社區互動和文化認同。綠化空間和水景亦提升物業價值和城市景觀吸引力，帶動旅遊和相關產業發展。這種設施的建設和維護還創造綠色就業機會，對城市經濟產生積極影響。

香港政府和相關部門已將藍綠基礎設施納入城市規劃和發展策略，如《香港 2030+》中強調藍綠空間的系統化規劃，著力於連接和擴增現有的綠色及水體空間網絡，推動都市森林策略和社區綠地建設，以提升城市韌性和宜居性。未來，香港將繼續通過跨部門協作，結合科技創新與公眾參與，推動藍綠基礎設施的深化應用，打造更環保、健康和可持續的城市環境。

圖十四、香港藍綠排水建設示意圖(圖片來源：香港渠務署[4])

[4] 香港特別行政區政府渠務署可持續性發展報告 2019-20：淨水防洪 創新建未來
https://www.dsd.gov.hk/TC/Publicity_and_Publications/Publicity/DSD_Sustainability_Reports/20/blue-green_drainage_infrastructure.html

- **「河湖長」制度：**

　　中國的河湖長制是指由各級黨政主要負責人擔任河長、湖長，負責該行政區域內河流、湖泊、水庫等水域的管理和保護工作的一項制度創新。該制度於 2016 年起在全國推廣，目的是落實地方黨政領導在河湖管理保護中的主體責任，實現河湖管理有領導、有責任、有保障，進而解決水資源保護、水污染防治、水環境治理等問題。該制度創新解決了過去多頭治理、水域管理職責不清、協調不力的問題，實現了“有人管、管得住、管得好”的管理目標，被視為保障中國水生態安全和推動生態文明建設的重要舉措。

河湖長制的核心內容包括：

- 明確設立省、市、縣、鄉四級河湖長，構建縱向到底的體系。省、市、縣黨委或政府主要領導擔任相應級別的總河長、河長，監督地方政府及相關部門履職。

- 明確責任落實，河湖長統籌協調河湖管理保護工作，推動水資源保護、水污染防治和生態修復。

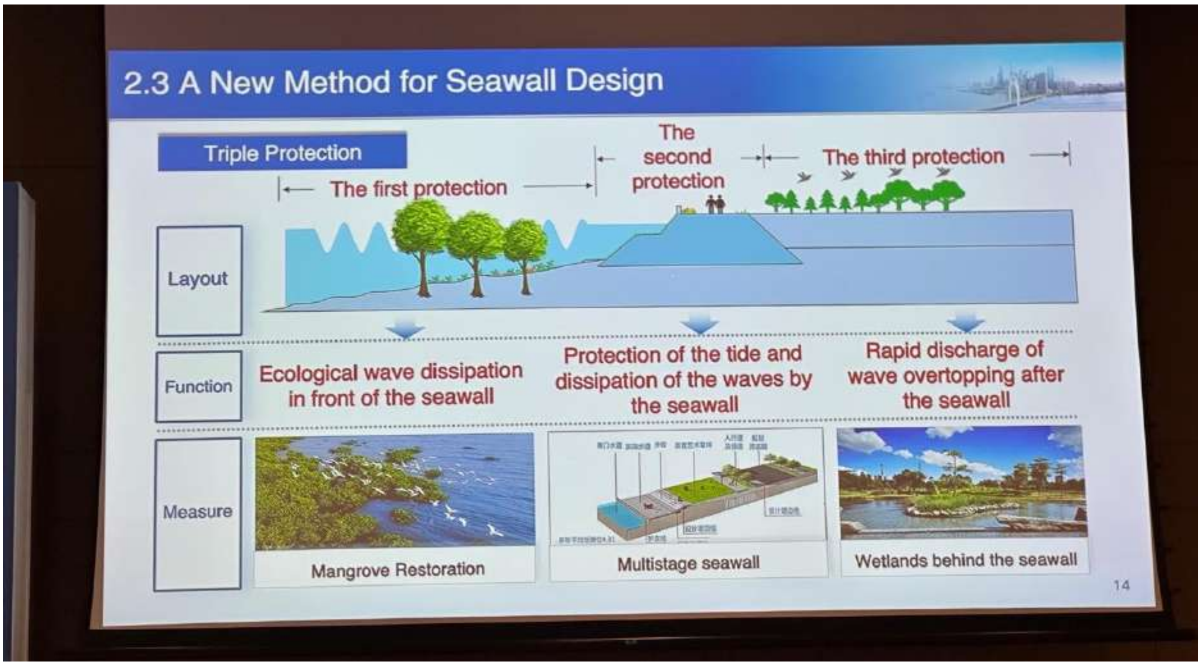
- 加強綜合治理，涵蓋水資源保護、水域岸線管理、防止非法圍墾、嚴格水污染治理、治理劣質水體和生態恢復。

- 建立機制保障，包括督導考核、執法監管和公眾參與，強化水環境保護力度，杜絕違法行為。

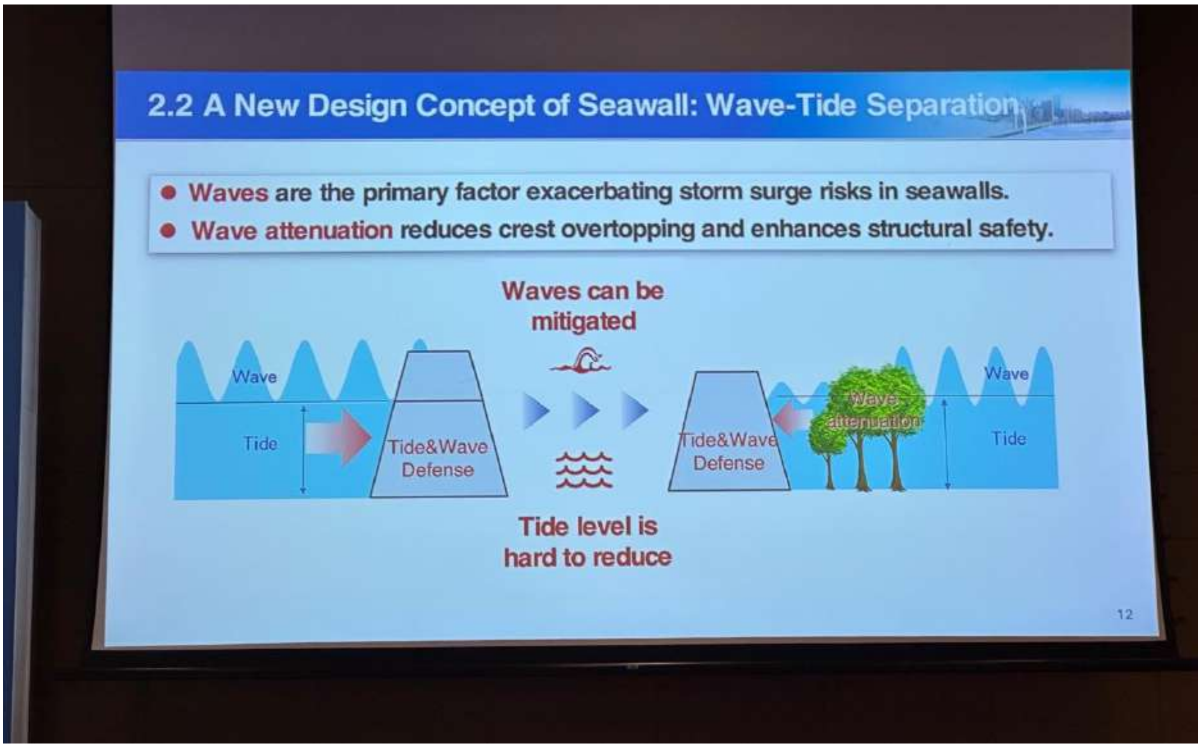
- **生態海堤消浪設計系統**

　　中國的生態海堤消浪設計系統是一種融合自然生態功能與工程技術的創新海岸防護體系，旨在實現海堤結構的防浪防潮效果同時，促進海岸生態系統的恢復和生物多樣性的保護。

該系統強調通過「三重防護」策略，包括堤前植物複合消浪、多級堤身逐級消浪及堤後越浪海向直排技術，有效降低波浪能量和減輕越浪對堤體的衝擊。透過堤前配置復合植物帶，以植物本身的韌性和形態吸收和破碎波浪；堤身多級結構逐級反射和消散波浪動能；堤後設計排水系統有效消納越浪水量，防止水位過高導致堤體損害。此類多層次、多模塊組合設計極大提升海堤的防護能力。



圖十五、中國生態海堤消浪設計系統之「三重防護」策略



圖十六、中國生態海堤消浪設計系統介紹

此外，生態海堤注重結構的生態友好性，運用生態混凝土、仿生結構及生物附著床等技術，促進牡蠣礁、海藻場及鹽沼濕地等生態系統在海堤結構上的形成，這些生物和植被不僅增強了堤體的結構穩定性，也提升了海岸的生物多樣性和自然防控功能。

中國在粵港澳大灣區等地推廣高標準生態海堤建設，以應對極端氣候和風暴潮威脅。該區海堤多為傳統剛性結構，存在防護標準低、越浪嚴重、缺少生態連通等問題。通過生態化改造，提高防浪消能效果，結合綠色基礎設施設計，達成兼顧安全防護與生態宜居的雙重目標。總體而言，中國生態海堤消浪設計系統是一種以生態工程思想為指導，結合多層次結構和生物多樣性的海岸防護策略，是推動海岸帶可持續發展和生態文明建設的重要技術路徑。

(三)水利工程中的數位轉型與智慧化管理

IAHR 主席 Philippe Gourbesville 先生指出，全球水挑戰的加劇，受快速人口增長、現代城市環境擴張以及河流、湖泊和水生生態系統品質惡化所驅動。IAHR 已將數位轉型列為其四大優先事項之一，貫穿氣候變遷調適、能源轉型、韌性提升等各個環節。IAHR 執行董事 Tom Soo 提到，數位轉型的目標是促進知識交流，建立新的合作夥伴關係，以產生實質影響。IAHR 副主席 Amparo Lopez 教授進一步闡述，數位轉型是 IAHR 的四大支柱之一，伴隨著氣候變遷調適、能源轉型和韌性提升。她強調，數位轉型正推動技術發展，並將是未來幾年 IAHR 及其所有活動的核心。

以新加坡為例，新加坡公用事業局(PUB)的數位轉型策略涵蓋四大類別：數據收集、數據分析、自動化及控制。PUB 首席資訊長 Kim Shin Lim 先生強調，這些分類與 IAHR 報告中的前兩大支柱(數據收集與分析)相似。

1.**數據收集(Collect Data)**：PUB 致力於優化感測器部署數量，並探索創新的數據獲取方式，因為不可能無限度地花費資金部署感測器。

➢ **創新數據源**：PUB 與科技合作夥伴如：Grab 合作，利用 Grab 網路預約計程車的雨刷數據及手機感測器，透過機器學習精準預測路面雨量及交通狀況，以提升洪水預警和應急響應效率。這是一種創新，能夠幫助 Grab 司機避免駛入洪水區域，同時也提供 PUB 相關即時雨情服務的目標。

圖十七、新加坡 PUB 與網路預約平台 Grab 合作收集資料

圖十八、網路預約平台 Grab 介紹

➢ **超本地化(hyper-local)監測**：「超本地化」是指一種極度在地化的天氣預報和資料收集方法，特別是在水資源管理和城市韌性方面。新加坡國立大學教授 Vladan Babovic 指出，全球各地的監視系統攝影機(CCTV)和手機等日常設備可作為「機會型訊號」，提供大量即時數據，實現「超本地化(hyper-local)」的監測和預測，尤其在數據稀缺的發展中國家更具潛

力。他提到，PUB 早在 2019 年(ChatGPT 出現的數年前)就支持了電腦視覺技術的開發，將閉路電視攝影機作為降雨感測器。這項技術經過多年發展，已應用於城市中一半的攝影機上。其核心概念與特點如下：

(1)**極小範圍的聚焦**：超本地化並非是數十平方公里的大範圍預報，而是針對非常非常小的地理區域。它追求極高的空間解析度，例如 100x100 公尺至 250x250 公尺。

(2)**即時與高頻率更新**：這種方法強調非常短的預報更新週期，理想情況下，每隔幾分鐘就更新一次預報。這是傳統水文預報(例如每六小時更新一次)對於像突發洪水這類快速發展的事件來說是遠遠不足的。

(3)利用**「機會型訊號」(Opportunistic Signals)**收集資料：超本地化的一個關鍵在於它能夠利用日常設備和現有基礎設施作為資料來源，而無需投入大量新的資本。

- CCTV 攝影機：新加坡公用事業局(PUB)自 2019 年以來，便支持開發電腦視覺技術，將城市中的閉路電視攝影機作為降雨感測器。這項技術經過多年的發展，目前已應用於該市約一半的攝影機上，且無需額外投資。

- 手機與智慧裝置：智慧型手機等個人裝置也可用作感測器。例如，PUB 與 Grab 等科技夥伴合作，利用網約車的雨刷數據及手機感測器，透過機器學習精準預測路面雨量及交通狀況，以提升洪水預警和應急響應效率。

圖十九、PUB 利用道路巡檢車搭配視訊鏡頭，蒐集排水孔堵塞情形

2.**數據分析(Analyze Data)**：PUB 的目標是從基本的描述性分析轉向預測性分析，並訓練員工理解數據，從中獲取洞察力。過去，數據分析多使用獨立軟體，但現在雲端技術的發展帶來了企業級數據分析軟體包，這改變了公用事業機構或從業者對數據分析的思維。例如，在供水管理中，模型可以預測管道洩漏、閥門操作對水流的影響，並估計需求。對於有多個水源(如新加坡的「四個國家水喉」)的國家，模型還能優化各水源的取水量，以實現成本效益最大化。

3.**自動化(Automate)**：自動化涵蓋了實體自動化和數位自動化兩個主要領域。

- 實體自動化：這包括工廠中的機器人操作和視訊分析技術。PUB 利用視訊分析技術監測其約 5,000 公里長的排水網絡，能夠自動識別受損的排水口並生成報告。這項技術將生產力顯著提升了 75 倍。過去，巡查人員需要步行檢查排水管，而現在這些手動任務已實現自動化。

- 數位自動化：涉及自動化審批流程和代理式人工智慧(Agentic AI)。例如，數位工作流程可以自動化審批流程，科技公司也開始談論代理式 AI，目前 PUB 也正在學習如何適應和運用這些 AI 工具。

4.**控制(Control)**：控制涉及到水處理廠和網絡運營的自動控制。然而，PUB 強調，在影響較大的流程中，仍需保持「人在迴路中」(human in the loop)，以進行風險評估和決策。這表明新加坡在追求效率的同時，也重視人為判斷在關鍵環節中的作用。

在數位孿生(Digital Twin)與基礎設施管理方面，PUB 首席資訊官 Kim Shin Lim 強調，數位孿生對於數位資產和網絡運營至關重要。IAHR 執行董事 Tom Soo 也提到，數位孿生係在建立一個能夠管理所有資訊系統的平台，整合模型、數據、地球觀測、照片等多元資訊，實現城市水循環的互聯互通。另 DHI 公司的 Stefan Szylkarski 副總裁表示，DHI 致力於構建城市水循環的數位孿生，以便在技術和社區層面共享水資源資訊。以下為數位孿生在水利工程中的效益包括：

- 優化資產管理與網絡運營。
- 預測系統未來狀況，例如管網預測或洪水模擬。
- 支援規劃與設計，例如評估新開發案對供水系統升級的需求。
- 強化風險評估與應急響應，例如分析關鍵管線故障對客戶的影響。

隨著類似濱海堤壩(Marina Barrage)的沿海防護基礎設施數量增長，人力卻無法同步增加。因此，安全遠端控制等數位解決方案變得不可或缺。新加坡的長島計畫(Long Island project)以及對八個近海島嶼的海平面上升脆弱性評估，也需要高科技工程技術和 GPU 加速的快速洪水模型。PUB 首席資訊官 Kim Shin Lim 表示，目前 PUB 在數位孿生方面仍處於起步階段，但會持續努力。

在水資源管理與洪水韌性中的數位應用方面，新加坡的水資源管理策略長期以來依賴於其「四個國家水龍頭」：本地集水區、馬來西亞柔佛州進口水、新生水和海水淡

化水。數位化工具在確保這些水源供應的穩定性和水質清潔方面發揮關鍵作用，例如透過線上感測器和無人機對水庫進行監測。

在洪水韌性方面，新加坡採取了綜合性方法，例如新加坡的 **Flood-wise F.L.A.S.H** 是一套針對城市洪水管理與預警的系統，旨在提升都市居民對暴雨和突發洪水事件的預警能力和應變反應。這項系統由新加坡 PUB 推動，結合先進的氣象監測技術和洪水預報模型，提供即時、可靠的降雨和洪水信息，幫助公眾及早做好準備並保護自身安全。

Flood-wise 計畫透過五大要素(F.L.A.S.H)進行洪水風險管理：

- **Forecast(預測)**：通過高精度雷達和氣象資料，監測和預測降雨強度和分布。
- **Locate(定位)**：識別可能出現洪水的高風險地點，提供詳細地理信息。
- **Alert(警報)**：及時發布洪水警報，提醒民眾注意即將到來的洪水風險。
- **Shield(防護)**：配合城市基礎設施加強防洪措施，減少洪患損失。
- **Help(協助)**：洪水發生時提供應急協助和資源支持。

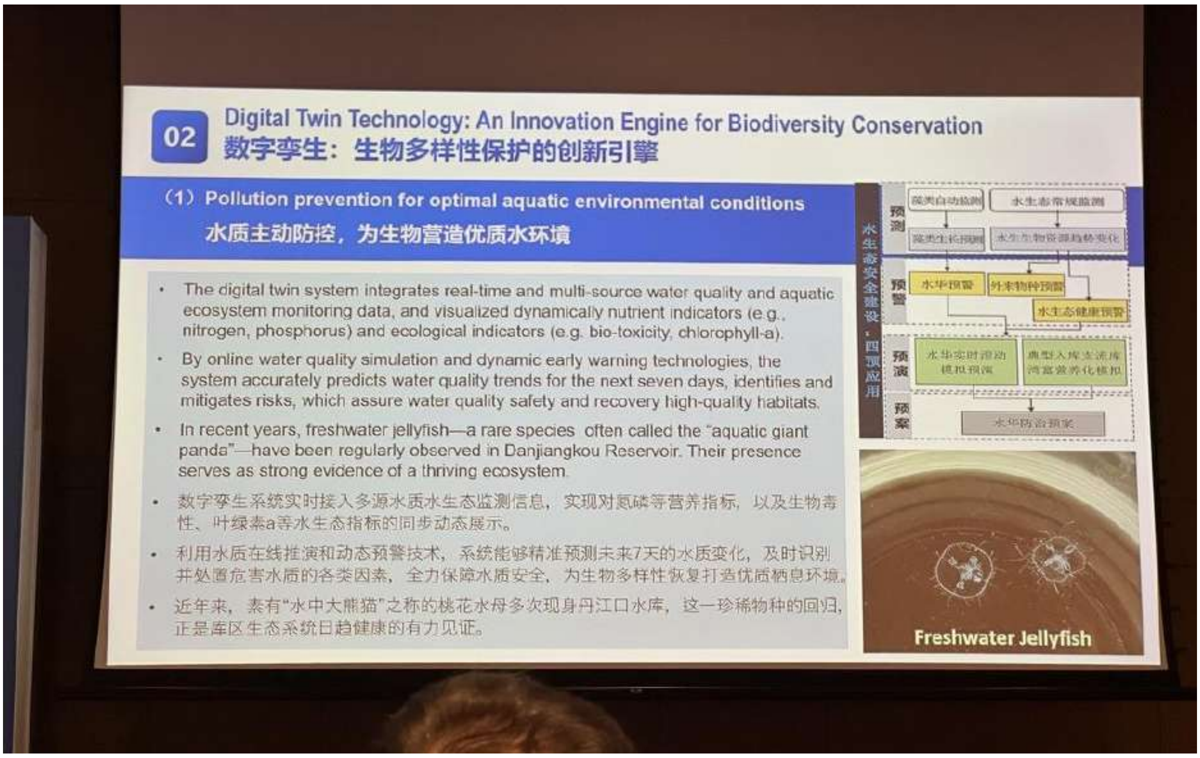
此系統同時重視社區參與與公眾教育，鼓勵市民了解洪水風險，掌握自我保護方法，並促進鄰里互助，增強整體防洪韌性。Flood-wise F.L.A.S.H 代表了新加坡利用科技與社會動員相結合，科學管理極端氣象挑戰的先進方案。目前，PUB 也啟動了「行動聯盟(Alliance for Action, AFA)」與業界專家合作，共同制定洪水韌性發展指南，預計於 2026 年中期發布。

圖二十、強化社區洪水韌性(Get Flood-wise in a F.L.A.S.H)介紹

另外，目前中國正大力推動數字孿生導入水利建設及水資源管理，以提升中國水資源領域治理及管理上的**數位化、網絡化、智慧化轉型**。今(2025)年 5 月，在中國成都的國際大壩委員會閉幕大會上，中國政府提出了加快構建數位大壩的理念及目標。本次大會中國南水北調工程集團的劉正斌總經理分享了中國南水北調中線工程核心水源地「丹江口水庫」的數字孿生建設經驗。透過構建了「天、空、地、水、工」全方位感知體系，實現對水庫大壩的全時映射。「丹江口水庫」數位孿生模型集「防洪調度」、「工程安全」、「生態保護」等多功能於一身，為中國南水北調中段工程水源地區，奠定丹江口水庫精細化管控的基礎。

劉總經理也說明透過「丹江口水庫」數位孿生模型執行至今，在水環境生態及生物多樣性保護方面，已有顯著成果，分述如下：

- **水質防控**：透過多股原水的環境生態監控訊息(大氣資訊、水溫、流速等物理資料)和水質(營養鹽組成、葉綠素、濁度等物化數值)，藉由線上即時運算推演技術，可以精準預測未來七天的水質變化，及時識別水質的危害風險，保障水質安全。例如：素有「水中大熊貓」之稱的桃花水母多次出現在丹江口水庫，足以證明該水庫保育健全及生態系功能完善。
- **藻類智慧監控**：利用「丹江口水庫」數位孿生模型可自動識別高通量藻類樣本及關鍵指標分析，作為後續研究藻類種類和優養化防治工作，提供高效且精準的解決方案。
- **精準評估與優化增殖放流策略**：構建「丹江口水庫」魚類遺傳資料庫，整體評估庫區魚類資源現狀，制定精準的增殖放流方案，健全庫區魚群健康發展。
- **動態優化補水生態效益**：依據「丹江口水庫」上中下游水量監控即時數據，「丹江口水庫」數位孿生模型可自動生成精準補水調度方案，目前已成功恢復並保障了 50 多條河流的生態功能。



圖二十一、數位孿生應用於水質保護及管控

圖二十二、數位孿生應用於藻類監測

圖二十三、數位孿生應用於生物多樣性保育

圖二十四、數位孿生應用於流域內河川生態補水分析

再者，近年因氣候變遷、短延時高強度的暴雨發生頻傳，導致如 2021 年河南鄭州水災等眾大災情，因此，中國政府在數個城市引入數位孿生系統，用於模擬淹水範圍，研訂應急方案，並即時動態調整相應對之工作。例如：武漢市透過修復東湖濕地群，增加了 1,200 萬立方公尺的雨水調節和蓄水能力；北京市建成雨水利用工程，每年節省 300 萬噸用水。此外，中國也建立了基於氣象衛星、雷達雨量站和水溫站的水情監測預報系統，強化氣象預報預警連動功能。

(四)氣候變遷下水資源領域的融資挑戰與跨部門合作

在全球水資源與氣候變遷危機日益嚴峻的背景下，兩者之間存在著密切的連動關係。自然生態系統若管理不當，會擾亂水的循環，進而驅使全球極端天氣事件頻繁發生，以致威脅人類生命、基礎設施和社區。IAHR 主席 Philippe Gourbesville 指出，全球水資源的挑戰加劇，主要係受快速人口增長、現代城市環境擴張以及河流、湖泊和水環境生態惡化所導致。面對這些複雜且相互關聯的艱難議題，水資源領域的融資困境與跨部門合作的缺乏，成為阻礙永續發展的關鍵障礙。

1.**氣候變遷下水資源面臨的嚴峻挑戰**：聯合國秘書長水事務特使 Retno Marsudi 女士表示，氣候變遷的影響已不再是遙遠的預測，而是日常的現實，全球各地正經歷頻繁且強烈的極端天氣事件，分述如下：

- **頻繁的極端天氣**：聯合國秘書長水事務特使 Retno Marsudi 女士表示，過去幾個月，東南亞面臨毀滅性的洪水，歐洲也創下有紀錄以來最溫暖的一年，並遭遇十年來最廣泛的洪水。美國國家海洋暨大氣總署(NOAA)數據顯示，1980 年至 2025 年間，美國因極端乾旱、嚴重風暴和極端洪水造成的累積經濟損失已超過 2.9 兆美元。

- **城市洪水與基礎設施壓力**：城市洪水是最具破壞性和令人不安的影響之一。世界銀行報告顯示，水災(包括洪水)佔 2024 年所有受災害影響人數的 90%，造成約 5500 億美元的經濟損失。近年中國水災、洪災頻發，造成水資源短缺、水環境生態衰退及污染等問題日益嚴重，儼然成為全球性的挑戰。今年榮獲 IAHR 大會榮譽會員獎的中國水利水電科學研究院彭靜教授表示，河南省會城市鄭州在 4 年前曾遭遇「720」水災極端事件，1 小時內降雨量超過 200 毫米，1 天內達到 600 毫米，遠超該城市全年降雨量，造成交通癱瘓、緊急服務受阻、資訊網絡延誤等多重系統性失效。

- **水資源短缺與水質惡化**：西班牙馬德里市議會能源與氣候變遷副總監 Juan Azcarate 提到，西班牙馬德里未來將面臨水資源不足的挑戰，降雨量減少且模式惡化。氣候變遷也導致水質惡化。

- **海平面上升與沿海地區脆弱性**：新加坡 PUB 助理執行長 Bernard Koh 表示，隨著海平面上升，沿海及低窪地區的洪水風險將進一步增加。新加坡約有 30%的土地低於海平面 5 公尺，預計到 2100 年海平面將上升 1.15 公尺，若加上高潮和暴潮，可能增至 4 至 5 公尺。

- **資料不足與預測不確定性**：新加坡國立大學 Vladan Babovic 教授強調，印尼雅加達僅有 5 個雨量計，而新加坡有 125 個，許多發展中國家缺乏足夠的水文監測網路系統。

- **基礎設施老化問題**：聯合國秘書長水事務特使 Retno Marsudi 女士指出，今天所目睹的洪水影響，部分原因是數十年來對水資源投資不足和災害韌性基礎設施的缺乏。聯合國教科文組織綜合與多學科水資源管理中心駐希臘塞薩洛尼基亞里斯多德大學 Elpida Kolokytha 教授也提到歐洲巴爾幹地區面臨基礎設施老化、漏水率高達 60%，是不得不解決的挑戰。

2.**水資源領域面臨的融資挑戰**：應對上述挑戰需要天文數字般的投資，但水資源領域的融資挑戰卻異常嚴峻：

- **投資嚴重不足**：聯合國秘書長水事務特使 Retno Marsudi 女士強調，對水韌性基礎設施的投資是關鍵。然而，荷蘭水務特使 Meike van Ginneken 表示，經濟合作暨發展組織(Organization for Economic Co-operation and Development, **OECD**)數據統計顯示，流向氣候調適的私人資金僅佔氣候變遷總私人投資的 9%。在世界銀行對基礎設施的私人融資中，不到 2% 流向水資源。

- **資金需求巨大**：IAHR 主席 Philippe Gourbesville 表示，為控制全球暖化在 2°C 以下，到 2050 年全球每年需要超過 3 兆美元的清潔能源投資，**水力基礎設施需額外增加** 300 GW 的投資。英國 ARUP 工程顧問公司 Mark Fletcher 說明，英國 Water UK 的水安全和韌性計畫未來 15 年預計將花費超過 500 億英鎊。

- **公眾與私人資本動員困難**：亞洲開發銀行(ADB) 水與城市發展部門資深總監 Norio Saito 指出，水安全和城市韌性的資源需求單靠公務部門無法滿足與日俱增的變化，故亟須加強與私人資本合作。另美國波士頓諮詢集團(Boston Consulting Group, BCG)管理總監兼合夥人 Dave Sivaprasad 也

指出，公共部門的資金和能力不足以應對氣候適應和韌性建設的需求，尤其在農業和食品生產等高度依賴水資源的領域。他提到，在東南亞某些國家，未來十年農業在氣候變遷調適上的年度支出，將會是該國現在農業部門預算的 5 倍以上。

- **商業交叉點難以尋找**：美國波士頓諮詢集團(Boston Consulting Group, BCG)管理總監兼合夥人 Dave Sivaprasad 認為，私人部門投入氣候變遷調適性投資的動機有 2 項：保護商業利益及尋找新的增長點。然而，在許多氣候變遷調適專案中，很難找到「商業交叉點」以吸引私人投資。他舉例說明，製糖業的原料面臨乾旱和洪水的衝擊，導致製糖產業上游原料產量下降，進而影響下游的飲料製造商。此時，整個產業價值鏈上的商業利益就會促使他們投資上游的氣候變遷調適專案。另外，假如還能結合灌溉、太陽能和水儲存，提出多功能農業解決方案，可透過出售多餘太陽能電力和收取灌溉服務費來創造金流，以吸引更多私人資金投入更多資源。

- **融資工具與優先順序的限制**：聯合國秘書長水事務特使 Retno Marsudi 女士提到，荷蘭每年每人平均在水資源管理的支出約 500 歐元，但這在許多開發中國家是不可負擔的。她指出，專案融資(project finance)不適用於許多水利設施，特別是藍綠基礎設施或沿海防護專案。因此，她建議從付費機制入手，例如：國家的水務管理單位或委員會透過徵稅獲得穩定收入流，進而獲得高信用評級並廉價借貸，再發行「藍色債券」持續投入水利工程建設。另外，世界銀行新加坡辦公室總監 Julia M Fraser 也提到，水資源通常跨多個機構，使其在財政部競爭優先權時面臨挑戰。

- **缺乏一致的資訊與標準**：DHI 公司執行副總裁 Stefan Szylkarski 指出，保險業需要一致的資訊來評估風險，但當前資訊系統的不一致，導致保險公司撤出市場，阻礙相關融資運作。他認為水利部門在資訊管理方面仍有不足之處。

3.跨部門與多層次合作的必要性：面對多重挑戰，跨部門協作、多層次治理以及公眾參與已成為不可或缺的解決方案。

- **彌合知識鴻溝與開發新方案**：IAHR 主席 Philippe Gourbesville 強調，政策制定者、營運商、研究人員和解決方案提供者之間必須密切合作，以彌合知識鴻溝並開發新解決方案。

- **國際與區域合作平台**：本次 2025 新加坡國際水週重點活動(SIWW Spotlight 2025)與 C40、亞洲開發銀行和世界銀行新加坡水資源中心合作，共匯聚全球 300 多位領導人一同參與。亞洲開發銀行(ADB)水與城市發展部門資深總監 Norio Saito 表示，ADB 已支持多個跨國合作專案，例如在越南與一家公用事業公司合作的「兩個月水資源擴張計畫」，涉及治理強化和信用增級。布吉納法索沃爾特河流域管理局(Volta Basin Authority)行動總監 Fofana Rafatou 女士表示，該局作為跨國界的河川流域管理組織，負責協調 6 個共享沃爾特河的國家(迦納、布吉納法索、貝南、象牙海岸、馬利、多哥)的水資源綜合管理，並強調採用參與式方法進行議題討論與決策。

- **政府與私人部門的夥伴關係**：亞洲開發銀行(ADB)水與城市發展部門資深總監 Norio Saito 提到，ADB 的業務多以公共部門主權貸款為主，但也積極與非主權部門合作，邀請私人資本參與城市和氣候議題。美國波士頓諮詢集團(Boston Consulting Group, BCG)管理總監兼合夥人 Dave Sivaprasad 也強調，公私部門的合作對於動員資源和專業知識至關重要。

- **部門間整合與系統思考**：中國水利水電科學研究院彭靜教授指出，城市係由交通、能源和水等多重子系統組成的複雜系統。她建議，在行政層面，需要建立更互聯的資訊共享和聯合監管機制，以促進跨部門協調。英國 ARUP 工程顧問公司 Mark Fletcher 先生也強調，水利不應被視為孤島，而是需要透過系統思考，將水與交通、能源、建築和公共衛生等城市系統整合。中國水利部長江水利委員會朱勇輝先生指出，中國的河

湖長制是一項創新的政策，透過各級政府負責人擔任河湖長，有效解決了水污染控制中的複雜協作問題，目前中國有 120 萬名河長執行職務，確保每條河流、湖泊都有人管理。

- **公眾參與與意識提升**：新加坡環境及永續發展部部長傅海燕(Grace Fu)提到，PUB 實施「Get Flood-Wise in a Flash」宣傳活動和桌面演練，藉此提高社區對洪水災害的認識和應對能力。政府間氣候變化委員會 Winston Chow 教授和 DHI 公司執行副總裁 Stefan Szylkarski 都強調公眾參與的重要性，但指出溝通方式需簡化，避免過於技術化。哥本哈根城市韌性與永續解方計劃總監 Lykke Leonardsen 女士分享哥本哈根將洪水調適計畫融入城市規劃，透過綠色口袋式公園和多功能防災公園，提升宜居性並方便管理水資源。

- **知識共享與能力建設**：聯合國教科文組織(UNESCO)政府間水文計畫(Intergovernmental Hydrological Programme, IHP)計劃專員 Sarantuyaa Zandaryaa 博士指出，水管理中的能力建設不足是阻礙氣候韌性水資源策略的主要問題。希臘塞薩洛尼基亞里斯多德大學 Elpida Kolokytha 教授也分享了巴爾幹地區在水利建設、可靠數據獲取和民眾意識提升能力方面挑戰頗大，並提到，即使帶來數位科技等前瞻技術，當地也缺乏受過適當培訓的人員來使用。最後政府間氣候變化委員會 Winston Chow 教授也呼籲各國水利專家參與相關報告審閱時，可提供地方成功經驗，讓報告更具操作性。

- **傳統與原住民知識的結合**：紐西蘭奧克蘭大學教授 Asaad Y. Shamseldin 強調，在水資源管理的應用上，應可將原住民知識與現代科學相互結合，以提供更全面的解決方案。他認為，特別是透過原住民的「水文化」傳統智慧概念，順應自然法則，可以為應對乾旱和洪水威脅提供寶貴啟示。

(五)水力發電與能源轉型中的永續發展挑戰

在全球氣候變遷日益加劇、能源需求不斷增長的背景下，水力發電在能源轉型中扮演著不可或缺的關鍵角色。然而，這項重要的再生能源形式也面臨著嚴峻的永續發展挑戰，尤其是在環境衝擊、社會公平、經濟可行性及治理模式等方面。IAHR 主席 Philippe Gourbesville 先生指出，全球水挑戰的加劇，受快速人口增長、現代城市環境擴張以及河流、湖泊和水生生態系統品質惡化所驅動。IAHR 已將能源轉型列為其四大優先事項之一，旨在推動相關解決方案。

1.**水力發電在能源轉型中的關鍵角色**：水力發電不僅僅是電力生產，更是水資源管理、支持生計和推進永續發展的關鍵工具。

(1)**基載電力與間歇性再生能源的平衡**：隨著世界轉向更多再生能源，水力發電至關重要，不僅提供基載能源，還能平衡風能和太陽能等間歇性來源。來自馬來西亞的 James Ong 教授(國際水力發電協會 IHA 代表)強調，水力發電對於平衡風能和太陽能等間歇性再生能源至關重要。負責巴西伊泰普水電站(Itaipu binational)的 Joni Madruga Garcia 技術總監提到，風能和太陽能在巴西呈爆炸式增長，而伊泰普水電站作為「天然電池」提供了系統所需的靈活性，幫助巴西系統應對再生能源的間歇性。

(2)**抽水蓄能水力發電(Pumped Storage Hydropower, PSH)**提供長時間的儲能，使得風能和太陽能等間歇性再生能源能更好地整合，透過在需求高或太陽能發電不足時釋放儲存的過剩能量。IAHR 水利結構技術委員會主席 Stefan Felder 先生強調，截至 2024 年，全球抽水蓄能容量新增 8GW，遠高於過去二十年的年均 2 到 4 GW，抽水蓄能對於實現淨零排放轉型絕對關鍵。。

(3)**全球容量與去碳化貢獻**：截至 2024 年，全球水力發電裝機容量接近 1,500 GW，約佔全球總發電量的 15%。中國持續主導東亞及太平洋地

區的水力發電發展，預計在 2030 年前超越 120 GW 的目標。國際水利發電協會 James Ong 教授分享，馬來西亞砂拉越能源公司已從碳氫化合物轉向以再生水力發電為主的能源結構，去碳化超過 70%。伊泰普水電站巴拉圭代表 Daniel Vázquez 土木工程師指出，伊泰普作為大型水力發電廠，避免了大量碳排放，其中，該廠 2016 年的發電量避免了使用煤炭而產生超過 8,700 萬噸的二氧化碳排放。

2.**水力發電永續發展面臨的挑戰**：儘管水力發電具有巨大潛力，其永續發展仍面臨多重挑戰，尤其是在環境、社會和經濟方面：

(1)**環境衝擊**：

- **河流破碎化與流量調節**：Silke Wieprecht 教授(IAHR 生態水力學社群代表)指出，全球約有 60,000 座大型(高於 15 公尺)水壩和 800,000 座小型水壩，大、小水壩嚴重衝擊河流環境生態系統，導致河流破碎化，缺乏自由流動的水道。全世界約 60% 的總河流流量受到水壩和水庫的調節。因此，她質疑許多小型水力發電廠的生態衝擊高昂，但能源產出卻很低，是否真的合理。IAHR 水利結構技術委員會主席 Stefan Felder 先生也指出，水工結構可能導致河流系統破碎化、泥沙淤積、水質惡化及水力尖峰等負面影響。

- **泥沙管理**：建設水壩等水利設施會導致上游泥沙淤積，影響水庫壽命和下游生態系統。負責巴西伊泰普水電站(Itaipu binational)的 Joni Madruga Garcia 技術總監提到，大型水力發電廠的泥沙問題是一個巨大的挑戰，難以單純透過工程措施管理。DHI 公司執行副總裁 Stefan Szylkarski 補充，水庫中的泥沙淤積導致水庫容量流失，興建新水庫的速度趕不上舊水庫被淤積的速度，這顯然不是永續的。此外，泥沙管理不僅是技術問題，也涉及環境影響，因為下游需要完整的粒徑分佈以維持生態健康。

- **生物多樣性與水質**： IAHR 水利結構技術委員會主席 Stefan Felder 提到澳洲抽水蓄能項目中遇到的入侵性魚種問題，水壩會阻礙魚類洄游，改變棲息地，且水力發電的水文狀況和結構也可能導致水質惡化。

- **氣候變遷下的水資源可用性及跨界水資源管理**：Stefan Felder 表示，澳洲是受極端氣候國家之一，目前正在面臨乾旱的挑戰，但在乾旱發生時期，作為抽水蓄能的水庫可能沒有足夠的水來運作。另外，孟加拉的 Mahun 教授也提出跨國界的水資源管理，對未來水資源短缺時期，將可能造成巨大的潛在影響。

(2)**社會衝擊與公平性**：雖然水力發電能為農村地區提供電力覆蓋，惠及偏遠社區，但其建設可能涉及土地徵用、社區搬遷，對當地居民生計和文化產生影響。也有不少學者認為，水利發電廠的興建與設置需要充分的社會對話，並討論我們真正想要什麼：是綠色能源，還是運作良好的環境？在場參與學者也強調，環境保護是有代價的，我們應為水力發電造成的環境影響付出代價。

(3)**經濟與融資挑戰**：

- **成本超支與工期延誤**：IAHR 水利結構技術委員會主席 Stefan Felder 指出，大型抽水蓄能專案(如澳洲 Snowy Hydros)面臨大規模延誤和成本超支，證明其建設並非微不足道。

- **外部性定價不足**：國際水利發電協會 James Ong 教授提到，環境損害(如破壞花草樹木、魚群滅失等)缺乏外部成本計算，政府和產業均未為此付出相關成本及代價。荷蘭水務特使 Meike van Ginneken 也強調，據世界銀行報告指出水利基礎設施投資每投入 1 美元可產生 15 美元效益，雖然能產生巨大效益，但將這些經濟

效益轉化為可持續的財政收入流，並動員私人資本參與，仍是全球性挑戰。

(4)**治理與合作不足**：

來自瑞士蘇黎世的 Robert Briss 教授指出，水利領域存在**倡議碎片化**的問題，許多解決方案被不斷重複發明，缺乏有效的傳播。他呼籲 IHA(國際水力發電協會)、ICOLD(國際大壩委員會)和 IAHR 等組織應合併倡議，採取更整體性的方法。

另外，Stefan Felder 主席及 James Ong 教授都認為，目前水利領域缺乏關於如何永續設計水工結構的統一指南，儘管有標準和法律，但各個國家在執行環境法規方面時，尤其在缺乏成本影響機制下，常面臨困難。

3.**永續水力發電的策略與解決方案**：面對這些挑戰，全球專家們正積極探索多樣化的策略與創新技術，以實現水力發電的永續發展：

(1)**永續標準與認證**：James Ong 教授指出，國際水利發電協會(IHA)和其成員致力於透過**聖荷西宣言(San José Declaration)**採納永續水力發電，承諾未來只接受永續水力發電。**水力發電永續標準(HSS)**則涵蓋 ESG 風險管理、生物多樣性保護和社區利益，透過認證的再生能源可獲得溢價，並提升行業聲譽和社會營運許可。

(2)**創新工程與設計**：

萊茵河上的 Rheinfelden 發電站是一個成功的改造案例，新結構發電量是舊結構的三倍，同時整合多項環境減緩措施，包括魚道、產卵地、水獺通道和棲息地恢復區。

另外，巴拉圭和巴西共有的伊泰普水電站透過 Pirame 魚類通道，**恢復了水庫與下游巴拉那河之間的魚類連通性**，監測結果顯示魚類能成功洄游。中國大峽工程也建設了「一中心雙魚道、雙增殖站、五人造生境」，並進行全流域、全生命週期的水生生態保護和治理模式創新。

Stefan Felder 主席提到**澳洲利用兩個舊露天礦坑作為水庫進行抽水蓄能的專案**，即使水質受到高度污染，仍能透過創新方式加以利用。

3. **整合式流域管理與系統思考：**

Silke Deprest 教授呼籲，在設計水力發電專案時，應採取**盆地尺度的整體觀點**，從初期就將生態環境需求納入考量，而非僅止於事後補償。

中國廣西大藤峽水利樞紐開發有限責任公司胡忙全副總經理分享，大峽工程面向流域、系統治理，建立了涵蓋工程監測管理和科學研究的生物多樣性保護格局，並在維護流域生物多樣性方面實施了多項措施，如水質保護、古樹名木保護和退耕還林等重要措施。

巴西伊泰普水電站(Itaipu binational)的 Joni Madruga Garcia 技術總監提到伊泰普水電站投資於自然解方和生態系統服務，透過流域尺度的管理來處理泥沙，延長水庫壽命。

參、心得與建議

一、整合灰色與藍綠基礎設施，提升城市綜合防洪韌性

鑑於氣候變遷下城市面臨日益頻繁且劇烈的極端天氣事件衝擊，單一的防洪策略已不足以應對。建議我國可借鑒新加坡的綜合方法，將傳統的「灰色基礎設施」與「自然為本解決方案」(Nature-Based Solutions, NBS) 緊密結合，並參考「藍綠系統」或「海綿城市」概念，透過模仿自然過程來管理徑流，形成混合解決方案，以達到最佳韌性效果，並增強生物多樣性、提供城市降溫等價值。另外，新加坡的「長島計畫」，將防洪、水資源管理與土地開發等多功能用途相結合，也是值得臺灣參考及學習的地方。

二、加速水利工程數位轉型，導入智慧化管理與預警系統

面對氣候變遷帶來的挑戰、水需求增長以及人力短缺等問題，水利工程的數位轉型已成為不可逆的趨勢。建議我國應加速水利工程的數位轉型，可採納新加坡 PUB 提出的四大策略：數據收集、數據分析、自動化及控制。在數據收集方面，我國資通訊產業發展成熟，且軟硬體整合及上下游產業鏈成熟，係我們的優勢，可借鏡新加坡政府與民間企業的合作模式，彌補傳統監測網絡點位建置不足的問題，特別是應對短時間高強度暴雨預警至關重要。在自動化方面，推廣影像分析技術監測排水堵塞情形。針對臺灣水利重大關鍵基礎可逐漸導入開發數位孿生系統，以中國丹江口水庫的開發經驗爲參考，可實現對水庫大壩等重要關鍵設施全天候感知與即時反饋，對於我國防洪調度、工程安全與生態保護有正面影響。

三、創新水資源融資機制，促進公私部門與跨部門深度合作

水資源領域的巨大投資需求與融資困境，是阻礙永續發展的關鍵障礙。世界銀行報告指出，水災造成高達 5500 億美元的經濟損失，而對水韌性基礎設施的投資每投入 1 美元可產生 15 美元效益。建議我國可借鑒亞洲開發銀行及各國經驗，將水的經濟效益轉化為可持續的收入流，例如透過徵收水費和稅收，並發行「藍色

債券」以吸引更多資金，或是同時導入民間資本進行合作，如亞洲開發銀行在越南的「兩個月水資源擴張計畫」。

四、推動水力發電永續標準，整合生態環境於流域管理

水力發電在全球能源轉型中扮演關鍵角色，尤其在平衡風能和太陽能等間歇性再生能源方面具有不可取代的價值，我國目前正全力發展太陽能、風能等再生能源，可參考巴西伊泰普水電站作為「天然電池」的案例，並採納國際水力發電協會 (IHA) 的「聖荷西宣言」和「水力發電永續標準 (HSS)」，將 ESG 風險管理、生物多樣性保護和社區利益納入所有水力發電專案的設計與評估中。如未來在規劃建置水利抽蓄發電廠時，建議採取以「整體流域」為尺度，從初期就將生態環境需求納入考量，而非僅止於事後補償，並可參考萊茵河上的 Rheinfelden 電站改造案例，透過創新工程設計整合多項環境減緩措施，包括魚道、產卵地、水獺通道和棲息地恢復區，以實現兼顧能源生產與生態保護的雙重目標。

五、加強公眾參與與能力建設，提升社會整體水環境素養

社會韌性是城市防洪與永續水資源管理的基石。如果僅不斷擴大排水系統並不全然可行，社區必須瞭解並認識洪水風險。建議我國應積極推動像是新加坡「Get Flood-wise in a Flash」的宣傳策略及防災演練，提升民眾對洪災風險的意識和應對能力，應賦予當地社區（特別是婦女和弱勢群體）權力，共同設計防洪解決方案，確保干預措施符合當地實際情況。此外，我國原住民屬南島語系的海洋民族，對於「水文化」傳統智慧，可能可以做為以自然為本的解決方案，來應對乾旱和洪水威脅。在水利管理領域的能力建設不足是阻礙氣候韌性水策略的主要問題，即使引進數位科技，如果缺乏受過適當培訓的人員來使用也可能造成問題。因此，建議我國應加強對水利專業人才的培訓與教育，培養具備系統性思維和多學科知識的工程師和管理者，並促進國際間的知識共享與技術交流，以確保水利建設與管理的前瞻性與永續性。

肆、附件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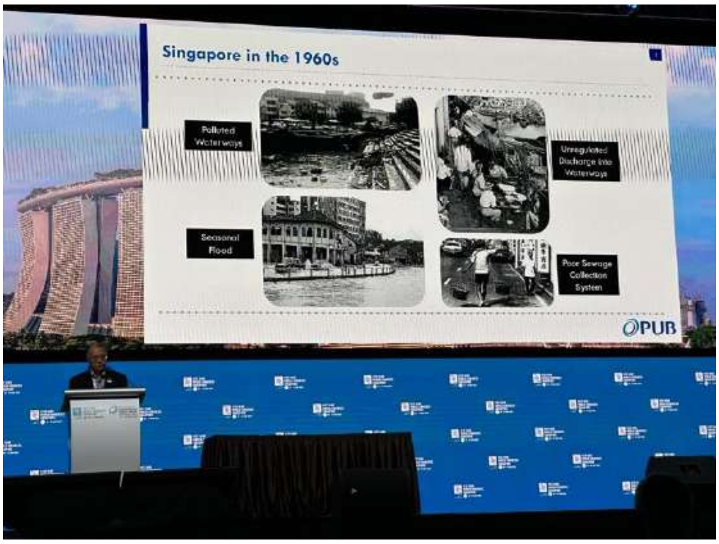
MAKE
EVERY
DROP
COUNT


