彼得·鲍斯文，马蒂亚斯·康道夫，帕特里克·韦伯，李诗瑶 . 变迁中的岛屿：韧性城市形态 [J]. 风景园林，2019，26（9）：45-56.

变迁中的岛屿——韧性城市形态

An Island in Transition: Adaptation of Urban Form

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中图分类号：TU986
文献标识码：A
文章编号：1673-1530(2019)09-0045-12
DOI：10.14085/j.fjyl.2019.09.0045.12
收稿日期：2019-05-11
修回日期：2019-07-23

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摘要：以城市设计作为工具，对 2 种琶东开发方案下该地区所需的蓄洪量进行检验。琶洲岛位于中国珠江三角洲，地处广州中心地带的南部。琶洲岛因毗邻广州金融区，成为城市战略性发展的黄金地段；琶洲岛西部地区也成为互联网创新集聚区的一部分。根据目前琶洲岛东部地区的城市设计方案推测，未来琶东将会成为地域性的商业中心。因此，对 2 种发展方案进行对比，并分析 2 种方案预计可为暴雨时节提供的蓄水量，以及面临洪水和汹涌潮汐时所需要的保护措施。方案 1 将开发所有可用的土地，而方案 2 则将目前地势较低的场地作为暴雨期间可被淹没的湿地。基于 1981—2017 年间出现过的最大蓄洪量需求进行计算，并得出结论：百年一遇的雨洪可被储存于 80 hm^2 的现有低洼地带中，深 1.34 m。最后，向地区政府提议，要求对琶洲岛周边地区进行适应性设计，以便进行防洪，并在低洼未建成区域进行适应性蓄水设计，免除方案 1 中建造昂贵蓄水装置的需求。还为岛上的村庄描绘了另一种未来蓝图，其中包括一个位于岛屿东南岸极易遭受台风和海浪灾害的渔村。

关键词：风景园林；珠江三角洲；琶洲岛；水资源管理；韧性城市形态

Abstract: The article introduces urban design as a tool to test the storm-water storage needs of two alternative development scenarios for the eastern portion of Pazhou Island in the Pearl River Delta. The island is located directly to the south of Guangzhou’s central area. As reflected in historical maps, the island was formed by long-term accretion of river sediments around two rock outcrops between the front channel of the Northern Pearl River and the Whampoa Canal. Pazhou Island’s strategic proximity to Guangzhou’s financial district has made it a prime location for urban development, and the western portion of the island became part of a media and new technology district in the second decade of the 21st century. In light of current proposals to turn the eastern part of the island into a major commercial concentration of the new Pearl River Bay polycentric region, we contrast two development scenarios and analyzed how well each could provide for the water storage needs required during heavy typhoonal rains, and the protections needed against riverine flooding and tidal surges. One scenario would develop all available land, while the other would leave currently low-lying land available as wetlands that can be flooded during storm events. We based our calculation of storm-water storage needs on a 1981—2017 maximum. daily precipitation record. We conclude that 100 year rainfall can be stored on 80 hm^2 existing low-lying wet-lands, 1.34m deep. We end the article with recommendations to the regional government for adaptable designs of the island perimeter for flood protection and for adaptable design of water storage in low-lying unbuilt areas thus largely avoiding the need for expensive water storage chambers or vaults under roads that would become necessary, if all available land would be developed. We also delineate alternative future conditions for the villages on the island, including a fishing village that is openly exposed to typhoonal wind and waves along the island’s south-eastern shore.

Keywords: landscape architecture; the Pearl River Delta; Pazhou Island; water management; adaptation of urban form


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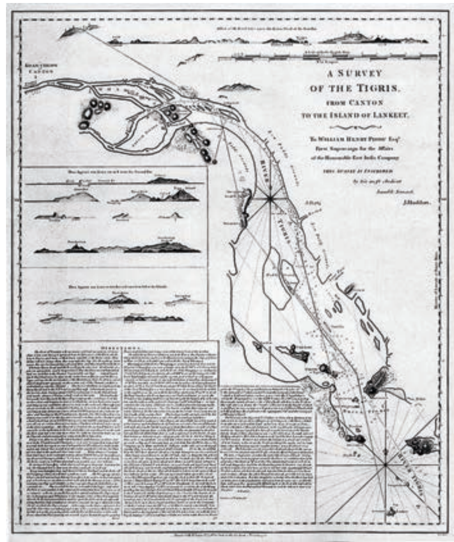


2

1《羊城山水形胜图》，1892 年（琶洲岛和黄埔码头位于图像的最右侧）
Guangzhou Landscape, 1892 (Pazhou Island and the Whampoa Anchorage are seen on the far right of the image)
2 1786 年关于底格里斯（虎门）的测绘（琶洲岛和黄埔码头位于图纸上方）
Survey of the Tigris (Humen) from 1786 (Pazhou Island and the Whampoa Anchorage are seen on the top of the survey)