PUB
Delivering Our Mission
PUB

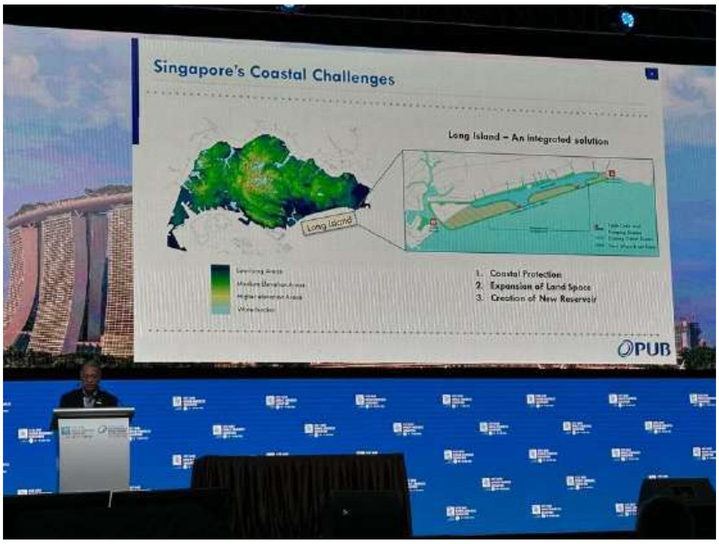

Singapore in the 1960s
PUB


Singapore in the 1960s
Polluted Waterways
Unregulated Discharge into Waterways
Seasonal Flood
Poor Sewage Collection System
PUB


Present Day Singapore
Marina Barrage
PUB


Marina Barrage
Water Supply
Flood Control
Lifestyle Attraction
Marina Barrage
PUB


Singapore's Coastal Challenges
Island Nation
Tropical Equatorial Climate
Low-Lying Areas
PUB


Singapore's Coastal Challenges
Long Island – An integrated solution
Long Island
1. Coastal Protection
2. Expansion of Land Space
3. Creation of New Reservoir
PUB


Singapore's FOUR National Taps
Local Catchment
Imported Water
NEWater
Desalinated Water
Climate-Resilient Water Sources
PUB


NEWater
Industry Demand
Indirect Potable Use
Economic Driver
Replenishing Reservoirs during Droughts
PUB

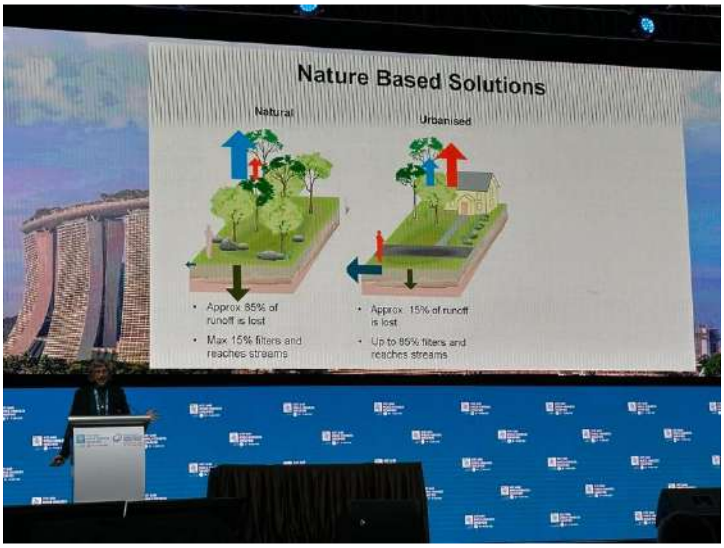

PUB


41ST IAHR
WORLD CONGRESS
SINGAPORE
22 – 27 JUNE 2025
INNOVATIVE WATER ENGINEERING
FOR SUSTAINABLE DEVELOPMENT
IAHR KEYNOTES


Climate Change + Pollution


Blue-Green Systems
improve livability of our cities
• Nature Based Solutions (NBS)
Europe
• Low Impact Development (LID)
USA
• Sponge City
China
• Water Sensitive Urban Design (WSUD)
Australia
QUT


Nature Based Solutions
Natural
• Approx 85% of runoff is lost
• Max 15% filters and reaches streams

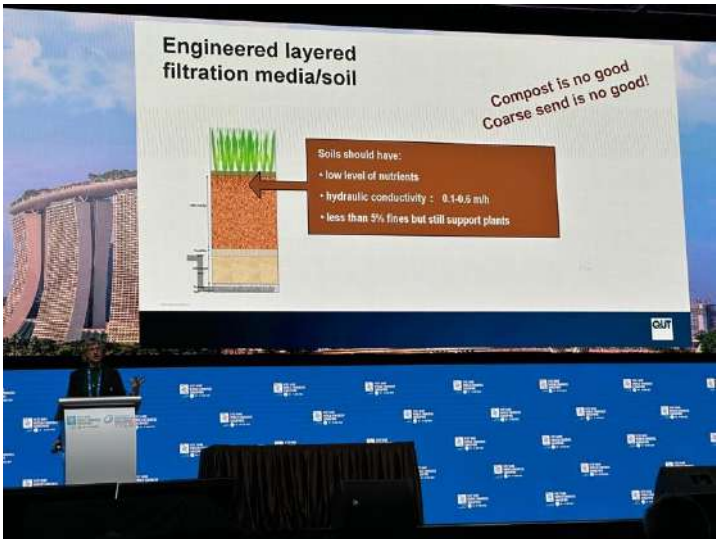

Nature Based Solutions
Natural
Urbanised
• Approx 85% of runoff is lost
• Max 15% filters and reaches streams
• Approx 15% of runoff is lost
• Up to 85% filters and reaches streams

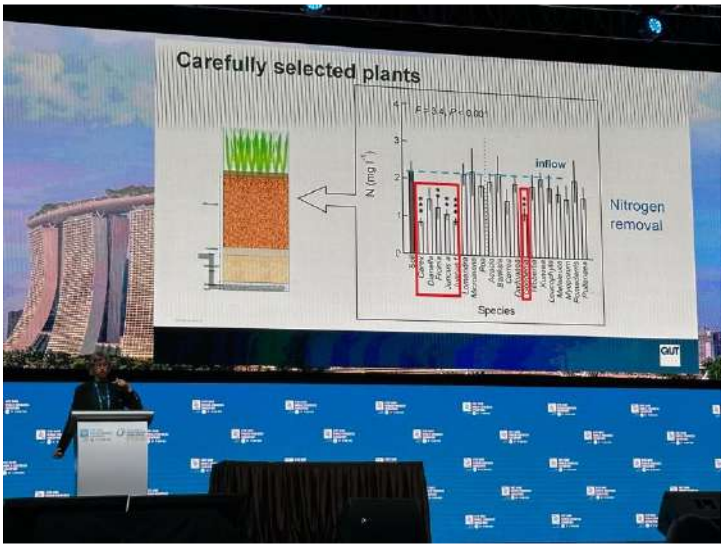

Nature Based Solutions
Natural
Urbanised
Harvesting & WSUD
• Approx 85% of runoff is lost
• Max 15% filters and reaches streams
• Approx 15% of runoff is lost
• Up to 85% filters and reaches streams
• Capture, detain, infiltrate, treat, use
• Back to natural

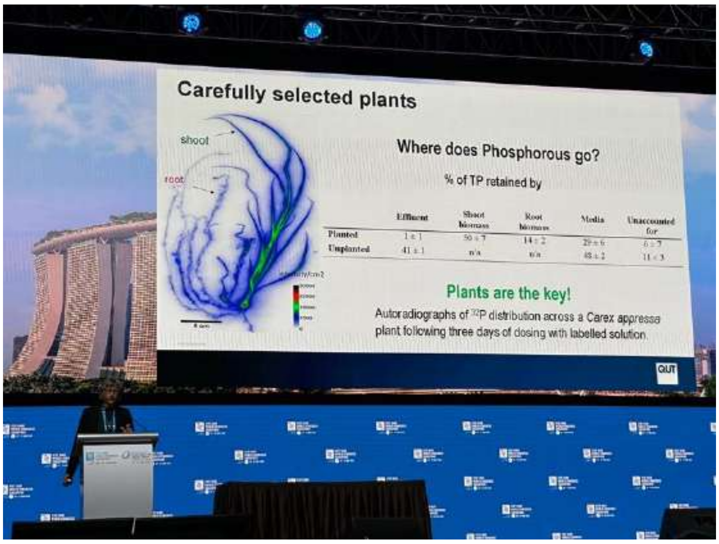

10,000
RainGardens
for improvement of water quality in the Yarra River in Melbourne

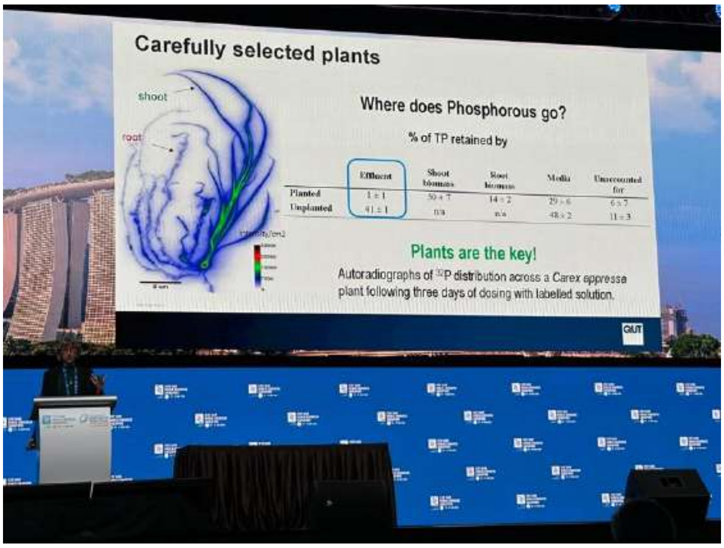

Singapore stormwater biofilter, 2008


Nanjing, China, 2018


Engineered layered filtration media/soil
Compost is no good
Coarse send is no good!
Soils should have:
• low level of nutrients
• hydraulic conductivity : 0.1-0.5 m/h
• less than 5% fines but still support plants


Carefully selected plants
Inflow
Nitrogen removal
Species


Carefully selected plants
shoot
root
Where does Phosphorous go?
% of TP retained by
Effluent
Shoot biomass
Root biomass
Media
Unaccounted for
Planted 1 ± 1 50 ± 7 14 ± 2 29 ± 6 6 ± 7
Unplanted 41 ± 1 n/a n/a 48 ± 2 11 ± 3
Plants are the key!
Autoradiographs of 32P distribution across a Carex appressa plant following three days of dosing with labelled solution.
QUT


Carefully selected plants
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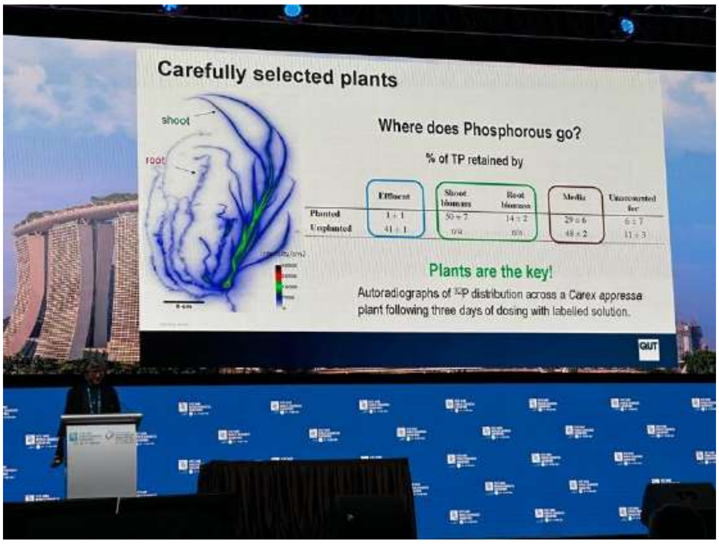
Carefully selected plants
shoot
root
Where does Phosphorous go?
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Shoot biomass
Root biomass
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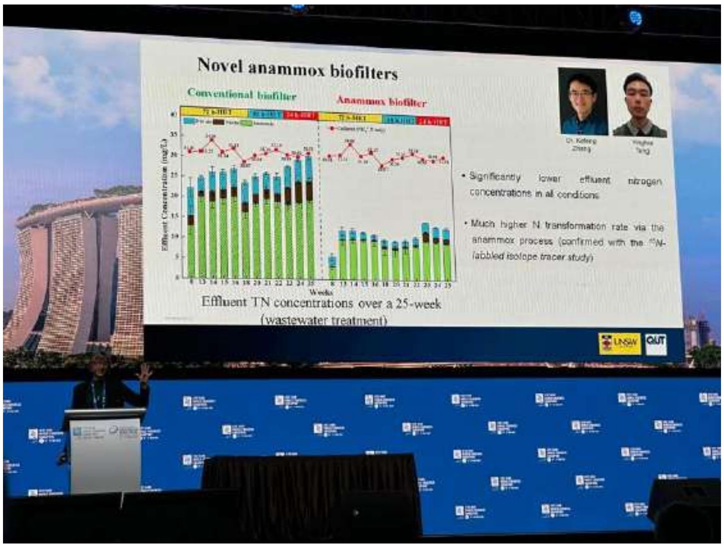
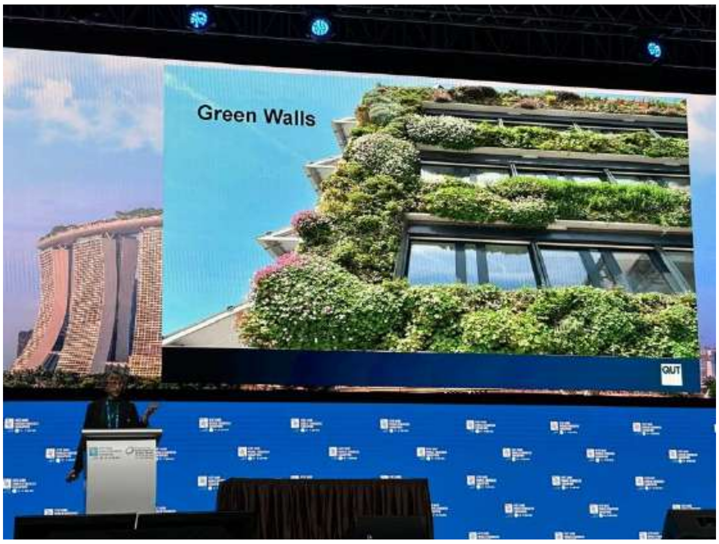
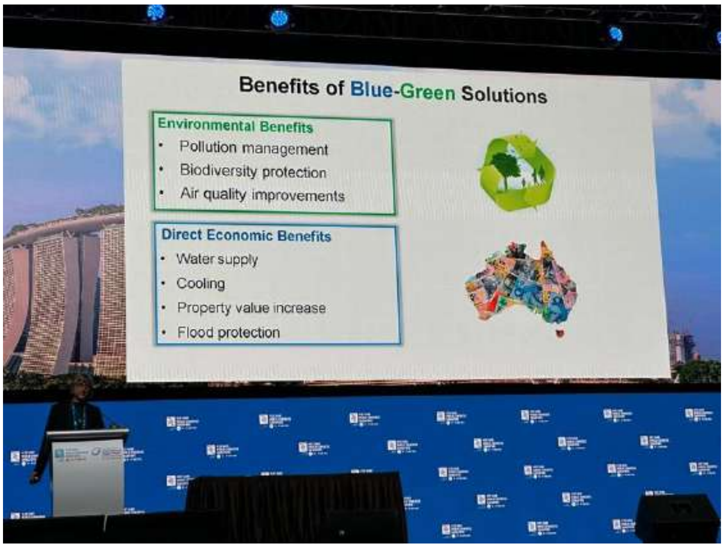

Novel anammox biofilters
Conventional biofilter
Anammox biofilter
Effluent Concentration (mg/L)
Weeks
Effluent TN concentrations over a 25-week (wastewater treatment)
Significantly lower effluent nitrogen concentrations in all conditions
Much higher N transformation rate via the anammox process (confirmed with the 15N-labbled isotope tracer study)
UNSW
QUT

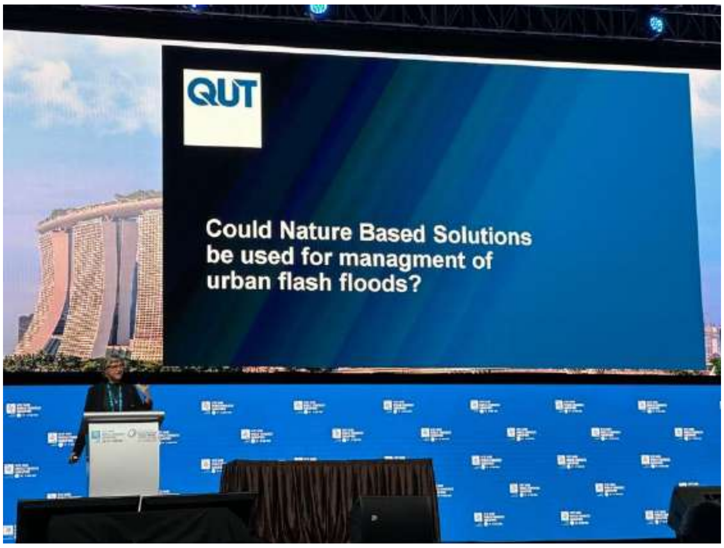

Green Walls
QUT

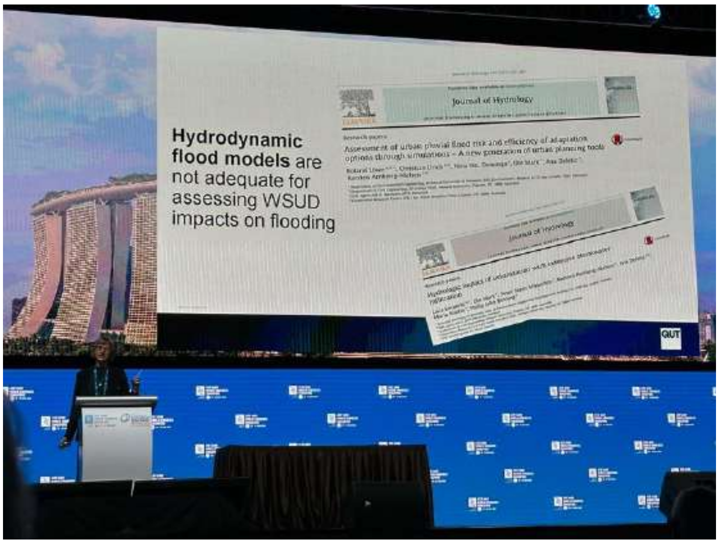

Blue Green Walls for Grey Water Treatment
QUT


Blue Green
Walls for
Grey Water
Treatment
QUT

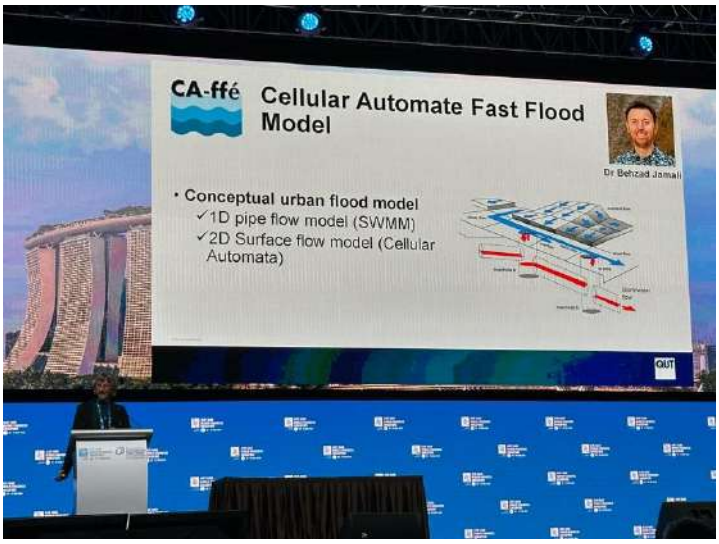

1 year of
operation with
greywater
QUT

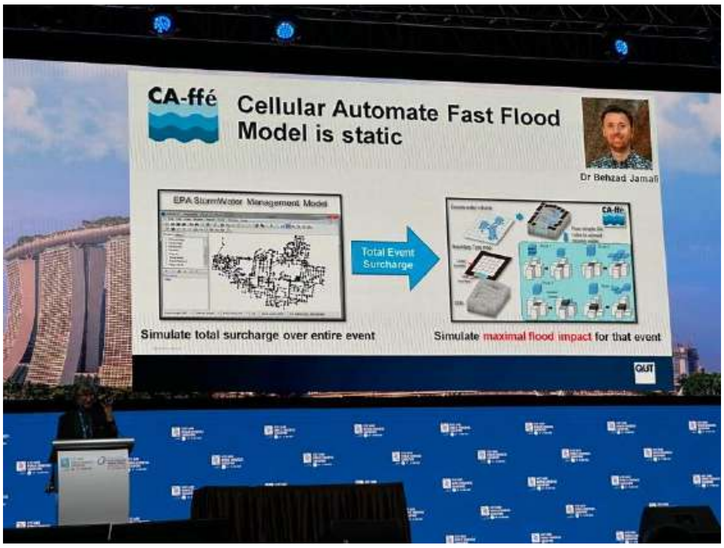

Benefits of Blue-Green Solutions
Environmental Benefits
• Pollution management
• Biodiversity protection
• Air quality improvements
Direct Economic Benefits
• Water supply
• Cooling
• Property value increase
• Flood protection

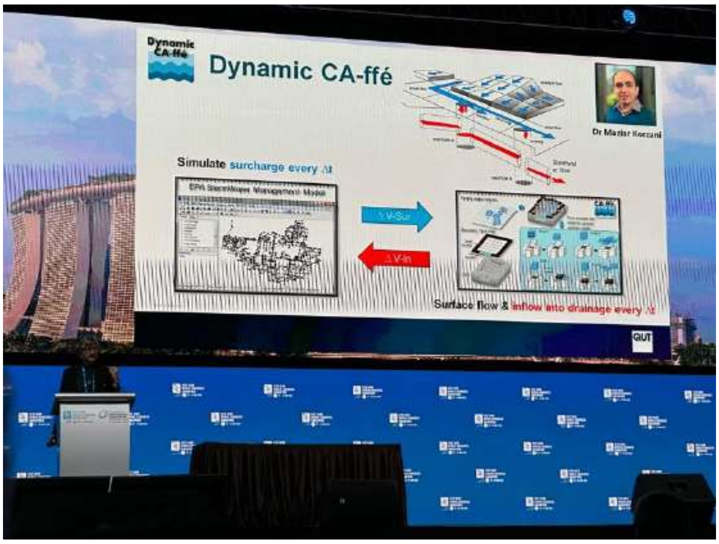

QUT
Could Nature Based Solutions
be used for managment of
urban flash floods?


Hydrodynamic
flood models are
not adequate for
assessing WSUD
impacts on flooding
Journal of Hydrology
QUT

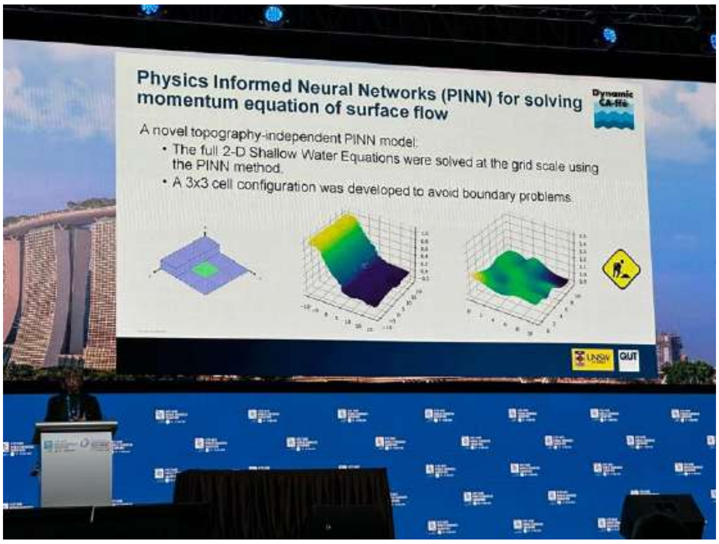

We need conceptual fast flood models!
• Fast: Simulation speed in the order of seconds to a few minutes
• Simple logic: Based on topography and water balance
QUT


CA-ffé
Cellular Automate Fast Flood Model
Dr Behzad Jamali
• Conceptual urban flood model
✓1D pipe flow model (SWMM)
✓2D Surface flow model (Cellular Automata)
QUT

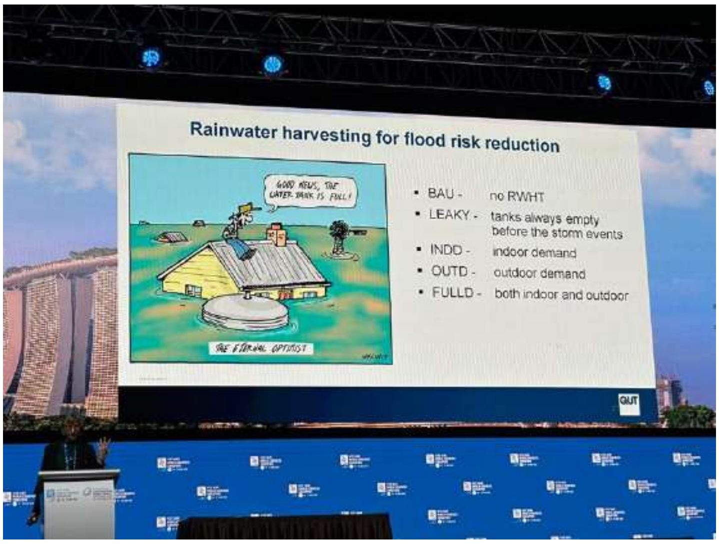

CA-ffé
Cellular Automate Fast Flood Model is static
Dr Behzad Jamali
EPA StormWater Management Model
Total Event Surcharge
Simulate total surcharge over entire event
Simulate maximal flood impact for that event
QUT

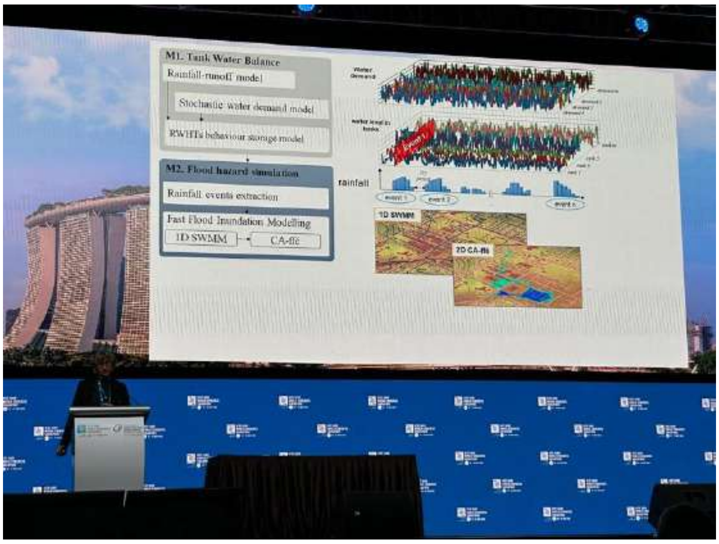

Dynamic CA-ffé
Dynamic CA-ffé
Dr Maziar Korzani
Simulate surcharge every Δt
EPA StormWater Management Model
Surface flow & inflow into drainage every Δt
QUT

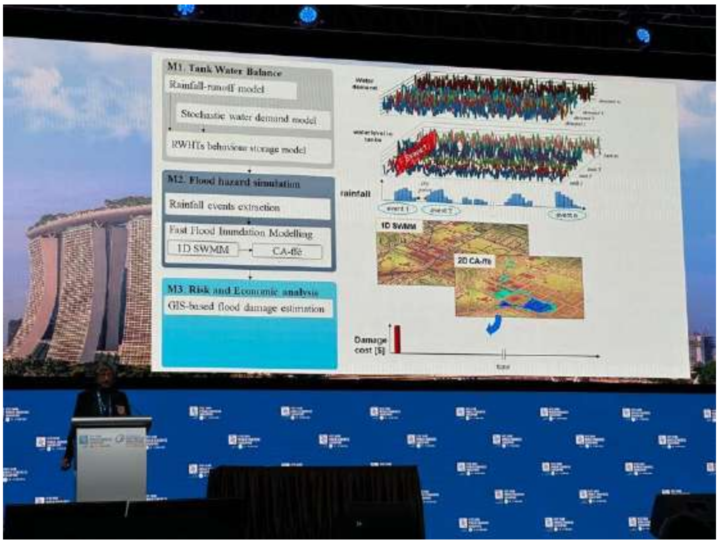

Dynamic CA-ffé
Dynamic CA-ffé
• Short simulation time (few minutes)
• Reasonable accuracy for the speed
• Nash-Sutcliffe Efficiency (NSE) ~ 0.7-0.9
• Root Mean Square Error (RMSE) ~ 5 - 15%
• Reporting inundation depth map (no velocities)
Coogee Bay, Sydney
Dynamic CA-ffé
TUFLOW
QUT

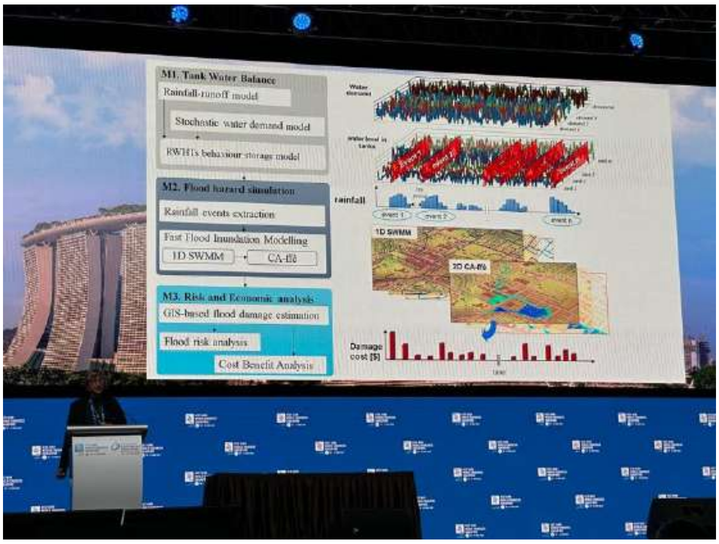

Physics Informed Neural Networks (PINN) for solving momentum equation of surface flow
Dynamic CA-ffé
A novel topography-independent PINN model:
• The full 2-D Shallow Water Equations were solved at the grid scale using the PINN method.
• A 3x3 cell configuration was developed to avoid boundary problems.
UNSW
QUT

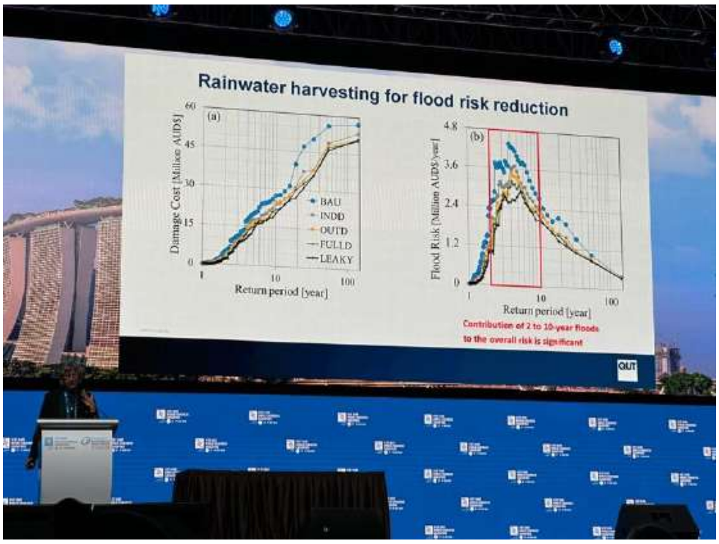

Rainwater harvesting for flood risk reduction
GOOD NEWS, THE WATER TANK IS FULL!
THE ETERNAL OPTIMIST
Scotchman's Creek Catchment
• 270 ha
• 2404 buildings (1 tank for each building)
• A total tank volume of ~9,200 m³
• 65-year historical rainfall series (6 min resolution)
QUT

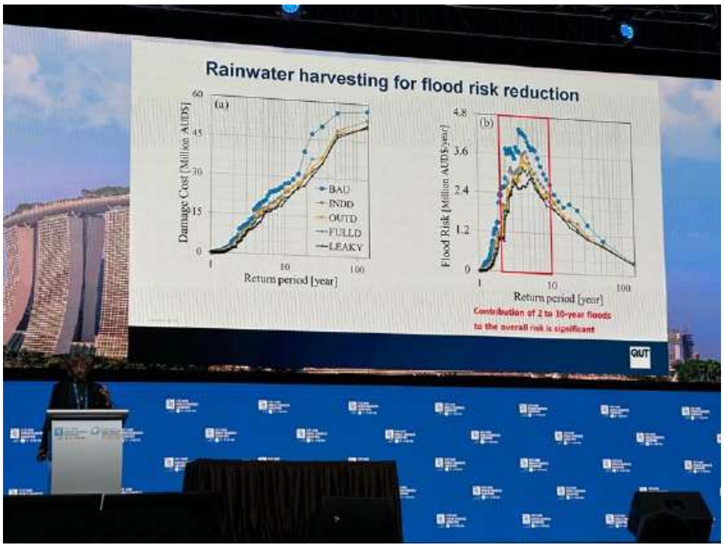

Rainwater harvesting for flood risk reduction
GOOD NEWS, THE WATER TANK IS FULL!
THE ETERNAL OPTIMIST
BAU - no RWHT
LEAKY - tanks always empty before the storm events
INDD - indoor demand
OUTD - outdoor demand
FULLD - both indoor and outdoor
QUT


M1. Tank Water Balance
Rainfall-runoff model
Stochastic water demand model
RWHTs behaviour storage model
M2. Flood hazard simulation
Rainfall events extraction
Fast Flood Inundation Modelling
1D SWMM
CA-ffé
rainfall
1D SWMM
2D CA-ffé


M1. Tank Water Balance
Rainfall-runoff model
Stochastic water demand model
RWHTs behaviour storage model
M2. Flood hazard simulation
Rainfall events extraction
Fast Flood Inundation Modelling
1D SWMM
CA-ffé
M3. Risk and Economic analysis
GIS-based flood damage estimation
rainfall
1D SWMM
2D CA-ffé
Damage cost [$]


M1. Tank Water Balance
Rainfall-runoff model
Stochastic water demand model
RWHTs behaviour storage model
M2. Flood hazard simulation
Rainfall events extraction
Fast Flood Inundation Modelling
1D SWMM
CA-ffé
M3. Risk and Economic analysis
GIS-based flood damage estimation
Flood risk analysis
Cost Benefit Analysis
rainfall
1D SWMM
2D CA-ffé
Damage cost [$]


Rainwater harvesting for flood risk reduction
(a)
Damage Cost [Million AUD$]
BAU
INDD
OUTD
FULLD
LEAKY
Return period [year]
(b)
Flood Risk [Million AUD$/year]
Return period [year]
Contribution of 2 to 10-year floods to the overall risk is significant
QUT


Rainwater harvesting for flood risk reduction
(a)
Damage Cost [Million AUD$]
BAU
INDD
OUTD
FULLD
LEAKY
Return period [year]
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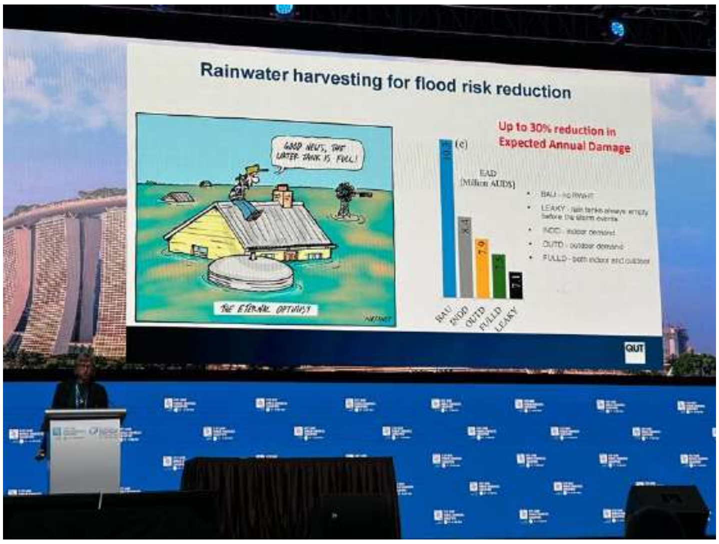
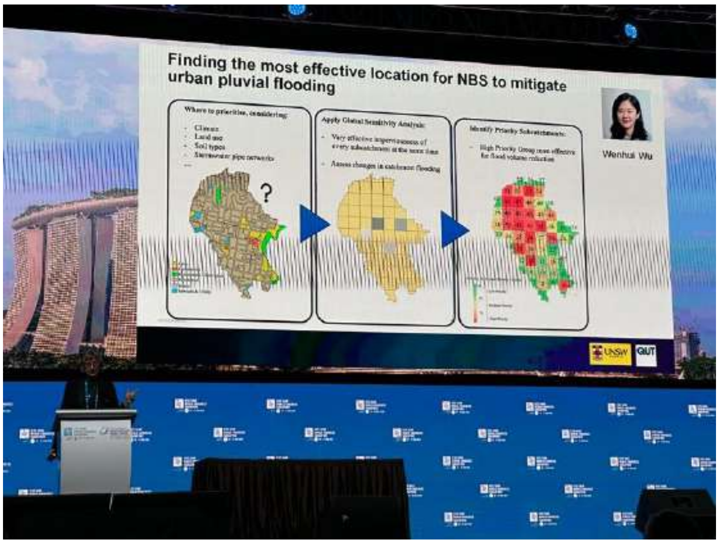
QUT


Rainwater harvesting for flood risk reduction
GOOD NEWS, THE WATER TANK IS FULL!
THE ETERNAL OPTIMIST
Up to 30% reduction in Expected Annual Damage
EAD (Million AUD$)
BAU
INDD
OUTD
FULLD
LEAKY
QUT

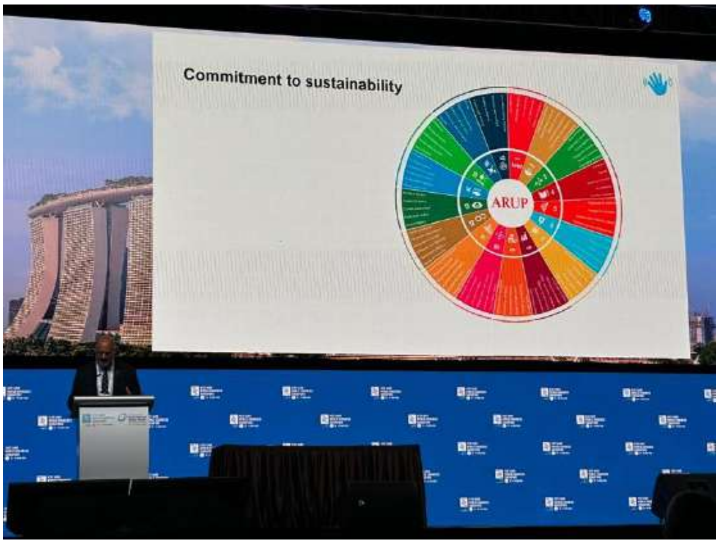

Finding the most effective location for NBS to mitigate urban pluvial flooding
Wenhui Wu
UNSW
QUT


Intelligent and Green Infrastructure for Managing Urban Flash Floods
QUT


ARUP
Sustainable water management
41st IAHR World Congress
Singapore
June 2025
Mark Fletcher FREng
Global Water Business Leader


Contents
1 Introduction
2 Challenges and opportunities
3 Working with nature
4 Applying our thinking
5 Learning from projects
6 Conclusions
#COCOP21

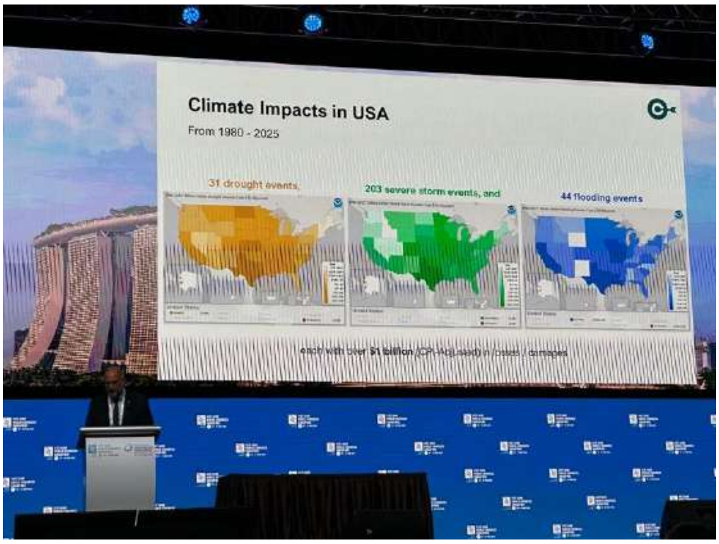

Our Projects
Reference Countries
1 Peru
2 USA
3 Australia
4 China
5 UK
6 South Africa
7 Philippines
8 Spain

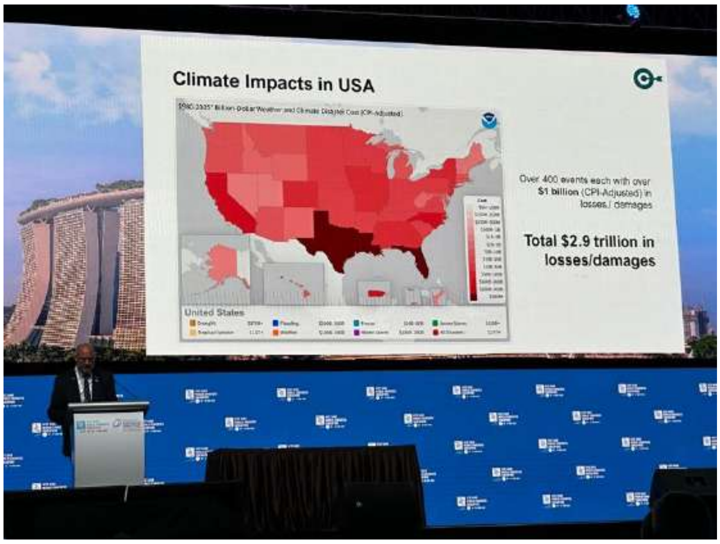

Commitment to sustainability
ARUP


We all live on one planet


Global Drivers
We have identified these key drivers that are affecting the world and will focus on them.
Nature is at the heart of all that we do.
In practical terms we have broken these Global Drivers down to some key issues that we can respond to.
CLIMATE CHANGE
WATER SECURITY
HEALTH
NATURE
New water resources, wastewater recycling, desalination, demand management
Combined sewer overflows and river pollution, wastewater epidemiology


“Climate change is costing the world more than $1.2 trillion annually”


Climate Impacts in USA
From 1980 - 2025
31 drought events,
203 severe storm events, and
44 flooding events
each with over $1 billion (CPI-Adjusted) in losses / damages

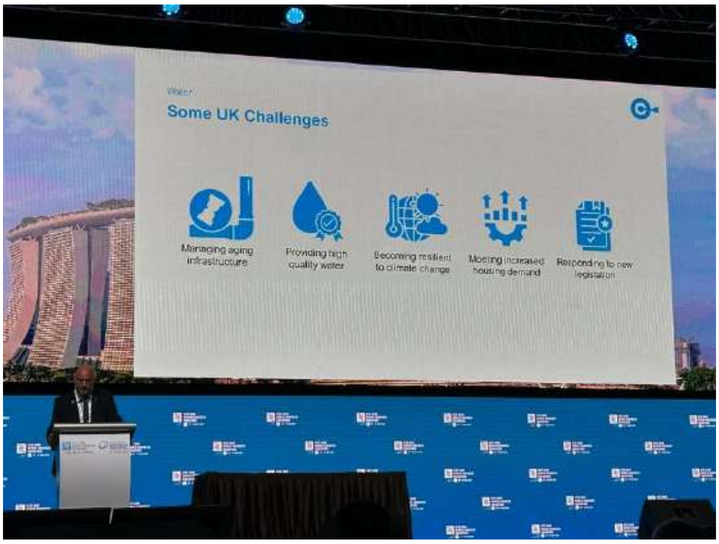

Climate Impacts in USA
United States
Over 400 events each with over $1 billion (CPI-Adjusted) in losses / damages
Total $2.9 trillion in losses/damages


We have dramatically changed our natural systems


Dependencies and inter-dependencies of systems


Cities
Challenges
Health Crisis
Physical/ Mental Wellbeing
Urban Noise
Loss of Urban Green
Air Pollution
Urban Heat
Stress
Drought
Flooding

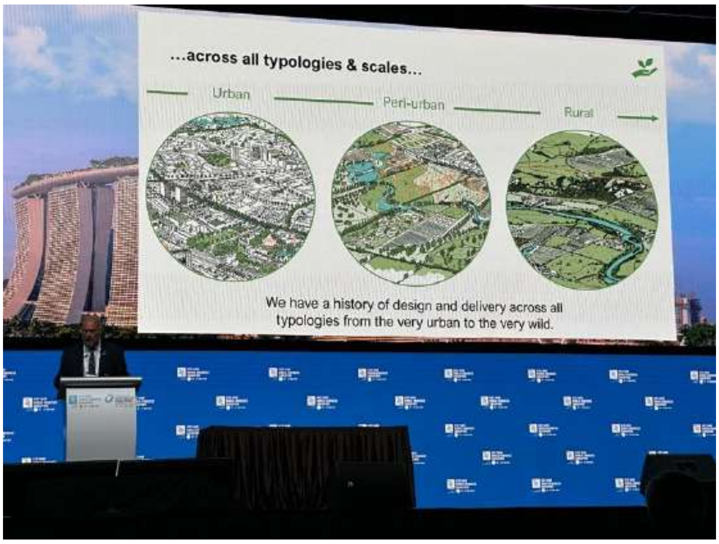

Biodiversity crisis
19%
151
16%
Nearly one in six species are threatened with extinction from Great Britain
State of Nature Report 2023


Water
Some UK Challenges
Managing aging infrastructure
Providing high quality water
Becoming resilient to climate change
Meeting increased housing demand
Responding to new legislation


Water
SMART & Sustainable Opportunities
Technical innovation
Nature-based Solutions (NbS)
Circular water economy
Community Engagement and Education
Policy and Governance Reform


Integrated design solutions for people, nature, water and urban greening


We integrate nature and systems thinking...
Harnessing wider
To delivering integrated

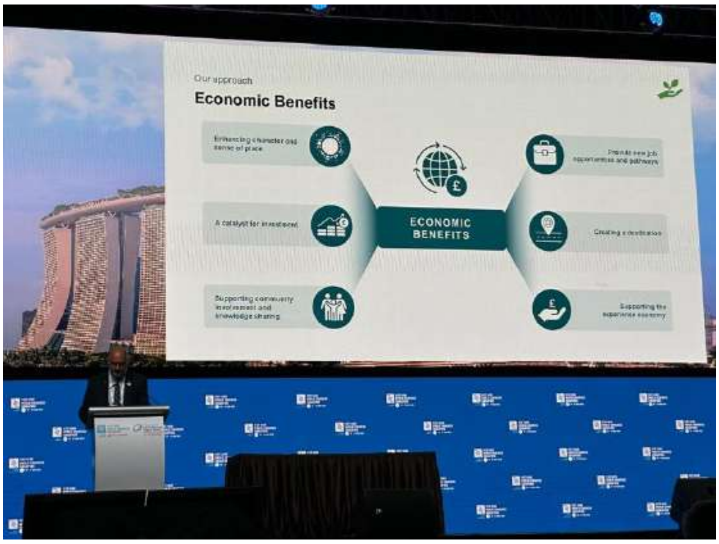

...across all typologies & scales...
Urban
Peri-urban
Rural
We have a history of design and delivery across all typologies from the very urban to the very wild.

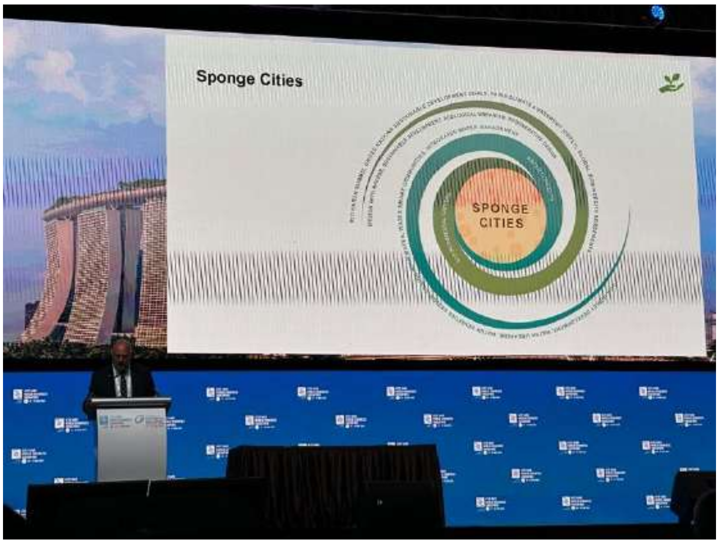

...working at all stages
Concept & Planning
Design
Management

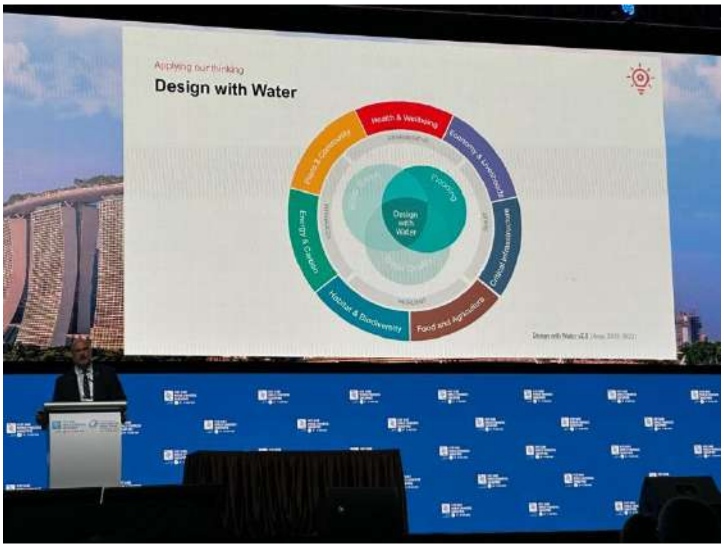

A vision that puts nature at the forefront of future regeneration

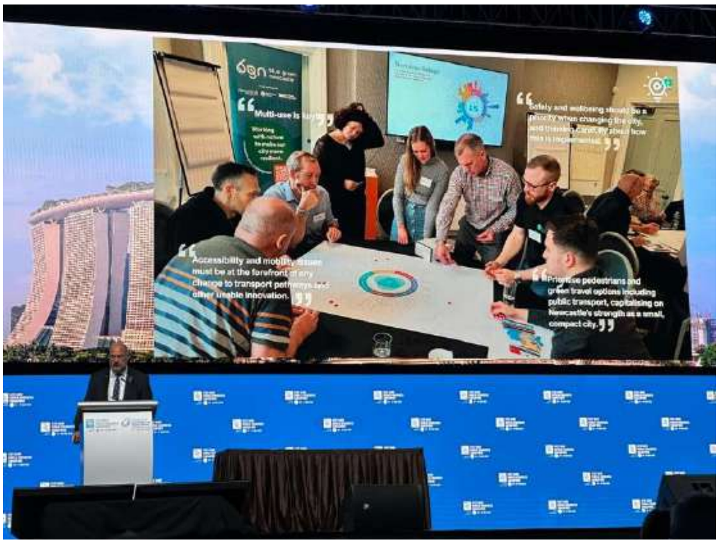

Our approach
Environmental Benefits
ENVIRONMENTAL BENEFITS

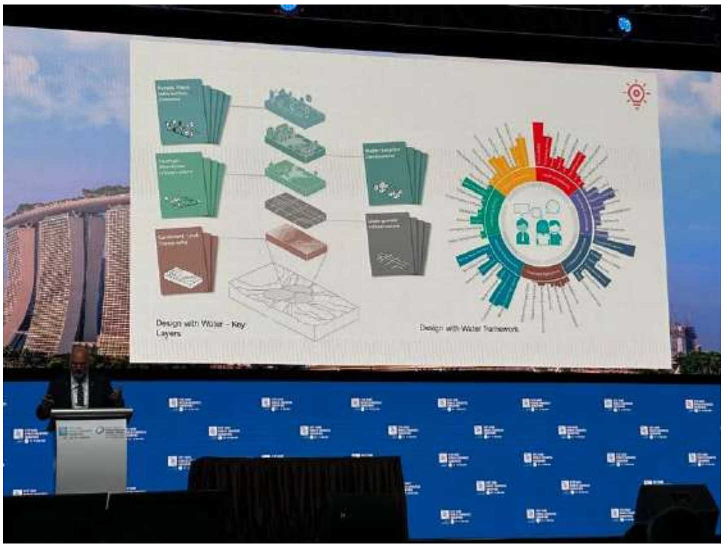

Our approach
Benefits for People
SOCIAL BENEFITS


Our approach
Economic Benefits
Enhancing character and sense of place
A catalyst for investment
Supporting community involvement and knowledge sharing
ECONOMIC BENEFITS
Creating a destination

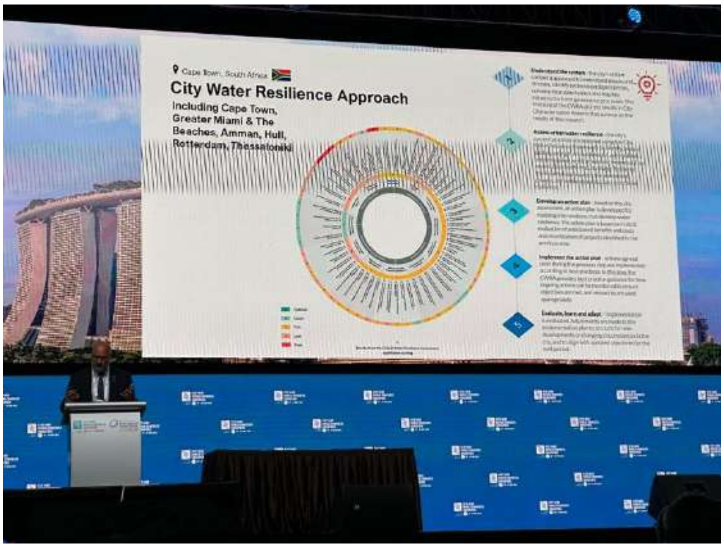

Sponge Cities
SPONGE CITIES


Applying our thinking
Design with Water
Health & Wellbeing
Economy & Livelihoods
Food and Agriculture
Habitat & Biodiversity
Energy & Carbon
Place & Community
Design with Water

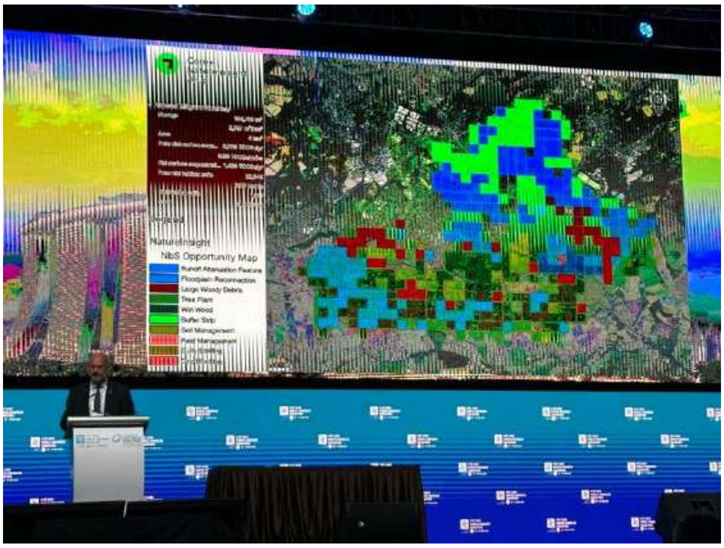

Multi-use is key

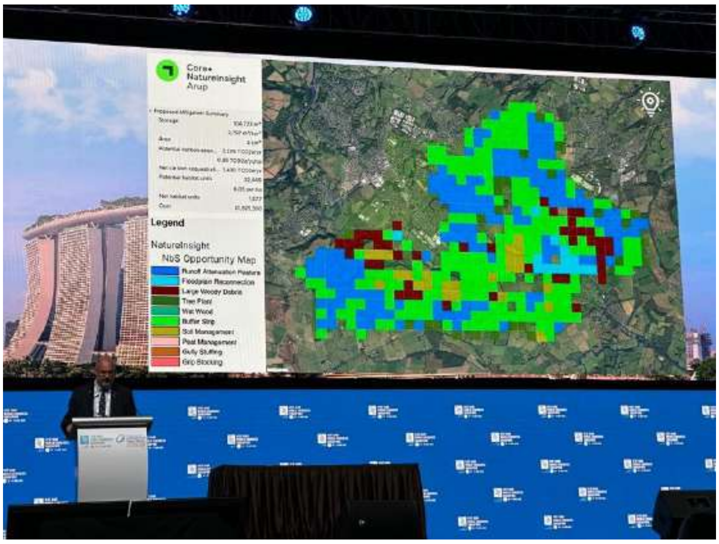

Design with Water – Key Layers
Design with Water Framework


City Water Resilience Approach
Including Cape Town, Greater Miami & The Beaches, Amman, Hull, Rotterdam, Thessaloniki


City Water Resilience Approach
Including Cape Town, Greater Miami & The Beaches, Amman, Hull, Rotterdam, Thessaloniki

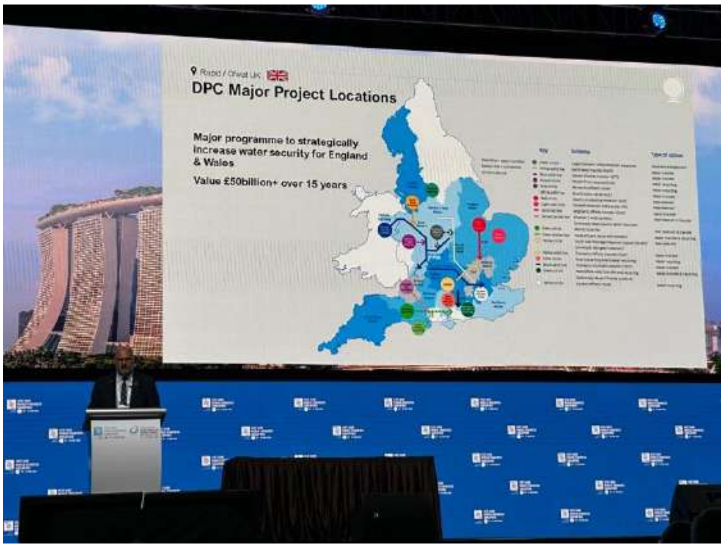

City Water Resilience Approach
Cape Town, Greater Miami & The Beaches, Amman, Hull, Rotterdam, Thessaloniki


NatureInsight
NbS Opportunity Map


Core+
NatureInsight
Arup
Legend
NatureInsight
NbS Opportunity Map


Flood Adaptation Programme
El-Nino Flood Reconstruction
National scale flood adaptation programme delivered as a G2G between Peru and UK

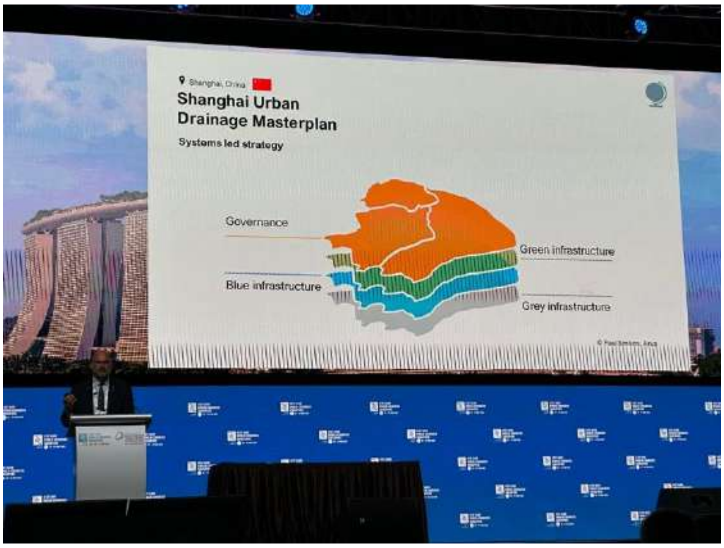

Peru
Flood Adaptation Programme
El-Nino Flood Reconstruction
National scale flood adaptation programme delivered as a G2G between Peru and UK
£6 billion+
17 River basins
7 Cities
NbS planned at catchment-scale


DPC Major Project Locations
Major programme to strategically increase water security for England & Wales
Value £50billion+ over 15 years


South East Strategic Reservoir Option (SESRO)
Major water resource to strategically increase water security for London and the South East of England
Value £2.2 billion+


Haweswater Aqueduct Resilience Programme (HARP)
Major 109 km water aqueduct 2.6m dia to strategically increase water security for Manchester
Value £2.5 billion+
Lake District
Manchester

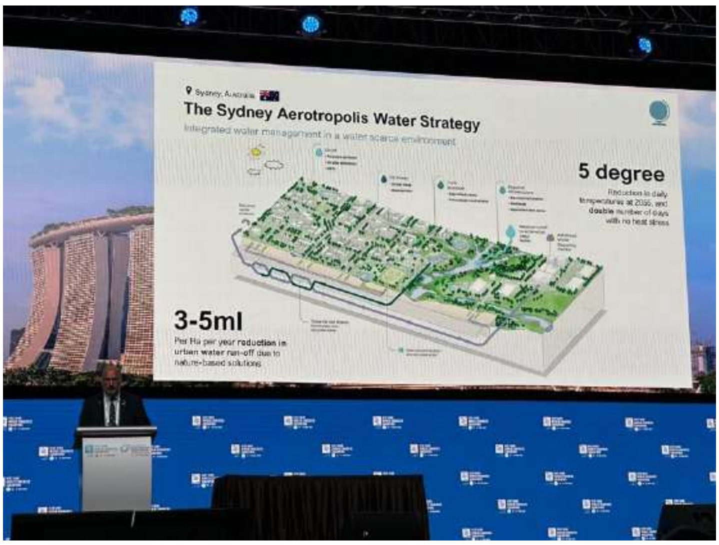

Shanghai, China
Shanghai Urban Drainage Masterplan
Integrating blue, green, grey and non-physical interventions to deliver wider benefits for ecology, economy and public health
>34m³
Stormwater capacity planned
640km²
Site area analysed


Shanghai, China
Shanghai Urban Drainage Masterplan
Systems led strategy
Governance
Green infrastructure
Blue infrastructure
Grey infrastructure


Terrain Tool
3%
10%
25%
2%
10%
20%
5%
5%
1%


Mansfield Sustainable Flood Resilience
One of the largest blue-green surface water management programmes in the UK
7 Types of blue green infrastructure
£85m
20,000
Blue-green solutions
58,000m3
Flood water storage

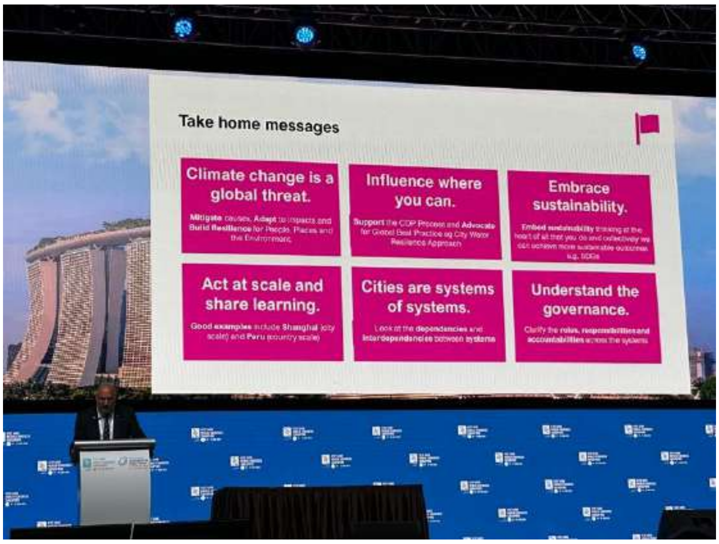

Mansfield Sustainable Flood Resilience


The Sydney Aerotropolis Water Strategy
5 degree
3-5ml
Per Ha per year reduction in urban water run-off due to nature-based solutions

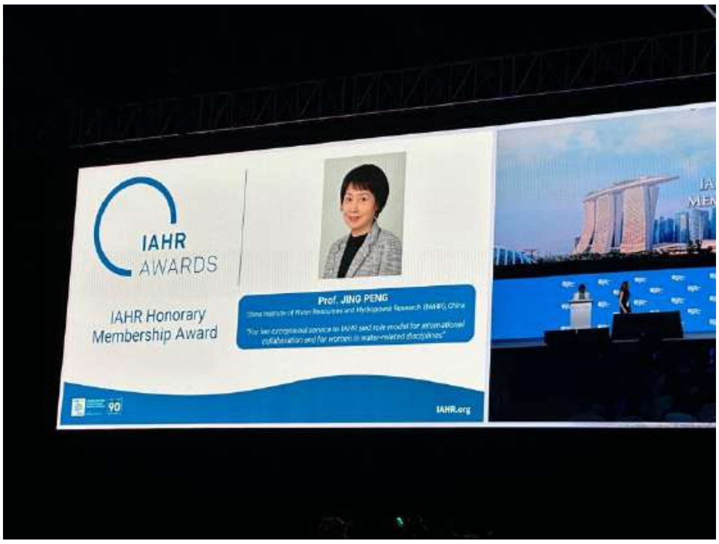

Connswater Community Greenway
NbS at the heart of bringing communities together
1.2km
Flood embankments
£40m
Project
4.1km
Reinforced concrete floodwalls


Little Island
2.4
400+
8
132


Little Island
"One of the things that is often overlooked is: Do the design choices we choose make living and working in whatever environment we're designing more sustainable?"


Take home messages
Climate change is a global threat.
Influence where you can.
Embrace sustainability.
Act at scale and share learning.
Cities are systems of systems.
Understand the governance.

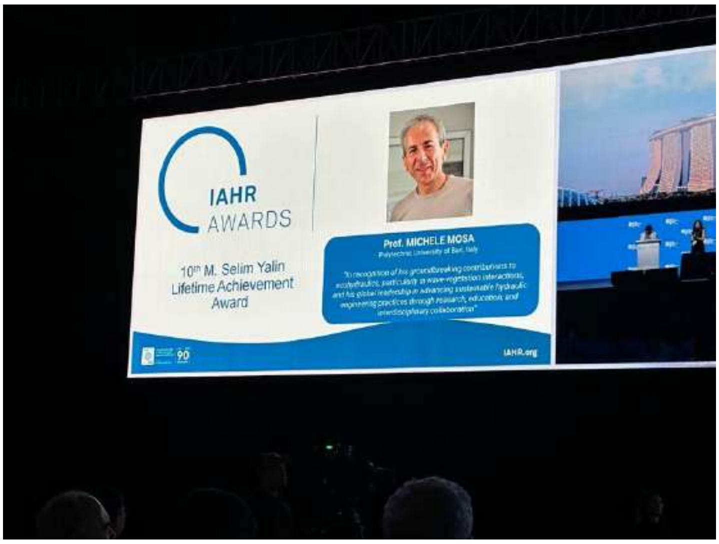

"If we fail on water, we fail on the Paris Climate Agreement, and we also fail on the Sustainable Development Goals"
Professor Johan Rockström
Director Potsdam Institute on Climate Impact Research


IAHR AWARDS
IAHR Honorary Membership Award
Prof. JING PENG
IAHR.org


IAHR
AWARDS
IAHR Honorary
Membership Award
Prof. VALLAM SUNDAR
IAHR.org


IAHR
AWARDS
IAHR Honorary
Membership Award
Dr. FEDERICO ESTRADA
IAHR.org

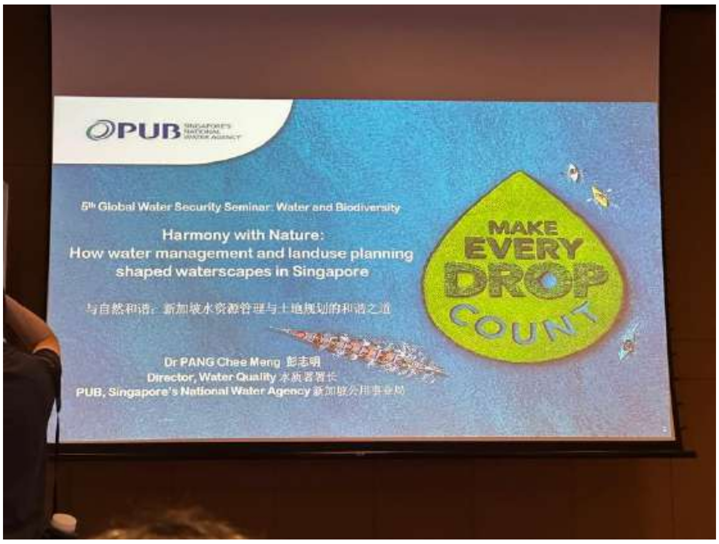

IAHR
AWARDS
24th Arthur Thomas
Ippen Award
Prof. Dr. Ing. BERNHARD VOWINCKEL
IAHR.org


IAHR
AWARDS
10th M. Selim Yalin Lifetime Achievement Award
Prof. MICHELE MOSA
IAHR.org


41ST IAHR WORLD CONGRESS SINGAPORE
22 – 27 JUNE 2025
INNOVATIVE WATER ENGINEERING FOR SUSTAINABLE DEVELOPMENT
M. SELIM YALIN LIFETIME ACHIEVEMENT AWARD

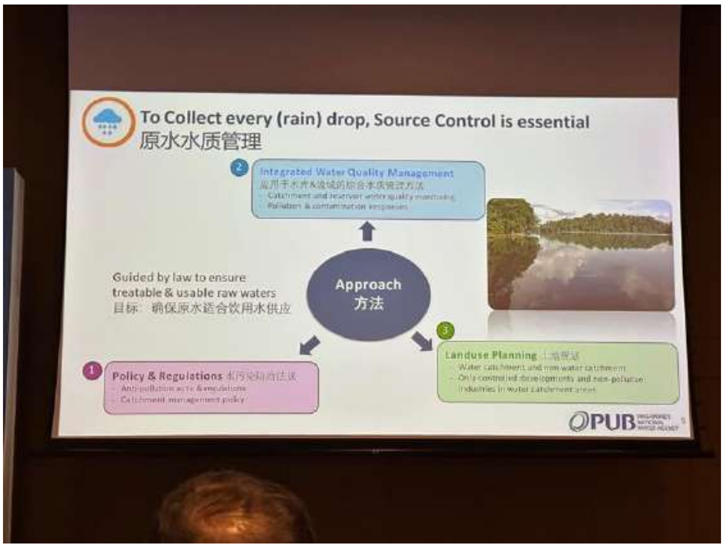

第41届世界水利学大会特别会议
The Special Session of the 41st IAHR World Congress
第五届全球水安全研讨会
The 5th Global Water Security Seminar
—水与生物多样性
—Water and Biodiversity


PUB
MAKE EVERY DROP COUNT
第41届
The Special
第五届
The 5th Glo


PUB
5th Global Water Security Seminar: Water and Biodiversity
Harmony with Nature:
How water management and landuse planning shaped waterscapes in Singapore
与自然和谐：新加坡水资源管理与土地规划的和谐之道
MAKE EVERY DROP COUNT
Dr PANG Chee Meng 彭志明
Director, Water Quality 水质署署长
PUB, Singapore's National Water Agency 新加坡公用事业局


Singapore's Today 今天的新加坡
A reservoir in the city centre of Singapore
NEWater
Water drinkable from the tap
PUB

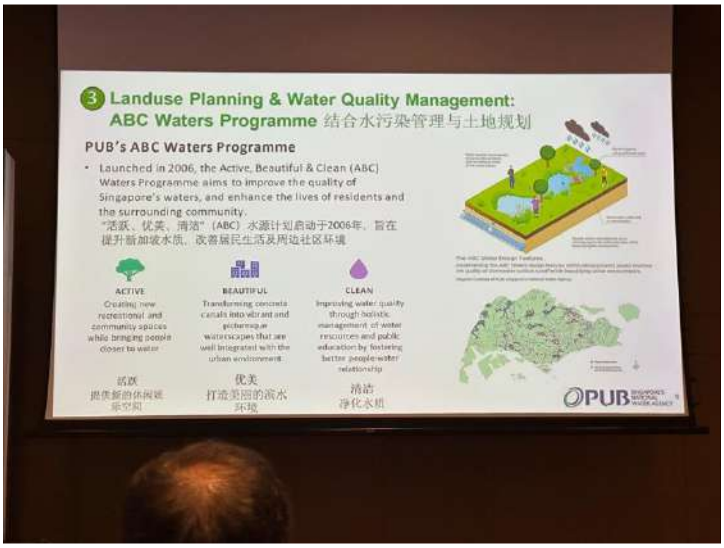

Singapore enjoys a good supply of water because we have closed the Water Loop
Collect Every Drop of water 收集每一滴雨水
2/3 of Singapore is water catchment
Reuse Water Endlessly 重复回收用后水
100% sewered
Full secondary treatment
NEWater
Desalinate more Seawater 海水淡化
An island surrounded by the sea
Membrane technology
PUB


To Collect every (rain) drop, Source Control is essential
原水水质管理
Integrated Water Quality Management
Guided by law to ensure treatable & usable raw waters
Approach
方法
Policy & Regulations
Landuse Planning
PUB


Policy & Regulations 水污染防治法规
National Environment Agency 环境局
PUB
公用事业局
Environmental Protection and Management Act (2008)
Environmental Pollution Control Act (1999)
Environmental Public Health Act (1987)
Trade Effluent Regulations
Legislative levers support source control efforts
立法杠杆支持源头控制工作
Public Utilities Act
Sewerage & Drainage Act
Public Utilities (Reservoir & Catchment Areas) Regulations

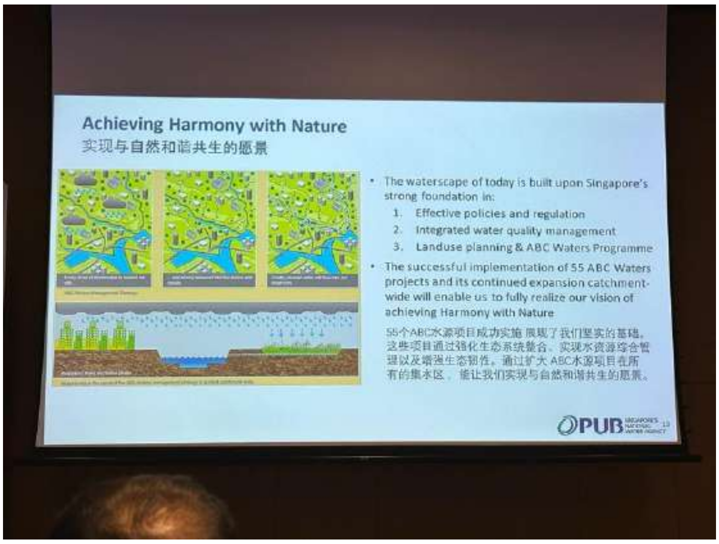

Integrated Water Quality Monitoring 综合水质监测方法
Raw Water Quality Monitoring
Pollution & Contamination Control
Training & Competency Building
Public Education
PUB

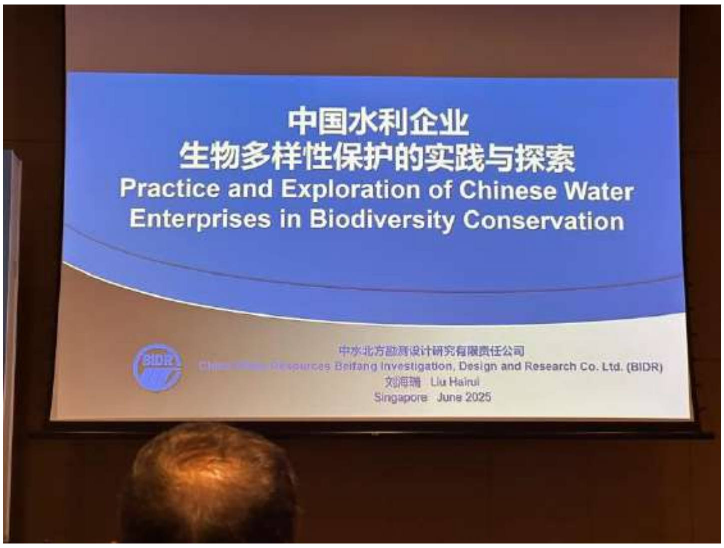

Landuse Planning 土地规划
Exclude pollutive industries and developments in water catchment areas
Pollution control measures incorporated in all developments like residential housing estates, flatted factories, marketplaces etc.
Pollutive industries such as heavy industries, manufacturing of chemicals and oils, shipbuilding and repair, metal plating are concentrated in the western part of Singapore outside water catchment
32 rivers and about 8,000km of drains, rivers and canals
17 impounding reservoirs
2/3 of land area is water catchment
Separate sewer & stormwater systems
100% sewered
PUB

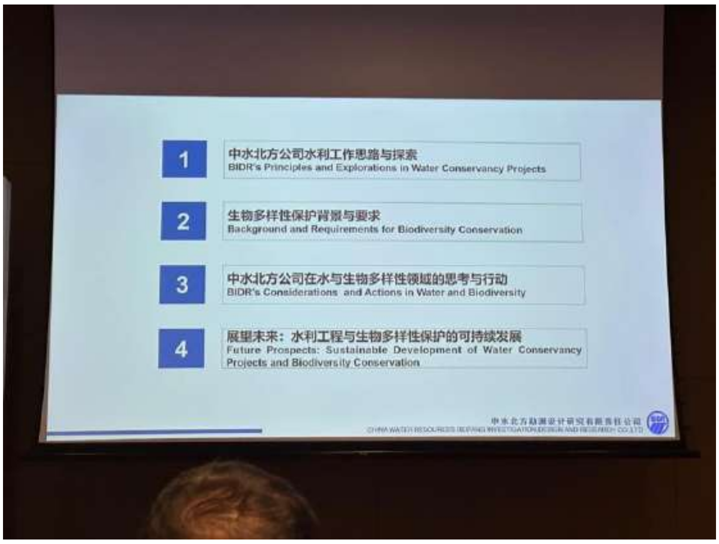

Landuse Planning & Water Quality Management:
ABC Waters Programme 结合水污染管理与土地规划
PUB's ABC Waters Programme
Launched in 2006, the Active, Beautiful & Clean (ABC) Waters Programme aims to improve the quality of Singapore's waters, and enhance the lives of residents and the surrounding community.
ACTIVE
BEAUTIFUL
CLEAN
活跃
优美
清洁
PUB

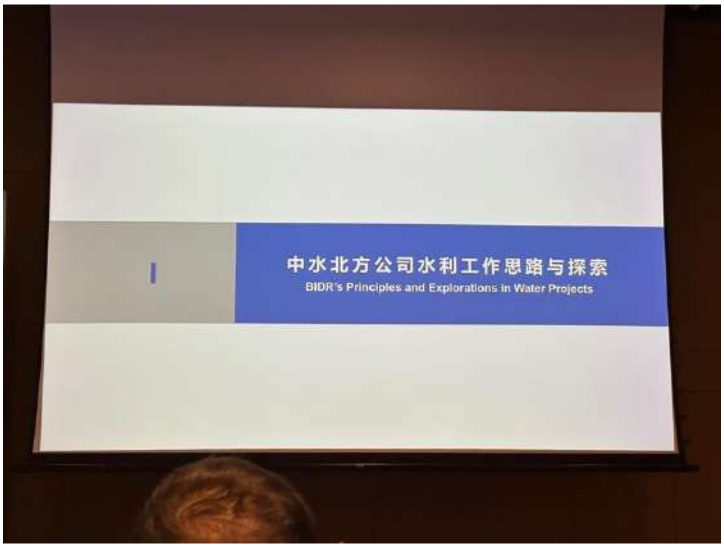

3 Example: Kallang River @ Bishan-Ang Mo Kio Park
ABC案列介绍： 碧山 - 宏茂桥公园和加冷河道
Singapore's 1st large-scale river restoration project
新加坡的第一个大型河道修复工程
2.7 km long concrete canal is naturalised into a 3.2 km meandering river
Integration of the river with the surrounding parkland using a floodplain concept
It serves as flood control, habitat creation and recreational space
A combination of vegetation, natural materials such as rocks, and civil engineering techniques is used to stabilise the river bank
Before Transformation 改造前
After Transformation 改造后
PUB

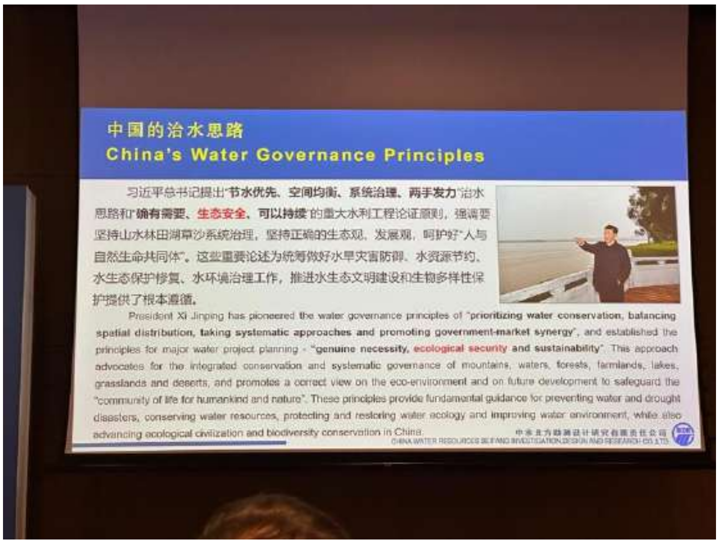

3 Biodiversity and PUB's ABC Waters Programme
Several features in PUB's ABC Waters Programme enable biodiversity to flourish:
Naturalised waterways and green spaces provide habitats to local flora and fauna (top left)
Cleansing biotopes are a form of constructed wetlands serve to treat the storm water and become an ecosystem for water birds, amphibians and aquatic plants (top right)
Sedimentation basin and bioretention swale, incorporated to manage storm water and encourage biological uptake of nutrients by plants, create microhabitats for aquatic species (bottom left and bottom right respectively)
PUB


Achieving Harmony with Nature
实现与自然和谐共生的愿景
The waterscape of today is built upon Singapore's strong foundation in:
1. Effective policies and regulation
2. Integrated water quality management
3. Landuse planning & ABC Waters Programme
The successful implementation of 55 ABC Waters projects and its continued expansion catchment-wide will enable us to fully realize our vision of achieving Harmony with Nature
55个ABC水源项目成功实施 展现了我们坚实的基础。这些项目通过强化生态系统整合、实现水资源综合管理以及增强生态韧性。通过扩大ABC水源项目在所有的集水区，能让我们实现与自然和谐共生的愿景。
PUB


中国水利企业
生物多样性保护的实践与探索
Practice and Exploration of Chinese Water Enterprises in Biodiversity Conservation
中水北方勘测设计研究有限责任公司
China Water Resources Beifang Investigation, Design and Research Co. Ltd. (BIDR)
刘海瑞 Liu Hairui
Singapore June 2025


1 中水北方公司水利工作思路与探索
BIDR's Principles and Explorations in Water Conservancy Projects
2 生物多样性保护背景与要求
Background and Requirements for Biodiversity Conservation
3 中水北方公司在水与生物多样性领域的思考与行动
BIDR's Considerations and Actions in Water and Biodiversity
4 展望未来：水利工程与生物多样性保护的可持续发展
Future Prospects: Sustainable Development of Water Conservancy Projects and Biodiversity Conservation


I
中水北方公司水利工作思路与探索
BIDR's Principles and Explorations in Water Projects

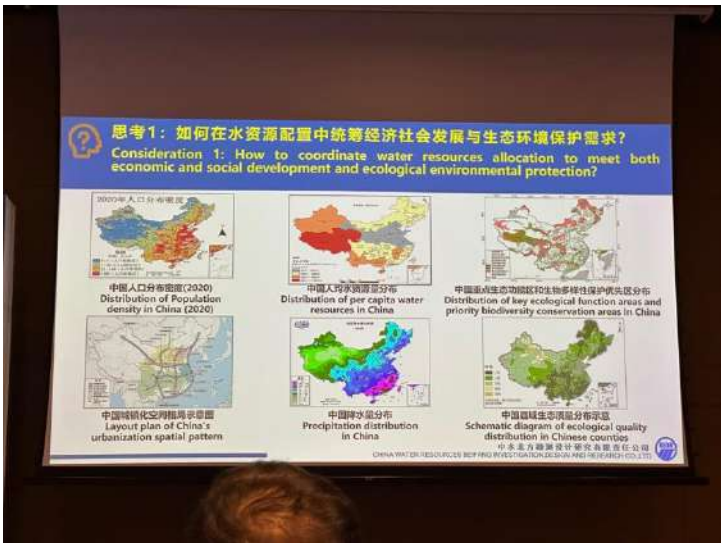

中国的治水思路
China's Water Governance Principles
习近平总书记提出"节水优先、空间均衡、系统治理、两手发力"治水思路和"确有需要、生态安全、可以持续"的重大水利工程论证原则，强调要坚持山水林田湖草沙系统治理，坚持正确的生态观、发展观，呵护好"人与自然生命共同体"。这些重要论述为统筹做好水旱灾害防御、水资源节约、水生态保护修复、水环境治理工作，推进水生态文明建设和生物多样性保护提供了根本遵循。
President Xi Jinping has pioneered the water governance principles of "prioritizing water conservation, balancing spatial distribution, taking systematic approaches and promoting government-market synergy", and established the principles for major water project planning - "genuine necessity, ecological security and sustainability". This approach advocates for the integrated conservation and systematic governance of mountains, waters, forests, farmlands, lakes, grasslands and deserts, and promotes a correct view on the eco-environment and on future development to safeguard the "community of life for humankind and nature". These principles provide fundamental guidance for preventing water and drought disasters, conserving water resources, protecting and restoring water ecology and improving water environment, while also advancing ecological civilization and biodiversity conservation in China.

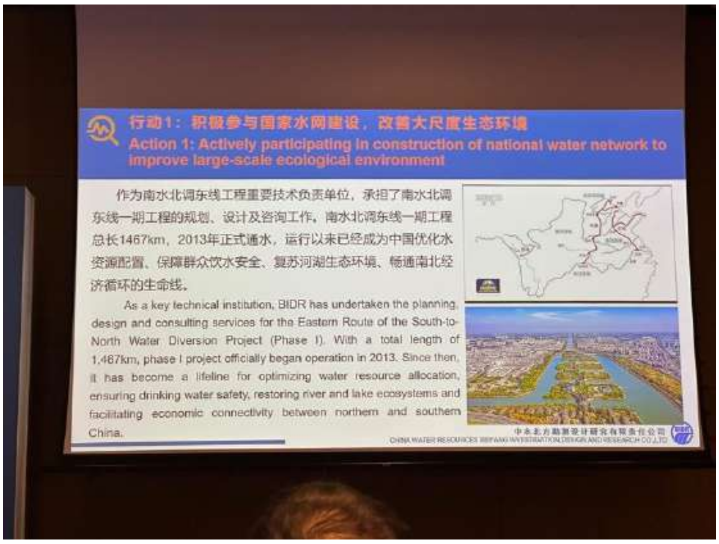

中水北方公司的思路与探索
BIDR's Principles and Explorations
中水北方公司作为水利部直属综合性科技型企业和商务部对外援助项目实施企业，带头积极践行中国治水思路，在项目策划、规划设计、投资决策和建设运维等关键环节，全面贯彻资源节约和生态保护理念，开展知识积累、技术迭代、产品研发等协同创新，在流域生态环境治理和重大水利工程生态保护方面积累了丰富的经验。
BIDR, as a comprehensive technology-based enterprises directly under the Ministry of Water Resources and an implementing agency for foreign aid projects under the Ministry of Commerce, has taken the lead in actively implementing China's water governance principles. We fully implement resource conservation and ecological protection concepts throughout all key stages such as project planning, design, investment, construction, and operation and maintenance. With collaborative innovation in knowledge accumulation, technology iteration and product R&D, we have accumulated extensive experience in watershed ecological environment governance and ecological protection of major water conservancy projects.


II
生物多样性保护背景与要求
Background and Requirements for Biodiversity Conservation


生物多样性保护的背景与要求
Background and Requirements for Biodiversity Conservation
中国是最早签署、批准《生物多样性公约》的国家之一，中方作为COP15主席国，引领会议达成"昆明—蒙特利尔框架"（GBF）。目前，中国已将生物多样性保护上升为国家战略，更新了中国生物多样性保护战略与行动计划(NBSAP)，不断推进跨部门跨行业的生物多样性主流化。
中国《水法》《长江保护法》《黄河保护法》等涉水法律法规中，都体现了生物多样性保护的要求，中国水利企业正在按照"推动绿色发展，促进人与自然和谐共生"的要求开展工作。
China is among the first countries to sign and ratify the Convention on Biological Diversity (CBD). As the presidency of COP15, China played a key role in advancing the Kunming-Montreal Global Biodiversity Framework (GBF). Currently, biodiversity conservation has been elevated to the level of national strategy. China has updated its National Biodiversity Strategy and Action Plan (NBSAP) and is actively promoting the mainstreaming of biodiversity across sectors and industries.
Biodiversity conservation is also reflected in China's water-related laws and regulations, including the Water Law, the Yangtze River Protection Law and the Yellow River Protection Law. Guided by the principle of "green development and harmony between humanity and nature", Chinese water enterprises are actively working in line with these requirements.