琶洲岛位于珠江前航道和广州的黄埔运河之间。该岛已成为广州金融、媒体、技术、贸易和展览区的一部分，并逐渐成为粤港澳大湾区的重要中心。自 2003 年以来，该岛中部新建成的琶洲会展中心成为广交会的举办场地。珠江新城毗邻琶洲岛西部，位于其中的广州塔是为迎接 2010 年广州亚运会开幕而建成的著名地标。琶洲岛西部目前已成为互联网创新集聚区。对比之下，该岛东西部发展呈现出不均衡的态势，对东部的开发已导致环境恶化和生态系统受损 [1]。将重点介绍该岛的东部。将基于一个城市设计实验来对比 2 种规划方案，并将在文中呈现二者的结果预期。第 1 种方案是开发该岛东部的所有可用土地，第 2 种方案则只发展可用土地的 2/3，并保留所有现有低洼地不做开发，利用其储蓄台风暴雨等带来的降水。这 2 种方案都可以保护岛屿不受洪水与潮汐的影响。通过回顾琶洲岛的自然与文化历史，计算 2 个方案下岛屿所需的蓄水总量来证明我们的实验。

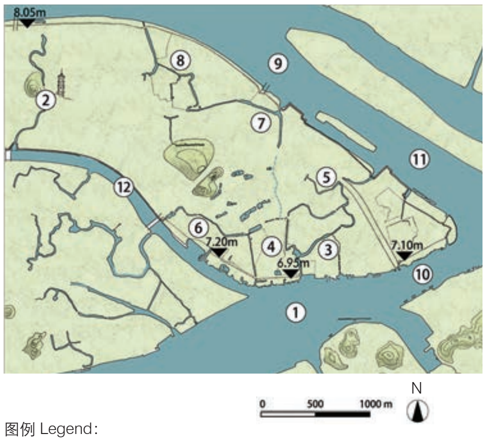
珠江三角洲的河流有着非常复杂的历史。现在的三角洲有 8 个相互连接的潮汐河口。而在 2 世纪，这里仍然是一片浅内陆海。广州的发展始于这大片海域的北岸，即中国南海的一个海湾。这座城市选址很好，因为它背靠观音山（越秀山）的南坡，地处洪水淹没不到的高地。随着时间的推移，内陆海逐渐转变为由溪流与潮汐涌组成的水文脉络。罗伯特·马克斯（Robert B. Marks）在他的《虎、米、泥、丝——帝制晚期华南的环境与经济》（*Tigers, Rice, Silt and Silk: Environment and Ecology in Late Imperial*）一书中展示了该地区的迷人景象。深入研究过去，记录了河流环境是如何在自然力和人力作用下形成的。书的标题中提到了老虎，因为三角洲周围的土地曾是茂密的森林，老虎频繁地出现在当地的地名和乡村传说中。大米则是由于繁荣的水稻种植文化（一年两熟）在由当地农民建造的堤坝和池塘中蓬勃发展。河流从山上运来了淤泥，农民使用这种材料，打造出越来越平坦且易种植的岛屿。清代，农民们在堤坝上种植桑树，以采集利用桑叶为依托的丝绸产业应运而生 [2]。

许多岛屿都是由地表岩石背面沉积物的堆积而逐渐形成。琶洲岛就是这样一个岛屿，因冲积沉积物积聚在 2 块露出表面的岩石之间而形成。明朝海鳌塔，即如今的琶洲塔就坐落在其中一块岩石上方。当时从虎门河航行到黄埔港港口的远洋帆船以 3 座宝塔为重要地标，琶洲塔是其中一座（图 1、2）。黄埔村位于历史悠久的港口上方，占据了第二块露出地表的岩石。黄埔村严格来说不是一个农业村庄。它是一个因与外国人通商而兴盛的聚居地。在这里，货物被转运到舢板上，并通过河流和运河运输到内陆（图 3、4）。

1 与雨洪共生

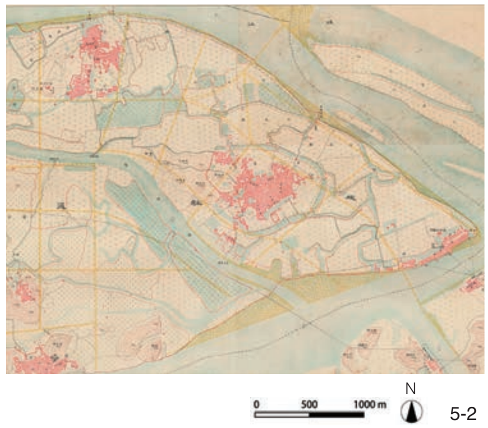
纵观历史，洪水改变了岛屿岸线的轮廓。清代的记载报道了从 1736—1839 年间的 44 次大洪水 [3]，平均每 2.4 年发生一次大洪水。这些洪水裹挟的泥沙，大部分沉积在广州等三角洲地区。洪水重塑了三角洲，因此岛屿的形状和范围随着大洪水的每次来临而变化，由此产生的冲积岛屿一直处于低海拔区域并持续遭受洪水侵袭。

与珠江三角洲的其他岛屿一样，琶洲岛受到的洪水威胁主要有 2 个来源：当地强降雨带来的洪水（“in-flooding”）和超出防护堤坝的防洪水位的汛期河水或风暴潮（“out-flooding”）。保护这 2 种不同的威胁需要不同的策略。第 1 种类型的洪水基本上是由降雨量超过可排水量所造成的，会导致城市街道淹水。在河流水位过高或涨潮期间，琶东这样被东、南、北侧堤坝环绕的盆地就像一个浴缸，堤坝外水位高于内部，不能排出所有集聚的雨水。使用水泵是一种解决方法，但泵



图例 Legend：
1 黄埔古港遗址 Historic Whampoa Anchorage
2 历史上的琶洲塔 Historic Pazhou Pagoda
3 年丰涌 Nianfeng Tidal Slough
4 新洲潮汐涌 Xinzhou Tidal Slough
5 合兴涌 HexingTidal Slough
6 黄埔外围运河 Whampoa Perimeter Canal
7 大涌 Da Tidal Slough
8 沙涌 Sand Tidal Slough
9 广州环城公路 Guangzhou Beltway
10 珠江前河道 Pearl River Front Channel
11 珠江后河道 Pearl River Back Channel
12 黄埔运河 Whampoa Canal

5-1



5-2

5

3 琶洲塔和黄埔村
Pazhou Pagoda and Whampoa Village
4 帆船在黄埔港装载转运
Sailing ships trans-loading at Whampoa Harbor
5 琶洲岛东部的潮汐涌、运河和池塘
Tidal sloughs, canals and ponds on Eastern Pazhou Island
5-1 现状
Present condition
5-2 1947 年的琶洲岛东部
Eastern portion of Pazhou Island in 1947

的排水量可能跟不上强降雨期间积水的速度，并且如果没有可靠的应急发电机，水泵在电源故障时将变得毫无用处。

在强降雨期间，400 hm^2 土地上的径流被 6 条规模可观的、穿过琶洲岛东部的潮汐涌所吸收（图 5）。这些河涌通常依照对角线流经过去及现在仍在使用的农田。位于东南部的年丰涌仍然在堤坝上种满了乔木和灌木。由于潮汐作用，该河涌在岛屿两侧的入河口处是双向流动的，通过机械操控的闸门控制。从前，新洲和合兴涌与黄埔村外围运河相连。2 条河涌都与年丰涌汇合，它们共同排出黄埔村南向斜坡上的积水。黄埔村北向斜坡将水流排入大涌和沙涌，它们的潮汐水流也由琶洲岛北岸的 2 个闸门控制。只要周边堤坝外的河流水位保持相对较低，这些潮汐涌就可以在降雨后将水排出岛屿。但是，如果河流中的洪水水位持续保持高位，或是遇上涨潮，则雨水将无法外流，因为堤坝外的水位仍然高于堤坝内水位。

因此在岛屿的低洼地区，在洪水没有破坏建筑物的情况下，具备足够的蓄水能力是在强降雨下保持可持续性的一个极其重要的策略。由于周边堤防外较高水位所产生的水力梯度的驱动，根据土壤渗透性，堤防内的水也可能会从土地向上渗透。我们通过将强风暴中预期的降水深度乘以降水所在的区域来计算蓄水需求。对于这种计算，假设根据预期的高地下水位和土壤饱和条件，渗透到土壤中的水可以忽略不计。我们使用了 1981—2017 年在中山大学测量的年均 24 h 最大降水记录（表 1、2）。仅在 37 年的记录中，24 h 降雨总量超过 210 mm 的情况已有 4 次，这表明这种降雨量的频率大致为 10 年一次。

根据这 37 年的降水频率分析表明：百年一遇的降水量将为 264 mm（Gumbel 极值分布）或 265 mm（对数 Pearson 分布）。这场百年一遇的降水将带来多少雨水量？如果以 24 h 降水量 265 mm 为例进行计算，则琶东地区将有 1 077 548 m^3 的雨水待处理（表 3）。假设没有雨水通过下渗流失（百年一遇的降水来临时，预计地下水位极高），则所有雨水需要被储存。那么需要多大的空间来储存这些降水？若将这些雨水储存在 80 hm^2 的低洼土地与河涌内，则水深将达到 1.34 m。现有的地形高差基本能够满足这个深度，局部湿地外围可能需要建设护坡堤来防止水流漫溢至建筑物密集区域。道路、停车场和建筑地下的储水箱可以作为额外的储水空间，但这种形式通常昂贵且难以维护。如果琶东土地被完全开发，而不保留 80 hm^2 的湿地，那么地下储水箱将可能是唯一的储水办法。洪水将给岛上的投资开发带来的严重威胁不容小觑。

关于雨洪的分析对未来琶洲岛土地利用有重要的指示作用。现有的 80 hm^2 低洼土地和河涌如果能够承受 1.34 m 的水位升高，则足以储存 1 077 548 m^3（百年一遇暴雨 24 h 内在琶洲岛产生的降水总量）的降水量。相比之下，地下储水箱则昂贵得多，且易出现故障。若能够将所有径流储存在 80 hm^2 的河涌与其毗邻的低洼场地中，将得到更为可靠且经济的蓄水系统。这是应当保留这 80 hm^2 土地的重要理由。当然，由于气候变化将带来更严重的暴风雨，建设额外的地下蓄水设施，并确保琶洲岛上蓄水平均深度为 1.3 m 也是合理的。