III
中水北方公司水与生物多样性领域的思考与行动
BIDR' s Considerations and Actions in Water and Biodiversity


思考1：如何在水资源配置中统筹经济社会发展与生态环境保护需求？
Consideration 1: How to coordinate water resources allocation to meet both economic and social development and ecological environmental protection?
中国人口分布密度(2020)
Distribution of Population density in China (2020)
Distribution of per capita water resources in China
Distribution of key ecological function areas and priority biodiversity conservation areas in China
Layout plan of China's urbanization spatial pattern
中国降水量分布
Precipitation distribution in China
Schematic diagram of ecological quality distribution in Chinese counties


行动1：积极参与国家水网建设，改善大尺度生态环境
Action 1: Actively participating in construction of national water network to improve large-scale ecological environment
作为南水北调东线工程重要技术负责单位，承担了南水北调东线一期工程的规划、设计及咨询工作。南水北调东线一期工程总长1467km，2013年正式通水，运行以来已经成为中国优化水资源配置、保障群众饮水安全、复苏河湖生态环境、畅通南北经济循环的生命线。
As a key technical institution, BIDR has undertaken the planning, design and consulting services for the Eastern Route of the South-to-North Water Diversion Project (Phase I). With a total length of 1,467km, phase I project officially began operation in 2013. Since then, it has become a lifeline for optimizing water resource allocation, ensuring drinking water safety, restoring river and lake ecosystems and facilitating economic connectivity between northern and southern China.
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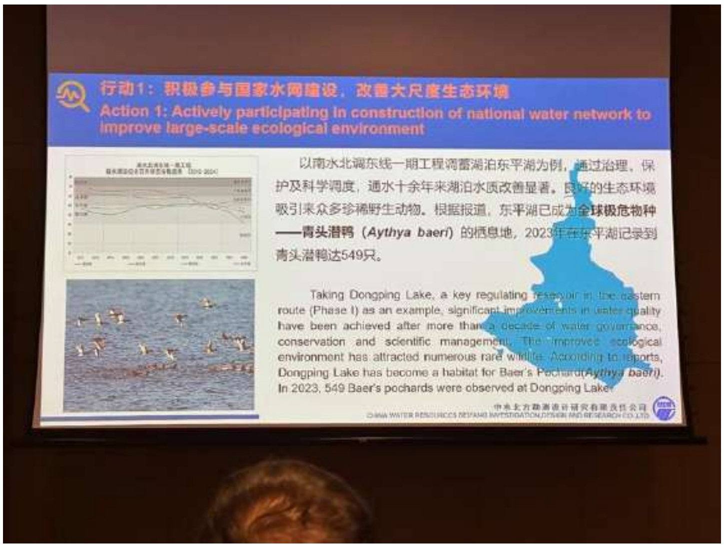
CHINA WATER RESOURCES BEIFANG INVESTIGATION,DESIGN AND RESEARCH CO.,LTD


行动1：积极参与国家水网建设，改善大尺度生态环境
Action 1: Actively participating in construction of national water network to improve large-scale ecological environment
以南水北调东线一期工程调蓄湖泊东平湖为例，通过治理，保护及科学调度，通水十余年来湖泊水质改善显著。良好的生态环境吸引来众多珍稀野生动物。根据报道，东平湖已成为全球极危物种——青头潜鸭（Aythya baeri）的栖息地，2023年在东平湖记录到青头潜鸭达549只。
Taking Dongping Lake, a key regulating reservoir in the eastern route (Phase I) as an example, significant improvements in water quality have been achieved after more than a decade of water governance, conservation and scientific management. The improved ecological environment has attracted numerous rare wildlife. According to reports, Dongping Lake has become a habitat for Baer's Pochard(Aythya baeri). In 2023, 549 Baer's pochards were observed at Dongping Lake.
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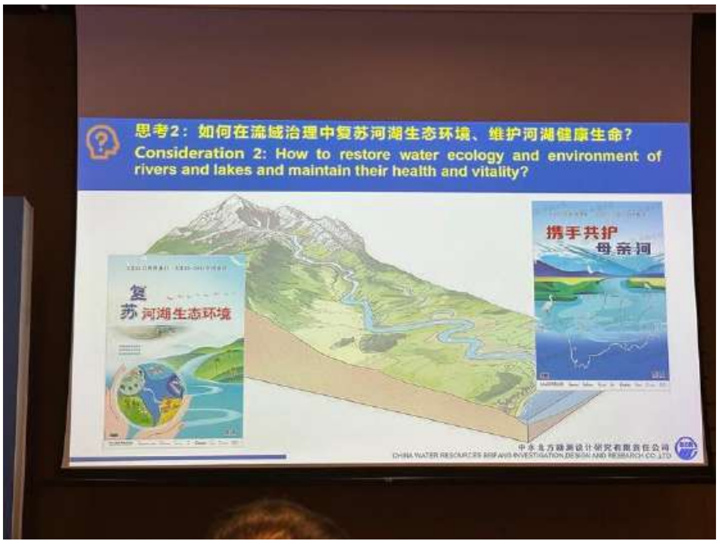
思考2：如何在流域治理中复苏河湖生态环境、维护河湖健康生命？
Consideration 2: How to restore water ecology and environment of rivers and lakes and maintain their health and vitality?
复苏河湖生态环境
携手共护母亲河
中水北方勘测设计研究有限责任公司
CHINA WATER RESOURCES BEIFANG INVESTIGATION,DESIGN AND RESEARCH CO.,LTD


行动2：从生态系统整体性和流域系统性出发,坚持山水林田湖草沙一体化保护和系统治理
Action 2: Adhering to integrated protection and systematic governance of mountains, waters, forests, farmlands, lakes, grasslands and deserts
Rural section of the plain (from Lianggezhuang to Qujiadian): elimination of flood-related safety hazards, wind prevention and sand encroachment, creation of pastoral ecological landscapes in nature
Urban section of the plain
Ecological water replenishment
震旦鸦雀
Paradoxornis heudei
永定河流域综合治理与生态修复总体布局
Overall layout for comprehensive governance and ecological restoration of the Yongding River basin
中水北方勘测设计研究有限责任公司
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行动2：从生态系统整体性和流域系统性出发,坚持山水林田湖草沙一体化保护和系统治理
Action 2: Adhering to integrated protection and systematic governance of mountains, waters, forests, farmlands, lakes, grasslands and deserts
中水北方公司承担的大理洱海生态廊道治理工程，实施后生物多样性得到恢复，海菜花等本土物种得以大量重现，鸟类及鱼类种群数量增加明显。
Erhai Lake Ecological Corridor Governance Project undertaken by BIDR contributes to the restoration of biodiversity, the reappearance of a large number of Haicai flower(Ottelia acuminate) and other native species as well as a significant increase of bird and fish populations.
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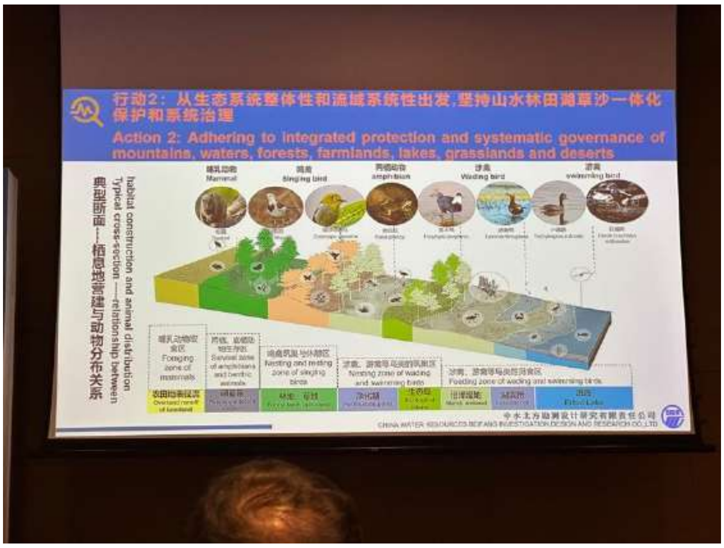
行动2：从生态系统整体性和流域系统性出发,坚持山水林田湖草沙一体化保护和系统治理
Action 2: Adhering to integrated protection and systematic governance of mountains, waters, forests, farmlands, lakes, grasslands and deserts
典型断面——栖息地营建与动物分布关系
Typical cross-section ——relationship between habitat construction and animal distribution
哺乳动物
Mammal
鸣禽
Singing bird
两栖动物
amphibian
涉禽
Wading bird
游禽
swimming bird
哺乳动物觅食区
Foraging zone of mammals
鸣禽筑巢与休憩区
Nesting and resting zone of singing birds
涉禽、游禽等鸟类的筑巢区
Nesting zone of wading and swimming birds
涉禽、游禽等鸟类觅食区
Feeding zone of wading and swimming birds
农田地表径流
Overland runoff of farmland
洱海
Erhai Lake
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思考3：如何通过技术措施有效减缓水利工程对生物多样性保护的影响？
Consideration 3: How to effectively mitigate the impacts of water conservancy projects on biodiversity through technical measures?
技术措施
Technical measures
优化调度
Scheduling optimization
河湖连通
River-lake interconnection
生态流量下泄
Ecological flow discharge
低温水减缓
Mitigation of low-temperature water impacts
栖息地保护
Habitat protection
过鱼设施
Fish passing facilities
增殖放流
Enhancement and releasing
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行动3：尊重自然，生态优先-（1）做好做足前期生态调查
Action 3: Respecting nature and prioritizing ecosystems – (1) making preliminary ecological surveys
所有重大工程论证前期均进行全面生态调查：采用多种方式调查生物多样性，除按照常规资料检索和采样调查外，近些年探索采用环境DNA（eDNA）和AI图像识别、声纹识别等新方法进行针对性生态调查。
Comprehensive ecological surveys are conducted in the preliminary assessment stage of all major projects. Biodiversity is investigated by various methods. In addition to conventional data collection and sampling, advanced techniques such as environmental DNA (eDNA), AI image recognition and voiceprint recognition, have been applied in targeted ecological surveys in recent years.
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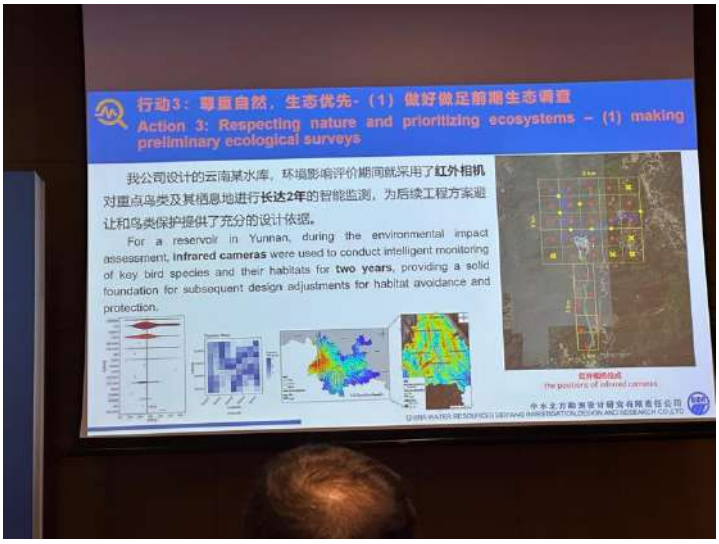
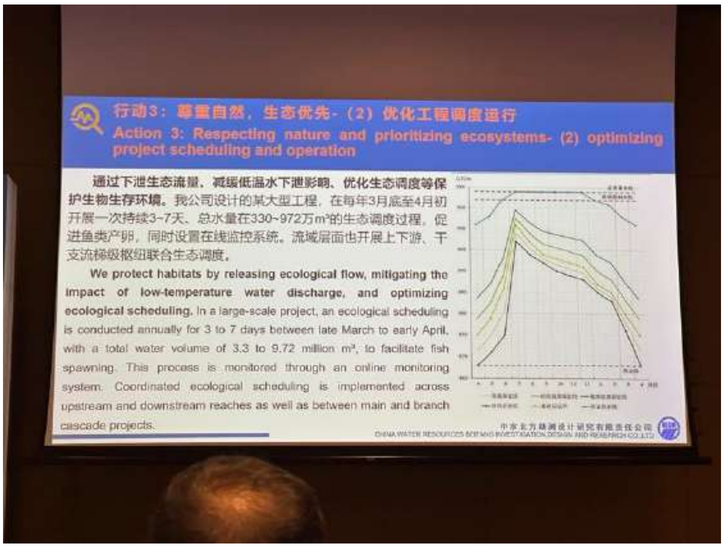

行动3：尊重自然，生态优先-（1）做好做足前期生态调查
Action 3: Respecting nature and prioritizing ecosystems – (1) making preliminary ecological surveys
我公司设计的云南某水库，环境影响评价期间就采用了红外相机对重点鸟类及其栖息地进行长达2年的智能监测，为后续工程方案避让和鸟类保护提供了充分的设计依据。
For a reservoir in Yunnan, during the environmental impact assessment, infrared cameras were used to conduct intelligent monitoring of key bird species and their habitats for two years, providing a solid foundation for subsequent design adjustments for habitat avoidance and protection.
红外相机位点
the positions of infrared cameras
中水北方勘测设计研究有限责任公司
CHINA WATER RESOURCES BEIFANG INVESTIGATION,DESIGN AND RESEARCH CO.,LTD


行动3：尊重自然，生态优先-（2）优化工程调度运行
Action 3: Respecting nature and prioritizing ecosystems- (2) optimizing project scheduling and operation
通过下泄生态流量、减缓低温水下泄影响、优化生态调度等保护生物生存环境。我公司设计的某大型工程，在每年3月底至4月初开展一次持续3~7天、总水量在330~972万m³的生态调度过程，促进鱼类产卵，同时设置在线监控系统。流域层面也开展上下游、干支流梯级枢纽联合生态调度。
We protect habitats by releasing ecological flow, mitigating the impact of low-temperature water discharge, and optimizing ecological scheduling. In a large-scale project, an ecological scheduling is conducted annually for 3 to 7 days between late March to early April, with a total water volume of 3.3 to 9.72 million m³, to facilitate fish spawning. This process is monitored through an online monitoring system. Coordinated ecological scheduling is implemented across upstream and downstream reaches as well as between main and branch cascade projects.
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行动3：尊重自然，生态优先-（3）设置过鱼设施
Action 3: Respecting nature and prioritizing ecosystems- (3) Setting up fish passing facilities
中水北方公司设计的海南省某大坝枢纽改造工程，为恢复已阻隔多年的洄游通道，通过多方案比选和模型试验，采用竖缝式鱼道方案，实现了上下游河流生态连通性的恢复。此外，我们在青藏高原海拔4300米以上的高寒地区也有高坝大库的过鱼设施设计经验。
In a dam renovation project we designed in Hainan Province, to restore migratory pathways that had been blocked for many years, we selected the vertical slot fishway design through multiple scheme comparisons and model tests, aiming to reestablish ecological connectivity between the upstream and downstream rivers. We have experience in designing fish passing facilities for high dams and large reservoirs in cold areas with an elevation of 4,300m on the Qinghai-Tibet Plateau.
中水北方勘测设计研究有限责任公司
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行动3：尊重自然，生态优先-（4）开展水生生物增殖放流
Action 3: Respecting nature and prioritizing ecosystems – (4) Restocking and releasing aquatic organisms
针对区域鱼类资源丰富或有重点保护鱼类的工程，通过建设工程鱼类增殖站，开展特殊鱼类繁育研究，长期进行增殖放流。如我公司设计的重庆某水库工程，将保护动物岩原鲤作为增殖放流对象，针对岩原鲤设计建设增殖站、开展繁育性科学研究，保护区域鱼类资源。
For projects located in areas with abundant fish resources or key protected fish species, we have built fish breeding stations to conducted research on the propagation of special fish species and carry out long-term restocking programs. For example, in a reservoir project we designed in Chongqing, the protected species Procypris rabaudi was selected as the target for restocking. A dedicated breeding station was built to conduct scientific studies on its propagation, contributing to the conservation of regional fish biodiversity.
中水北方勘测设计研究有限责任公司
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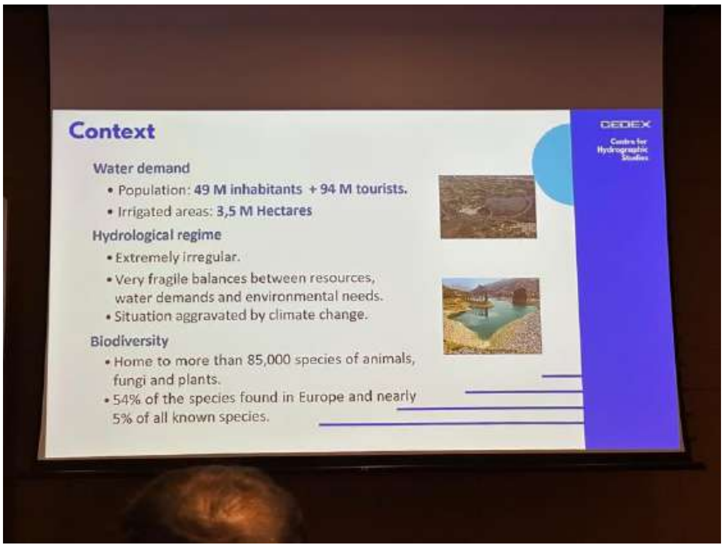
IV
展望未来：水利工程与生物多样性保护的
可持续发展
Future Prospects: Sustainable Development of Water Conservancy Projects
and Biodiversity Conservation

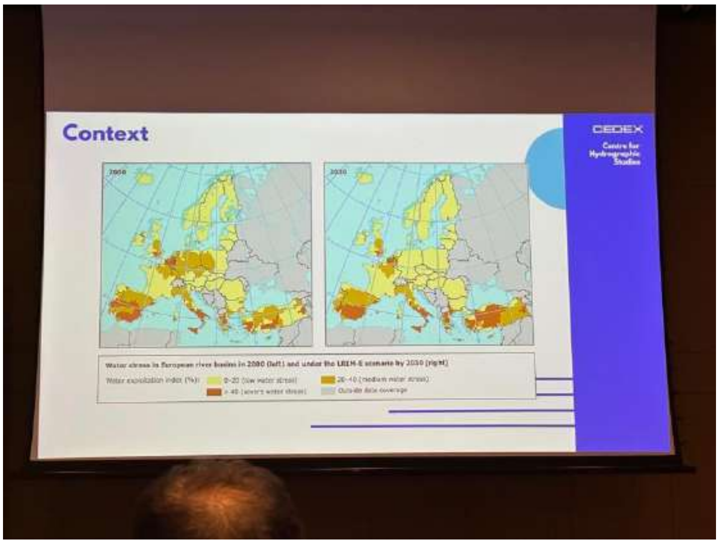

展望未来
Future Prospects
绿色发展理念推动双赢 Green development concepts for win-win cooperation
建构河流伦理
Constituting River Ethics
探索可持续发展
Explorations of sustainable development
科技创新引领生态保护Scientific innovations driving ecological protection
Application of remote sensing and AI technologies
Technological innovation of eco-friendly water conservancy projects
国际合作与经验交流International cooperation and experience sharing
国际交流与项目合作
International exchanges and project cooperation
发展中国家的技术交流与合作
Technical exchanges and cooperation among developing countries


第41届世界水利学大会特别会议
The Special Session of the 41st IAHR World Congress
第五届全球水安全研讨会
The 5th Global Water Security Seminar
——水与生物多样性
—Water and Biodiversity
主办/Hosted by
Ministry of Water Resources of China World Water Council
承办/Organized by
Singapore
June 23, 2025


Centre for Hydrographic Studies
CEDEX
WATER AND BIODIVERSITY:
Best practices in Spain
Federico Estrada Lorenzo
Director


Centre for Hydrographic Studies
CEDEX
WATER AND BIODIVERSITY:
Best practices in Spain
Federico Estrada Lorenzo
Director


Context
CEDEX
Centre for Hydrographic Studies
Water demand
• Population: 49 M inhabitants + 94 M tourists.
• Irrigated areas: 3,5 M Hectares
Hydrological regime
• Extremely irregular.
• Very fragile balances between resources, water demands and environmental needs.
• Situation aggravated by climate change.
Biodiversity
• Home to more than 85,000 species of animals, fungi and plants.
• 54% of the species found in Europe and nearly 5% of all known species.


Context
CEDEX
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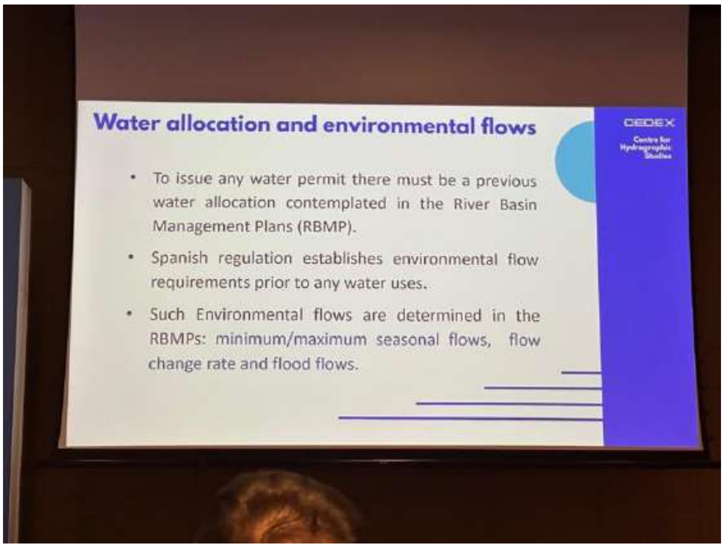
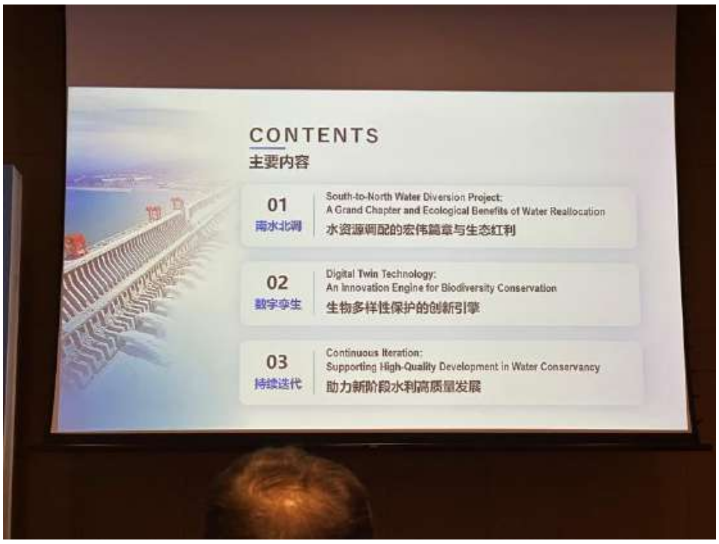
Basic principles of water governance in Spain
CEDEX
Centre for Hydrographic Studies
Stable legal and institutional framework
Basin management through RBO
Integrated Water Resource Management
Environmental flows are a restriction for water uses
Water allocation assessed and defined through the RBMPs
Measures to reach water planning goals in RBMPs
Users' & stakeholders' active participation in water management


River Basin Management Plans
CEDEX
Centre for Hydrographic Studies


Water allocation and environmental flows
CEDEX
Centre for Hydrographic Studies
To issue any water permit there must be a previous water allocation contemplated in the River Basin Management Plans (RBMP).
Spanish regulation establishes environmental flow requirements prior to any water uses.
Such Environmental flows are determined in the RBMPs: minimum/maximum seasonal flows, flow change rate and flood flows.


Fishway
CEDEX
Centre for Hydrographic Studies
hydrolink
THE EFFICIENCY OF A VERTICAL SLOT FISHWAY


DIGITAL TWIN EMPOWERING BIODIVERSITY CONSERVATION IN THE SOUTH-TO-NORTH WATER DIVERSION PROJECT
数字孪生赋能南水北调工程生物多样性保护新路径
LIU ZHENGBING/2025.6.23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A Grand Chapter and Ecological Benefits of Water Reallocation
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02
数字孪生
Digital Twin Technology:
An Innovation Engine for Biodiversity Conservation
生物多样性保护的创新引擎
03
持续迭代
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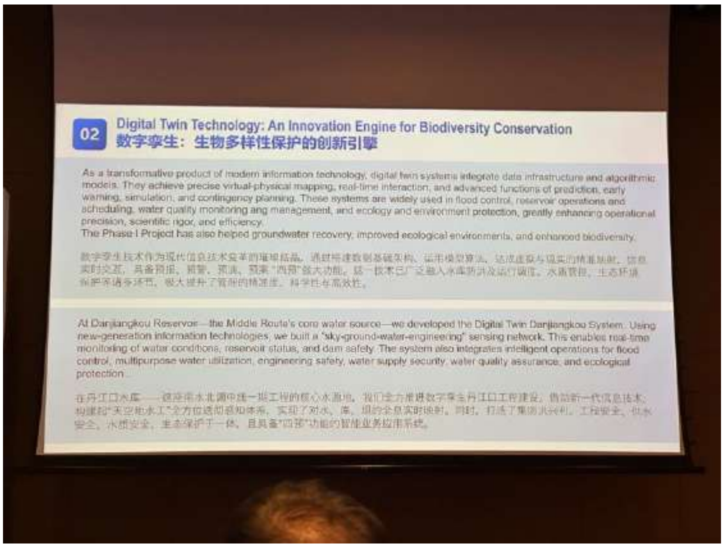
Supporting High-Quality Development in Water Conservancy
助力新阶段水利高质量发展


01
South-to-North Water Diversion Project: A Grand Chapter and Ecological Benefits of Water Reallocation
南水北调：水资源调配的宏伟篇章与生态红利
China's water resources show a clear spatial-temporal imbalance characterized by "summer floods, winter droughts, water scarcity in the north, abundance in the south".
The South-to-North Water Diversion Project is a strategic cross-basin water transfer initiative. It addresses northern water shortages and optimizes water allocation. Through its Eastern, Middle, and Western Routes, it ingeniously connects the Yangtze, Yellow, Huaihe, and Haihe River basins. This forms a vast water resource allocation network characterized by its "four horizontal and three vertical" configuration, enabling south-to-north water diversion and east-west mutual supplementation.
The Phase I Project has also helped groundwater recovery, improved ecological environments, and enhanced biodiversity.
four horizontal and three vertical configuration
south-to-north water diversion
east-west mutual supplementation
South-to-North Water Diversion Project
summer floods and winter droughts
scarcity in the north and abundance in the south


01
South-to-North Water Diversion Project: A Grand Chapter and Ecological Benefits of Water Reallocation
南水北调：水资源调配的宏伟篇章与生态红利
Since the Eastern and Middle Routes became fully operational a decade ago, the Phase I Project has delivered over 80 billion cubic meters of water to northern regions. This benefits 45 major and medium-sized cities and 185 million residents.
More than 11 billion cubic meters of ecological water has replenished over 50 northern rivers where ecosystems have been revitalized such as in the Hutuo River and Baiyangdian Lake.
Notably in 2021, the Middle Route Project restored year-round flow to the Yongding River for the first time in 25 years, boosting regional ecological recovery.
Baiyangdian Lake
Hutuo River
Yongding River


02
Digital Twin Technology: An Innovation Engine for Biodiversity Conservation
数字孪生：生物多样性保护的创新引擎
As a transformative product of modern information technology, digital twin systems integrate data infrastructure and algorithmic models. They achieve precise virtual-physical mapping, real-time interaction, and advanced functions of prediction, early warning, simulation, and contingency planning. These systems are widely used in flood control, reservoir operations and scheduling, water quality monitoring ang management, and ecology and environment protection, greatly enhancing operational precision, scientific rigor, and efficiency.
The Phase-I Project has also helped groundwater recovery, improved ecological environments, and enhanced biodiversity.
At Danjiangkou Reservoir—the Middle Route's core water source—we developed the Digital Twin Danjiangkou System. Using new-generation information technologies, we built a "sky-ground-water-engineering" sensing network. This enables real-time monitoring of water conditions, reservoir status, and dam safety. The system also integrates intelligent operations for flood control, multipurpose water utilization, engineering safety, water supply security, water quality assurance, and ecological protection.

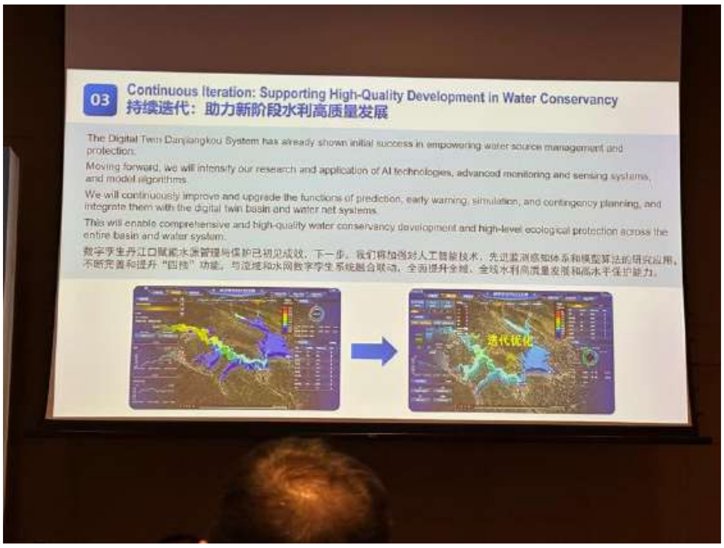

02
Digital Twin Technology: An Innovation Engine for Biodiversity Conservation
数字孪生：生物多样性保护的创新引擎
During the development of the Digital Twin Danjiangkou System, we fully embedded ecological protection into its functional modules. By leveraging digital twin advantages, we achieved measurable success in enhancing environmental quality and biodiversity restoration.
生物多样性智慧监测体系

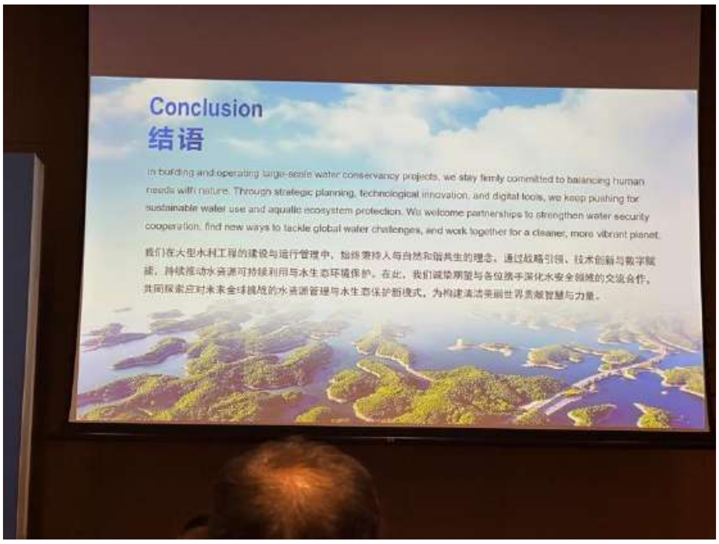

02
Digital Twin Technology: An Innovation Engine for Biodiversity Conservation
数字孪生：生物多样性保护的创新引擎
(1) Pollution prevention for optimal aquatic environmental conditions
水质主动防控，为生物营造优质水环境
The digital twin system integrates real-time and multi-source water quality and aquatic ecosystem monitoring data, and visualized dynamically nutrient indicators (e.g., nitrogen, phosphorus) and ecological indicators (e.g. bio-toxicity, chlorophyll-a)
By online water quality simulation and dynamic early warning technologies, the system accurately predicts water quality trends for the next seven days, identifies and mitigates risks, which assure water quality safety and recovery high-quality habitats.
In recent years, freshwater jellyfish—a rare species often called the "aquatic giant panda"—have been regularly observed in Danjiangkou Reservoir. Their presence serves as strong evidence of a thriving ecosystem.
Freshwater Jellyfish

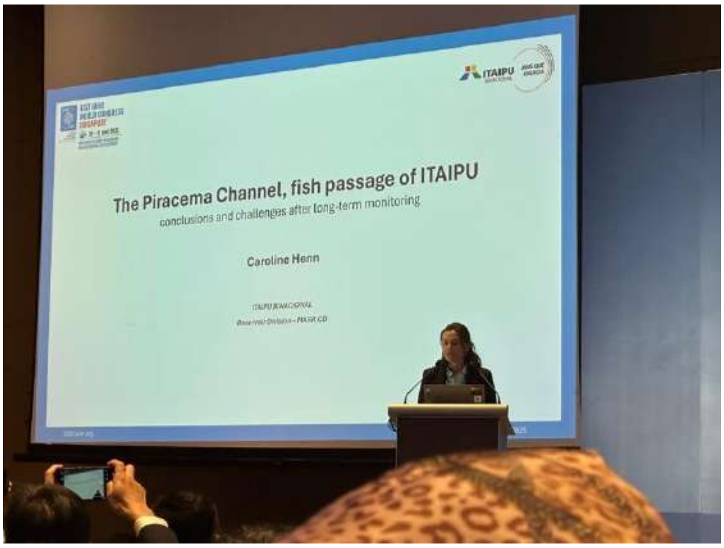

02
Digital Twin Technology: An Innovation Engine for Biodiversity Conservation
数字孪生：生物多样性保护的创新引擎
(2) Intelligent Algae Monitoring for Aquatic Ecosystem Balance
藻类智能监测，助力水生态系统平衡
The digital twin system enables full-process automation in algae sample injection, focusing, capturing, identification, and quantification.
Under unmanned operation, it autonomously analyzes and outputs algae species, proportions, and density. This enables efficient and precise planktonic algae research and algal bloom prevention, thereby (从而) stabilizing (稳定) aquatic ecosystems.
in situ phytoplankton flow cytometry system - Cytosub
map of Water Quality Monitoring Station Network in the Danjiangkou Reservoir Area

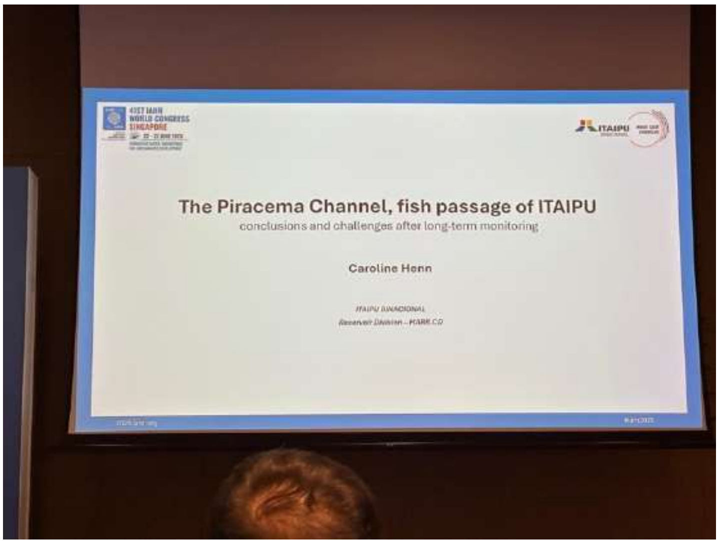

02
Digital Twin Technology: An Innovation Engine for Biodiversity Conservation
数字孪生：生物多样性保护的创新引擎
(3) Precise Fish Stock Assessment to Optimize Stock Enhancement
精准评估鱼情，优化增殖放流策略
The Digital Twin Danjiangkou System includes a reservoir fish genetic database. It fully manages genetic archives and scientifically evaluates fish populations.
Comprehensive datasets and intelligent protocols support targeted fish stock enhancement plans, thereby promoting sustainable fishery management.
Fish Genetic Database of Danjiangkou Reservoir Stocking and Enhancement Station
fish stock enhancement


02
Digital Twin Technology: An Innovation Engine for Biodiversity Conservation
数字孪生：生物多样性保护的创新引擎
(4) Dynamic Water Replenishment Optimization to Revitalize River Ecosystems
动态优化补水，复苏河道生态活力
Digital twin technology generates optimized water replenishment schedules using real-time data. It improves floodwater utilization and guarantees ecological flows for downstream river of Danjiangkou Dam and the northern rivers along the water diversion routes.
To date, over 50 rivers have restored fundamental ecological functions, bringing back the landscapes of "clear waters, green banks, and flowing fishes".


03
Continuous Iteration: Supporting High-Quality Development in Water Conservancy
持续迭代：助力新阶段水利高质量发展
The Digital Twin Danjiangkou System has already shown initial success in empowering water source management and protection.
Moving forward, we will intensify our research and application of AI technologies, advanced monitoring and sensing systems, and model algorithms.
We will continuously improve and upgrade the functions of prediction, early warning, simulation, and contingency planning, and integrate them with the digital twin basin and water net systems.
This will enable comprehensive and high-quality water conservancy development and high-level ecological protection across the entire basin and water system.
迭代优化


Conclusion
结语
In building and operating large-scale water conservancy projects, we stay firmly committed to balancing human needs with nature. Through strategic planning, technological innovation, and digital tools, we keep pushing for sustainable water use and aquatic ecosystem protection. We welcome partnerships to strengthen water security cooperation, find new ways to tackle global water challenges, and work together for a cleaner, more vibrant planet.
我们在大型水利工程的建设与运行管理中，始终秉持人与自然和谐共生的理念，通过战略引领、技术创新与数字赋能，持续推动水资源可持续利用与水生态环境保护。在此，我们诚挚期望与各位携手深化水安全领域的交流合作，共同探索应对未来全球挑战的水资源管理与水生态保护新模式，为构建清洁美丽世界贡献智慧与力量。


ITAIPU
The Piracema Channel, fish passage of ITAIPU
conclusions and challenges after long-term monitoring
Caroline Henn


The Piracema Channel, fish passage of ITAIPU
conclusions and challenges after long-term monitoring
Caroline Henn
ITAIPU


103,100
20
83,800
7.9
14
196
PARAGUAY
BRAZIL


Piracema Channel - concept


Piracema Channel – 10.3 km
6.7 km – Bela Vista river


Piracema Channel – 10.3 km
6.7 km – Bela Vista river


Piracema Channel – 10.3 km
6.7 km – Bela Vista river


Piracema Channel


Piracema Channel


Piracema Channel

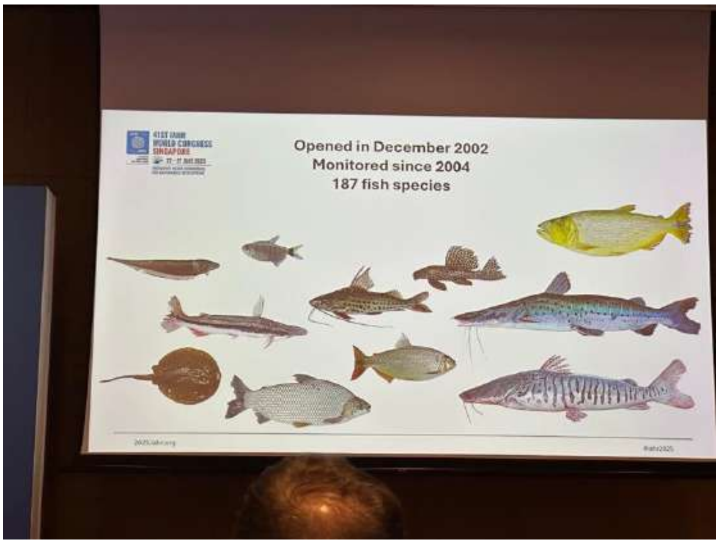

Piracema Channel


Piracema Channel


Piracema Channel

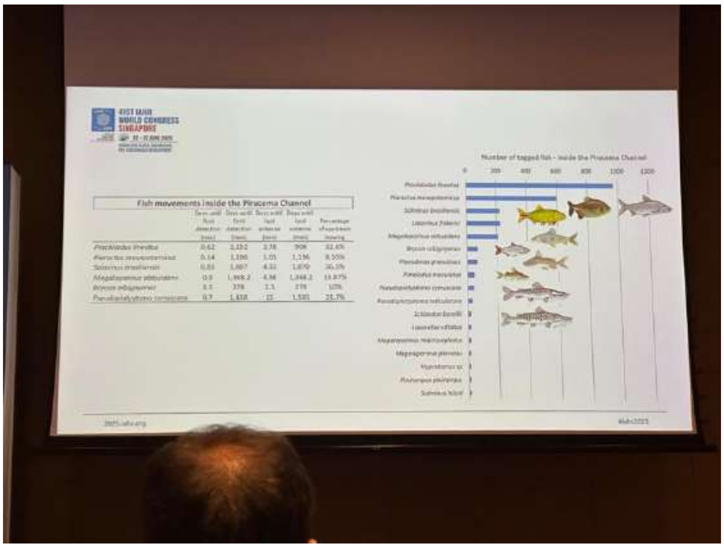

Piracema Channel

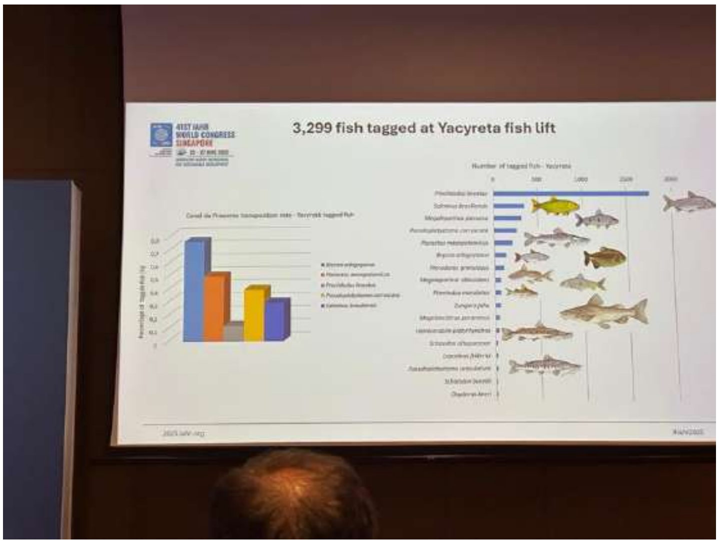
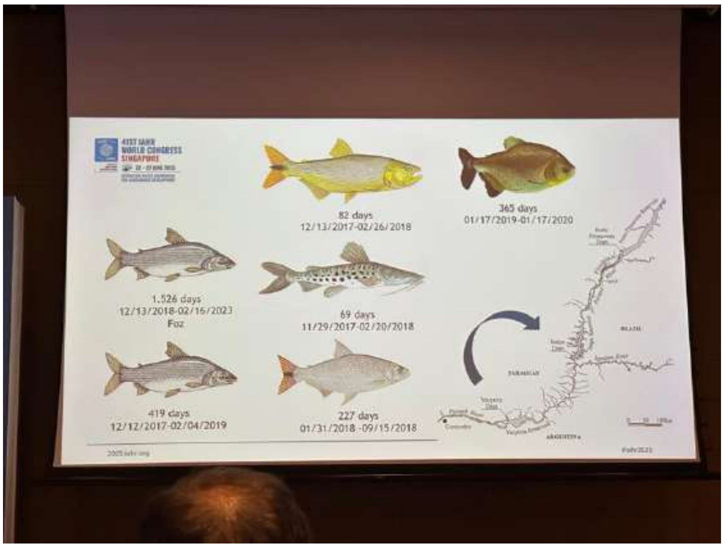
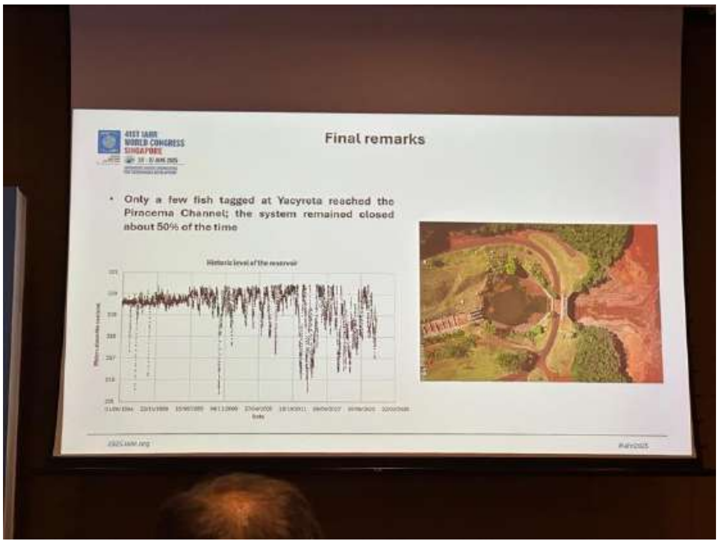

Piracema Channel


Opened in December 2002
Monitored since 2004
187 fish species


Fish sampling
• 7 field trips by year / 24h effort at each point
• Gill nets / cast nets / electrofishing / longline


PIT telemetry antenna designs
PIT tag


Fish movements inside the Piracema Channel


3,299 fish tagged at Yacyreta fish lift

82 days
12/13/2017-02/26/2018
365 days
01/17/2019-01/17/2020
1,526 days
12/13/2018-02/16/2023
Foz
69 days
11/29/2017-02/20/2018
419 days
12/12/2017-02/04/2019
227 days
01/31/2018-09/15/2018

Final remarks
• Only a few fish tagged at Yacyreta reached the Piracema Channel; the system remained closed about 50% of the time
Historic level of the reservoir

Structural adjustment

生物多样性在大藤峡水利枢纽
建设中的实践创新
Innovative Practices of Biodiversity in the
Construction of the Datengxia Gorge
Water Conservancy Project

大藤峡
DATENGXIA
生物多样性在大藤峡水利枢纽
建设中的实践创新
Innovative Practices of Biodiversity in the
Construction of the Datengxia Gorge
Water Conservancy Project
胡忙全 副总经理
HU Mangquan Vice General Manager
广西大藤峡水利枢纽开发有限责任公司
Guangxi Datengxia Gorge Water Conservancy Development Co.Ltd.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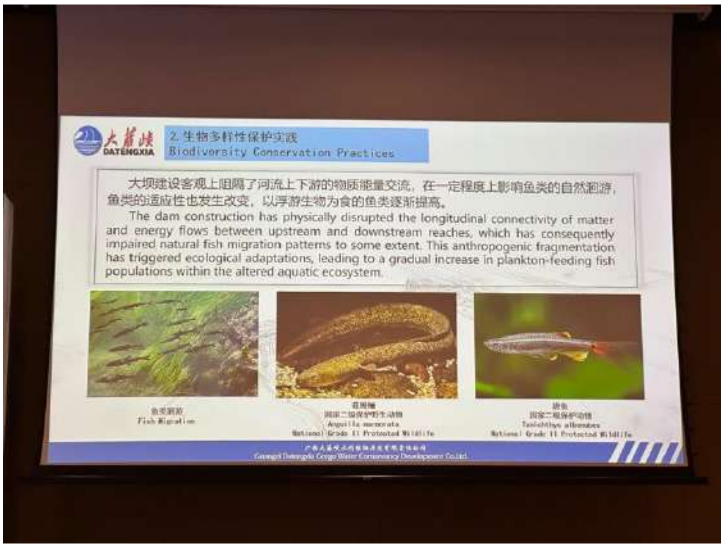
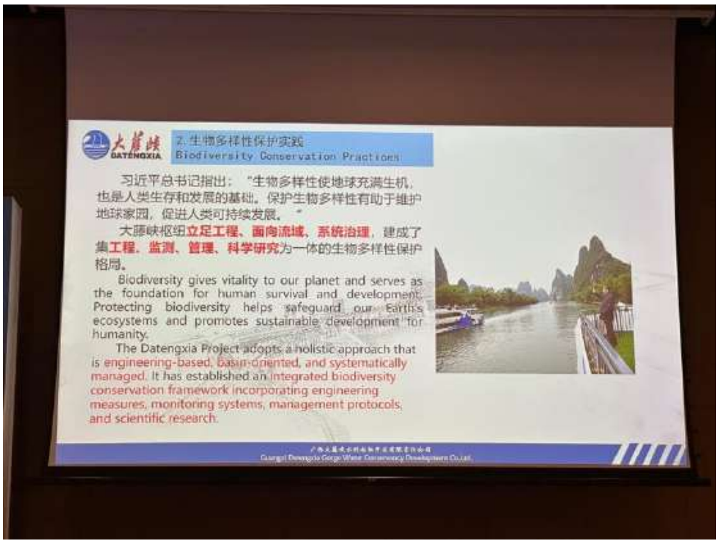
1. 工程概况
Project Overview
2.生物多样性保护实践
Biodiversity Conservation Practices
3.生物多样性保护成效
Biodiversity Conservation Effectiveness


DATENGXIA
1. 工程概况
Project Overview
大藤峡工程位于珠江流域西江水系黔江干流，是珠江流域防洪和水资源配置的关键性工程。
坝址以上集水面积19.86万平方公里，约占西江水系流域面积的56%。水库正常蓄水位61米，总库容34.79亿立方米，防洪库容15亿立方米。
工程主要建筑物包括挡水坝、泄水闸、发电厂房、船闸及鱼道等。工程任务为防洪、航运、发电、补水压咸和灌溉等综合利用。
Datengxia Project is situated on the mainstream of the Qianjiang River in the West River System of the Pearl River Basin, serving as critical infrastructure for flood control and water resources allocation in the Pearl River Basin.
The catchment area above the dam site covers 198,600 square kilometers, representing approximately 56% of the total watershed area of the Xijiang River system. The reservoir operates at a normal storage level of 61 meters, with a total storage capacity of 3.479 billion cubic meters and flood control storage capacity of 1.5 billion cubic meters.
The main structures of the project include the retaining dam, sluice gates, power plant, ship lock, fishways, and others. The project serves multiple purposes, including flood control, navigation, power generation, water replenishment and salt tide suppression, and irrigation.

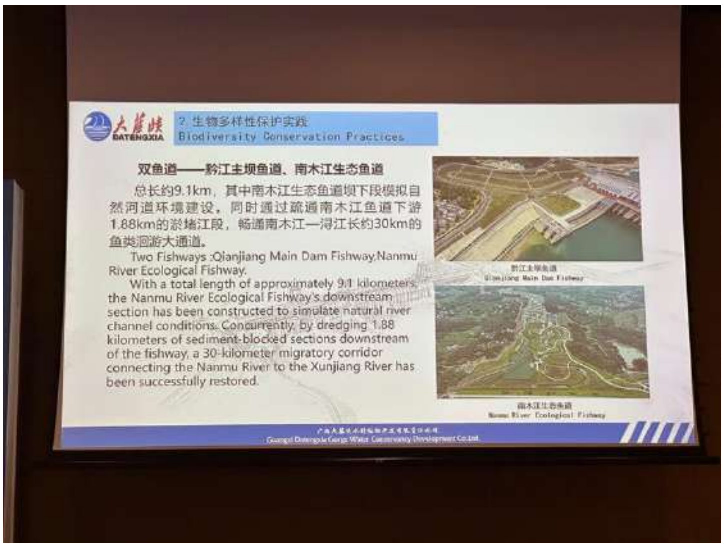

DATENGXIA
1. 工程概况
Project Overview
Domestically Highest Hydraulic Head Single-stage Ship Lock: Featuring herringbone gates with a height of 47.5 meters and width of 20.2 meters, setting a global benchmark in hydraulic gate engineering.
China's Largest Kaplan Turbine Generator Units: Rated capacity of 200 MW per unit


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
大坝建设客观上阻隔了河流上下游的物质能量交流，在一定程度上影响鱼类的自然洄游，鱼类的适应性也发生改变，以浮游生物为食的鱼类逐渐提高。
The dam construction has physically disrupted the longitudinal connectivity of matter and energy flows between upstream and downstream reaches, which has consequently impaired natural fish migration patterns to some extent. This anthropogenic fragmentation has triggered ecological adaptations, leading to a gradual increase in plankton-feeding fish populations within the altered aquatic ecosystem.
Fish Migration
National Grade II Protected Wildlife
National Grade II Protected Wildlife


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
习近平总书记指出："生物多样性使地球充满生机，也是人类生存和发展的基础。保护生物多样性有助于维护地球家园，促进人类可持续发展。"
大藤峡枢纽立足工程、面向流域、系统治理，建成了集工程、监测、管理、科学研究为一体的生物多样性保护格局。
Biodiversity gives vitality to our planet and serves as the foundation for human survival and development. Protecting biodiversity helps safeguard our Earth's ecosystems and promotes sustainable development for humanity.
The Datengxia Project adopts a holistic approach that is engineering-based, basin-oriented, and systematically managed. It has established an integrated biodiversity conservation framework incorporating engineering measures, monitoring systems, management protocols, and scientific research.


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
(1) 工程措施
Engineering Measures
工程建成了"一中心、双鱼道、双增殖站、五人造生境"的全国水利工程最大的水生态保护体系，创新全流域全生命周期的流域水生态保护和治理模式。
The project has established China's largest aquatic ecological protection system among water conservancy projects, featuring "one conservation center, two fishways, two breeding stations, and five artificial habitats." This initiative has pioneered a watershed-scale, full-life-cycle model for aquatic ecological conservation and management.
双鱼道
双增殖站
一中心
五人造生境
水生态保护体系


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
一中心——红水河珍稀鱼类保育中心
负责流域鱼类的繁殖、保育、监测等工作，是全国首个由政府搭建、梯级运营、流域管理的鱼类保育中心。
One Conservation Center — The Hongshui River Rare Fish Conservation Center
The Conservation Center is responsible for fish propagation, conservation, and monitoring throughout the river basin. It represents China's first government-established, cascade-operated, and basin-managed fish conservation center.

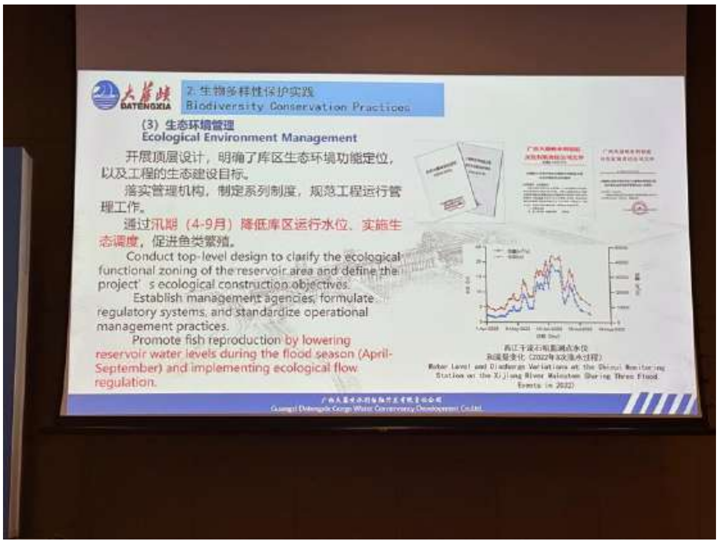

DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
双鱼道——黔江主坝鱼道、南木江生态鱼道
总长约9.1km，其中南木江生态鱼道坝下段模拟自然河道环境建设，同时通过疏通南木江鱼道下游1.88km的淤堵江段，畅通南木江—浔江长约30km的鱼类洄游大通道。
Two Fishways :Qianjiang Main Dam Fishway,Nanmu River Ecological Fishway.
With a total length of approximately 9.1 kilometers, the Nanmu River Ecological Fishway's downstream section has been constructed to simulate natural river channel conditions. Concurrently, by dredging 1.88 kilometers of sediment-blocked sections downstream of the fishway, a 30-kilometer migratory corridor connecting the Nanmu River to the Xunjiang River has been successfully restored.