2 应对过高水位和涌潮

琶洲岛东部沿岸地区受防洪堤坝的保护，然而沿岸的堤坝并不完整，并且局部堤防明显过低。水务局的防洪标准要求堤坝高出海面 8.68 m 以上。而北岸岛屿防洪堤的实际高度仅 8.05 m。在东南岸，堤坝高度甚至更低，为 7.10 m 与 6.95 m[1]。东南沿岸的部分地区甚至没有堤防，即使是相对较常见的小规模水灾也会使这些地区遭遇洪水泛滥问题。

表 1 1981—2017 年 24 h 广州最大降水量记录
Tab.1 Max daily precip Guangzhou 1981—2017

年份 Year	最大日降水量 Max daily precpit/mm
1981	172.6
1982	90.9
1983	210.9
1984	72.4
1985	123.6
1986	109.5
1987	109.1
1988	128.3
1989	215.3
1990	45.8
1991	168.4
1992	144.1
1993	156.4
1994	119.8
1995	99.4
1996	78.9
1997	99.0
1998	75.9
1999	239.0
2000	111.6
2001	163.9
2002	82.6
2003	111.7
2004	90.7
2005	109.9
2006	107.4
2007	99.4
2008	138.1
2009	82.0
2010	214.7
2011	106.6
2012	93.1
2013	100.2
2014	136.4
2015	139.4
2016	124.4
2017	164.1

表 2 基于 1981—2017 年 24 h 广州最大降水量记录的频率分析
Tab. 2 Frequency analysis of precipitation for Guangzhou based on max daily precipitation data from 1981 to 2017

概率 Probability (p)	重现期 Recurrence interval (T)/years	标准差 Standard deviation (P)/mm		
		Gumbel 极值分布 Gumbel extreme value distribution	对数 Pearson 分布 Log Pearson distribution	正态分布 Normal distribution
0.99	1.01	53	53	22
0.5	2	118	118	125
0.2	5	157	158	163
0.1	10	183	185	182
0.05	20	208	209	198
0.02	50	240	241	216
0.01	100	264	265	228
0.005	200	288	289	239
0.002	500	320	321	253

表 3 琶洲岛东部的径流计算
Tab. 3 Run-off calculations for the Eastern Portion of Pazhou Island

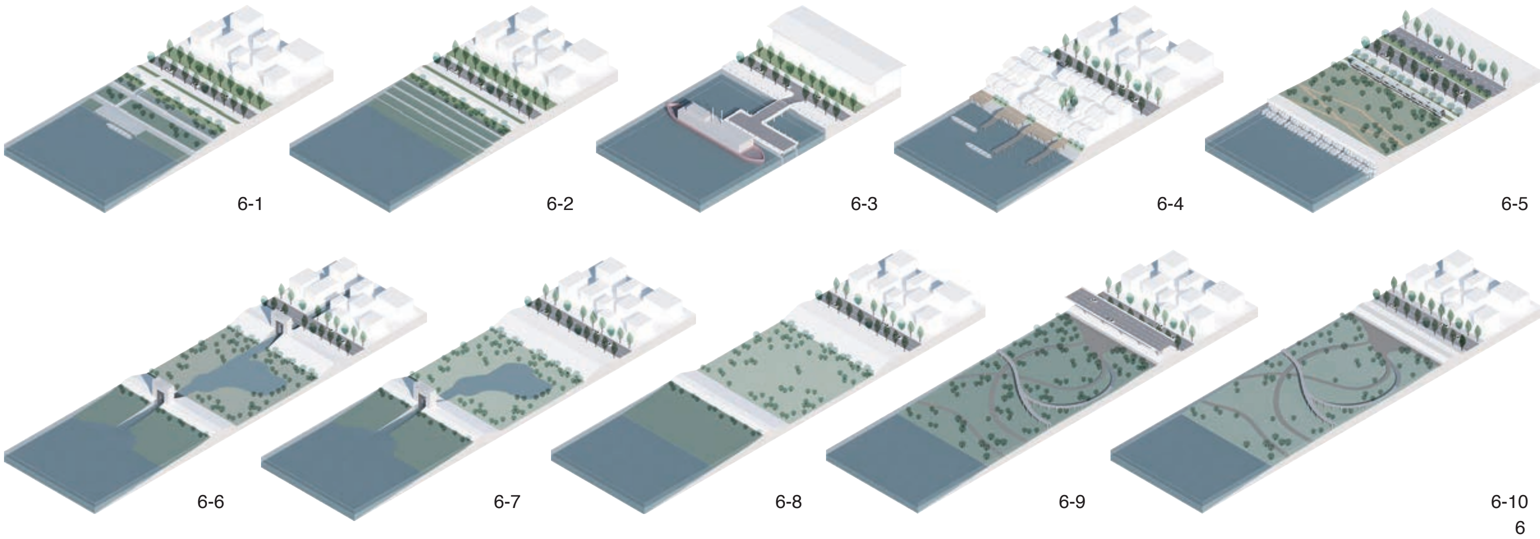
琶东地区总地面面积与积水量 WATER ACCUMULATION PER GROSS AREA					
降水级别 Event	降水量 Volume/mm	场地面积 Study area/m^2		积水总量 Water volume/m^3	
百年一遇级降水 100 YR Event	265	4 066 217		1 077 548	
各方案蓄水能力比较 WATER STORAGE POTENTIAL OF DESIGN SCENARIOS					
可被开发的蓄水场地 Undeveloped storage	蓄水系数 Storage factor/m^3	方案 1 Scenario ONE		方案 2 Scenario TWO	
		长度 Length/m	蓄水量 Storage volume/m^3	长度 Length/m	蓄水量 Storage volume/m^3
低洼农田 Low lying farmland	1	186 543	187 543	800 000	801 000
水道 Waterways	6	8 747	52 482	11 764	70 583
低洼农田 & 水道蓄水总量 Total low-lying land&waterway storage			239 025		870 583
202.2 mm 降水量所需的额外蓄水量 Additional storage required per 202.2 mm event			838 523		206 965
道路 Roadways					
道路类型 1 Road typology 1	10	18 520	182 792	21 634	213 530
道路类型 2 Road typology 2	15	11 267	166 774	12 632	186 982
道路类型 3 Road typology 3	20	6 957	137 313	10 796	213 067
道路总蓄水量 Total roadway storage			656 424		752 845
总蓄水潜力 Total potential storage			895 449		1 623 418