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
双增殖站——大藤峡鱼类增殖站、来宾珍稀鱼类增殖保护站
总建筑面积1.6万平方米，共建有室外鱼池54个。主要增殖放流乌原鲤、单纹似鳡、斑鳠、长臀鮠等19种鱼类，其中乌原鲤、单纹似鳡、斑鳠为国家二级保护动物，设计年放流规模392万尾。
Dual Breeding Stations—Datengxia Fish Breeding Station,Laibin Rare Fish Breeding & Conservation Station
The facility comprises 16,000 square meters of total floor area with 54 outdoor fish rearing ponds. The main stock enhancement and release involves 19 fish species, including Procypris merus, Luciocyprinus langsoni, Mystus guttatus, and Cranoglanis bouderius. Among them, Procypris merus, Luciocyprinus langsoni, and Mystus guttatus are second-class national protected animals. The designed annual release scale is 3.92 million fry.


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
五人造生境——4处人工鱼巢、1处人工产卵场
在河段产卵场设置4处人工鱼巢、1处人工产卵场，补充和修复鱼类栖息地。
Five artificial habitats - 4 artificial fish nests and 1 artificial spawning ground
Artificial fish habitats will be supplemented and restored by setting up 4 artificial fish nests and 1 artificial spawning ground in the river section's spawning areas.
Floating Island-type Artificial Fish Nest
Floating Artificial Fish Nest
Shore-based Artificial Fish Nest


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
(2) 生态环境监测
Ecological Environment Monitoring
建立严格的环境监测体系，持续开展生态环境监测工作。
Establish a rigorous environmental monitoring system and implement ongoing ecological monitoring.

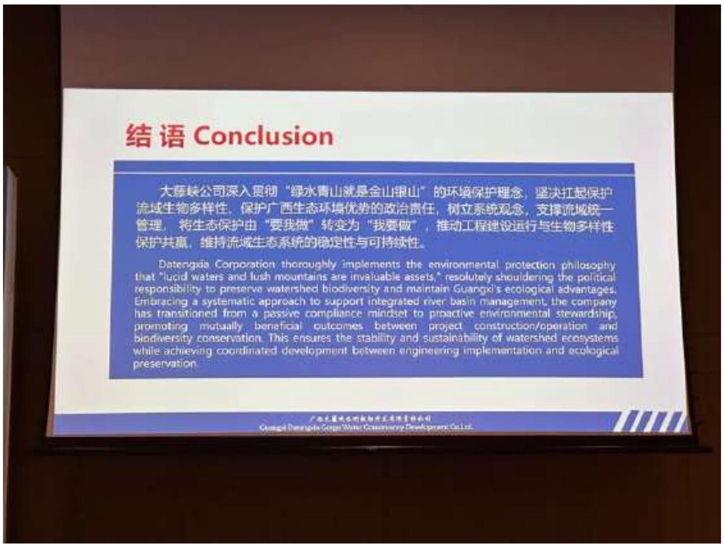

DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
(3) 生态环境管理
Ecological Environment Management
开展顶层设计，明确了库区生态环境功能定位，以及工程的生态建设目标。
落实管理机构，制定系列制度，规范工程运行管理工作。
通过汛期（4-9月）降低库区运行水位、实施生态调度，促进鱼类繁殖。
Conduct top-level design to clarify the ecological functional zoning of the reservoir area and define the project' s ecological construction objectives.
Establish management agencies, formulate regulatory systems, and standardize operational management practices.
Promote fish reproduction by lowering reservoir water levels during the flood season (April-September) and implementing ecological flow regulation.
西江干流石咀监测点水位和流量变化（2022年3次涨水过程）
Water Level and Discharge Variations at the Shizui Monitoring Station on the Xijiang River Mainstem During Three Flood Events in 2022)


DATENGXIA
2. 生物多样性保护实践
Biodiversity Conservation Practices
(4) 科学研究
Scientific Research
通过科学研究，解决鳄蜥迁移、珍稀鱼类繁育、敏感河段生态复苏等方面技术难题。
Address key technical challenges through scientific studies, including: Crocodile lizard (Shinisaurus crocodilurus) relocation,Breeding of rare fish species,Ecological restoration of sensitive river reaches
王浩院士团队技术交流
Technical Exchange with Academician Wang Chao's Team
鳄蜥监测-红外相机布设
Crocodile Lizard Monitoring - Infrared Camera Deployment
珍稀鱼类繁育研究
Research on Rare Fish Breeding and Propagation


DATENGXIA
3. 生物多样性保护成效
Biodiversity Conservation Effectiveness
（1）工程累计放流鱼苗1545万尾，其中乌原鲤、黄尾鲴等国家二级保护动物或珍稀特有经济鱼类243万尾；鱼道观测过鱼种类达82种，有效保护流域水生态资源。人工鱼巢、人造产卵场实施，也有效补充流域鱼类繁殖生境。
The project released 15.45 million fish fry, including 2.43 million rare and endemic economic fish species, such as the barbless carp (Procypris merus) and yellowtail bream (Xenocypris davidi), which are national second-class protected animals.
Fishways monitoring recorded 82 fish species, effectively conserving aquatic ecological resources in the basin. Additionally, the implementation of artificial fish nests and man-made spawning grounds has effectively restored fish breeding habitats in the watershed.
Stock enhancement and release activities
Fishway detection and monitoring
Fish egg adhesion

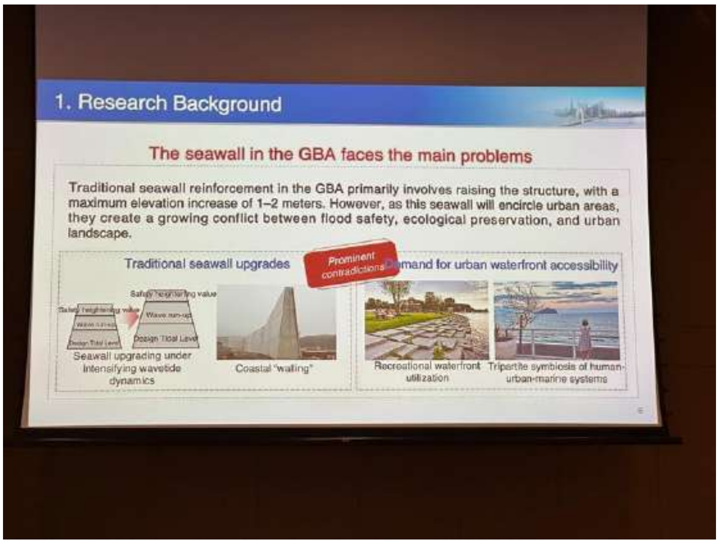

DATENGXIA
3. 生物多样性保护成效
Biodiversity Conservation Effectiveness
（2）成功突破了乌原鲤、长臀鮠等10种珍稀鱼类人工繁育技术，有力支撑流域水生态保护工作。
Successfully achieved breakthroughs in the artificial breeding technology of 10 rare fish species, including the Procypris merus and the Cranoglanis bouderius, providing strong support for water ecosystem conservation in the basin.
鱼苗孵化（孵化桶）
Fry hatching (Hatching Basket)
乌原鲤种苗
barbless carp fry


DATENGXIA
3. 生物多样性保护成效
Biodiversity Conservation Effectiveness
（3）加强水质保护，为西江干流沿岸区域及粤港澳大湾区提供优质水源。累计为粤港澳大湾区应急补水38.2亿立方米。
Strengthen water quality protection to provide high-quality water resources for areas along the main stream of the Xijiang River and the Guangdong-Hong Kong-Macao Greater Bay Area. A cumulative total of 3.82 billion cubic meters of emergency water supply has been provided to the Greater Bay Area.
（4）搭建生态环境保护交流平台，推动生态环保科普教育、科技创新发展。
Establish a platform for ecological and environmental protection exchanges to promote the popularization of eco-environmental science education and the development of technological innovation.

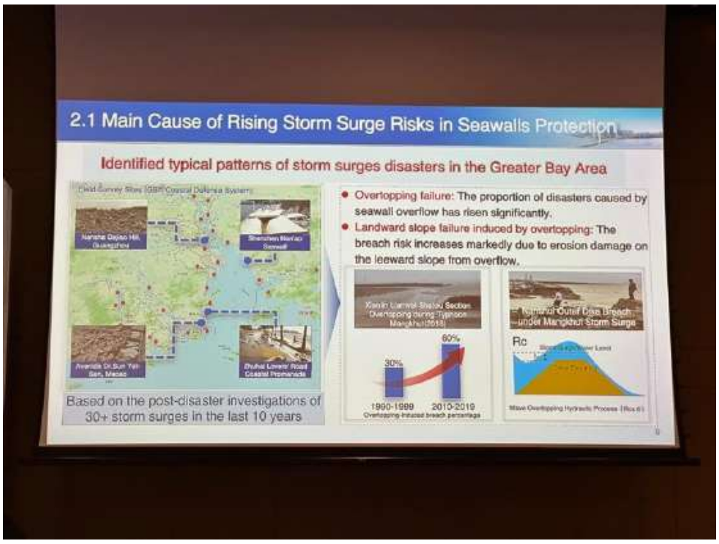

结 语 Conclusion
大藤峡公司深入贯彻“绿水青山就是金山银山”的环境保护理念，坚决扛起保护流域生物多样性、保护广西生态环境优势的政治责任，树立系统观念，支撑流域统一管理，将生态保护由“要我做”转变为“我要做”，推动工程建设运行与生物多样性保护共赢，维持流域生态系统的稳定性与可持续性。
Datengxia Corporation thoroughly implements the environmental protection philosophy that "lucid waters and lush mountains are invaluable assets," resolutely shouldering the political responsibility to preserve watershed biodiversity and maintain Guangxi's ecological advantages. Embracing a systematic approach to support integrated river basin management, the company has transitioned from a passive compliance mindset to proactive environmental stewardship, promoting mutually beneficial outcomes between project construction/operation and biodiversity conservation. This ensures the stability and sustainability of watershed ecosystems while achieving coordinated development between engineering implementation and ecological preservation.

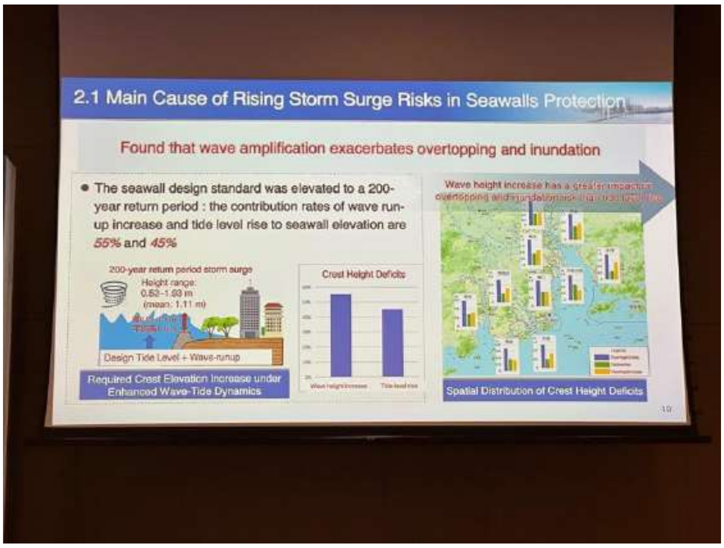

1. Research Background
There is an international consensus on applying nature-based solutions (NBS) to mitigate extreme weather risks.
China has also been actively exploring solutions in this regard.
The GBA has achieved remarkable accomplishments in the construction of the urban seawall.
9+2 City Cluster
Guangdong-Hong Kong -Macao Greater Bay Area (GBA)
Area
56000 km²
Population
86.31 million
GDP
12.6 trillion
Urbanization Rate
≈ 85%
Highly developed and populated

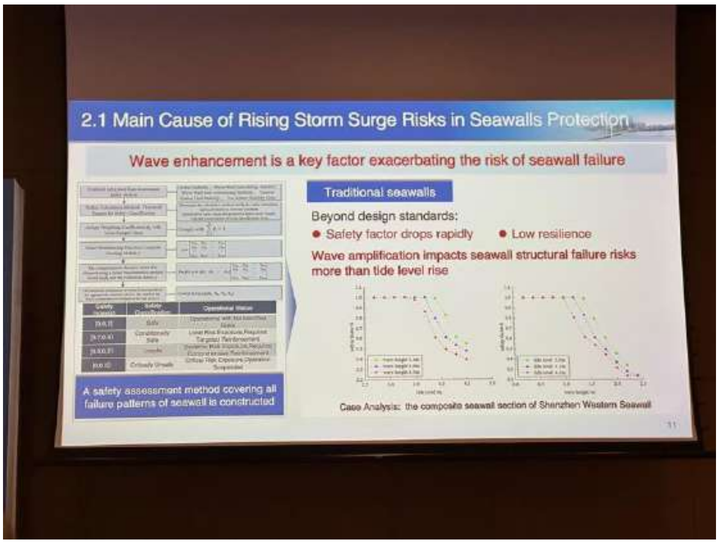

1. Research Background
The seawall serves as a critical barrier against storm surges in the GBA
Zhuhai Hato (2017)
South China Sea
Storm surges occur frequently (5–6 times a year)
The Length 2500 km


1. Research Background
The seawall in the GBA faces the main problems
Traditional seawall reinforcement in the GBA primarily involves raising the structure, with a maximum elevation increase of 1–2 meters. However, as this seawall will encircle urban areas, they create a growing conflict between flood safety, ecological preservation, and urban landscape.
Traditional seawall upgrades
Prominent contradictions
Demand for urban waterfront accessibility
Seawall upgrading under intensifying wavetide dynamics
Coastal "walling"
Recreational waterfront utilization
Tripartite symbiosis of human-urban-marine systems

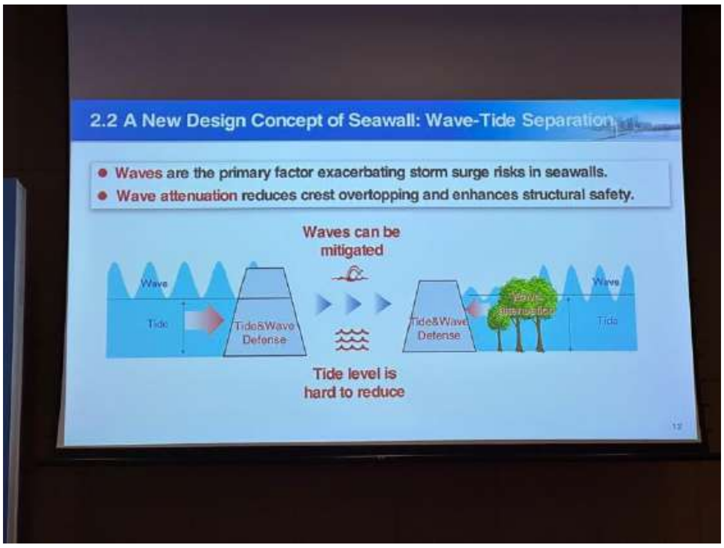

1. Research Background
How to innovate seawall design concepts and develop hazard mitigation technologies that achieve integrated enhancement of both storm surge protection and urban landscapes under height restrictions?
This represents a pressing frontier in scientific and technological innovation requiring urgent solutions.


2.1 Main Cause of Rising Storm Surge Risks in Seawalls Protection
Identified typical patterns of storm surges disasters in the Greater Bay Area
Overtopping failure: The proportion of disasters caused by seawall overflow has risen significantly.
Landward slope failure induced by overtopping: The breach risk increases markedly due to erosion damage on the leeward slope from overflow.
30%
60%
1990-1999
2010-2019
Based on the post-disaster investigations of 30+ storm surges in the last 10 years


2.1 Main Cause of Rising Storm Surge Risks in Seawalls Protection
Found that wave amplification exacerbates overtopping and inundation
The seawall design standard was elevated to a 200-year return period : the contribution rates of wave run-up increase and tide level rise to seawall elevation are 55% and 45%
200-year return period storm surge
Crest Height Deficits
Design Tide Level + Wave-runup
Required Crest Elevation Increase under Enhanced Wave-Tide Dynamics
Spatial Distribution of Crest Height Deficits

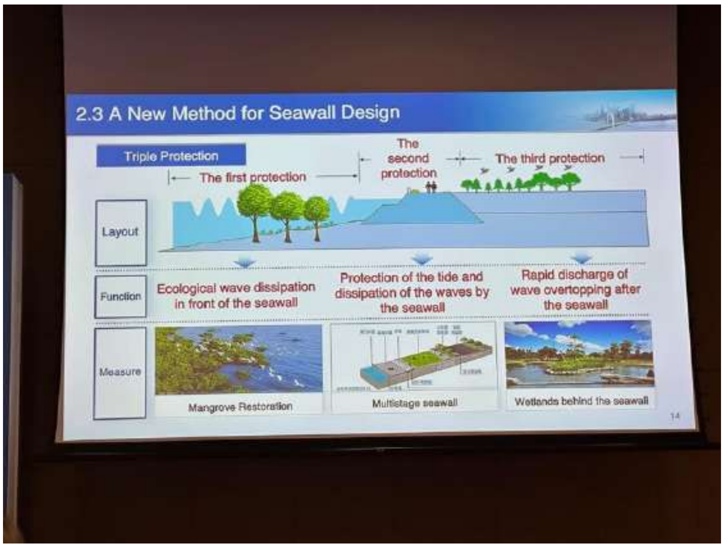


2.1 Main Cause of Rising Storm Surge Risks in Seawalls Protection
Wave enhancement is a key factor exacerbating the risk of seawall failure
Traditional seawalls
Beyond design standards:
Safety factor drops rapidly
Low resilience
Wave amplification impacts seawall structural failure risks more than tide level rise
A safety assessment method covering all failure patterns of seawall is constructed
Case Analysis: the composite seawall section of Shenzhen Western Seawall
11

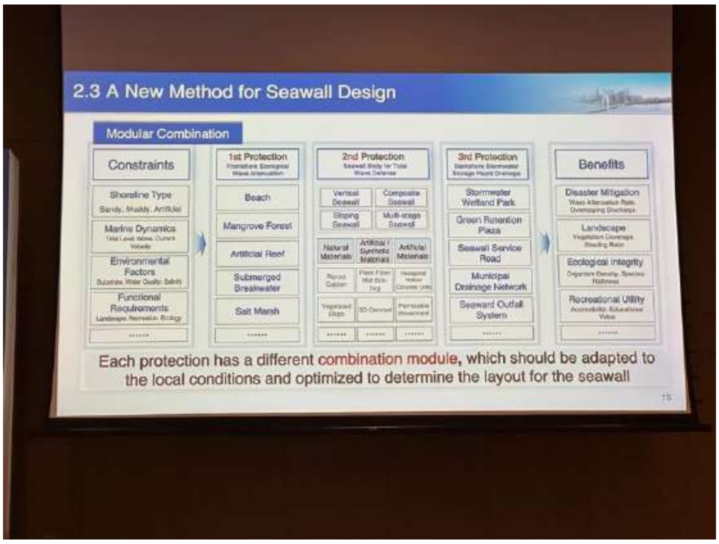


2.2 A New Design Concept of Seawall: Wave-Tide Separation
Waves are the primary factor exacerbating storm surge risks in seawalls.
Wave attenuation reduces crest overtopping and enhances structural safety.
Waves can be mitigated
Wave
Tide
Tide&Wave Defense
Tide level is hard to reduce
Tide&Wave Defense
Wave
Tide
12

2.2 A New Design Concept of Seawall: Wave-Tide Separation
Comparison of Construction Systems
Integrated defense against waves and tides
Separate defense against waves and tides
Engineering Composition
Seawall Engineering
Wave Dissipation Measures in Front of the Embankment + Seawall + Wave Storage Facilities behind the Embankment
Crest Elevation of the Embankment
Design Tide Level + Wave Run-up + Safety Freeboard
Design Tide Level + Safety Freeboard
Disaster Prevention Resilience
Low Protective Resilience of Engineering Confrontation
Strong Protective Resilience of Ecological Adaptability
Engineering Investment
High construction costs for large-scale demolition, construction and renovation
Utilize the Old Embankment, Road Park to Reduce Engineering Investment
Function
Safety
Safety
Landscape
Ecology
Recreation
13



2.3 A New Method for Seawall Design
Triple Protection
The first protection
The second protection
The third protection
Layout
Function
Ecological wave dissipation in front of the seawall
Protection of the tide and dissipation of the waves by the seawall
Rapid discharge of wave overtopping after the seawall
Measure
Mangrove Restoration
Multistage seawall
Wetlands behind the seawall
14



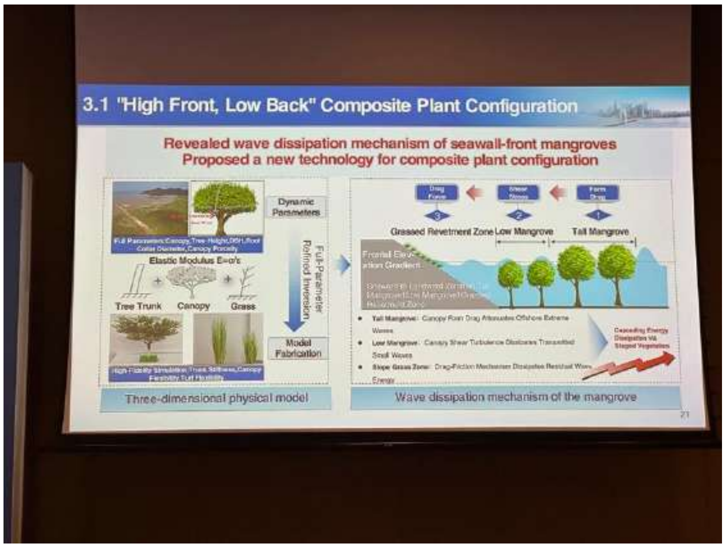
2.3 A New Method for Seawall Design
Modular Combination
Constraints
Shoreline Type
Sandy, Muddy, Artificial
Marine Dynamics
Environmental Factors
Functional Requirements
1st Protection
Beach
Mangrove Forest
Artificial Reef
Submerged Breakwater
Salt Marsh
2nd Protection
Vertical Seawall
Composite Seawall
Sloping Seawall
Multi-stage Seawall
Natural Materials
Artificial Materials
3rd Protection
Stormwater Wetland Park
Green Retention Plaza
Seawall Service Road
Municipal Drainage Network
Seaward Outfall System
Benefits
Disaster Mitigation
Landscape
Ecological Integrity
Recreational Utility
Each protection has a different combination module, which should be adapted to the local conditions and optimized to determine the layout for the seawall
15

2.3 A New Method for Seawall Design
Systematic Optimization
Modular Selection
Scenario Simulation
Effectiveness Evaluation
Optimization of Synergistic Cumulative Effects
Systematic optimization ensures that dispersed modules work together across different dimensions, which improves the design efficiency of the seawall.
16


2.3 A New Method for Seawall Design
Applicable to various functional requirements of different embankment spaces
9+2 City Cluster
Guangdong-Hong Kong-Macao Greater Bay Area (GBA)
Zhuhai Lovers' Road Ecological Seawall for Shorelines with Limited Revetment Space
Dajiaoshan Coastal Park Ecological Seawall -For Shorelines with Foreshore Zone
Lingshan Island Tip Super Embankment-For Shorelines with Ample Space

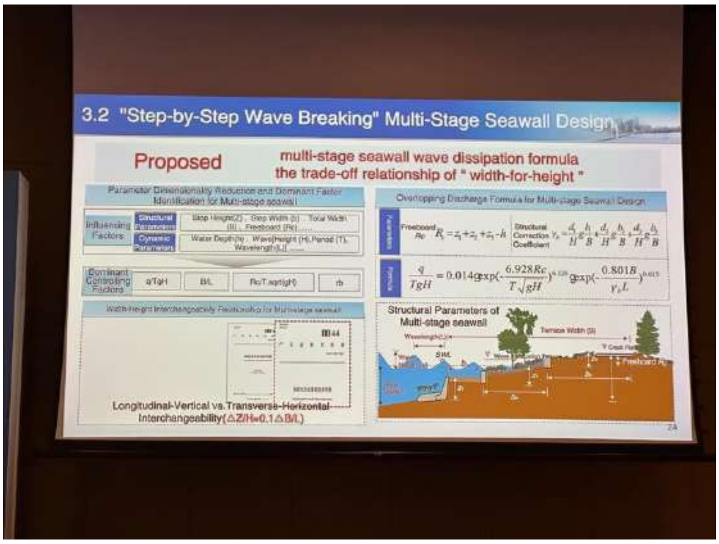

3 Key Technology of Wave Dissipation, Storage and Drainage
The technical system for the whole process of wave dissipation, storage and drainage from the front to the rear of the embankment
Ecological wave dissipation in front of the embankment
Tide and wave blocking by the embankment body
Rapid water storage and drainage behind the embankment
Mangrove forest
Multi-level embankment
Backflow and drainage structure

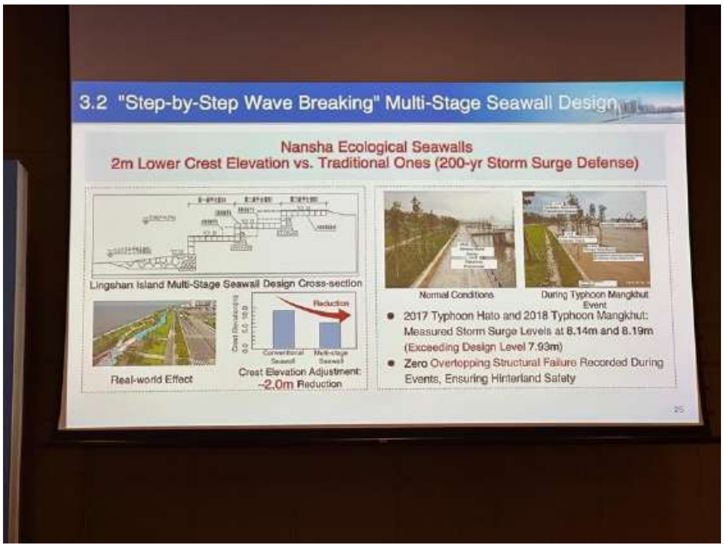

3.1 "High Front, Low Back" Composite Plant Configuration
Analyzed drawbacks of traditional mangrove wave dissipation on beaches
Mangrove Functions: Wave dissipation & flow reduction
Mangrove Challenges:
Planting method limitations: relies too much on manual experience
GBA-specific constraint: Narrow beach width in front of seawalls
Conventional Planting Configuration
Causes of Inadequate Wave Dissipation Capacity
Planar Direction
Vertical Direction
Empirical Planting Method
Limited Usable Space


3.1 "High Front, Low Back" Composite Plant Configuration
Revealed wave dissipation mechanism of seawall-front mangroves
Proposed a new technology for composite plant configuration
Dynamic Parameters
Full-Parameter Rational Inversion
Model Fabrication
Tree Trunk
Canopy
Grass
Grassed Revetment Zone
Low Mangrove
Tall Mangrove
Three-dimensional physical model
Wave dissipation mechanism of the mangrove

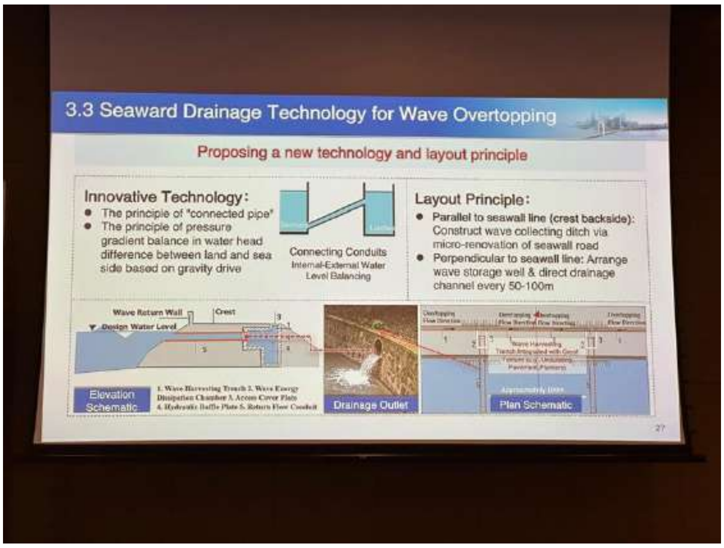

3.1 "High Front, Low Back" Composite Plant Configuration
Application in the ecological construction of the Jiangmen Yinhu Bay seawall
Inadequate Flood Defense Standards, Excessive Hardening
Pre-vegetation Configuration State
Integrated Vegetation Configuration Methodology
Maximized Wave Dissipation in Limited Planting Space and Integrated Ecological-Landscape Enhancement
Composite Vegetation Application Performance

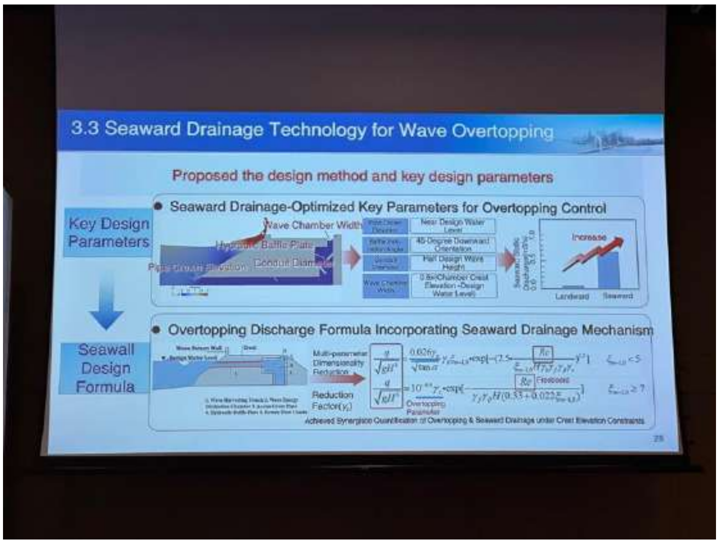

3.2 "Step-by-Step Wave Breaking" Multi-Stage Seawall Design
Multi-stage seawalls: integrated functions
V.S.
lacking design specs
Prevailing Seawall Typology
Multi-Stage Seawall Configuration
Structure: Waterside stepped multi-functional terraces, structure width >50m
Applicability: New urban core areas with sufficient land reserve
Lack of Design Codes
Absence in Conventional Codes
Unvalidated Run-up Overtopping Calculations
Empirical Design Approach
Unquantified Wave Attenuation
Ambiguous Crest Elevation Criteria
Multi-stage Seawall ?


3.2 "Step-by-Step Wave Breaking" Multi-Stage Seawall Design
Proposed
multi-stage seawall wave dissipation formula
the trade-off relationship of " width-for-height "
Parameter Dimensionality Reduction and Dominant Factor Identification for Multi-stage seawall
Influencing Factors
Structural Parameters
Dynamic Parameters
Dominant Controlling Factors
Overtopping Discharge Formula for Multi-stage Seawall Design
Structural Parameters of Multi-stage seawall
Terrace Width (B)
Longitudinal-Vertical vs. Transverse-Horizontal Interchangeability(△Z/H=0.1△B/L)
24

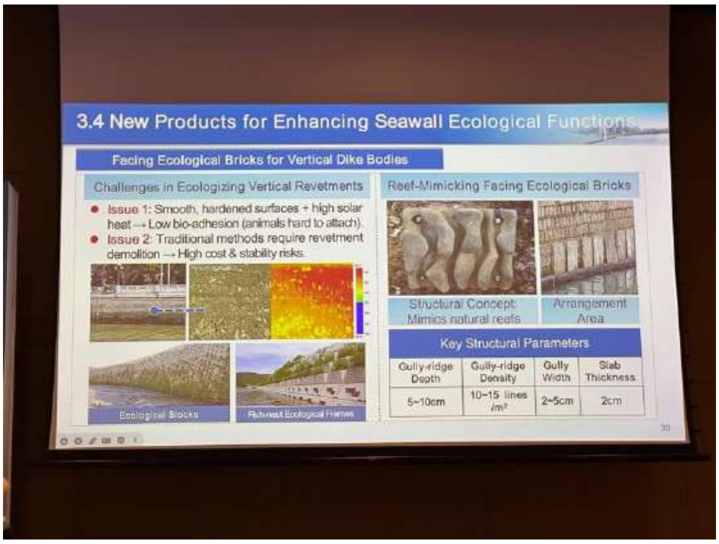
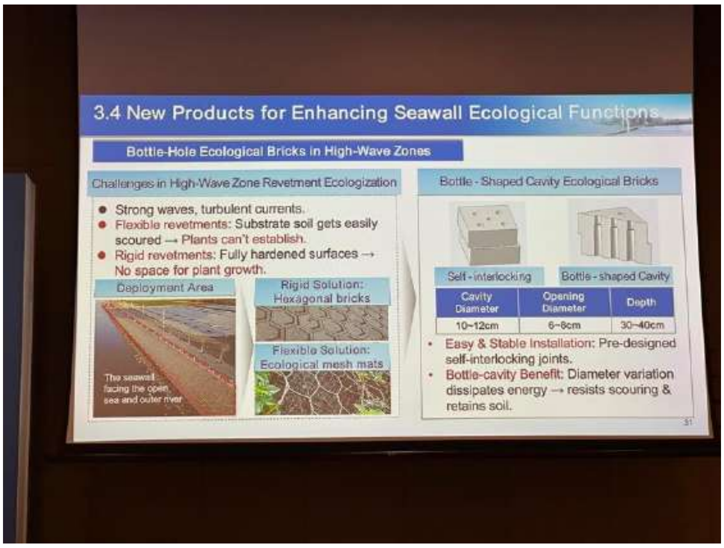

3.2 "Step-by-Step Wave Breaking" Multi-Stage Seawall Design
Nansha Ecological Seawalls
2m Lower Crest Elevation vs. Traditional Ones (200-yr Storm Surge Defense)
Lingshan Island Multi-Stage Seawall Design Cross-section
Real-world Effect
Reduction
Conventional Seawall
Multi-stage Seawall
Crest Elevation Adjustment: -2.0m Reduction
Normal Conditions
During Typhoon Mangkhut Event
2017 Typhoon Hato and 2018 Typhoon Mangkhut: Measured Storm Surge Levels at 8.14m and 8.19m (Exceeding Design Level 7.93m)
Zero Overtopping Structural Failure Recorded During Events, Ensuring Hinterland Safety
25


3.3 Seaward Drainage Technology for Wave Overtopping
The traditional drainage method is easy to intensify the urban flooding problem
Traditional drainage method:
Seawall backside drainage ditch collects overtopped water
Drains to rivers via municipal systems
City challenges:
High surface impermeability (limited water storage)
Outdated municipal facilities → insufficient drainage capacity
Storm surges exacerbate urban flooding
Conventional Drainage System
Drainage Ditch
Traditional Drainage Infrastructure
Urban Waterlogging in Protected Hinterland
26


3.3 Seaward Drainage Technology for Wave Overtopping
Proposing a new technology and layout principle
Innovative Technology:
The principle of "connected pipe"
The principle of pressure gradient balance in water head difference between land and sea side based on gravity drive
Connecting Conduits
Internal-External Water Level Balancing
Layout Principle:
Parallel to seawall line (crest backside): Construct wave collecting ditch via micro-renovation of seawall road
Perpendicular to seawall line: Arrange wave storage well & direct drainage channel every 50-100m
Wave Return Wall
Crest
Design Water Level
Elevation Schematic
Drainage Outlet
Plan Schematic
27


3.3 Seaward Drainage Technology for Wave Overtopping
Proposed the design method and key design parameters
Key Design Parameters
Seaward Drainage-Optimized Key Parameters for Overtopping Control
Wave Chamber Width
Hydraulic Baffle Plate
Conduit Diameter
Increase
Landward
Seaward
Seawall Design Formula
Overtopping Discharge Formula Incorporating Seaward Drainage Mechanism
Multi-parameter Dimensionality Reduction
Reduction Factor(γ_s)
Achieved Synergistic Quantification of Overtopping & Seaward Drainage under Crest Elevation Constraints
28


3.3 Seaward Drainage Technology for Wave Overtopping
Nansha Lingshan Island & Huigu:
40-50% Less Wave Overtopping into Municipal Systems vs. Landward Drainage
Return Flow Structure
Wave Energy Dissipation Chamber
Chamber Access Cover Plate
Long-term Layout Vision
Construction Close-up
Simple Construction with Minimal Impact on Seawall Integrity
2017 Super Typhoon Hato 2018 Super Typhoon Mangkhut: Overtopping Flow Autonomously Drained to Estuary, Ensuring Hinterland Flood Control Coastal Safety
29


3.4 New Products for Enhancing Seawall Ecological Functions
Facing Ecological Bricks for Vertical Dike Bodies
Challenges in Ecologizing Vertical Revetments
Issue 1: Smooth, hardened surfaces + high solar heat → Low bio-adhesion (animals hard to attach).
Issue 2: Traditional methods require revetment demolition → High cost & stability risks.
Ecological Blocks
Reef-Mimicking Facing Ecological Bricks
Structural Concept: Mimics natural reefs
Arrangement Area
Key Structural Parameters
Gully-ridge Depth
Gully-ridge Density
Gully Width
Slab Thickness
5~10cm
10~15 lines /m²
2~5cm
2cm

3.4 New Products for Enhancing Seawall Ecological Functions
Bottle-Hole Ecological Bricks in High-Wave Zones
Challenges in High-Wave Zone Revetment Ecologization
Strong waves, turbulent currents.
Flexible revetments: Substrate soil gets easily scoured → Plants can't establish.
Rigid revetments: Fully hardened surfaces → No space for plant growth.
Deployment Area
The seawall facing the open sea and outer river
Rigid Solution: Hexagonal bricks
Flexible Solution: Ecological mesh mats
Bottle - Shaped Cavity Ecological Bricks
Self - interlocking
Bottle - shaped Cavity
Cavity Diameter
Opening Diameter
Depth
10~12cm
6~8cm
30~40cm
Easy & Stable Installation: Pre-designed self-interlocking joints.
Bottle-cavity Benefit: Diameter variation dissipates energy → resists scouring & retains soil.
31

3.4 New Products for Enhancing Seawall Ecological Functions
Water-Retaining Ecological Reefs for Seawall Toes in High-Wave Zones
Challenges in Ecologizing Seawall Toes (High-Wave Zones)
Armor units lack water-retention spaces → intertidal organisms dehydrate at low tide.
Concrete matrices are strongly alkaline → Restrict biodiversity of attached species.
Traditional square reefs have poor self-stability → Prone to overturning under strong wave forces.
Natural intertidal zone (naturally retains water for organisms)
Traditional tetrapod blocks (non-ecological, unstable design)
"Olive-Kernel Shaped" Water-Retaining Ecological Reefs
Structural Features
Deployment Area
Key Design Parameters
Long Axis
Short Axis
Cavity Size
Cavity Ratio
1.2~1.8m
0.8~1.2m
0.2~0.6m
20%~45%
32

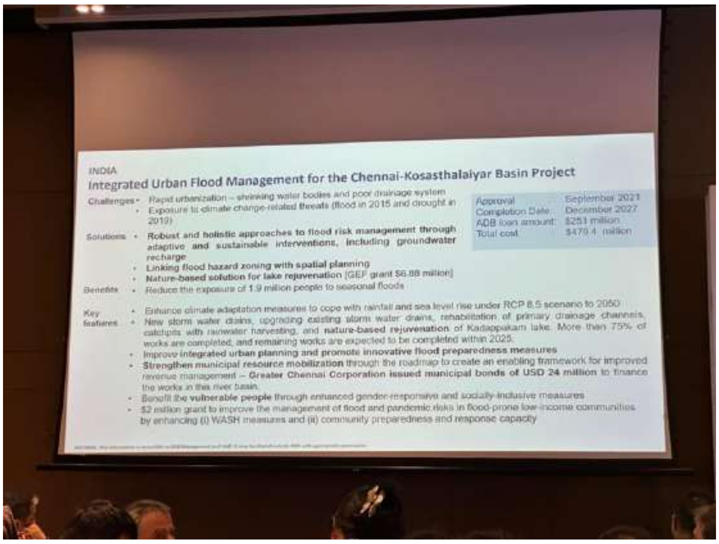
3.5 Global Approval
Tech Achievements Applied to Nansha Lingshan Island Ecological Seawall
– Widely Noticed and Highly Recognized by International Peers

41ST IAHR WORLD CONGRESS SINGAPORE
Singapore International Water Week

41ST IAHR WORLD CONGRESS SINGAPORE
Singapore International Water Week
Water, Cities and Climate:
Interconnectedness for a Sustainable Future


23 - 25 JUNE 2025
FLOOD RESILIENT CITIES:
APTING TO CLIMATE CHANGE
pluvia.ai
ARUP
Strategic Partners
ADB
C40 CITIES
SWA


Adaptation with co-benefits
Recreational value
Biodiversity
Meeting places – social resilience
Health
Improved microclimate (UHI)
Synergy with urban renewal
Rainwater recycling
Accessibility and safety
Economic growth
Architecture and local identity

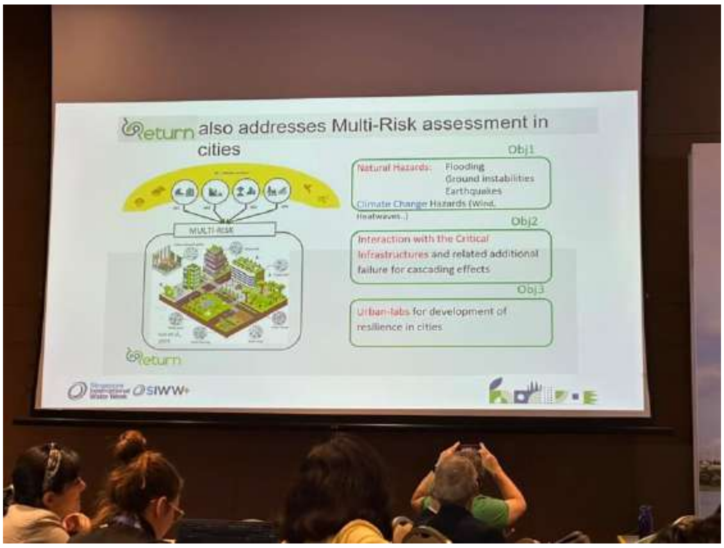

INDIA
Integrated Urban Flood Management for the Chennai-Kosasthalaiyar Basin Project
Challenges • Rapid urbanization – shrinking water bodies and poor drainage system
• Exposure to climate change-related threats (flood in 2015 and drought in 2019)
Solutions • Robust and holistic approaches to flood risk management through adaptive and sustainable interventions, including groundwater recharge
• Linking flood hazard zoning with spatial planning
• Nature-based solution for lake rejuvenation (GEF grant $6.88 million)
Benefits • Reduce the exposure of 1.9 million people to seasonal floods
Key features • Enhance climate adaptation measures to cope with rainfall and sea level rise under RCP 8.5 scenario to 2050
• New storm water drains, upgrading existing storm water drains, rehabilitation of primary drainage channels, catchpits with rainwater harvesting, and nature-based rejuvenation of Kadappakam lake. More than 75% of works are completed, and remaining works are expected to be completed within 2025.
• Improve integrated urban planning and promote innovative flood preparedness measures
• Strengthen municipal resource mobilization through the roadmap to create an enabling framework for improved revenue management – Greater Chennai Corporation issued municipal bonds of USD 24 million to finance the works in this river basin.
• Benefit the vulnerable people through enhanced gender-responsive and socially-inclusive measures
• $2 million grant to improve the management of flood and pandemic risks in flood-prone low-income communities by enhancing (i) WASH measures and (ii) community preparedness and response capacity
Approval September 2021
Completion Date December 2027
ADB loan amount $251 million
Total cost $470.4 million

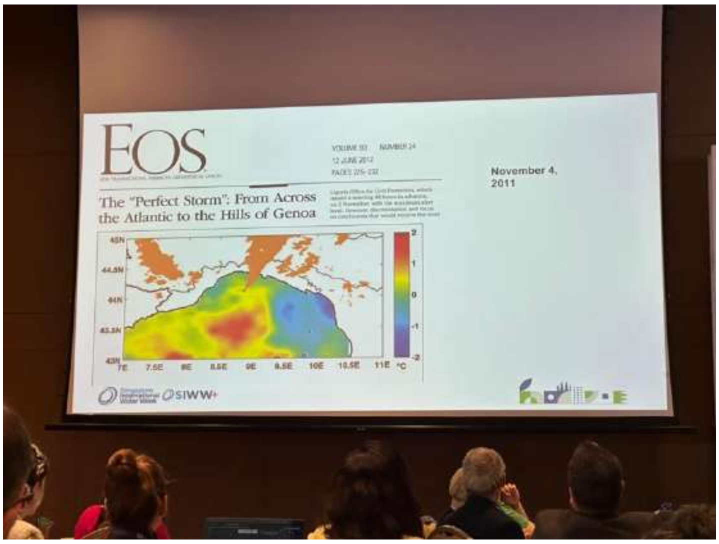

Creating social interaction – and flood protection
Jacobs
RSK
xylem
ARUP


Flood-Resilient Cities: How do we get there?