2018 年 9 月 15 日，据中山大学验潮站（距琶洲岛东部上游约 10 km）监测，台风“山竹”的最高潮位高于平均海平面 8.227 m。当涌潮和台风暴雨同时来袭，降水将无法排出，只能通过水泵使之越过堤坝排入相邻的泛滥河流，但也可能会由于洪水淹没过堤坝而造成大量漫溢。关于淹没堤防的一个关键问题是堤坝的完整性，以及当堤防失效时可能面临的灾难性后果——对人居环境造成致命危险的滔天洪水将迅速席卷而来。近几十年来，所谓“百年一遇洪水”的频率有所增加 [4]。并且随着海平面上升的加速，即使是海拔 8.68 m 的连续完整堤防系统也必须在设计中考虑适应未来的更高水位。目前尚不清楚水利管理当局的防洪堤标准在多大程度上考虑了风力驱动海浪，即将堤坝高度提高至高于预期最高水位（即术语中的“freeboard”，在美国通常设为 0.9 m）。当然，在未来海平面上升和极端天气模式的情况下，洪水水位上升似乎是不可避免的。因此建议将堤防提高至平均海平面以上至少 9.50 m（图 6）。

3 琶洲岛上的村庄

黄埔村是琶洲岛上 6 个最大、最古老的村庄之一。自宋代以来，黄埔码头在世界各地的商贾中闻名。清代所有外国船只被禁止通过位于黄埔码头东南部的一座岛屿的山坡背风面上的一个天然港口，因此被迫中止了往返琶洲岛东南部的行程。帆船乘着 6—9 月的夏季风抵达这里，并于 11 月—次年 2 月期间离开。船只停靠黄埔码头期间，货物被转运到舢板上，并被带到广州。船舶和索具都可以在黄埔村当地进行修理。与外国船员的接触支持了村里的产业发展，并使之保持开放性，这样的场景在其他村庄里都是前所未有的。因此，黄埔村与琶洲岛上的其他 5 个村庄相异，有着独一份的鲜明的特质。

南部的石基村几乎是黄埔的附属。同样，在广州环城高速公路的另一侧，东北面的杨青村则可以看到更多现代发展的痕迹。这 3 个村庄都采用梳式布局，房屋排成排，一幢在另一幢后面排列着。该布局之所以被称为梳式布局，是因为一排排房屋都以祠堂为参照平行布置，并且垂直于运河或池塘。这个布局遵循中国风水理



6

6 保护岛屿外围片区
Protecting the Island perimeter
6-1 外围堤防，不同标高的平台适应不同的水位线
Perimeter dike with platforms adapting to different water levels
6-2 外围堤防，面向河流侧为斜坡，以减轻溢流
Perimeter dike with a slope towards the river to mitigate overtopping
6-3 堤防
Embankment
6-4 浮桥式结构，保护渔民新村
Boardwalk-type structure to protect the New Fisherman's Village
6-5 堤防面向河流侧为大面积缓坡，以防止溢流
Dike with extensive slope to prevent overtopping
6-6 潮汐涌穿过低洼地带的主闸口和次级闸口
Tidal slough traverses low-lying land with primary and secondary sluicegates
6-7 将水排放到低洼地带所通过的水闸
Sluicegate to allow discharge onto low-lying land
6-8 低洼地带
Low-lying land
6-9 外围堤防以外设置广泛的可灌溉（可被淹没）土地
Extensive floodable land outside perimeter dike
6-10（穿越水面或湿地的）堤道
Causeway

论，但也通过引导气流从较冷的水面流向道路、庭院和房屋的方式来改善微气候。黄埔村的梳式结构比其他村庄更复杂。以不同方向面对池塘和运河的祠堂决定了村庄的整体结构[5]。