INNOVATIVE WATER EN
FOR SUSTAINABLE DE

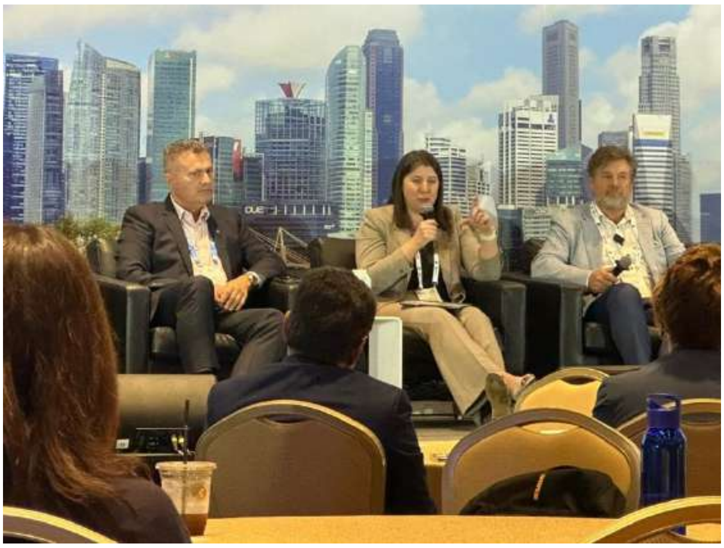

Return
Multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate
~ 120 Mio €
36 months
~ 1000 researchers
> 100 New Researchers
15 public research entities, 6 private entities, 4 no-profit org.
National Dept of the Civil Protection
SIWW


Return also addresses Multi-Risk assessment in cities
Obj1
Natural Hazards: Flooding
Ground instabilities
Earthquakes
Climate Change Hazards (Wind, Heatwaves...)
Obj2
Interaction with the Critical Infrastructures and related additional failure for cascading effects
Obj3
Urban-labs for development of resilience in cities
MULTI-RISK
Return
SIWW

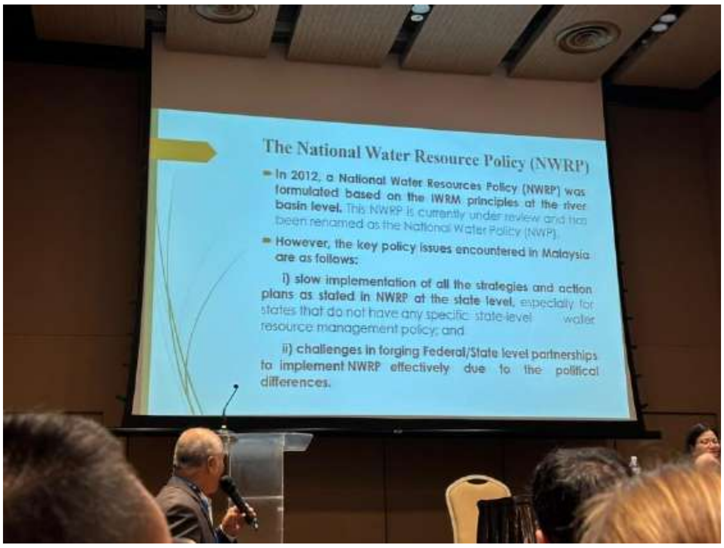

EOS
The "Perfect Storm": From Across the Atlantic to the Hills of Genoa
November 4, 2011
SIWW


INNOVATIVE WATER ENGINEERING FOR SUSTAINABLE DEVELOPMENT

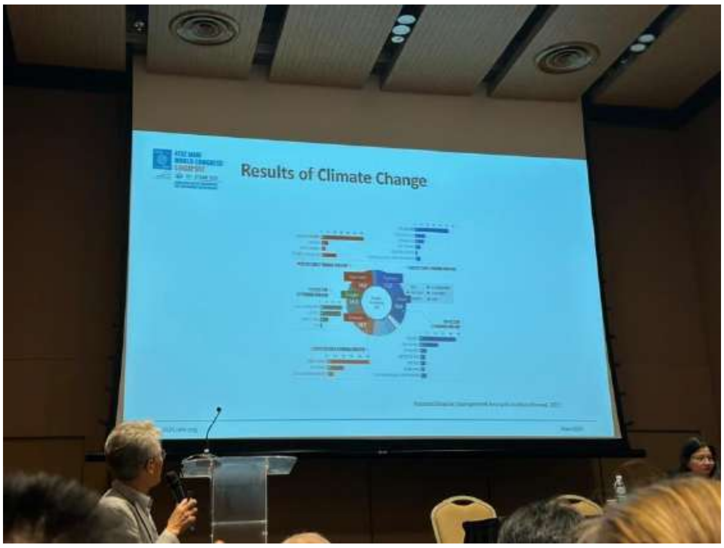

41ST IAHR WORLD CONGRESS SINGAPORE
22 – 27 JUNE 2025
INNOVATIVE WATER ENGINEERING FOR SUSTAINABLE DEVELOPMENT
Singapore International Water Week
SPOTLIGHT 2025
23 - 25 JUNE 2025
FLOOD RESILIENT CITIES: ADAPTING TO CLIMATE CHANGE
AECOM
Jacobs
RSK

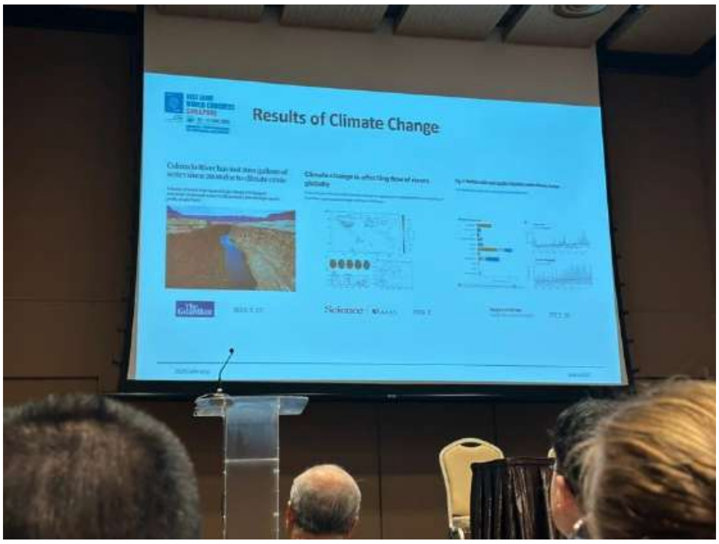



Status and Issues
Related to the Implementation of
Integrated River Basin Management
in Malaysia
Chow Hock LIM1, University Nottingham Malaysia
Fang Yenn TEO2, University Nottingham Malaysia
1 evxcl6@nottingham.edu.my
2 FangYenn.Teo@nottingham.edu.my

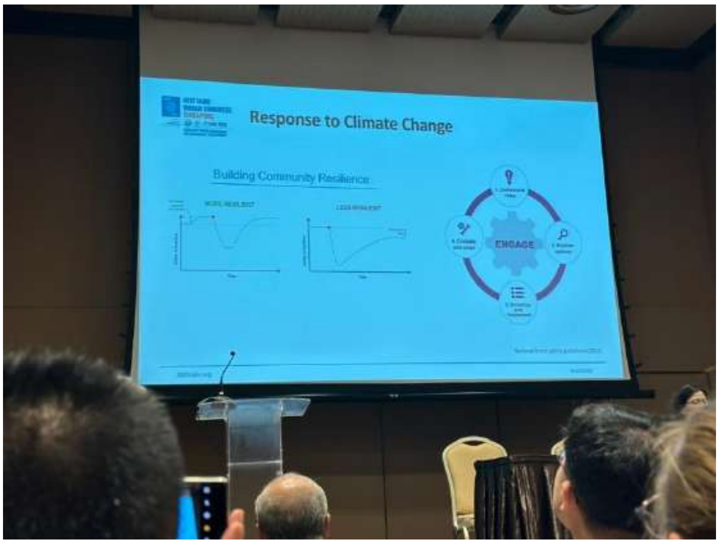

The National Water Resource Policy (NWRP)
In 2012, a National Water Resources Policy (NWRP) was formulated based on the IWRM principles at the river basin level. This NWRP is currently under review and has been renamed as the National Water Policy (NWP).
However, the key policy issues encountered in Malaysia are as follows:
i) slow implementation of all the strategies and action plans as stated in NWRP at the state level, especially for states that do not have any specific state-level water resource management policy; and
ii) challenges in forging Federal/State level partnerships to implement NWRP effectively due to the political differences.

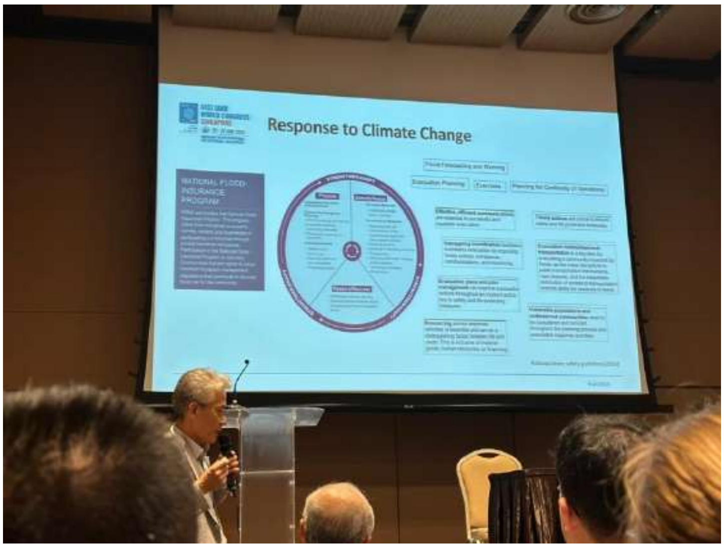

Stakeholder Engagement & Participation
Stakeholder participation is important because stakeholders who are interested in, and accepting of the water resource management system, can ensure its sustainable implementation on the ground.
Communication with all relevant stakeholders is also important to raise the awareness of the river basin stakeholders and educate them on the benefits of their participation in the management of the river basin.
Challenges related to effective stakeholder engagement include: i) Low inclusivity, ii) Lack of selection criteria, iii) Lack of proper planning for engagement, iv) Inadequate budget, and v) Relatively low organizational commitment.


Results of Climate Change


Results of Climate Change
Science

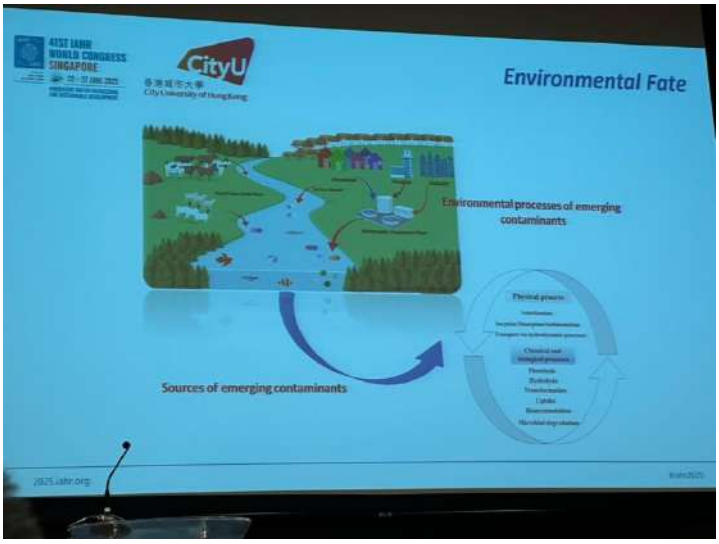

Results of Climate Change


Response to Climate Change
Building Community Resilience
ENGAGE


Response to Climate Change
NATIONAL FLOOD INSURANCE PROGRAM


CityU
Modelling for Understanding and Managing
the Risks of Emerging Contaminants in Water Systems
in Singapore and China
Xuneng TONG
School of Energy and Environment
State Key Laboratory of Marine Pollution
City University of Hong Kong


CityU
Problem Emerging
Emergence
Impact?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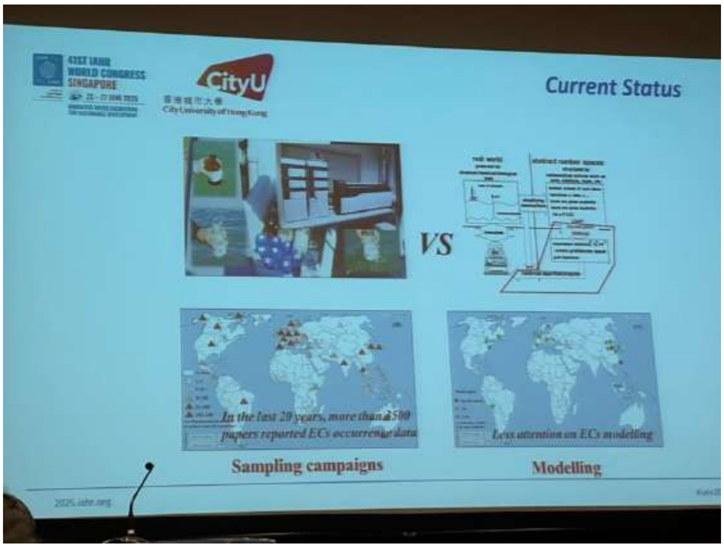
CityU
香港城市大學
City University of Hong Kong
Environmental Fate
Environmental processes of emerging contaminants
Sources of emerging contaminants
2025.iahr.org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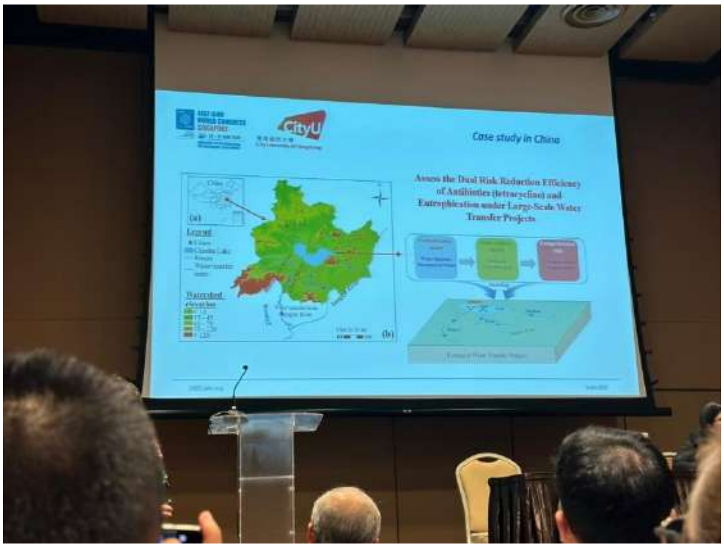
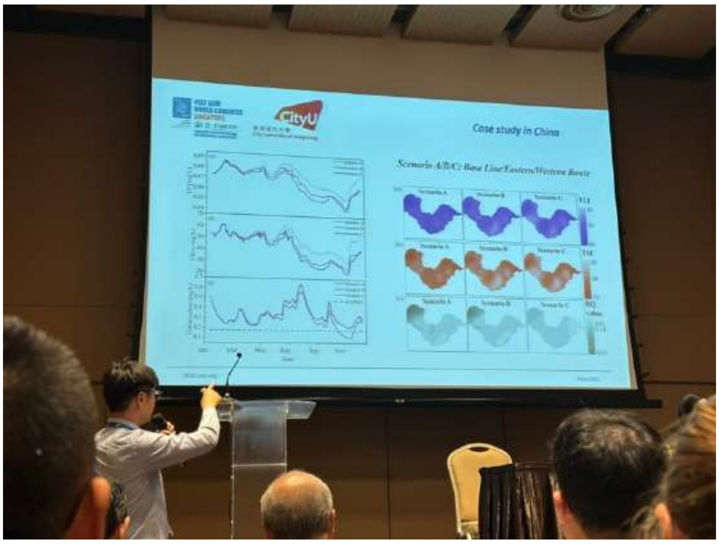
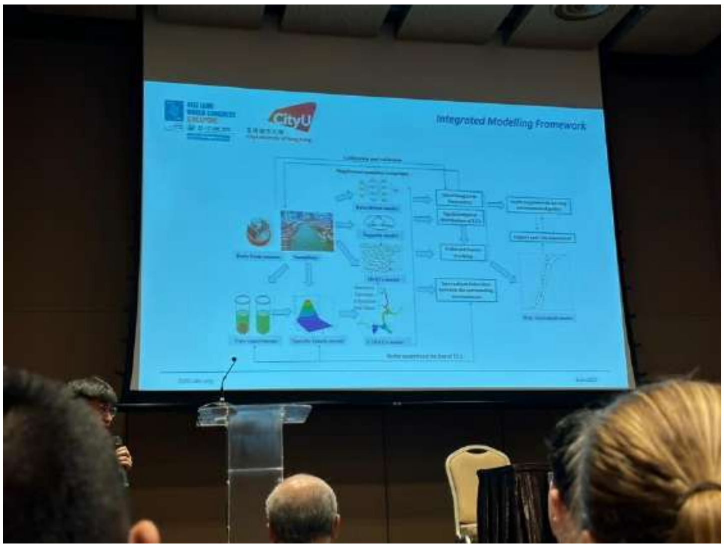
CityU
香港城市大學
City University of Hong Kong
Current Status
VS
Less attention on ECs modelling
Sampling campaigns
Modelling
2025.iahr.org


CityU
Case study in China
Groundwater
Groundwater
Lake


CityU
Case study in China
Assess the Dual Risk Reduction Efficiency of Antibiotics (tetracycline) and Eutrophication under Large-Scale Water Transfer Projects


CityU
Case study in China
Scenario A/B/C: Base Line/Eastern/Western Route


CityU
Integrated Modelling Framework


长江科学院
Innovative policy approach in addressing pollution control over the Yangtze from source to sea
Basin Enhanced River Chief System
Changjiang River Scientific Research Institute, China
2025.06


River Chief System
Mechanism
长江科学院
The RCS is China's innovation to implement local governments' entity responsibility for protection and management of rivers by appointing government's principal leader as the river chief.
Over 1.2 million

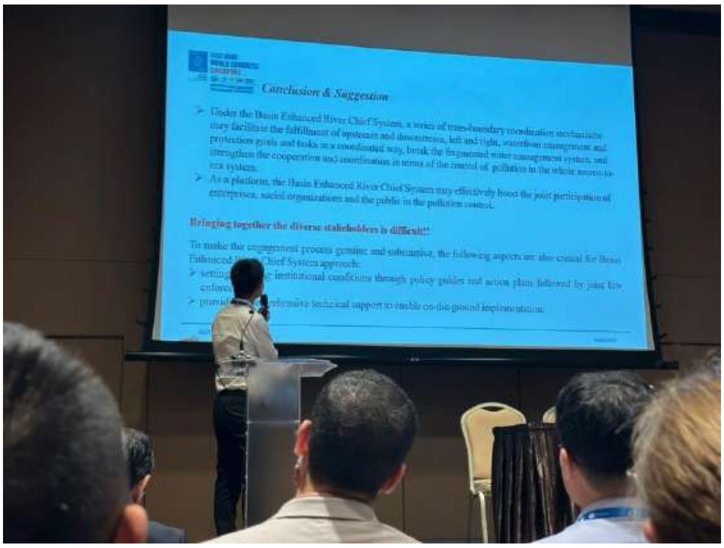

River Chief System
Mechanism
长江科学院


River Chief System
Introducing Source to Sea Approach
长江科学院
Challenge
Solution:

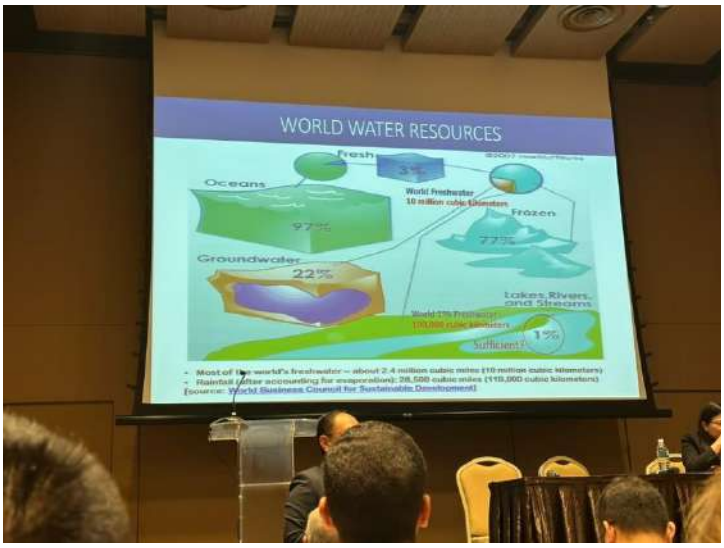

River Chief System with S2S
Basin Enhanced River Chief System
长江科学院
Holistic
Context-dependent
RCS &
S2S
Collaborative
Result-oriented
Participatory
Adaptive
Basin Enhanced River Chief System


Basin Enhanced River Chief System
长江科学院
Holistic
Collaborative


Basin Enhanced River Chief System
长江科学院
Result-oriented
Adaptive


Conclusion & Suggestion

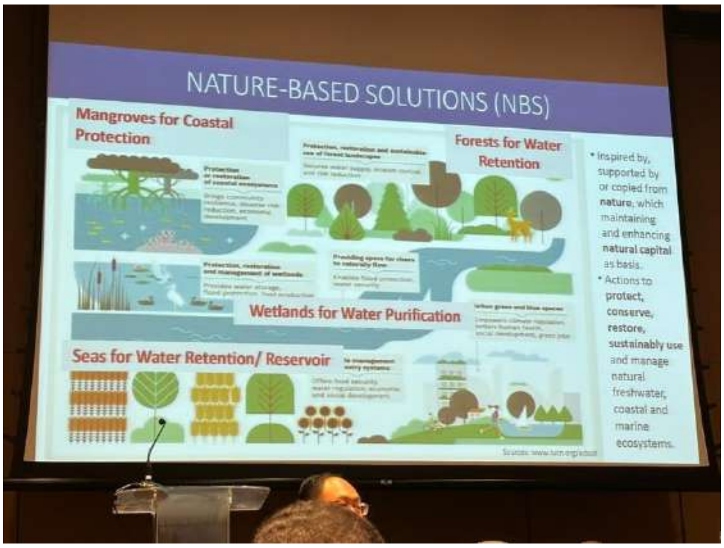

University of Nottingham
POTENTIAL AND SUSTAINABILITY OF NATURE-BASED SOLUTIONS TO GLOBAL WATER CHALLENGES
Prof. Ir. Ts. Dr. Teo Fang Yenn
41st International Association for Hydro-Environment Engineering and Research (IAHR) World Congress (IAHR2025 Singapore)
24 June 2025, Singapore


WORLD WATER RESOURCES
Oceans
97%
Fresh
3%
Frozen
77%
Groundwater
22%
Lakes, Rivers, and Streams
1%
Sufficient?


WORLD WATER ACCESSIBILITY
Proportion of the population using improved sources of drinking water

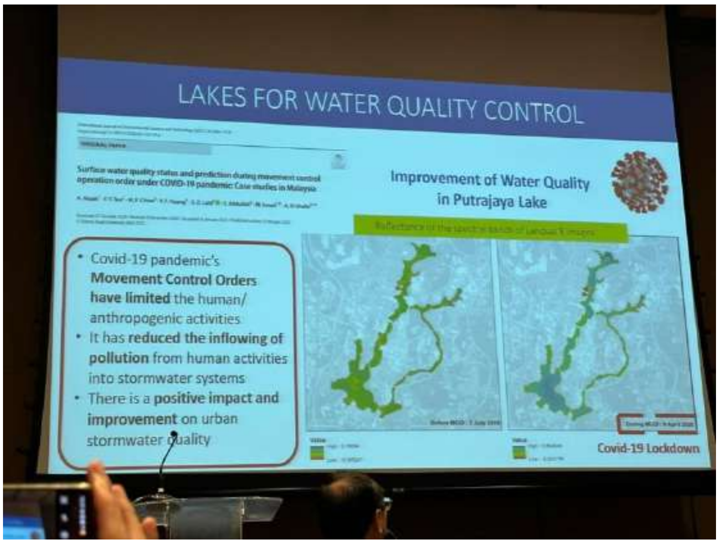

WATER SHORTAGE AND EXCESS
Flash floods strike KL
Drought in Australia seen from above – in pictures

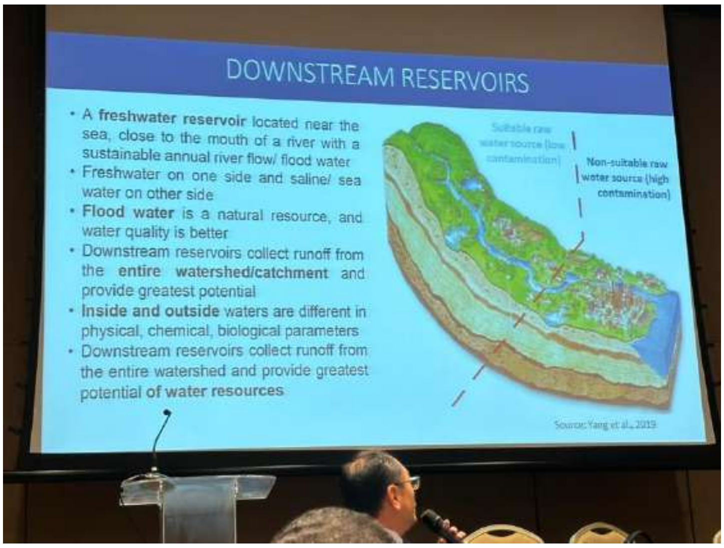

INTEGRATING WATER SOLUTIONS WITH NATURE
• Across ecosystems from hills to seas, different Nature-Based Solutions (NBS) can work together to build climate resilience
• NBS leverage natural processes to address water environmental challenges
MOUNTAINS, FORESTS, AND WATERSHEDS
RIVERS AND WETLANDS
FARMLAND
CITIES
COASTS
Source: World Resources Institute & Bapna et al. 2019

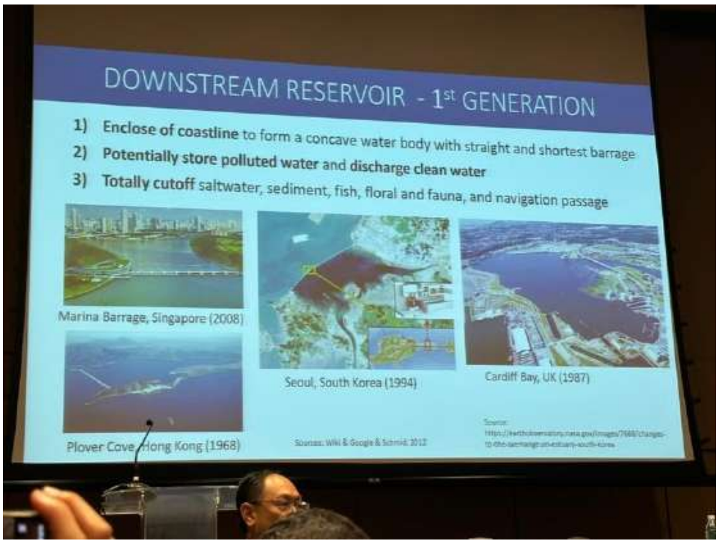

NATURE-BASED SOLUTIONS (NBS)
Mangroves for Coastal Protection
Forests for Water Retention
Wetlands for Water Purification
Seas for Water Retention/ Reservoir
• Inspired by, supported by or copied from nature, which maintaining and enhancing natural capital as basis.
• Actions to protect, conserve, restore, sustainably use and manage natural freshwater, coastal and marine ecosystems.


BUILDING WITH NATURE FROM HILLS
WWF
Forests for Water Retention
• Highland forest at Long Semadoh, Lawas in Sarawak, Malaysia
• Main issues: drought, flooding on paddy field and river bank erosion
• Supported by WWF (World Wildlife Fund) and CIMB Islamic Bank
• Forest for water retention and watershed management with local community involvement and knowledge transfer
• Natural materials for live-fencings, brush walls, coconut coir geotextile
• Knowledge transfer to local community – green solution/ nature-based solution, bio-engineering – river bank protection, retention ponds, upstream reservoirs

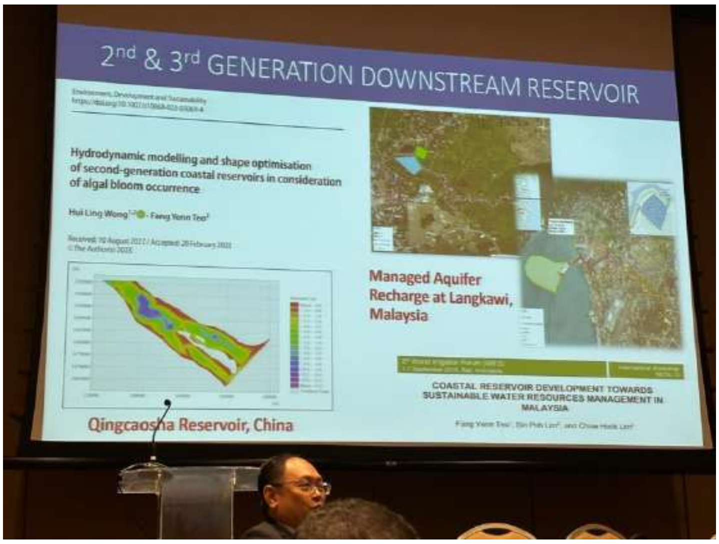

GREEN MEASURES AS UPSTREAM SOLUTIONS
Nature-Based Solutions and Green/ Bio-engineering Measures
Editorial: Potential and limitations of Nature-based Solutions (NbS) to global water challenges
Brush Wall
Bamboo Fence
• Flood retention ponds, wetlands, upstream reservoirs to assess their potential benefits
• Building with nature which uses green/ bio-engineering measures to create riparian buffers for nutrient runoff reduction
Installation of Green/ Bio-engineering Measures at Trusan River basin, Sarawak

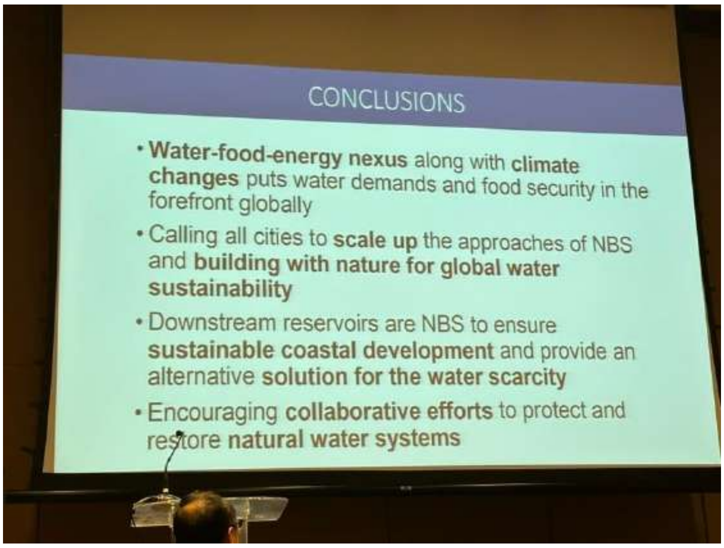

LAKES FOR WATER QUALITY CONTROL
Surface water quality status and prediction during movement control operation order under COVID-19 pandemic: Case studies in Malaysia
Improvement of Water Quality in Putrajaya Lake
• Covid-19 pandemic's Movement Control Orders have limited the human/ anthropogenic activities
• It has reduced the inflowing of pollution from human activities into stormwater systems
• There is a positive impact and improvement on urban stormwater quality
Covid-19 Lockdown


DOWNSTREAM RESERVOIRS
• A freshwater reservoir located near the sea, close to the mouth of a river with a sustainable annual river flow/ flood water
• Freshwater on one side and saline/ sea water on other side
• Flood water is a natural resource, and water quality is better
• Downstream reservoirs collect runoff from the entire watershed/catchment and provide greatest potential
• Inside and outside waters are different in physical, chemical, biological parameters
• Downstream reservoirs collect runoff from the entire watershed and provide greatest potential of water resources
Suitable raw water source (low contamination)
Non-suitable raw water source (high contamination)
Source: Yang et al., 2019


DOWNSTREAM RESERVOIR - 1st GENERATION
1) Enclose of coastline to form a concave water body with straight and shortest barrage
2) Potentially store polluted water and discharge clean water
3) Totally cutoff saltwater, sediment, fish, floral and fauna, and navigation passage
Marina Barrage, Singapore (2008)
Seoul, South Korea (1994)
Cardiff Bay, UK (1987)
Plover Cove, Hong Kong (1968)
Sources: Wiki & Google & Schmid, 2012


DOWNSTREAM RESERVOIR - 2nd & 3rd GENERATION
✓ Convey water body with curved and long barriers
✓ By pass polluted water and store clean water
✓ Minimum environment and social-economic impacts
✓ Wetland pre-treatment and managed aquifer recharge (optional)
✓ Underground curtain to create groundwater reservoir
Qingcaosha Reservoir, China
Source: NASA, 2018
• Qingcaosha Reservoir is located at the alluvial terrace in the northwest of Changxing Island, Shanghai (the largest city in China with population > 27 Million)
• Its water quality meets the national standard of Class II, with a water supply rate of over 7.19 million m³/d, which accounts for more than 50% of the water supplement in Shanghai and benefits more than 11 million people
Source: Yang et al., 2019
Source: Google


2nd & 3rd GENERATION DOWNSTREAM RESERVOIR
Hydrodynamic modelling and shape optimisation of second-generation coastal reservoirs in consideration of algal bloom occurrence
Managed Aquifer Recharge at Langkawi, Malaysia
COASTAL RESERVOIR DEVELOPMENT TOWARDS SUSTAINABLE WATER RESOURCES MANAGEMENT IN MALAYSIA
Qingcaosha Reservoir, China

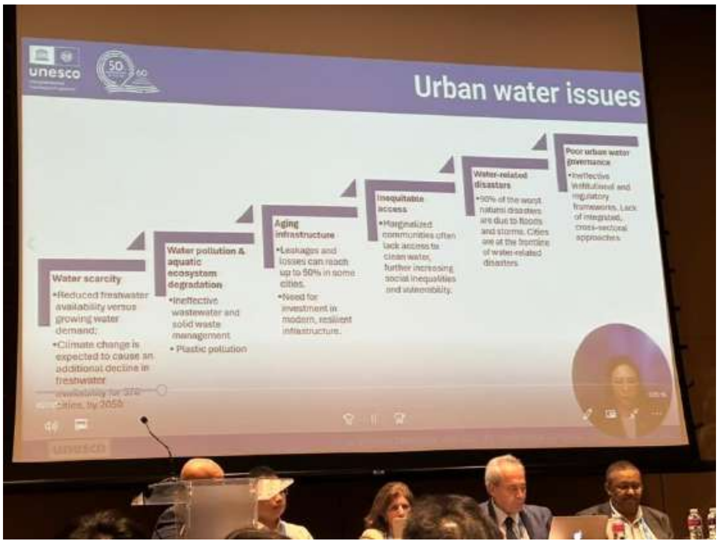

CONCLUSIONS
• Water-food-energy nexus along with climate changes puts water demands and food security in the forefront globally
• Calling all cities to scale up the approaches of NBS and building with nature for global water sustainability
• Downstream reservoirs are NBS to ensure sustainable coastal development and provide an alternative solution for the water scarcity
• Encouraging collaborative efforts to protect and restore natural water systems


41ST IAHR WORLD CONGRESS
SESSION 13
ENHANCING WATER AND SOCIAL RESILIENCE IN URBAN AREAS
A CALL FOR CITY WATER LEADERS
OPENING ADDRESS
MODERATOR
INVITED SPEAKERS


SESSION 13
ENHANCING WATER AND SOCIAL RESILIENCE IN URBAN AREAS
A CALL FOR CITY WATER LEADERS
OPENING ADDRESS
MODERATOR
INVITED SPEAKERS


SESSION 13


unesco
Global water challenges
Over 2 billion people lack access to safe drinking water, including 1.2 billion people lacking a basic level of service.
2 billion people lack basic sanitation.
Food security and food production are at risk due to water scarcity
Water pollution is worsening worldwide with as a result of discharges of untreated, or insufficiently treated, wastewater, nutrient runoff from agriculture, emerging pollutants and plastic/microplastic pollution
Significant future reductions in renewable water, affecting the availability, quality and reliability of water resources
Competition over water resources will be exacerbated
Water-related disasters are increasing in intensity and frequency due to climate change, with 90% of natural disasters being water-related


unesco
Urban water issues
Water scarcity
•Reduced freshwater availability versus growing water demand;
•Climate change is expected to cause an additional decline in freshwater
Water pollution & aquatic ecosystem degradation
•Ineffective wastewater and solid waste management
• Plastic pollution
Aging infrastructure
•Leakages and losses can reach up to 50% in some cities.
•Need for investment in modern, resilient infrastructure.
Inequitable access
•Marginalized communities often lack access to clean water, further increasing social inequalities and vulnerability.
Water-related disasters
•90% of the worst natural disasters are due to floods and storms. Cities are at the frontline of water-related disasters
Poor urban water governance
•Ineffective institutional and regulatory frameworks. Lack of integrated, cross-sectoral approaches.


unesco
UNESCO
Intergovernmental
Hydrological
Programme (IHP)
IHP Theme "Water for Human Settlements"
Promotes research, scientific cooperation, knowledge generation and sharing, capacity building to foster innovative solutions and evidence-based policymaking for resilient and equitable urban water systems capable of meeting current and future demands, contributing to global agendas on Water and climate: SDG 6 "Safe water and sanitation for all", SDG 11 "Sustainable cities and communities"


unesco
Integrated Urban Water Management
Knowledge and best practice sharing
Urban Water
Integrated Urban Water Management is an approach to managing the entire urban water cycle in an integrated way—a key to achieving the sustainability of resources and services.
It provides the framework for:
• the systematic consideration of the various dimensions of water, including surface and groundwater resources, quality and quantity issues
• managing interactions of water systems with other environmental systems
• harnessing water's role in social and economic development.


unesco
Cities for a climate-resilient water future
The Need for Strong Leadership in Urban Water Management
Cultivate a new generation of visionary water leaders committed to resilient, sustainable cities
Drivers of Change & Innovation
Lead reforms and innovations in water management
Policy Architects
Develop and implement effective water policies
Stewards of Sustainability
Promote urban growth in harmony with environmental preservation
Community Leaders
Engage citizens in water and climate community action
Strategic Alliance Facilitators
Foster partnerships between government, academia, private sector, and communities


41ST IAHR WORLD CONGRESS SINGAPORE
长江科学院
Flood resilience and coping strategies for urban areas in China under climate change
Yonghui Zhu,
Hongyang Wang
Changjiang River Scientific Research Institute, CWRC, China


41ST IAHR WORLD CONGRESS SINGAPORE
1.Background
长江科学院
Global climate change leads to frequent urban flooding
Increase in extreme weather events
Global warming intensifies the hydrological cycle, leading to a significant rise in frequency and intensity of extreme precipitation events
Urbanization amplifies vulnerability
Rapid urbanization expands impervious surfaces and degrades natural drainage systems.
Regional disparities in climate impacts
Global average temperature has risen by about 1.2°C since 1850, and rate of warming increased.
Severe floods in Central Europe in 2024

 1.Background 长江科学院 Global climate change leads to frequent urban flooding Increase in extreme weather events Global warming intensifies the hydrological cycle, leading to a significant rise in frequency and intensity of extreme precipitation events Urbanization amplifies vulnerability Rapid urbanization expands impervious surfaces and degrades natural drainage systems. Regional disparities in climate impacts Geographical variations result in different climate vulnerability. (Source: NOAA) Global average temperature has risen by about 1.2°C since 1850, and rate of warming increased Severe floods in Central Europe in 2024	 1.Background 长江科学院 Global climate change leads to frequent urban flooding Rising economic costs The average annual loss from global urban floods has exceeded 100 billion US dollars, and the direct economic losses caused by urban waterlogging in China account for over 30% of the total losses from natural disasters. SDG target correlation Enhancing urban flood resilience is directly linked to the SDGs 11 and 13. This requires building disaster-resilient urban infrastructure, with a focus on strengthening cities' capacity to withstand extreme weather events, reducing disaster exposure risks, and ensuring the sustainability of urban system transitions. Major global weather and climate events in 2023 The global temperature rise rate over the past 50 years has reached the highest level in the last 2,000 years. Sea-level rise trends will persist, significantly increasing flooding frequency in coastal cities. (IPCC AR6)
 2.Urban flood challenges 长江科学院 In 2020, due to heavy rainfall, runoff in the Huai River Basin increased by 1.5 to 2 times, and in the middle and lower reaches of the Yangtze River increased by 40 to 60%, triggering severe flooding. China faces frequent flooding disasters, with immense challenges in urban flood management Accelerated urbanization: In 2020, China's urban population reached 902 million, with an increase of 443 million in the first two decades of 21st century -equivalent to total population of EU. Losses caused by catastrophic floods are on the rise: In 2020, floods in southern China caused losses of 200 billion RMB. Staggering scale of affected population: Since 2020, total number of people affected by rainstorm and flood disasters in China has exceeded 200 million. Non-linear correlation between economic losses and population affected: Although only 1.2 million people affected by floods in Henan in 2021, losses exceeded 100 billion yuan, reflecting higher vulnerability of flooding in economically intensive areas.	 2.Urban flood challenges 长江科学院 Intertwined problems of ecological imbalance, inadequate design standards for urban drainage systems, and aging pipeline networks in urbanization process exacerbate urban flood management pressure Rapid increase in impermeable area Hardening rate typical urban built-up areas over 70%. Permeable area in Beijing decreased by 28% in past 20 years Decline in natural storage function Previously, land reclamation leading to reduction in lake areas and decrease in flood storage capacity Fracture of soil hydrological cycle Hardened ground blocks rainwater infiltration, causing decline of groundwater levels and exacerbating surface runoff Inadequate drainage system design standards and aging pipelines Nearly one-third urban drainage pipelines over 30 years old. About 15% suffer from varying degrees of damage or blockage. Most urban drainage networks still use standard of 1-3 year return period
 2.Urban flood challenges 长江科学院 Shortcomings in monitoring and early warning system Inadequate precision of early warning Pprediction accuracy of existing models for short-term heavy rainfall still insufficient. "7·20" rainstorm in Zhengzhou (2021), actual rainfall significantly exceeded predictions. Lag in intelligent applications As of 2023, urban drainage pipes totaled approximately 95.25 million km in China, however, coverage of intelligent monitoring terminals insufficient, many regions still rely on traditional management methods.	 3.Flood resilience of urban areas 长江科学院 Flood resilience construction in coastal cities (e.g. Shanghai) High-standard embankment system Adopting "once-in-a-millennium" flood prevention standard to construct Huangpu River flood prevention wall, combined with Suzhou River tidal barrier to form a closed defense line. Smart monitoring and early warning AI meteorological forecasting models named "Rain Master" and "Fuyao" have been developed, improving accuracy of severe convective weather warnings by 6% to 10%. Forecasting frequency increased from hourly to every 10 minutes. Ecological buffer zone construction Building a 50 meter wide coastal wetland protection forest in Lingang New Area, reducing impact of storm surges through natural wave dissipating zones. High-standard embankment of Shanghai Wave-dissipating dam - salt marsh vegetation synergistic enhancement for ecological hazard reduction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3.Flood resilience of urban areas
长江科学院
Flood resilience construction in inland cities (e.g., Wuhan and Chongqing)
Optimization of flood diversion and storage system
Wuhan established a flood diversion system, constructing flood diversion areas and water storage ponds in lakes. By coordinating operation of rivers and lakes, enhances water storage and regulation capabilities.
Three-dimensional drainage systems in mountainous cities
Chongqing implements "High Interception, Middle Diversion, Low Discharge" mode, advancing pipe network expansion and sewage tunnel construction, adopting terraced vegetated swales, to establish a resilient flood prevention framework integrating "source reduction, pipe network discharge, and integrated storage/discharge"
Construction of digital twin systems
Wuhan established a digital twin system based on flood big data to simulate inundation range under different rainfall scenarios and guide dynamic adjustment of emergency plans
Flood storage and detention areas around Wuhan
Urban waterlogging intelligent monitoring and early warning system


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3.Flood resilience of urban areas
长江科学院
Sponge city construction and rainwater management
What is sponge city?
A transformation urban drainage ideas from traditional "fast discharge" to "slow release", with measures of "infiltration, retention, storage, purification, utilization, and drainage".
Low impact development technology
By implementing facilities such as permeable paving, rain gardens, and green roofs, city's ability to infiltrate, store, and purify rainwater enhanced, reducing peak surface runoff and alleviating waterlogging pressure.
Urban blue and green space network construction
Integrating blue spaces such as wetlands, lakes, and parks with green space systems to form an ecological corridor that combines water storage and drainage functions. (Wuhan increased capacity of water regulation and storage during rainstorm by 12 million m³ by repairing East Lake wetland group)
Rainwater resource utilization system
Construction rainwater collection and reuse facilities to use rainwater for greening irrigation, road flushing, etc. (Beijing built a rainwater utilization project in sub center, saving 3 million tons of water annually)
Diagram water cycle collection and release in a sponge city
East lake of Wuhan


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4.Coping strategies and suggestion
长江科学院
Urban flood resilience requires systematic coordination and comprehensive management
Solution to complex urban water issues requires adapting measures to local conditions, fostering synergy, and coordinating use of blue, green, and grey methods. Facilitate engineering solutions conducive to overall and sustainable development through non-engineering approaches.
Adverse Effects
Project Benefits
Economic and Social Development
Strategies and measures for enhancing resilience of urban water conservancy infrastructure
In comprehensive water management, essential to shift from "excessiveness" to "moderation," embracing concept of ecological civilization


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4.Coping strategies and suggestion
长江科学院
Optimizing urban planning and enhancing urban ecological environment
Ecological flood retention space protection
Strictly define urban blue and green lines, prohibit activities such as filling lakes and encroaching on rivers, and restore regulating and storage functions of natural wetlands and lakes
Promotion sponge city technologies
Adopt permeable paving in hardened areas such as roads and squares. Construct facilities such as rain gardens and sunken green spaces to increase local infiltration of rainwater and reduce peak surface runoff
Construction of underground water storage facilities
In combination with development of underground space, build large-scale storage tanks or underground reservoirs to temporarily store rainwater during rainstorm to relieve pressure on drainage networks


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4.Coping strategies and suggestion
长江科学院
Improving emergency management system and early warning mechanism
Dynamic monitoring and intelligent warning
Using IoT sensors and GIS technology to monitor real-time data such as pipeline water level and rainfall intensity, combined with short-term meteorological forecasts, establish AI-driven flood risk warning models
Graded response mechanism
Develop multi-tier emergency response plans, clarify responsibilities of each department (such as traffic control, emergency team dispatch), ensure that the plan is launched within a certain time before rainstorm, and carry out regular drills
Disaster information sharing platform
Integrate data from meteorological, water conservancy, transportation and other departments to build a "one map" command system for urban floods, enabling real-time disaster reporting and precise allocation of rescue resources


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4.Coping strategies and suggestion
长江科学院
Enhancing cross-departmental collaboration and public participation
Multi-departmental joint covernance
Establish a flood prevention headquarters with participation of departments such as water affairs, planning, emergency response, and environmental protection, and regularly hold joint meetings to coordinate and address cross-field issues such as drainage network renovation and river dredging
Public education and participation
Publicize knowledge of flood management and disaster avoidance through new media, open public reporting channels to reward identification of pipeline network hidden dangers, organize volunteers to participate in distribution of emergency supplies, etc


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长江科学院
Long term climate adaptation strategy formulation
"At first, no one heeded the disaster-just a typhoon, a rainstorm, waterlogged streets in one town, the paralysis of a single city. Until the day this calamity became inextricably bound to every soul alive!"
Formulate long-term climate adaptation strategies and jointly build a community with a shared future!

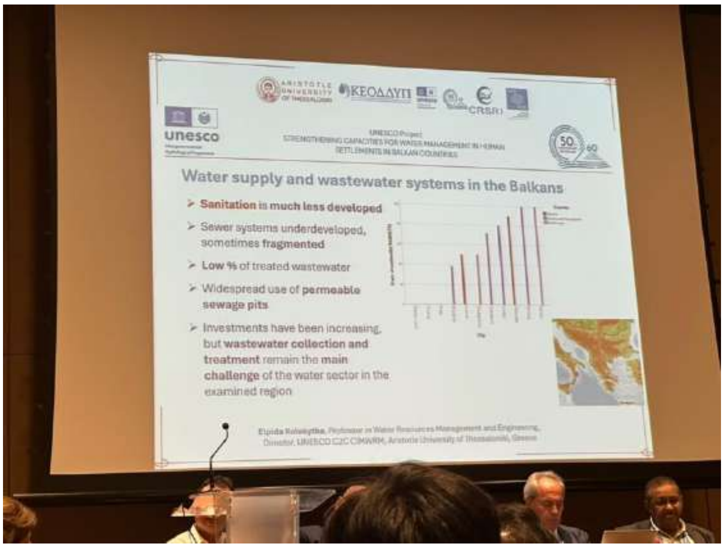

SPECIAL SESSION 13: City Water Leaders: Enhancing Water and Social Resilience in Urban Areas
Prof. Elpida Kolokytha
Centre on Integrated and Multidisciplinary Water Resources Management (CIMWRM), under the auspices of UNESCO, hosted at the Aristotle University of Thessaloniki (AUTH), Greece
41ST IAHR WORLD CONGRESS SINGAPORE
22 – 27 JUNE 2025

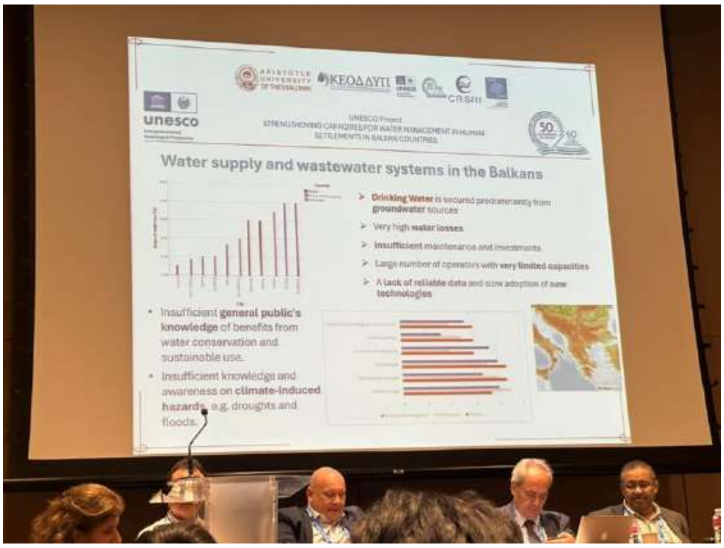

The project and regional impact
Implemented by:
UNESCO IHP, in collaboration with:
UNESCO Communication & Information Sector Sarajevo Antenna & Science Unit
UNESCO Water Centres: C2C IRTCUD (Serbia) & C2C CIMWRM (Greece)
Countries Covered:
•Albania, Bosnia & Herzegovina, Montenegro
Objective:
•Support national efforts to reach SDG 6 targets
•Strengthen trust and operational capacity of local water agencies
•Conduct gap analysis and develop capacity-building recommendations
•Capacity development through targeted training courses


Round table discussion
Promote a "learning cities approach" - Promote policy dialogue and peer learning among cities, develop partnerships, provide capacity development, and develop tools to evaluate progress.
Promote Integrated Urban Water Management – Discuss holistic approaches that integrate water supply, wastewater management, urban ecosystems, social and human development, urban planning, and climate adaptation and mitigation.
Strengthen Social Resilience – Identify strategies to enhance community engagement, equity, and the human right to access to water resources.
Foster collaboration between academia, industry, policy makers, decision makers, society.