与梳式村庄相比，岛屿东端的新洲村遵循严格的线性布局。新洲村与珠江后河道有直接关联。如今的珠江后河道仍然作为跨河、跨海航行的通道被充分利用着。黄埔以北的东围村地处于历史悠久的农业片区中，它的北面是一片菜地，这个村庄也遵循梳式结构布局（图 7）。

由于社会和自身方面的原因，渔民新村没有一个正式名称。这个村庄位于朝南的海岸，因此会直接暴露于浪潮与台风的危险之中。这些村民与琶洲岛上的其他社群相隔离，也没有正规道路作为连接，只能通过步道和水相连。高达 4 层的结构建在船上，水在下方流动。渔民新村是疍家人的聚居地，疍家人在粤语中是用来描述“船屋住民”的贬义词。流行的理论认为疍家人是自史前时代以来居住在中国南方的少数民族——“百越族”的成员。当汉族人在宋代从中国东部迁移到三角洲时，百越人则流亡到广阔的河流上，在船只和舢板上生活[6]。村民们现居住于陆地上，但在日常运作与宗教信仰上仍与水保持着密切关系。村里年长的居民也仍以在码头和船只上钓鱼为生（图 8）。

琶洲岛的东部有一个造船厂，在 20 世纪 70 年代末改革开放之前曾用于制造渔船。造船厂和工人宿舍现已闲置。目前，一些厂房被改造用于新技术产业。岛上其他地方的其他轻型制造和后勤设施已被拆除或重新用于与设计有关的活动或其他活动。

我们难以准确估计 6 个村庄的现有人口。因为村庄里包括大量的租户，他们仍保留农村户口，流动到广东寻找就业机会。在我们的设计中，按照琶洲东区未来有 30 000 居住人口的预期进行设计[1]。作为设计目标，建议保留（并在可能的情况下改善）所有村民的赖以生计的工作，并避免重新安置现有的租户。岛上的低收入居民就业机会将增加，并为目前年轻务工人员保留足够的供出租房屋。如果岛上所有可用的土地都用于开发新的商业用途，则可能无法满足该人口预期下的住房需求。基于此，笔者于 2019 年 1 月进行了一次实验性设计。

4 城市设计作为检验政策影响的工具

广东省和广州市目前的政策是集中利用琶洲东部作为新兴广州多核心湾区的就业中心。地铁线和轻轨线延伸段的建设已获批资金。从琶洲展馆到机场和广州南站的快速列车线路也在修建当中。岛上也计划增建几条隧道，以辅助现有的位于岛屿最东端的两座桥，满足往来车流量的需求。

在实验性设计中，建议政府不仅应支持商业办公的开发，也应更多地支持住宅用地建设，来创造一个与已建成亟待建成的公交系统充分结合，而对汽车依赖性更小的社区。通过建设覆盖全岛的公共交通，给出开车出行的替代方案。对于这 2 种开发方案，都假设未来的商业和住宅楼面积比将为 6∶4。

广州环城高速以东总面积 306 hm^2。黄埔村和历史港口占地 37.5 hm^2，二者都受到遗产保护条例的保护，应从总面积中剔除。黄埔

村包含大量“不可移动的文物”，它们受到严格的规章保护。剩下的 5 个村庄占地总面积 92 hm^2，但受到保护的级别与黄埔村并不相同。因此，可以在环城公路以东开发 270 hm^2。如果在环城公路的西北部增加 72 hm^2 的东围村土地，可开发土地总面积将达到 340 hm^2。由于政府当下已经在与东围村民谈判购买村里集体所有的土地，因此将东围村土地纳入规划蓝图是切合实际的。另一方面，340 hm^2 土地同时进行开发也是不现实的。因此，对 2 个方案进行比较：第 1 种方案将开发 270 hm^2，并留下 70 hm^2 作为部分村庄自主发展用地。第 2 种方案将 170 hm^2 土地用于开发，并将保护所有村庄现有的低洼农田。通过对季风时节雨洪量的计算，得出岛屿东部所有适宜蓄水（包括水道、池塘和湿地）的低洼土地的范围。该类土地面积约 80 hm^2，是 2 种方案下对土地面积利用率的主要差异。2 种方案中都采用了相同的建筑覆盖率与平均容积率（0.25）。

2 种方案都使商业开发集中在地铁站附近。方案 1 在未来的 3 个地铁站周边都采用了商业集中开发模式，形成脊状结构的超高层建筑群。方案 2 则在中央地铁站周围形成了一个山丘状超高层建筑群。拟建的地面轻轨服务将延伸至岛的东端，并可能继续延伸形成完整环状交通。在 2 种方案中，轻轨都将为岛上的居民服务（图 9）。

这 2 种方案在治水策略上有所不同。方案 1 依赖于道路、开放空间与停车区域地下的储水箱储水。百年一遇的暴雨将会给琶东带来 1 077 548 m^3 的降水量。将这些雨水储存于道路、停车场和建筑地下将需要极大容量且极昂贵的蓄水箱。更可持续而不易发生故障的是方案 2，它将保留现有的 80 hm^2 河涌与低洼土地来储存雨水。这 80 hm^2 的低洼土地足以储蓄上述的所有降水，水深为 1.34 m。然而，径流路径需要被设计以适应现实中水流的集聚，这意味着部分无法及时排水的地区需要建设一些蓄水设施。地表径流可以被引流至砂滤器过滤后排入潮汐涌。