Methodology & Outcomes
1.Policy & Document Review:
Legal, institutional, funding, infrastructure aspects
National and international sources
2.Web-Based Survey:
58 questions, open/closed/semi-structured
Targeted key stakeholders across cities covering 50%+ of national populations
3. In-Situ Focus Groups:
Expert meetings in each country for qualitative insights
Expected Outcomes:
•Comparative analysis across three countries
•Recommendations for strategic investments and reforms
•Model for other regions facing similar water challenges


unesco
Water supply and wastewater systems in the Balkans
All three countries are the EU candidate countries.
All three countries have abundant water resources unevenly distributed in time and space.
The abundancy of water resources gives the impression that there are no water problems or that those countries will not be affected by climate crisis.
In all countries financial constraints and limited institutional capacity have limited an effective response to climate hazards (floods & droughts).
Public Water Supply is relatively well developed, covering vast majority of population, however ageing infrastructure, urbanisation and low investments lead to occasional supply shortages or water quality disturbances.


unesco
Water supply and wastewater systems in the Balkans
Sanitation is much less developed
Sewer systems underdeveloped, sometimes fragmented
Low % of treated wastewater
Widespread use of permeable sewage pits
Investments have been increasing, but wastewater collection and treatment remain the main challenge of the water sector in the examined region


unesco
Water supply and wastewater systems in the Balkans
Drinking Water is secured predominantly from groundwater sources
Very high water losses
Insufficient maintenance and investments
Large number of operators with very limited capacities
A lack of reliable data and slow adoption of new technologies
Insufficient general public's knowledge of benefits from water conservation and sustainable use.
Insufficient knowledge and awareness on climate-induced hazards, e.g. droughts and floods.


Key Gaps in Technical Expertise and Awareness in the Balkan region
Technical Knowledge & Skills Deficiencies
Limited expertise in:
Asset management & lifecycle costing
Digital water technologies (GIS, metering, remote sensing)
Integrated water & wastewater management
Awareness Gaps
Weak understanding of climate change impacts on water sustainability
Climate risks not integrated into water policies or infrastructure planning
Limited public and institutional awareness campaigns
Weak Implementation of Best Practices
Inadequate leakage detection → high NRW levels
Poor wastewater treatment performance
Low adoption of climate-resilient and energy-efficient practices
Over-reliance on supply-side approaches vs. Water Demand Management
EU Policy Knowledge Deficiencies
Poor understanding of EU Water Framework, UWWT & Drinking Water Directives
Inadequate training on policy compliance
Weak communication between policymakers and water professionals


Institutional and Capacity Development barriers in the Western Balkans
Fragmented Governance
•Overlapping roles between national, regional & local water authorities
•Poor coordination delays implementation & resource allocation
•Weak support for local utilities
Financial Constraints
•Low water tariffs and poor billing → insufficient revenue
•Limited funds for training & infrastructure upgrades
•Lack of investment in research and innovation
Human Resource Gaps
•Shortage of skilled engineers and managers
•Difficulty recruiting and retaining qualified personnel
•Outdated or insufficient training programs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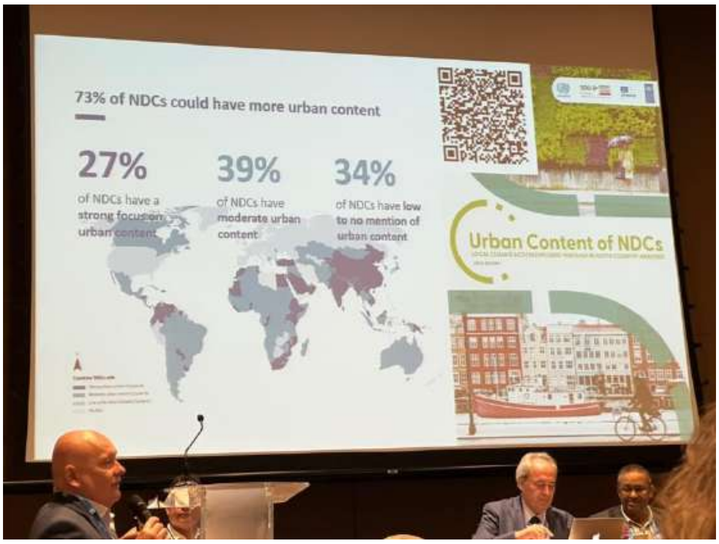
Water and social resilience in the Balkans
Challenges:
✓ Aging infrastructure and leakage losses (up to 60%)
✓ Limited access to safe drinking water in rural areas
✓ Overexploitation and pollution of water sources
Climate Impacts:
• Reduced precipitation and rising temperatures
• Seasonal water shortages and drought stress
Needs:
• Enhance of social awareness
• Investment in smart water management
• Promotion of water-saving technologies
• Flood/ drought preparedness and protection


73% of NDCs could have more urban content
27%
of NDCs have a strong focus on urban content
39%
of NDCs have moderate urban content
34%
of NDCs have low to no mention of urban content
Urban Content of NDCs


2024 Analysis
The urban water focus of the Nationally Determined Contributions
Nicola Tollin, Maria Pizzorni and Yu Liu
UNESCO Chair on Urban Resilience at the University of Southern Denmark
SDU
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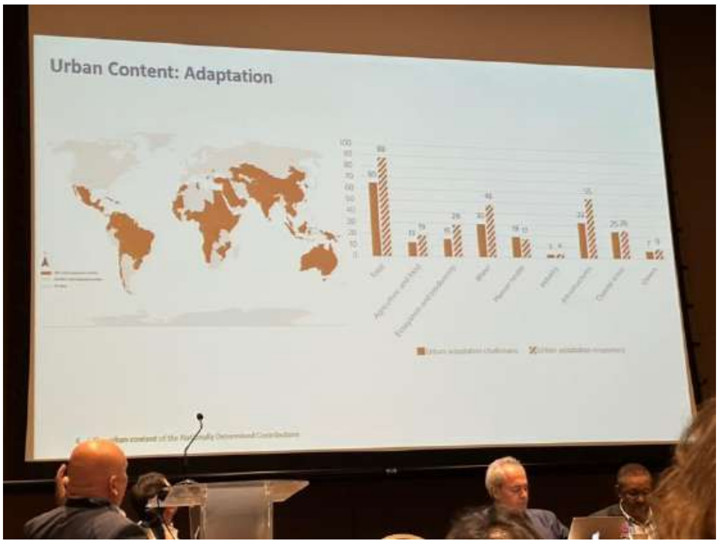
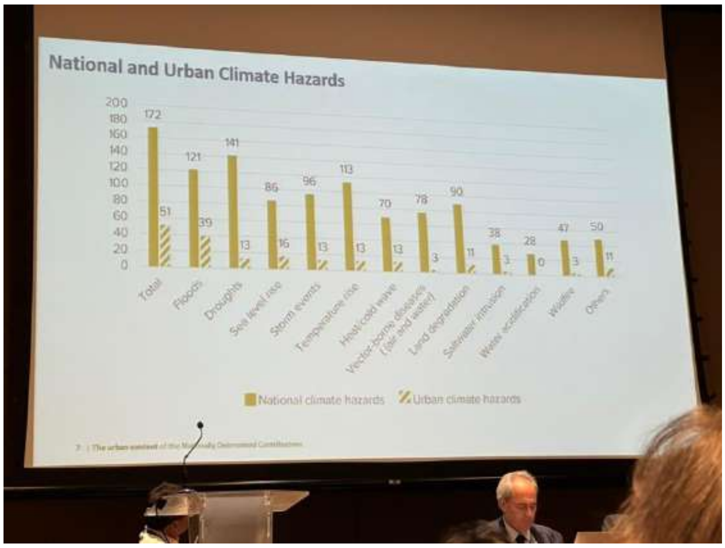
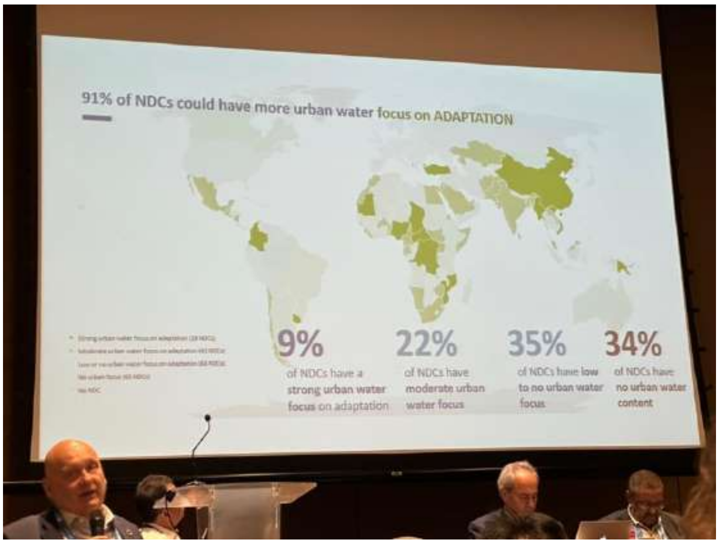
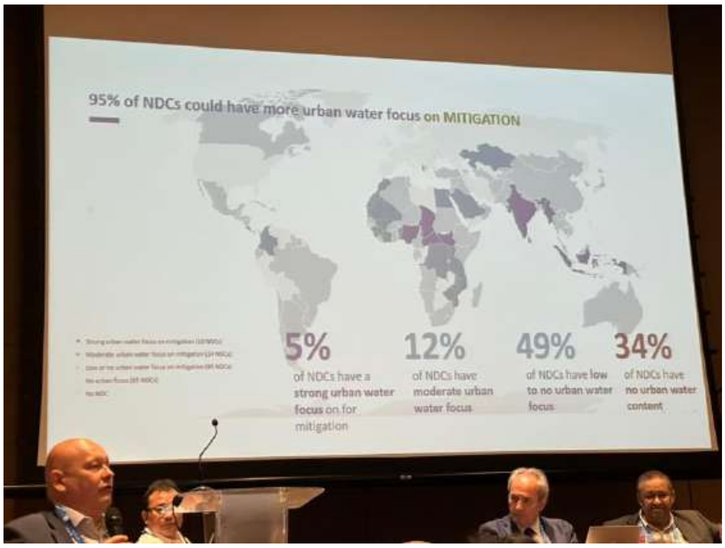
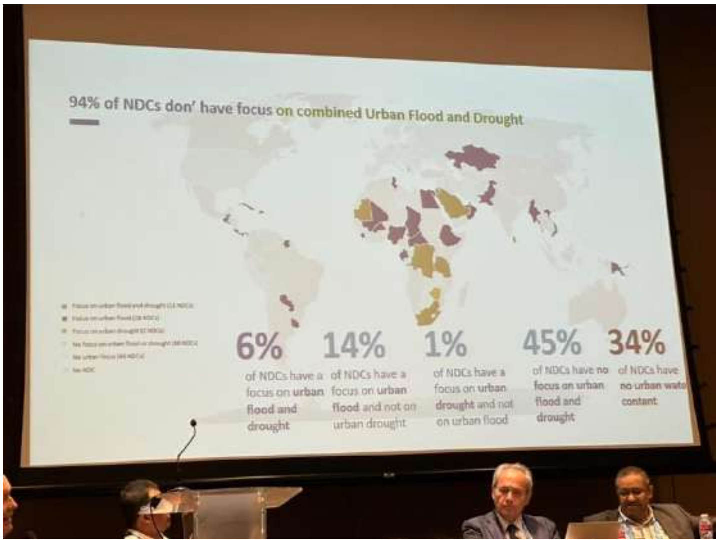
unesco


Urban Content: Adaptation


National and Urban Climate Hazards
Total
Floods
Droughts
Sea level rise
Storm events
Temperature rise
Heat/cold wave
Vector-borne diseases (air and water)
Land degradation
Saltwater intrusion
Water acidification
Wildfire
Others
National climate hazards
Urban climate hazards


91% of NDCs could have more urban water focus on ADAPTATION
9%
of NDCs have a strong urban water focus on adaptation
22%
of NDCs have moderate urban water focus
35%
of NDCs have low to no urban water focus
34%
of NDCs have no urban water content


95% of NDCs could have more urban water focus on MITIGATION
5%
of NDCs have a strong urban water focus on for mitigation
12%
of NDCs have moderate urban water focus
49%
of NDCs have low to no urban water focus
34%
of NDCs have no urban water content


94% of NDCs don' have focus on combined Urban Flood and Drought
6%
of NDCs have a focus on urban flood and drought
14%
of NDCs have a focus on urban flood and not on urban drought
1%
of NDCs have a focus on urban drought and not on urban flood
45%
of NDCs have no focus on urban flood and drought
34%
of NDCs have no urban water content


SESSION 13
ENHANCING WATER AND SOCIAL RESILIENCE IN URBAN AREAS: A CALL FOR CITY WATER LEADERS
OPENING ADDRESS
MODERATOR
INVITED SPEAKERS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22 – 27 JUNE 2025
INNOVATIVE WATER ENGINEERING FOR SUSTAINABLE DEVELOPMENT
The WEFE Nexus Approach for Nature-Based Solutions as Enablers of Climate Resilience in the Volta Basin
Dr. Rafatou FOFANA (Hydrologist & IWRM Expert)
Director of the Volta Basin Observatory
@ the Volta Basin Authority (VBA)
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2-Technische Universiteit Delft (TUD),Nederland;
3-Trans-African Hydro-Meteorological Observatory (TAHMO), Kenya
4-Kungliga Tekniska Hoegskolan University (KTH), Sweden
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6-University of Energy and Natural Resources (UENR), Ghana ;
7-Kenya Agricultural And Livestock Research Organization (KALRO), Kenya ;
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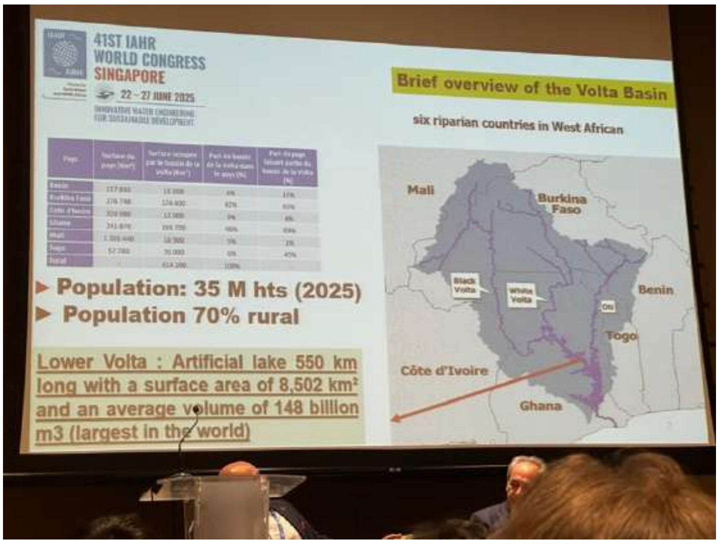
VOLTA BASIN AUTHORITY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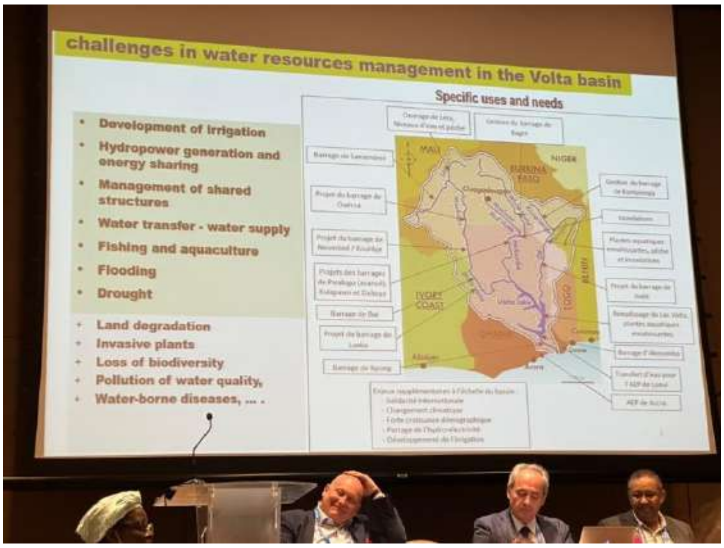
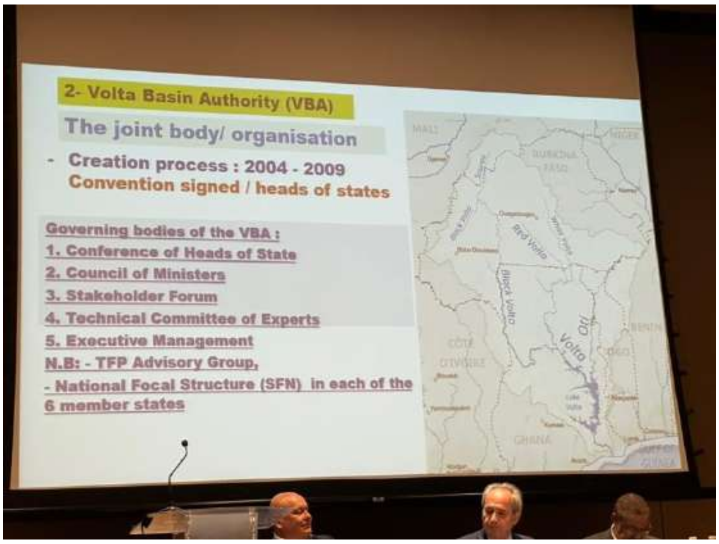
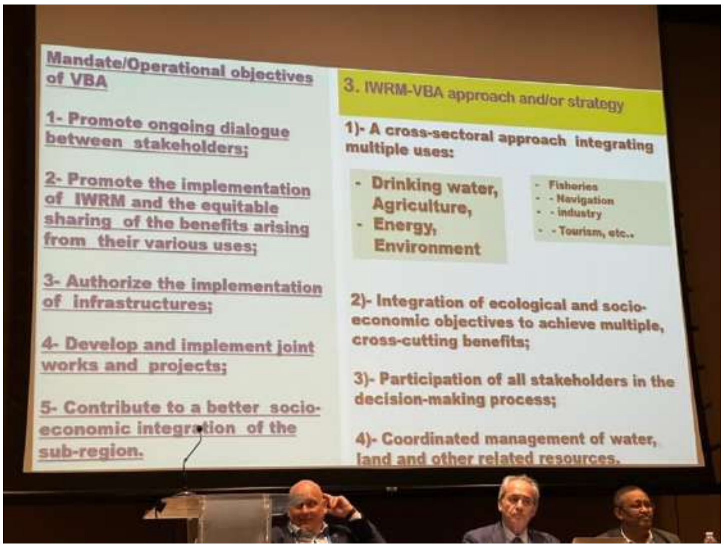
Brief overview of the Volta Basin
six riparian countries in West African
Mali
Burkina Faso
Benin
Togo
Côte d'Ivoire
Ghana
Black Volta
White Volta
Oti
Population: 35 M hts (2025)
Population 70% rural
Lower Volta : Artificial lake 550 km long with a surface area of 8,502 km² and an average volume of 148 billion m3 (largest in the world)

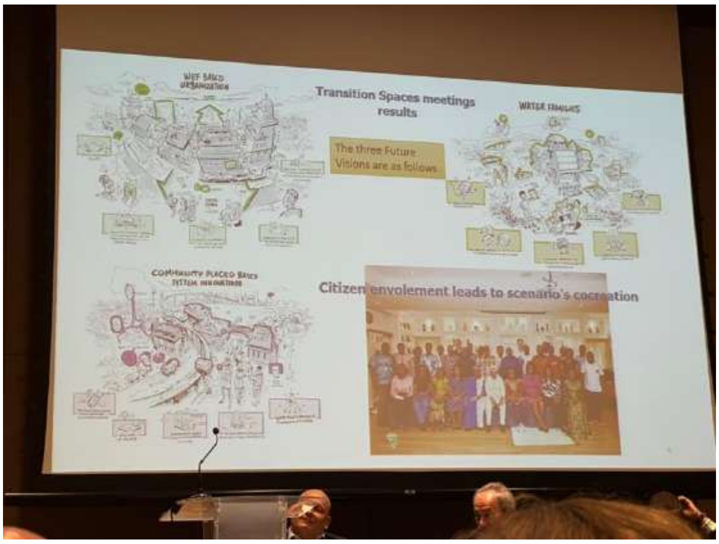

challenges in water resources management in the Volta basin
Specific uses and needs
Development of irrigation
Hydropower generation and energy sharing
Management of shared structures
Water transfer - water supply
Fishing and aquaculture
Flooding
Drought
Land degradation
Invasive plants
Loss of biodiversity
Pollution of water quality,
Water-borne diseases, ...
MALI
BURKINA FASO
NIGER
IVORY COAST
TOGO
BENIN

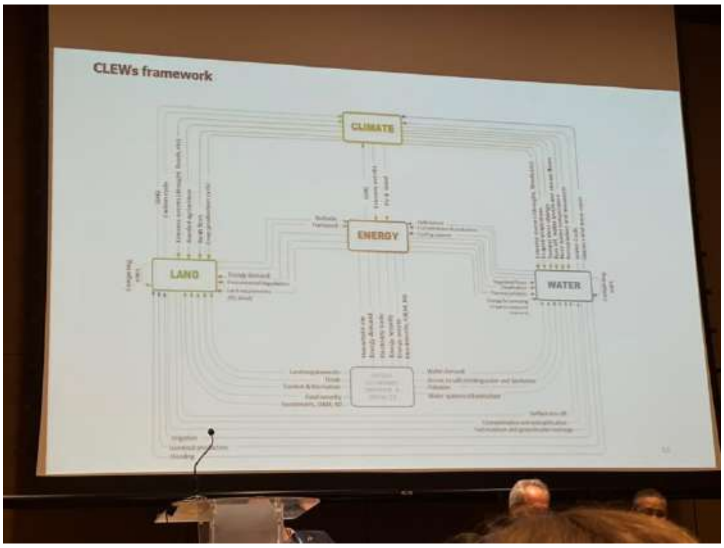

2- Volta Basin Authority (VBA)
The joint body/ organisation
- Creation process : 2004 - 2009
Convention signed / heads of states
Governing bodies of the VBA :
1. Conference of Heads of State
2. Council of Ministers
3. Stakeholder Forum
4. Technical Committee of Experts
5. Executive Management
N.B: - TFP Advisory Group,
- National Focal Structure (SFN) in each of the 6 member states
Black Volta
Volta
Oti

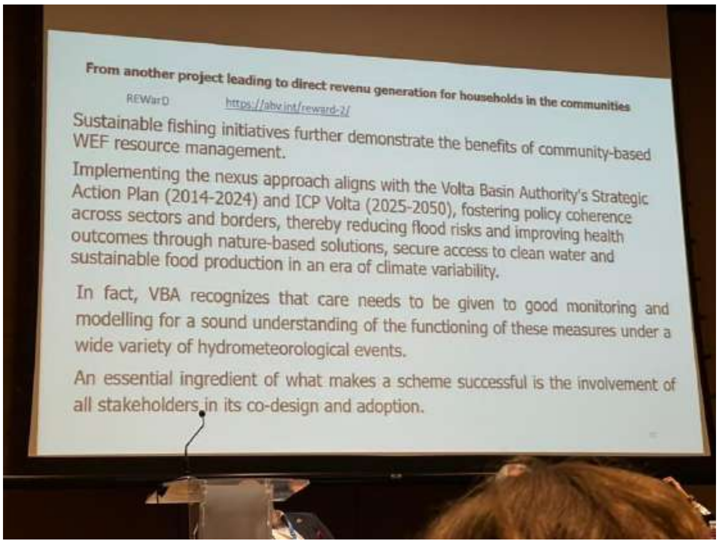

Mandate/Operational objectives of VBA
1- Promote ongoing dialogue between stakeholders;
2- Promote the implementation of IWRM and the equitable sharing of the benefits arising from their various uses;
3- Authorize the implementation of infrastructures;
4- Develop and implement joint works and projects;
5- Contribute to a better socio-economic integration of the sub-region.
3. IWRM-VBA approach and/or strategy
1)- A cross-sectoral approach integrating multiple uses:
- Drinking water,
Agriculture,
- Energy,
Environment
- Fisheries
- - Navigation
- - industry
- - Tourism, etc..
2)- Integration of ecological and socio-economic objectives to achieve multiple, cross-cutting benefits;
3)- Participation of all stakeholders in the decision-making process;
4)- Coordinated management of water, land and other related resources.


Programmes / solutions
The Water-Energy-Food-Ecosystem (WEFE) nexus offers an integrated approach to enhance climate resilience in the transboundary Volta basin
The nexus strategy recognises the interdependence of water, agriculture, energy, environment, and health sectors, broadening Integrated Water Resources Management.


TUDelft
vito
TAHMO
The project's objectives broadly include:
1. Designing and developing a long-term WEF optimization model for the basin countries
2. Validating these WEF models for operational functionality and dispatchability by considering future climate and market scenarios, and building WEF models with high spatial and temporal definition
3. Enhancing science-policy interactions through the establishment of Transition Spaces and establishing a research network to co-create and validate modelling tools and outputs
4. Creating and growing a CLEWs Data Observatory to support data-driven decision-making
Preliminary actions : Assessing WEFE systems , mapping gouvernance and mapping stakeholders for each sector and cross sectors ; assessing policies , mesures and actions
Along the way: Provide climat Services and Data Infrastructure
The EPIC Africa project, engages institutional stakeholders and citizens, enabling communities to build climate resilience through coordinated resource management and systematic mapping of WEF interactions
This participatory approach addresses flooding vulnerabilities by promoting nature-based solutions that support sustainable agriculture and energy while preserving natural water retention landscapes.
Innovative projects like "Water Families" and "Water Farm" illustrate how integrated management, informed by citizen input, can enhance ecosystem services that mitigate flood risks.


Transition Spaces meetings results
The three Future Visions are as follows
Citizen envolement leads to scenario's cocreation


CLEWs framework
CLIMATE
ENERGY
LAND
WATER


From another project leading to direct revenu generation for households in the communities
REWarD https://abv.int/reward-2/
Sustainable fishing initiatives further demonstrate the benefits of community-based WEF resource management.
Implementing the nexus approach aligns with the Volta Basin Authority's Strategic Action Plan (2014-2024) and ICP Volta (2025-2050), fostering policy coherence across sectors and borders, thereby reducing flood risks and improving health outcomes through nature-based solutions, secure access to clean water and sustainable food production in an era of climate variability.
In fact, VBA recognizes that care needs to be given to good monitoring and modelling for a sound understanding of the functioning of these measures under a wide variety of hydrometeorological events.
An essential ingredient of what makes a scheme successful is the involvement of all stakeholders in its co-design and adoption.


High Level Panel 3:
Empowering a Just and Inclusive Energy Transition:
The Strategic Role of Hydropower

High Level Panel 3:
Empowering a Just and Inclusive Energy Transition:
The Strategic Role of Hydropower

iha
sarawak energy
Empowering a Just and Inclusive Energy Transition:
The Role of Hydropower
Advancing Hydropower for Sarawak and Beyond
Ir. James Ung

Multipurpose Roles of
Hydropower
iha
sarawak energy

Global Trends
iha
sarawak energy
1,443

Five-Rolling Trends
PSH Picking Up
iha
sarawak energy


Progress Towards 2050 Net Zero
iha
sarawak energy


Sustainable Hydropower
iha
sarawak energy
Sustainable hydropower is a clean, green, modern, affordable solution to climate change.
'Going forward, the only acceptable hydropower is sustainable hydropower'
San José Declaration on Sustainable Hydropower
Resilient Infrastructure
Prosperous Communities
Healthy Ecosystems
Good Governance


Energy Transition in Sarawak
iha
sarawak energy
Regional Renewable Powerhouse
2030
10GW
2025
5,800MW
2050

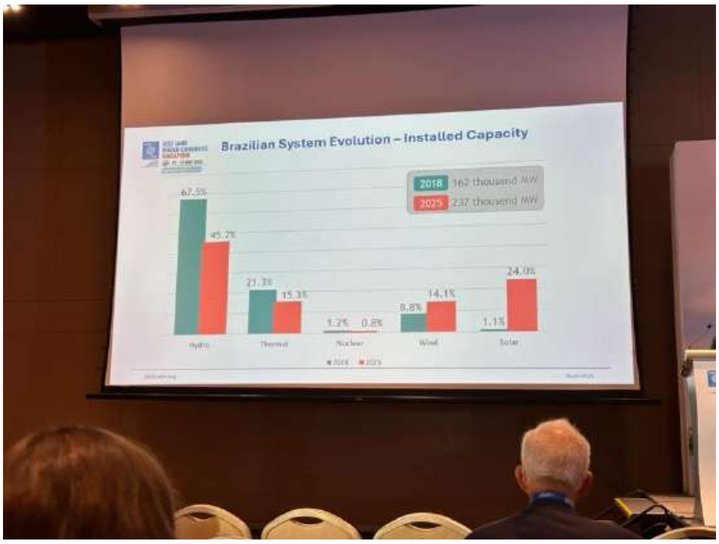

iha
sarawak energy
International Forum
Pumped Storage Hydropower
Partnerships for Our Goals
See you at SARSF 4.0

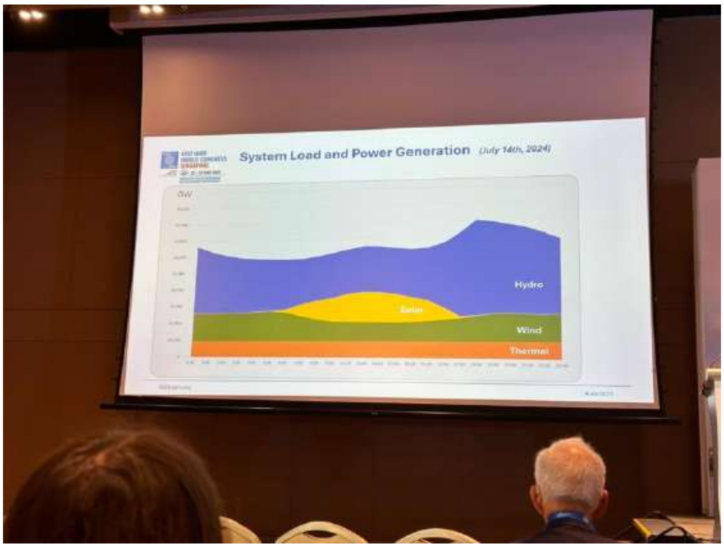

Empowering a Just and Inclusive Energy Transition:
The Role of Hydropower
Itaipu Binacional: a binational hydropower plant powering the energy transition
Joni Madruga Garcia


Who we are
Binational company
Brazil and Paraguay
14,000 MW
20 x 700 MW
World Leader
Clean and renewable energy
Production


Where we are
Paraná River
Border between BR and Py


Itaipu's Official Acts
Treaty
Annexes
Binationality
Co-management
Parity

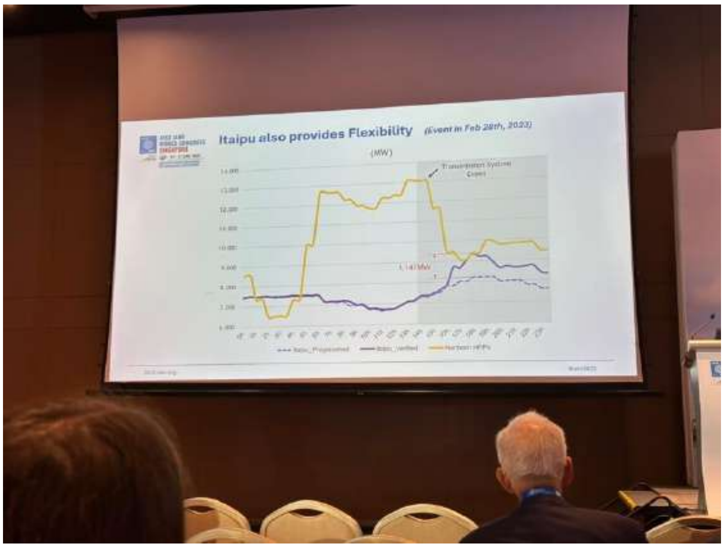

Brazilian System Evolution – Installed Capacity
2018 162 thousand MW
2025 237 thousand MW
67.5%
45.7%
21.3%
15.3%
1.2%
0.8%
8.8%
14.1%
1.1%
24.0%
Hydro
Thermal
Nuclear
Wind
Solar


System Load and Power Generation (July 14th, 2024)
Hydro
Solar
Wind
Thermal


Hydro Contribution to the Load Ramp (July 14th, 2024)
Hydro Generation (BR System)
13 – 18h:
+105%

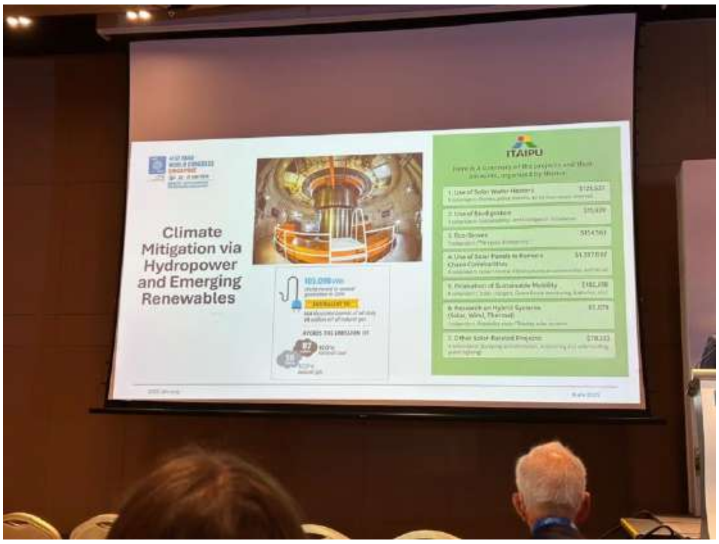

Hydro Contribution to the Load Ramp (July 14th, 2024)
Hydro Generation (BR System)
13 – 18h:
+105%
Itaipu Supply
13 – 18h:
+72%


Itaipu Generation Profile
+ 4 UG
+ 2 UG


Itaipu also provides Flexibility (Event in Feb 28th, 2023)
(MW)


Empowering a Just and Inclusive Energy Transition:
The Role of Hydropower
Hydropower and Climate Responsibility – Itaipu's Integrated
Approach to Mitigation, Adaptation, and Social Equity
Daniel Vázquez Bado


Climate Responsibility Framework
Integrated approach: Mitigation, Adaptation, and Equity
Aligned with SDGs and National Climate Strategies
Role in the National Climate Change Commission of Paraguay


Climate
Mitigation via
Hydropower
and Emerging
Renewables
ITAIPU


Forest-Based Carbon Sequestration
CO₂ BUDGET
10 Protected areas


Adaptation to Climate Change


Governance and Strategic Partnerships
Active role in CNCC
NDCs | GHG Inventories | BRT, and others
Collaboration with Institutions
National: Ministries, Academia, research centres
International: UNFCCC Secretariat, IHA, UNESCO MAB, UNESCO IHP, Smithsonian, International Association for Hydro-Environment Engineering and Research (IAHR) and others,
"Over time, several collaborations have been essential in advancing our climate efforts and aligning with global agendas. They continue to inspire our commitment to scientific exchange and international cooperation."


Empowering a Just and Inclusive Energy Transition:
The Role of Hydropower
Power with Purpose: Designing Sustainable Hydraulic Structures for the 21st Century
Stefan Felder


Hydraulic Structures technical excellence underpins hydropower development globally...
Large hydropower
→ Reservoir dams
Run-of-river hydropower
→ Weirs
Pumped storage hydropower
→ Connected Reservoirs
Critical infrastructure that needs to operate safely at all times!
Therefore, holistic technical expertise is essential!


41ST IAHR WORLD CONGRESS SINGAPORE
Hydraulic Structures technical excellence underpins hydropower development globally...
Large hydropower
→ Reservoir dams
Run-of-river hydropower
→ Weirs
Pumped storage hydropower
→ Connected Reservoirs
Spitallamm Dam, Switzerland
Baldeneysee Weir, Germany
Wivenhoe Dam, Australia
Critical infrastructure that needs to operate safely at all times!
Therefore, holistic technical expertise is essential!


41ST IAHR WORLD CONGRESS SINGAPORE
...but, we are now at a crossroads, to consider their holistic impact
Besides their tremendous positive impact, hydraulic structures may have social and environmental impacts as well:
Fragmentation of rivers affects aquatic species
Alteration of flows and sediment transport
Water quality degradation and hydropeaking
Displacement of people and inundation of cultural sites
Impacts on industries
Impacts of hydraulic structures extend well beyond the location of the structure!


A balanced approach can unlock sustainable hydraulic structures development
Need for sustainable hydraulic structures
Historically, societal developments closely linked with hydraulic structures
Essential for transition to net zero
Sustainability frameworks required to achieve benefits while minimising negative impacts
WILEY
Hydraulic structures engineering: An evolving science in a changing world
Hydraulic structures at a crossroads towards the Sustainable Development Goals
Hydraulic Structures
At the Heart of 21st Century Global Sustainable Development


Empowering a Just and Inclusive Energy Transition:
The Role of Hydropower
A view of the Ecohydraulics Community
Silke Wieprecht


Anthropogenic Impacts due to Dams and Hydropower
Hydropower plays an important role in electricity production
in 2023: app. 47% of electricity from renewable sources is from Hydropower
app. 60 000 large dams (>15m), 800 000 smaller dams (<2m)
Stored Volume: 10 000km³ (5 x volume of all rivers worldwide)


Anthropogenic Impacts due to Dams and Hydropower
Hydropower plays an important role in electricity production
in 2023: app. 47% of electricity from renewable sources is from Hydropower
However, they have massive impacts on ecology, hydrology,...
60% of total stream flow is regulated by dams and reservoirs
Societal Challenges are a key factor
"battle" between economy (cheap/ clean energy) and ecological functionality
Societal discourse required
app. 60 000 large dams (>15m), 800 000 smaller dams (<2m)
Stored Volume: 10 000km³ (5 x volume of all rivers worldwide)


Our Dreams of perfect nature
Tagliamento
Gemona del Friuli
Italy


Our Reality of Nature in use
Rhine River
Rheinfelden
Germany/Switzerland

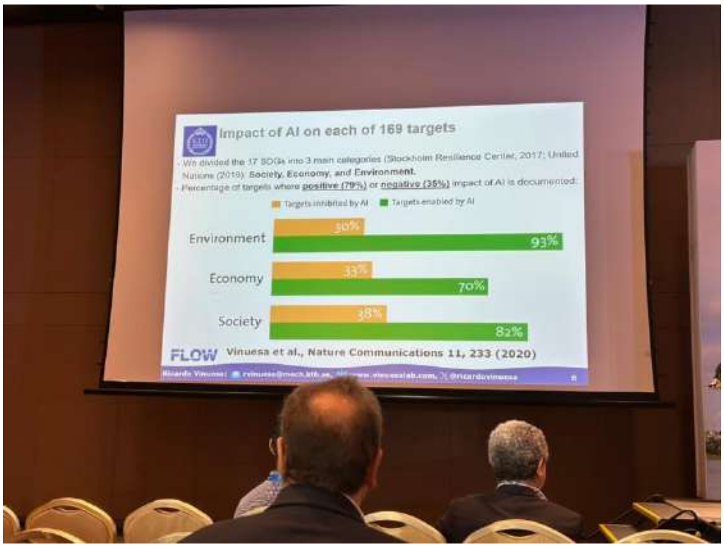

41ST IAHR
WORLD CONGRESS
SINGAPORE
22 - 27 JUNE 2025

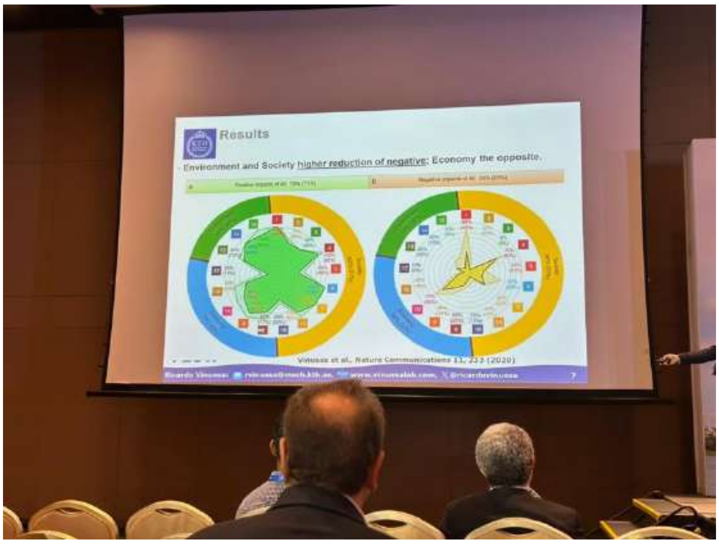

Donald R. F. Harleman Lectureship:
Improving turbulence control through explainable deep learning
25 June 2025


Improving turbulence control through explainable deep learning
Ricardo Vinuesa1,2
FLOW
SeRC
erc
digital futures
1FLOW, KTH Engineering Mechanics, Stockholm, Sweden.
2Swedish e-Science Research Centre (SeRC), Stockholm, Sweden.
25 June 2025, 41st IAHR World Congress, Harleman Lecture (Singapore)


The Sustainable Development Goals (SDGs)
SUSTAINABLE DEVELOPMENT GOALS
2030 Agenda for Sustainable Development adopted by all United Nations Member States in 2015
Shared blueprint for peace and prosperity for people and the planet
Recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests
17 different Sustainable Development Goals (SDGs); 169 targets
FLOW

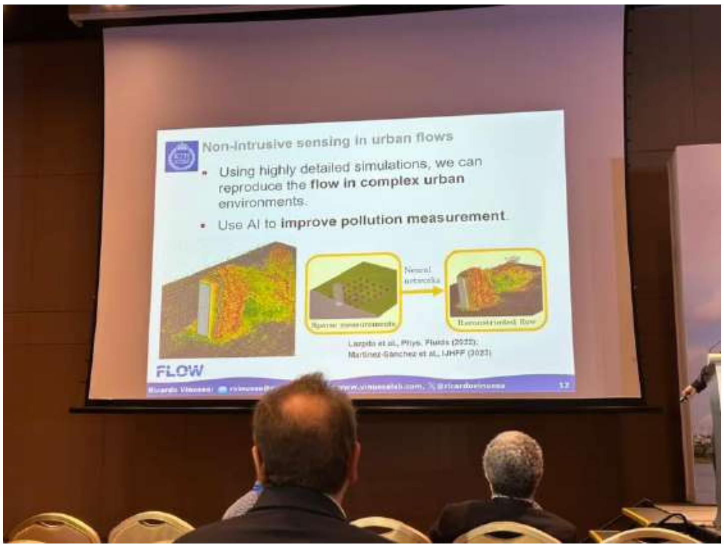

Dividing the 17 SDGs into 3 main pillars
We divided the 17 SDGs into 3 main categories (Stockholm Resilience Center, 2017; United Nations, 2019): Society, Economy, and Environment.
FLOW
Vinuesa et al., Nature Communications 11, 233 (2020)

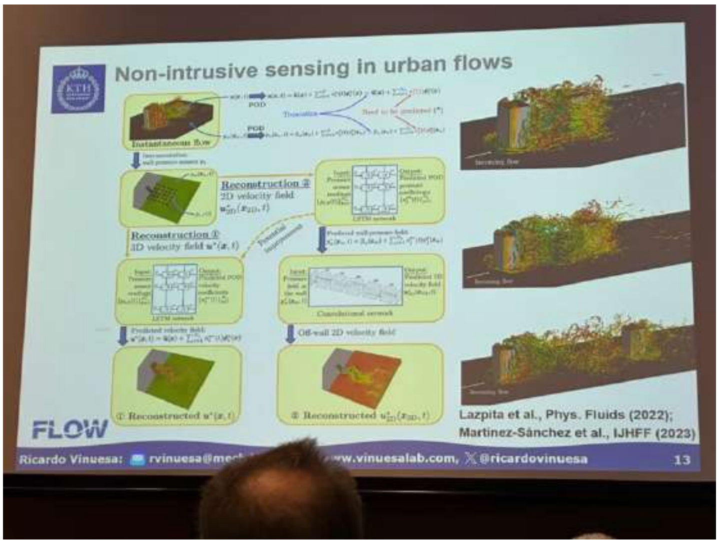

Impact of AI on each of 169 targets
We divided the 17 SDGs into 3 main categories (Stockholm Resilience Center, 2017; United Nations (2019): Society, Economy, and Environment.
Percentage of targets where positive (79%) or negative (35%) impact of AI is documented:
Targets inhibited by AI
Targets enabled by AI
Environment
30%
93%
Economy
33%
70%
Society
38%
82%
FLOW
Vinuesa et al., Nature Communications 11, 233 (2020)


Results
Environment and Society higher reduction of negative; Economy the opposite.
Vinuesa et al., Nature Communications 11, 233 (2020)


Some key results
POSITIVE: AI-enabled technology which may help overcome current barriers (satellite data to track poverty, SDG1).
NEGATIVE: Uneven opportunities to access AI resources may end up increasing inequalities (SDG 10).
FLOW
Vinuesa et al., Nature Communications 11, 233 (2020)


One application: SDG11 on sustainable cities
POSITIVE: Positive impact of AI on all 10 targets within SDG 11 on sustainable cities. In particular, AI will be able to help us build more accurate and robust technology to measure air pollution in cities, which causes 800,000 deaths each year in Europe alone.
FLOW
Vinuesa et al., Nature Communications 11, 233 (2020)


Non-intrusive sensing in urban flows
Using highly detailed simulations, we can reproduce the flow in complex urban environments.
Use AI to improve pollution measurement.
Neural networks
Sparse measurements
Reconstructed flow
Lazpita et al., Phys. Fluids (2022);
Martinez-Sanchez et al., IJHFF (2023)
FLOW