5 结论：应对气候变化的原因和后果

以上 2 个方案都会遭到当权者的质疑。现有的琶洲岛东部未来蓝图中，只有商业办公楼的开发，而没有新的住宅开发项目。文中阐述的 2 种方案都包括了新住宅社区的建设。同样，文中所示的以街道为核心的城市形态与中国当代城市开发模式并不一致。在我们的设计中，以街道为核心的城市形态，弱化以往特定街区的单一高层塔楼周围常见的开放空间。积极地利用街区外围的道路将促使人行道更多地被行人使用。该设计方案鼓励人们沿着绿树成荫的街道行走，并且街道两侧有面向街道的住宅入口或有商铺开放。住宅与办公结合开发，并提高街区的步行方便程度，将降低人们对汽车的依赖性；若两者共同应用，将使琶洲岛未来的新发展更为低碳可持续。

也许有人会提出更进一步的质疑：村庄附近的低洼土地目前被视为未来城市发展中具有潜力的开发区域。然而，如方案 2 中所提出的保留所有低洼土地用于蓄水的观点与目前的发展战略相矛盾。关于这一点，在我们的设计过程中，的确有人提出，琶洲岛的未来发展应符合世界级标准。世界范围内的三角洲地区，发展战略正在发生出乎意料的变化[7]。气候变化要求必须为应对雨洪灾害而考虑设计的适应性。这些曾经被认为极端和罕见的自然状况，现在更为频繁地发生。琶洲岛需要的世界级设计，必然应长远地为未来可能的灾害做好准备。因为这样的远见将有助于预防实体层面以及社会层面上的灾难。

纵观历史，由珠江水系至南海间的平缓坡度[3]使远洋航行的轮船能够到达位于距离海洋 120 km 内陆上的广州。每天 2 次涨潮使船只能够乘浪上升，而黄埔港的锚地也因此欣欣向荣。未来的每一天仍将潮起潮落，潮水亦会日复一日地来到广州。但由于海平面上升的缘故，海潮之于广州将由优势转变为一种负担。在暴风雨后，河流系统中更高的水位对蓄水量的需求将十分巨大。方案 1 中将 270 hm^2 用于开发，雨洪防护几乎依赖于路面地下的蓄水箱来完成，建造和维护成本很高。方案 2 则只允许在 170 hm^2 的土地上进行开发，并保留琶洲岛上的 80 hm^2 低洼土地作为湿地以储存雨水，直至堤坝外水位下降后排放进入河流系统中。

根据实验，笔者建议采取以下治水策略：

1）在东部琶洲岛内满足其自身蓄水需求。

该政策下将保护目前用作农田的所有现存低洼土地。在未来，这片土地将要作为湿地并被设计成能够在暴风雨后储水的形式。这将意味着我们需要重新设计琶洲岛外围的水闸和潮汐涌断面。

2）保护琶洲岛周边免受浪潮威胁以及预防洪水淹没堤坝、海堤或防护堤。

本策略意味着将岛外围堤坝强制性高度从目前海拔 8.68 m 提高到海拔 9.50 m。外围防护的设计有多种方式，本文已对它们进行了解释说明（图 10）。

致谢：

文中所提及的工作内容得到了琶洲概念性城市设计国际工作坊，孙一民工作室与华南理工大学的鼎力支持。合著者：Eleni Oikonomaki、Andrew Salmon、施德松、Preeti Shrinivasan、孙思晗、陈碧琳、王登月、薛明琦、朱明熙、怀露、罗苑菁、卢培骏、李凡姝、蔡梓煜，图像处理：李诗瑶。

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图表来源：

图 1 作者梁石友（广东省中山图书馆藏）；图 2© 香港科技大学；图 3©The Picture Art Collection / Alamy Stock Photo；图 4©Niday Picture Library / Alamy Stock Photo；图 5~10 为作者绘；表 1~3 为作者绘。

（编辑 / 王一兰）

Pazhou island is located between two branches of the Northern Pearl River and the Whampoa Canal in Guangzhou. The island has become part of the city's financial, media and technology, trading and exhibition district. The ambitions go further to make the island an important center in the emerging Guangzhou, Shenzhen, and Hong Kong, Macao polycentric metropolitan region, referred to as the Greater Guangzhou Bay Area. Since 2003, the island's central portion has hosted the Canton Fair inside new mega structures, Zhujiang New Town followed to the west of Pazhou Island with the Canton Tower as Guangzhou's prominent landmark that opened for the Asia Games in 2010. The western portion on Pazhou Island is currently developed into a New Technology and Internet — Media concentration. By contrast, development on the eastern portion of the island is officially characterized as unbalanced with a deteriorating environment and a damaged eco system[1]. This article focuses on the eastern portion of the island. We report on an urban design experiment to test two contrasting development scenarios. The first utilizes all land available on the eastern portion of the island, the second scenario develops only two thirds of the available land and leaves all existing low lying land undeveloped, to accommodate water from intense typhoonal rains. Both scenarios protect the island from riverine flooding, and tidal surges. We justify our experiment by reviewing the natural and cultural history of Pazhou Island and by computing the water storage needs of the island under the two development scenarios.