Non-intrusive sensing in urban flows
Instantaneous flow
Reconstruction ②
2D velocity field
Reconstruction ①
3D velocity field
LSTM network
Convolutional network
Off-wall 2D velocity field
① Reconstructed
② Reconstructed
FLOW
Lazpita et al., Phys. Fluids (2022);
Martinez-Sánchez et al., IJHFF (2023)
Ricardo Vinuesa:
@ricardovinuesa
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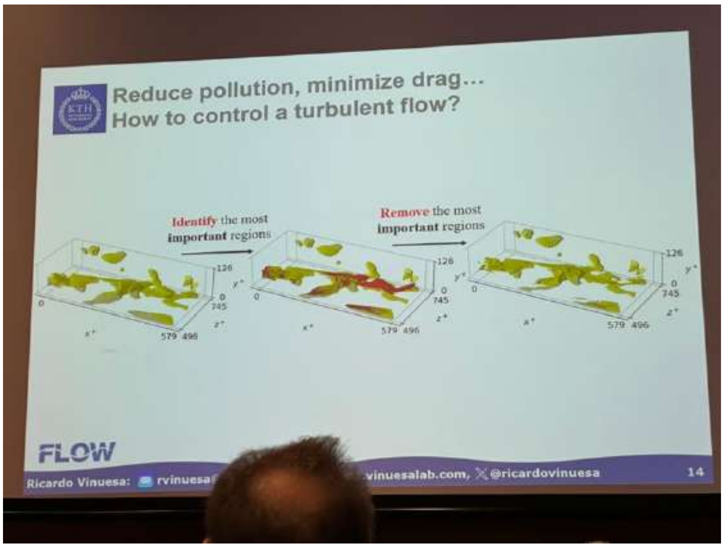
Reduce pollution, minimize drag...
How to control a turbulent flow?
Identify the most important regions
Remove the most important regions
FLOW
Ricardo Vinuesa:
vinuesalab.com, @ricardovinuesa
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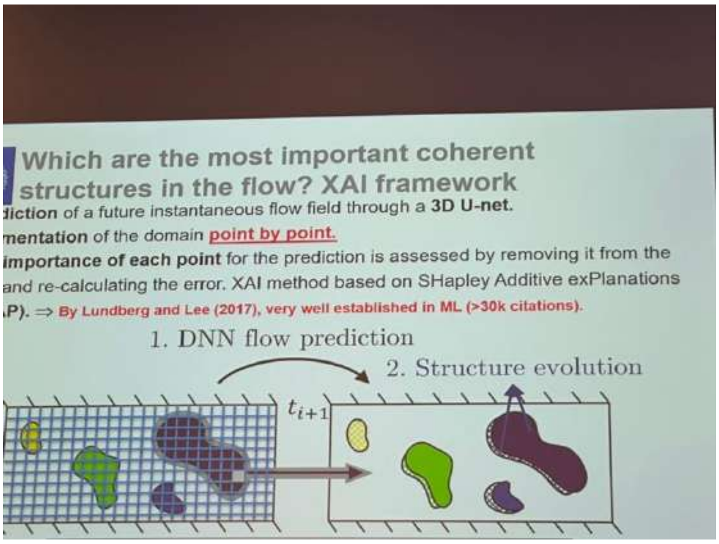
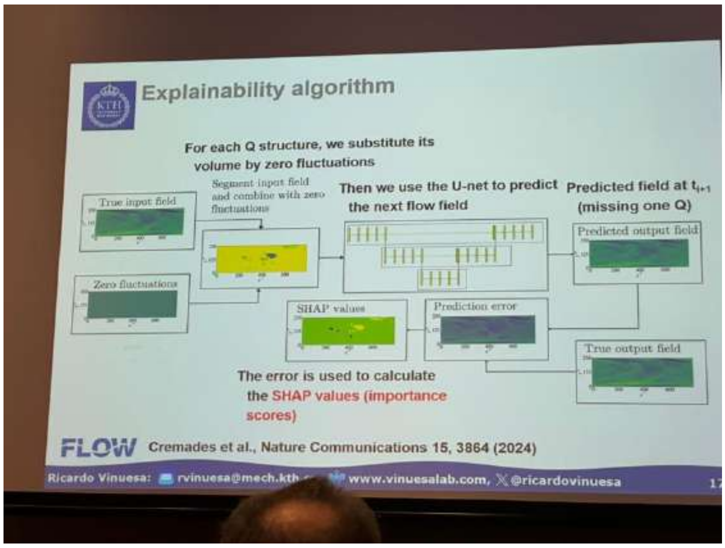
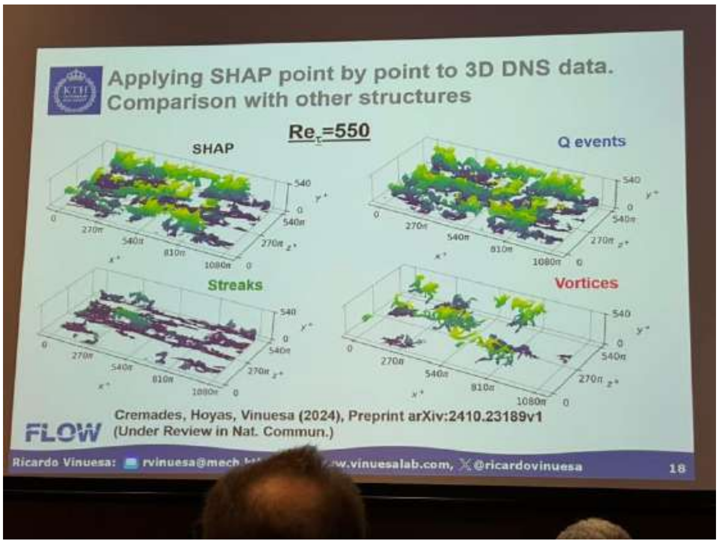

Which are the most important coherent structures in the flow? XAI framework
diction of a future instantaneous flow field through a 3D U-net.
mentation of the domain point by point.
importance of each point for the prediction is assessed by removing it from the and re-calculating the error. XAI method based on SHapley Additive exPlanations P). ⇒ By Lundberg and Lee (2017), very well established in ML (>30k citations).
1. DNN flow prediction
2. Structure evolution
t_{i+1}


Explainability algorithm
For each Q structure, we substitute its volume by zero fluctuations
Segment input field and combine with zero fluctuations
True input field
Zero fluctuations
Then we use the U-net to predict the next flow field
Predicted field at t_{i+1} (missing one Q)
Predicted output field
SHAP values
Prediction error
True output field
The error is used to calculate the SHAP values (importance scores)
FLOW Cremades et al., Nature Communications 15, 3864 (2024)
Ricardo Vinuesa: rvinuesa@mech.kth www.vinuesalab.com, @ricardovinuesa


Applying SHAP point by point to 3D DNS data. Comparison with other structures
Re_τ=550
SHAP
Q events
Streaks
Vortices
Cremades, Hoyas, Vinuesa (2024), Preprint arXiv:2410.23189v1 (Under Review in Nat. Commun.)
FLOW
Ricardo Vinuesa: rvinuesa@mech w.vinuesalab.com, @ricardovinuesa
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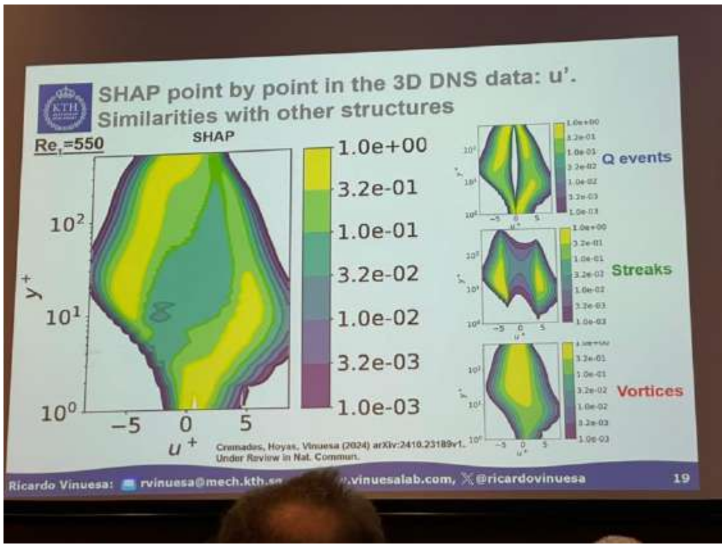
SHAP point by point in the 3D DNS data: u'. Similarities with other structures
Re_τ=550
SHAP
1.0e+00
3.2e-01
1.0e-01
3.2e-02
1.0e-02
3.2e-03
1.0e-03
y^+
u^+
Q events
Streaks
Vortices
Cremades, Hoyas, Vinuesa (2024) arXiv:2410.23189v1. Under Review in Nat. Commun.
Ricardo Vinuesa: rvinuesa@mech.kth.se .vinuesalab.com, @ricardovinuesa
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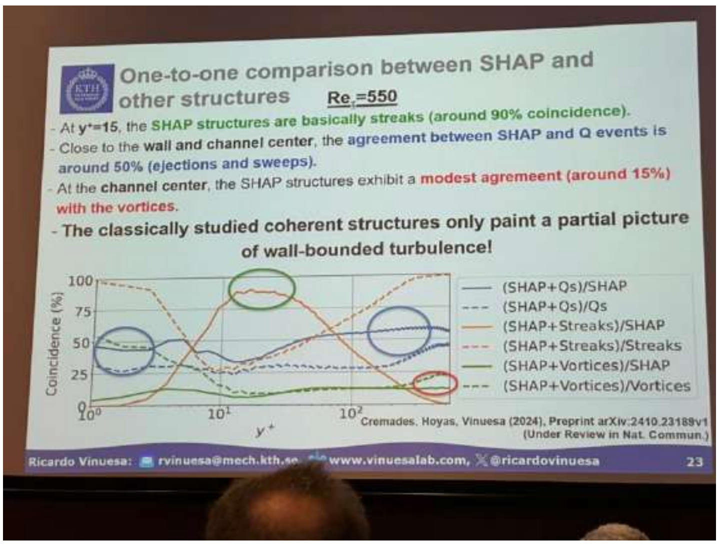
One-to-one comparison between SHAP and other structures
Re_τ=550
- At y^+=15, the SHAP structures are basically streaks (around 90% coincidence).
- Close to the wall and channel center, the agreement between SHAP and Q events is around 50% (ejections and sweeps).
- At the channel center, the SHAP structures exhibit a modest agremeent (around 15%) with the vortices.
- The classically studied coherent structures only paint a partial picture of wall-bounded turbulence!
Coincidence (%)
y^+
(SHAP+Qs)/SHAP
(SHAP+Qs)/Qs
(SHAP+Streaks)/SHAP
(SHAP+Streaks)/Streaks
(SHAP+Vortices)/SHAP
(SHAP+Vortices)/Vortices
Cremades, Hoyas, Vinuesa (2024), Preprint arXiv:2410.23189v1 (Under Review in Nat. Commun.)
Ricardo Vinuesa: rvinuesa@mech.kth.se www.vinuesalab.com, @ricardovinuesa
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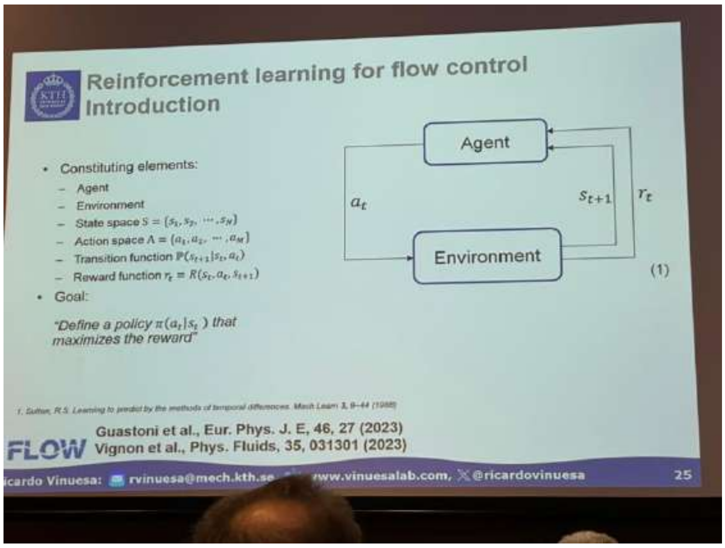
Reinforcement learning for flow control Introduction
Constituting elements:
Agent
Environment
State space $S = \{s_1, s_2, \cdots, s_N\}$
Action space $A = \{a_1, a_2, \cdots, a_M\}$
Transition function $\mathbb{P}(s_{t+1}|s_t, a_t)$
Reward function $r_t = R(s_t, a_t, s_{t+1})$
Goal:
"Define a policy $\pi(a_t|s_t)$ that maximizes the reward"
Agent
Environment
a_t
s_{t+1}
r_t
(1)
Guastoni et al., Eur. Phys. J. E, 46, 27 (2023)
Vignon et al., Phys. Fluids, 35, 031301 (2023)
FLOW
icardo Vinuesa: rvinuesa@mech.kth.se ww.vinuesalab.com, @ricardovinuesa
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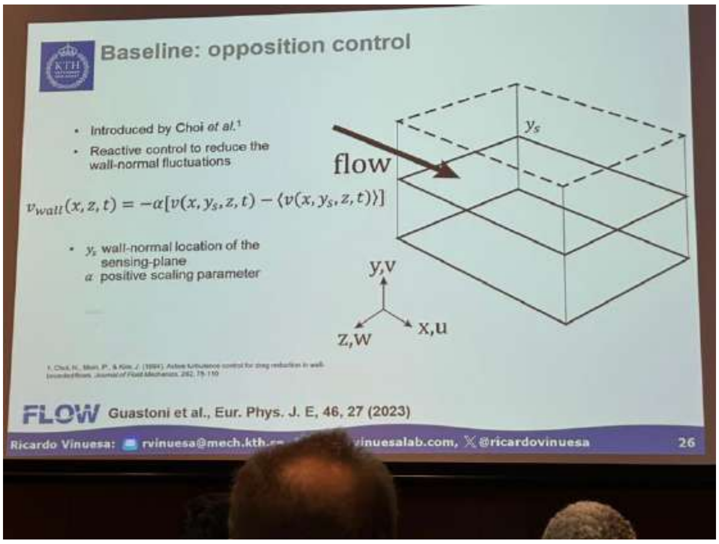
Baseline: opposition control
Introduced by Choi et al.[1]
Reactive control to reduce the wall-normal fluctuations
$v_{wall}(x,z,t) = -\alpha[v(x,y_s,z,t) - \langle v(x,y_s,z,t)\rangle]$
y_s wall-normal location of the sensing-plane
α positive scaling parameter
flow
y_s
y,v
z,w
x,u
FLOW Guastoni et al., Eur. Phys. J. E, 46, 27 (2023)
Ricardo Vinuesa:
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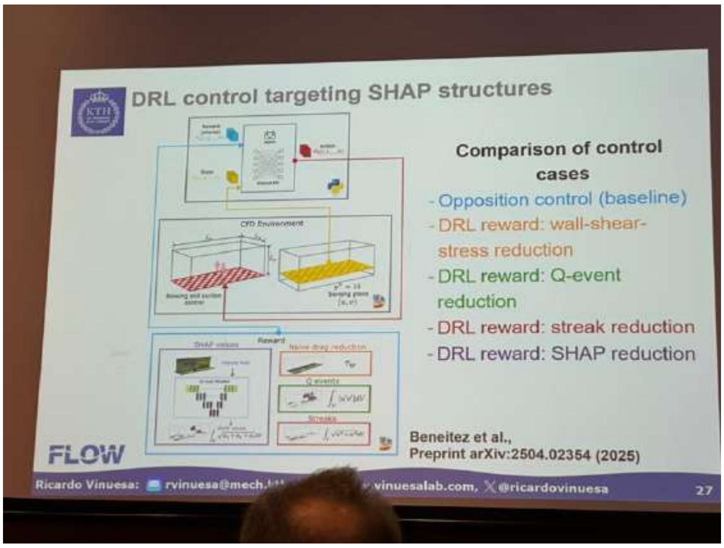
DRL control targeting SHAP structures
Comparison of control cases
- Opposition control (baseline)
- DRL reward: wall-shear-stress reduction
- DRL reward: Q-event reduction
- DRL reward: streak reduction
- DRL reward: SHAP reduction
CFD Environment
FLOW
Beneitez et al., Preprint arXiv:2504.02354 (2025)
Ricardo Vinuesa:
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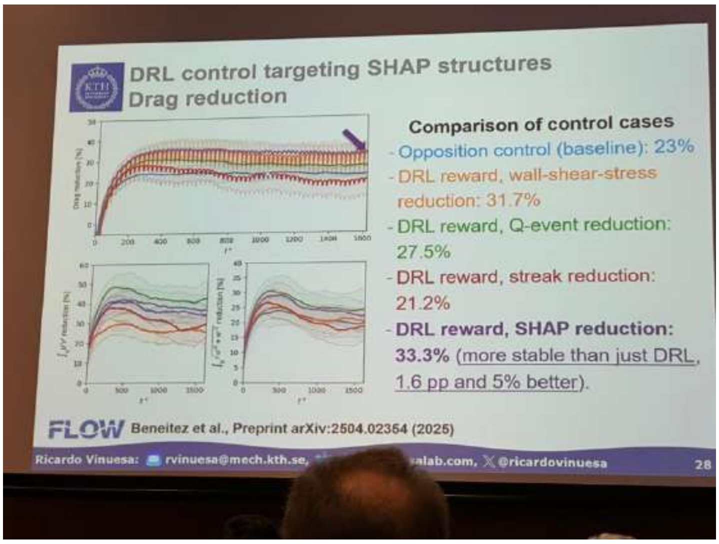
DRL control targeting SHAP structures
Drag reduction
Comparison of control cases
- Opposition control (baseline): 23%
- DRL reward, wall-shear-stress reduction: 31.7%
- DRL reward, Q-event reduction: 27.5%
- DRL reward, streak reduction: 21.2%
- DRL reward, SHAP reduction: 33.3% (more stable than just DRL, 1.6 pp and 5% better).
FLOW Beneitez et al., Preprint arXiv:2504.02354 (2025)
Ricardo Vinuesa: rvinuesa@mech.kth.se,
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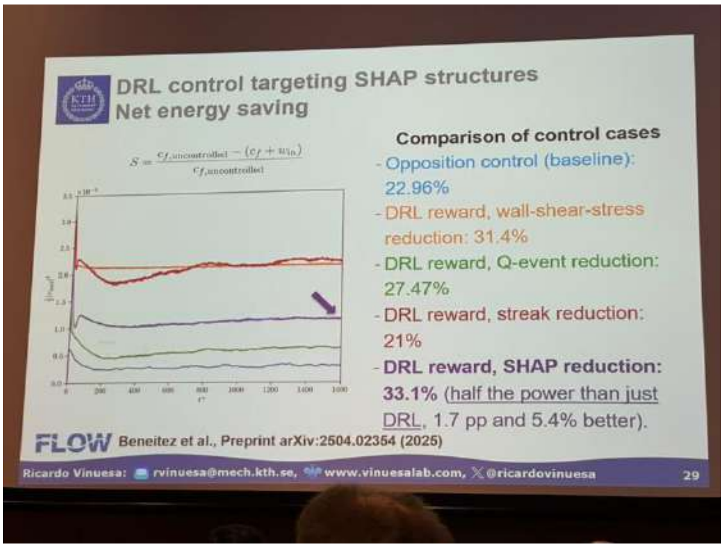
DRL control targeting SHAP structures
Net energy saving
Comparison of control cases
- Opposition control (baseline): 22.96%
- DRL reward, wall-shear-stress reduction: 31.4%
- DRL reward, Q-event reduction: 27.47%
- DRL reward, streak reduction: 21%
- DRL reward, SHAP reduction: 33.1% (half the power than just DRL, 1.7 pp and 5.4% better).
FLOW Beneitez et al., Preprint arXiv:2504.02354 (2025)
Ricardo Vinuesa: rvinuesa@mech.kth.se, www.vinuesalab.com, @ricardovinuesa
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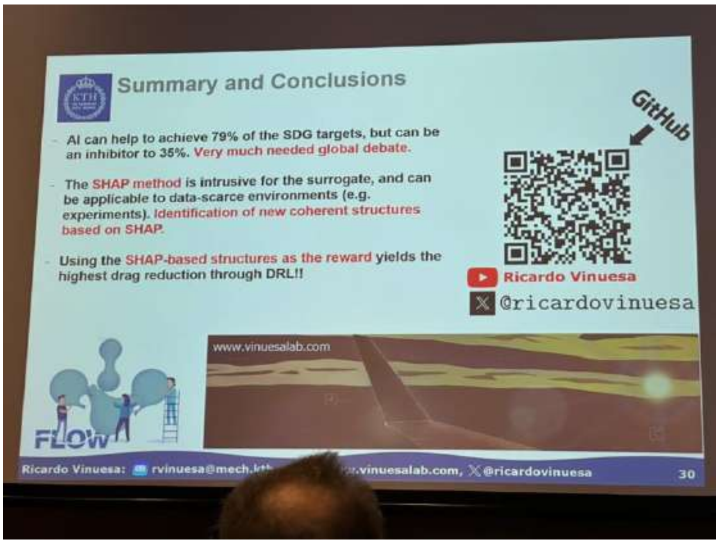
Summary and Conclusions
AI can help to achieve 79% of the SDG targets, but can be an inhibitor to 35%. Very much needed global debate.
The SHAP method is intrusive for the surrogate, and can be applicable to data-scarce environments (e.g. experiments). Identification of new coherent structures based on SHAP.
Using the SHAP-based structures as the reward yields the highest drag reduction through DRL!!
GitHub
Ricardo Vinuesa
@ricardovinuesa
www.vinuesalab.com
FLOW
Ricardo Vinuesa: rvinuesa@mech.kth
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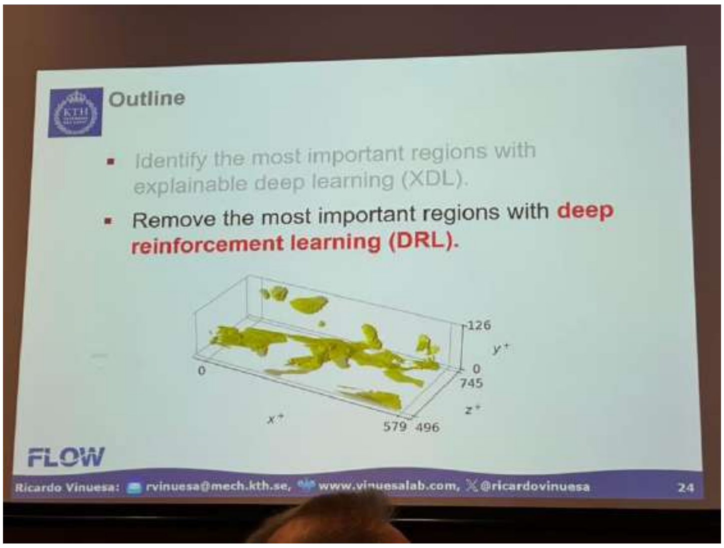
Outline
Identify the most important regions with explainable deep learning (XDL).
Remove the most important regions with deep reinforcement learning (DRL).
FLOW
Ricardo Vinuesa: rvinuesa@mech.kth.se, www.vinuesalab.com, @ricardovinuesa
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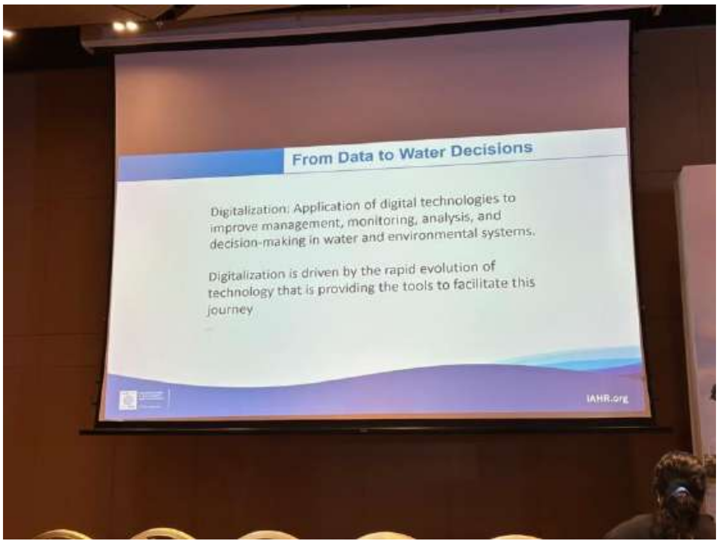
High Level Panel 4:
Empowering a Just and Inclusive Energy Transition:
The Strategic Role of Hydropower


High Level Panel 4:
From Digital Acceleration to Real-World Impact:
Scaling Innovation in Water Engineering
SUEZ

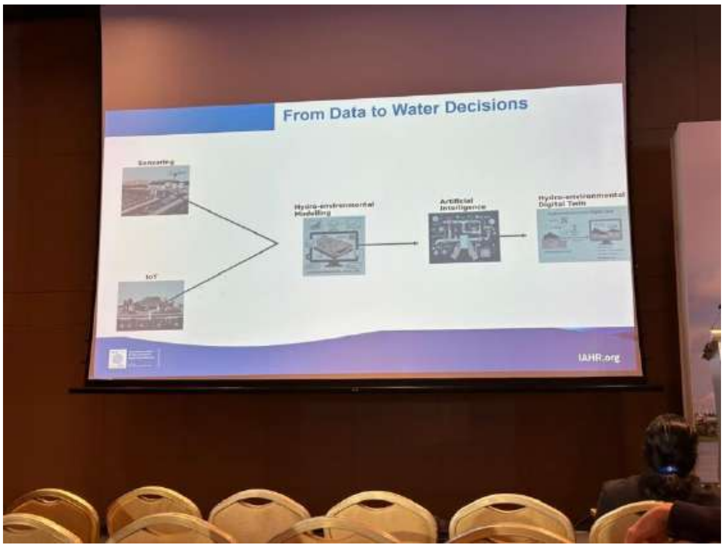

IAHR
Global Water Institutes Report
2025
From Data to Water Decisions:
Accelerating the Digital Journey
P. Amparo López Jiménez
IAHR Vice President
IAHR.org


From Data to Water Decisions
International Association for Hydro-Environment Engineering and Research (IAHR) strives to deliver the global hub of knowledge and innovation for holistic water engineering; and is committed to advancing water science, engineering, and environmental solutions
IAHR.org

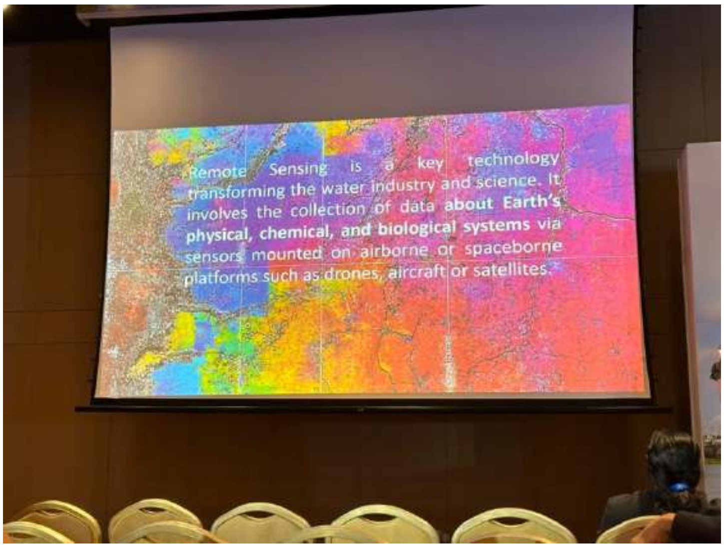

From Data to Water Decisions
Digitalization: Application of digital technologies to improve management, monitoring, analysis, and decision-making in water and environmental systems.
Digitalization is driven by the rapid evolution of technology that is providing the tools to facilitate this journey
IAHR.org


Digitalization is transversal


From Data to Water Decisions
Digital Accelerators
Data, Remote sensing, Earth Observation
Data, on-site sensing, Internet of Things
Advanced modelling
AI and Machine learning
Digital Twins
IAHR.org


From Data to Water Decisions
Hydro-environmental Modelling
Artificial Intelligence
Hydro-environmental Digital Twin
IoT
IAHR.org


Data, Remote sensing, Earth Observation


Remote Sensing is a key technology transforming the water industry and science. It involves the collection of data about Earth's physical, chemical, and biological systems via sensors mounted on airborne or spaceborne platforms such as drones, aircraft or satellites.


Data, Remote sensing, Earth Observation
IAHR.org


Data, Remote sensing, Earth Observation
Benefits
Challenges and Risks
Not a replacement for in-situ data – should compliment and enhance in-situ data collection
Scalability – sometimes developed EO solutions do not transfer well to other regions, especially when using ML/AI. Also, commercial data can be expensive.
Vulnerability - by nature, all space technologies are at risk of being damaged
IAHR.org

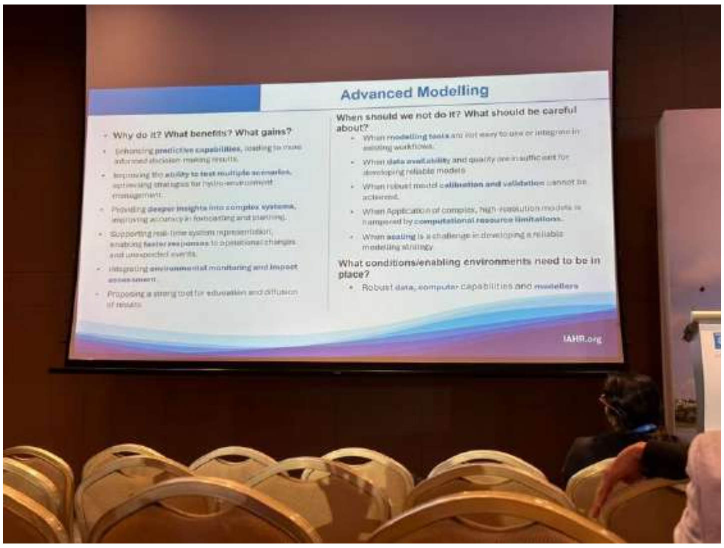

Data, Remote sensing, Earth Observation
What innovations/trends should we keep an eye on?
IAHR.org


The Internet of Things (IoT) is the connection of a variety of sensors to a network along with the real-time transmission of the data for analysis and decision making

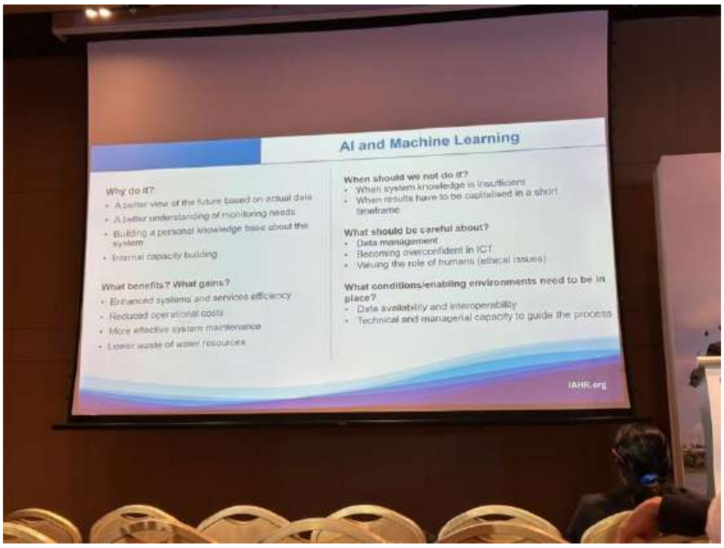

Benefits and Opportunities
Data, Sensors and the Internet of Things
Benefits
Real-time water monitoring;
Ensure an adequate supply of quality water;
Enhance the efficiency of wastewater management and control;
Manage rainfall effectively;
Improve the accuracy and efficiency of predictions;
Increase availability of water
Long-term sustainability and improved quality of life.
Challenges and Risks
High costs;
Adoption in developing countries;
Data accessibility;
Obstacles to equipment access;
Replay attacks;
Lack of integration - IoT and IA techniques for different applications; consistency; standardization;
Energy consumption.
IAHR.org


Hydro-environmental models can be used to describe real hydro-environmental systems: flow over floodplains or through hydraulic structures such as dams, floodgates, culverts, bridges, etc.
With these modelling tools, hydro-environmental simulations can be used to make decisions that would otherwise be too complex to make


Advanced Modelling
Data
IAHR.org


Advanced Modelling
Why do it? What benefits? What gains?
When should we not do it? What should be careful about?
What conditions/enabling environments need to be in place?
IAHR.org


Artificial intelligence and machine learning are fields of computer science that focus on creating algorithms that analyzes, interprets, and understands data in complex ways.
Artificial Intelligence (AI) and Machine Learning (ML) help water managers analyse complex water systems to uncover patterns humans might miss.

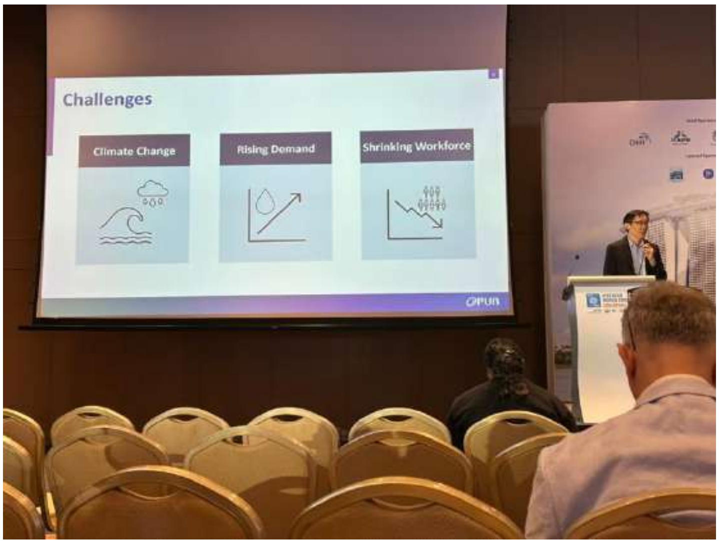

AI and Machine Learning
Why do it?
A better view of the future based on actual data
A better understanding of monitoring needs
Building a personal knowledge base about the system
Internal capacity building
What benefits? What gains?
Enhanced systems and services efficiency
Reduced operational costs
More effective system maintenance
Lower waste of water resources
When should we not do it?
When system knowledge is insufficient
When results have to be capitalised in a short timeframe
What should be careful about?
Data management
Becoming overconfident in ICT
Valuing the role of humans (ethical issues)
What conditions/enabling environments need to be in place?
Data availability and interoperability
Technical and managerial capacity to guide the process
IAHR.org


Digital Twins


Overview
Digital Twins
IAHR.org


Benefits and Opportunities
Digital Twins
Benefits
Challenges and Risks
Lack of scalability and sustainability - require significant computing power and infrastructure
Reducing human expertise and critical thinking - over-reliance on digital twins for decision-making
Vulnerable to disrupted data streams - critical dependency on real-time data
Stakeholder trust concerns - unintended consequences of automated decision-making based on digital twins
IAHR.org


From Data to Water Decisions
IAHR.org


Challenges
Climate Change
Rising Demand
Shrinking Workforce
PUB


Supply Good Water
IOT
AI
Collect
Analyse
• Hydraulic & water quality (~500 Sensors)
• Acoustic sensors (~1500 sensors)
• Demand Forecast
• Detect Potential Leaks
• Reduce water discoloration incidents
PUB


Tame Stormwater
IOT
AI
Collect
Analyse
• Identify Defects
PUB


Tame Stormwater
IOT
AI
Collect
Analyse
• Identify Defects
PUB

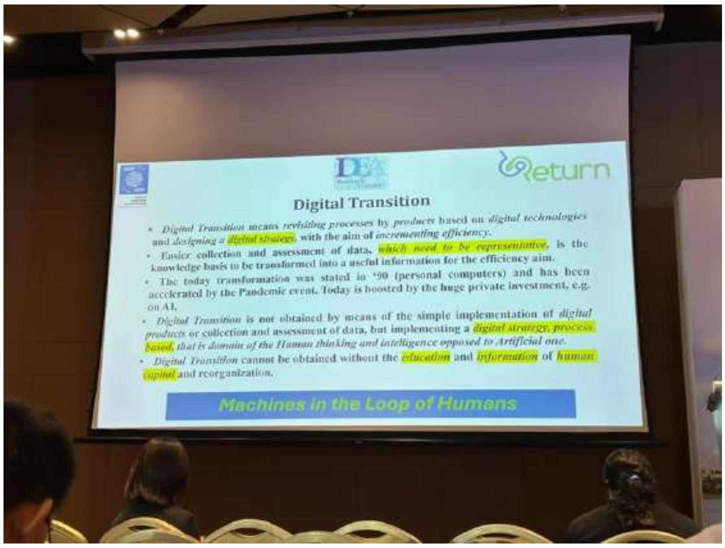

Tame Stormwater
IOT
Collect
Multiple data sources for more accurate rain
Self-reporting
Wiper Data
Third-party Data
In collaboration wit GrabMaps
PUB


Resist Rising Seas
Model
Coastal Model
• Surge/tide modelling
• Wave modelling
Inland Model
• Rainfall-runoff (2D)
• Hydraulics (1D)
• Overland flow (1D/2D)
PUB


Moving Forward
"Less Man" Day to Day Operation
"Digital Twins" for Water Operation & Asset Management
"Human Centric" Operation
PUB


WORLD CONGRESS
SINGAPORE
22 – 27 JUNE 2025
INNOVATIVE WATER ENGINEERING
FOR SUSTAINABLE DEVELOPMENT


Driving the Change & Digital Water
Machines in the Loop of Humans


Return
Digital Transition
Machines in the Loop of Humans


The Road from Singapore to Bari
DIGITAL WATER
Knowledge Application & Hydroinformatics

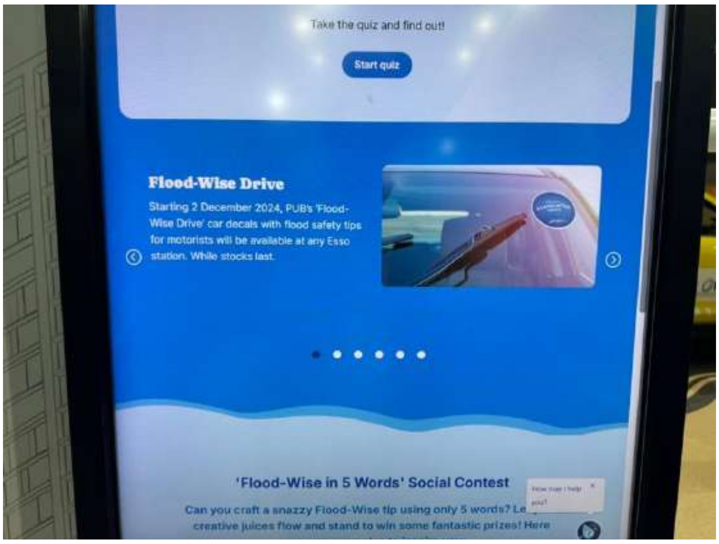

41ST IAHR
WORLD CONGRESS
SINGAPORE

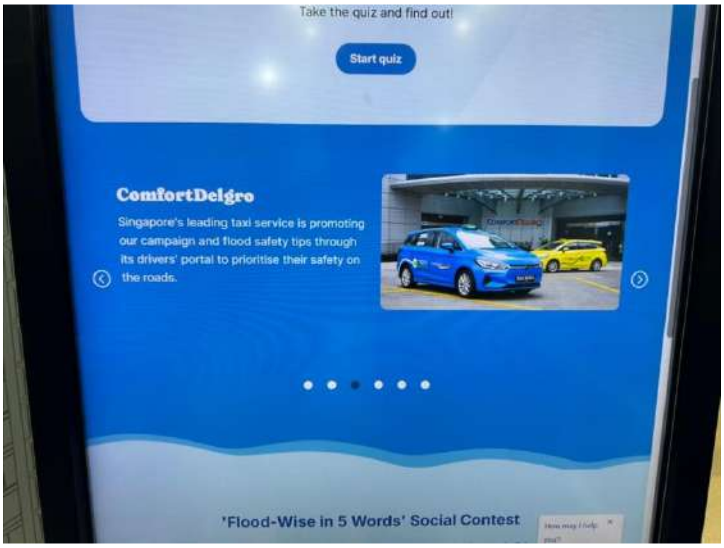

41ST IAHR WORLD CONGRESS SINGAPORE
Singapore International Water Week SPOTLIGHT 2025
23 - 25 JUNE 2025
Download the SIWW-IAHR-2025 App now!
SOLUTIONS MARKETPLACE
ADMISSION POLICY
FLOORPLAN
EXHIBITOR LISTING

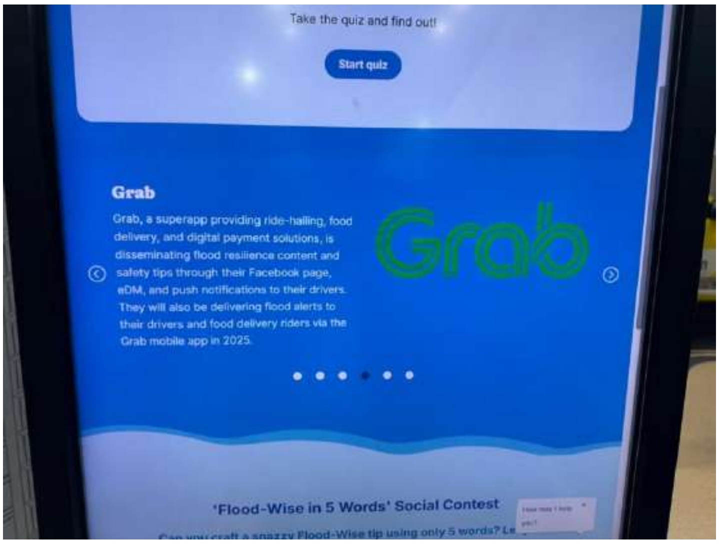

PUB

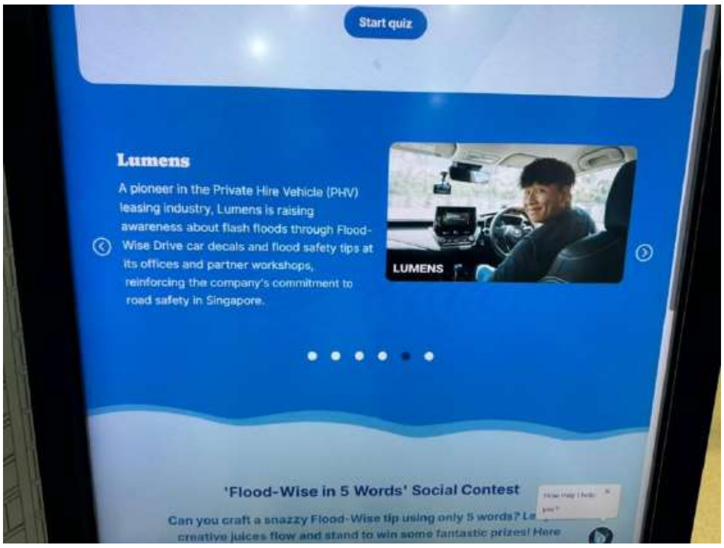

PUB SINGAPORE'S NATIONAL WATER AGENCY
Singapore's Climate Vulnerability and Response

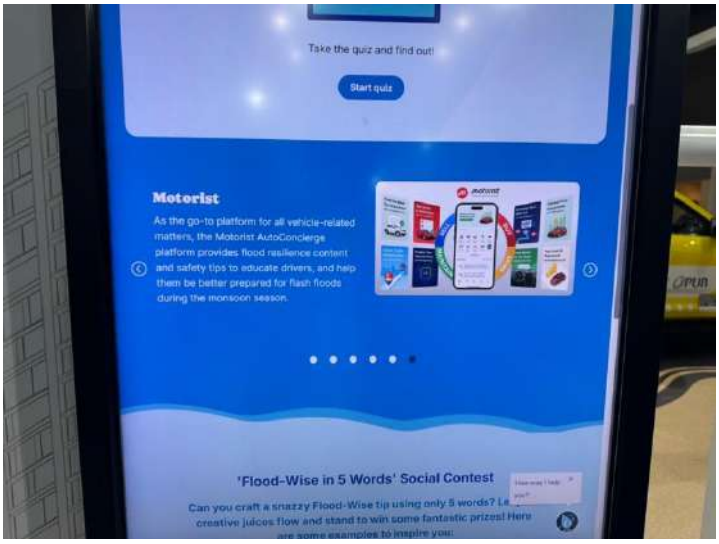

FLOOD RESILIENCE
Strengthening our Community Flood Resilience
Climate change will result in more extreme and unpredictable weather. Intense rainfall can still overwhelm drains temporarily, causing flash floods. Thus, eliminating floods dues to weather extremes is not possible and it is important that we strengthen community flood resilience and manage flood risk collectively.
Our community engagement efforts aim to:
• Create AWARENESS on flood risks
• Foster ACCEPTANCE of flood risks
• Motivate ACTION within community
Creating Awareness
Moving towards Acceptance and Action
F.L.A.S.H


Take the quiz and find out!
Start quiz
Flood-Wise Drive
Starting 2 December 2024, PUB's 'Flood-Wise Drive' car decals with flood safety tips for motorists will be available at any Esso station. While stocks last.
'Flood-Wise in 5 Words' Social Contest
Can you craft a snazzy Flood-Wise tip using only 5 words?
creative juices flow and stand to win some fantastic prizes! Here


Take the quiz and find out!
Start quiz
ComfortDelgro
Singapore's leading taxi service is promoting our campaign and flood safety tips through its drivers' portal to prioritise their safety on the roads.
'Flood-Wise in 5 Words' Social Contest


Take the quiz and find out!
Start quiz
Grab
Grab, a superapp providing ride-hailing, food delivery, and digital payment solutions, is disseminating flood resilience content and safety tips through their Facebook page, eDM, and push notifications to their drivers. They will also be delivering flood alerts to their drivers and food delivery riders via the Grab mobile app in 2025.
Grab
'Flood-Wise in 5 Words' Social Contest


Start quiz
Lumens
A pioneer in the Private Hire Vehicle (PHV) leasing industry, Lumens is raising awareness about flash floods through Flood-Wise Drive car decals and flood safety tips at its offices and partner workshops, reinforcing the company's commitment to road safety in Singapore.
LUMENS
'Flood-Wise in 5 Words' Social Contest
Can you craft a snazzy Flood-Wise tip using only 5 words?
creative juices flow and stand to win some fantastic prizes! Here


Take the quiz and find out!
Start quiz
Motorist
As the go-to platform for all vehicle-related matters, the Motorist AutoConcierge platform provides flood resilience content and safety tips to educate drivers, and help them be better prepared for flash floods during the monsoon season.
'Flood-Wise in 5 Words' Social Contest
Can you craft a snazzy Flood-Wise tip using only 5 words?
creative juices flow and stand to win some fantastic prizes! Here
are some examples to inspire you:


Stamford Detention Tank and Stamford Diversion Canal
Stamford Detention Tank
28m
38,000m²
15
Stamford Diversion Canal
1km


Syed Alwi Pumping Station
Syed Alwi Pumping Station is a 'pathway' solution which is part of Singapore's wider efforts to adapt to climate change.


Did you know? More than:
350,000
data points
assimilated from various sources every day as data input
1,500
sensors
deployed to gather data for integration into the CWOs
170
storms
since 2017 where actionable insights were provided
150
situations
where CWOS correctly advised operators on pump and gate operations


The Catchment and Waterways Operations System (CWOS)
With more frequent and intense rainfall, the ability to forecast and monitor impending heavy storms is more important than ever. Officers are on duty round the clock to conduct flood monitoring on Catchment and Waterways Operations System (CWOS).
CWOS provides real-time monitoring of Singapore's stormwater network. Operating round-the-clock, it integrates data from water level sensors, radars, CCTVs, quality sensors and rain gauges across all catchments.
CWOS utilises data analytics to predict flood risks, optimise Quick Response Team (QRT) deployment, and highlight water quality anomalies in reservoirs and waterways.
By integrating Internet of Things (IoT) and advanced data analytics capabilities with PUB's operational expertise, CWOS enhances day-to-day drainage and flood operations, reservoir operations and water quality management through real-time monitoring and anticipation of issues.


Alkaff Lake
The new Alkaff Lake demonstrates PUB's approach to managing flood risks in land-constrained Singapore - a multifunctional solution that serves as both a recreational space and a stormwater retention pond during intense rainfall.
Integrated within the 10ha Bidadari Park, Alkaff Lake serves as a retention pond to temporarily hold stormwater runoff during heavy storms. It takes pressure off the downstream public drainage system, mitigating flood risks. During dry weather, Alkaff Lake serves as a community and recreation zone with features such as terraced wetlands and a cascading creek.
Alkaff Lake is a 'pathway' solution under PUB's holistic Source-Pathway-Receptor approach to manage stormwater, which introduces adaptability and flexibility to Singapore's drainage system when looking at solutions for flood protection.
Sungei Tampines
In 2018, PUB commenced works to upgrade a 1.4km upstream section of Sungei Tampines from Tampines Avenue 7 to Tampines Expressway (TPE) to serve new HDB estates in the area. As part of this drainage improvement project, PUB also introduced new features along the waterway to enhance overall liveability. As part of the makeover, PUB converted a concrete canal into a naturalised river, constructed new recreation and community spaces for residents and enhanced the area's connectivity to the adjacent Tampines Eco Green park. The works were completed in July 2022.
Sungei Tampines incorporates an extensive stretch of naturalisation, approximately 1km long, along one bank of the canal at Tampines Eco Green and at the canal base. This naturalisation process utilised soil bioengineering techniques similar to those employed at Kallang River – Bishan-Ang Mo Kio Park. The other bank is integrated seamlessly with a concrete cantilevered park connector adjacent to the nearby housing estates and features lookout decks that bring the public closer to the waterway. Together with ABC Waters enhancements such as rain gardens and greening of the canal walls, these features have created a vibrant and liveable space for all to enjoy.


Active, Beautiful, Clean Waters Programme
Active, Beautiful, Clean Waters Programme
Kallang River – Bishan-Ang Mo Kio Park


QUICK RESPONSE PUB


SINGAPORE
SINGAPORE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CHINA WATER


第41届水利学大会
中国馆交流活动
节水优先 空间均衡
系统治理 两手发力
Prioritizing Water Conservation
Balancing Spatial Distribution
Taking Systematic Approaches
Promoting Government-market Synergy


Reimagining
our Coastlines
Holistic Risk
Assessment
Assess Combined Flood Risks from
Extreme Sea Level Rise and Rainfall


SINGAPORE
EXPO
Playground of Possibilities


SINGAPORE
EXPO
Playground of Possibilities