The fluvial history of the Pearl River Delta is highly complex. What is now a delta with eight interconnected tidal estuaries, was a shallow inland sea in the second century AD when Guangzhou originated at the northern shore of this large body of water, a bay of the South China Sea. The location for the city was well chosen because Guangzhou originated on the south-facing slope of the Guanyin Mountain, on higher ground above the reach of floods. Through time the inland sea transformed into a hydrographic net of steams and tidal sloughs. Robert Marks (1998) gives a fascinating portrait of the region in his *Tigers, Rice, Silt and Silk: Environment and Ecology in Late Imperia.* Taking a long range view into the past, the book documents how the riverine environment was shaped by natural forces and anthropogenic changes. Tigers are mentioned in the title of the book, because the land around the delta was once densely forested, and tigers lived on in place names and village folklore. Rice is because of the prosperous rice growing culture (supporting two harvests a year) that flourished in the dike and pond landscape created by farmer-built levees. The rivers transported silt from the mountains. Farmers used the material and cultivated more and more flat and easy to cultivate islands. Lastly in the Qing Dynasty, the silk industry emerged utilizing leaves from Mulberry trees that farmers planted on the levees[2].

Many islands grew as deposits in the lee of rock outcrops. Pazhou Island is such an island, alluvial deposits having accumulated between two outcrops. One outcrop served as the foundation of the Ming Dynasty Hai-o, or Pazhou, Pagoda, which was one of three pagodas that directed sailing ships on their ascent up the Humen (Tigris) Estuary to Whampoa Harbor (Fig. 1, 2). Whampoa Village, just above the historic port, occupies the second rock outcrop. Whampoa was not strictly speaking an agricultural village; it was a settlement oriented

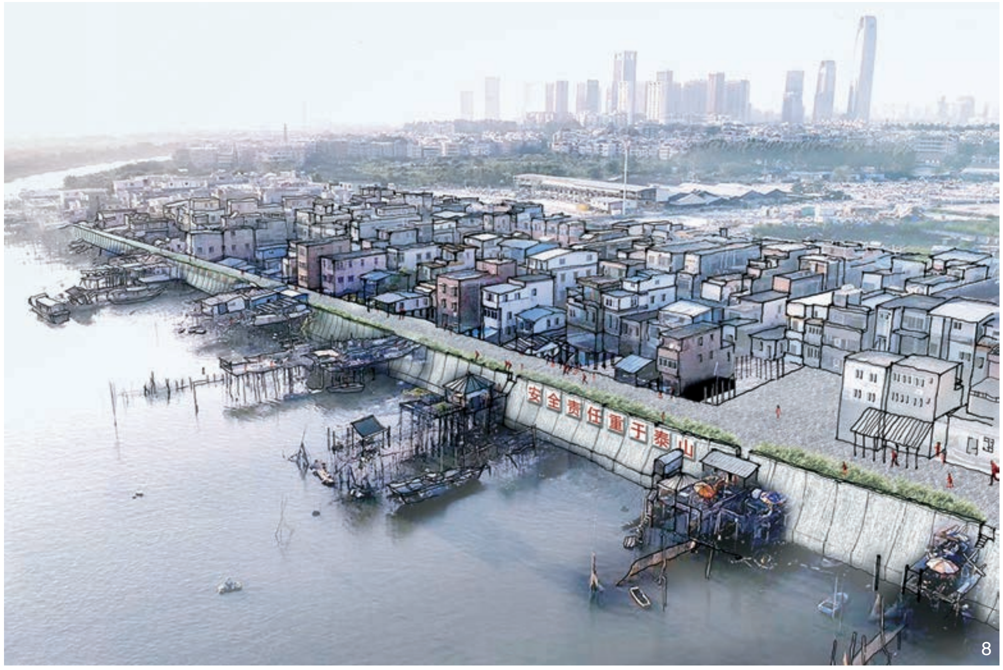
7

7 5 个村庄及它们毗邻的低洼地带都在图中展示出来。低洼地区的总面积，包括方案 2 中的“中央公园”，面积为 $80\ hm^2$

The five villages are shown with their associated low lying land. The land area of all low-lying land, including the "central park" in Scenario TWO amounts to $80\ hm^2$

7-1 杨青村 Yangqing village
7-2 东围村 Dongwei village
7-3 石基村 Shiji village
7-4 新洲村 Xinzhou village
7-5 渔民新村 New Fisherman's village
7-6 黄埔村 Whampoa village

to trade with foreigners. Here cargo was trans-loaded onto sampans and shipped further inland on rivers and canals (Fig. 3, 4).



8 海堤对渔民新村的保护（设想手绘图，基于谢光源拍摄的无人机照片绘制）
Protection of the New Fisherman's Village by a seawall. (Sketch based on a drone photo by Aaron Xie)

1 Living with Rain Water and Floods

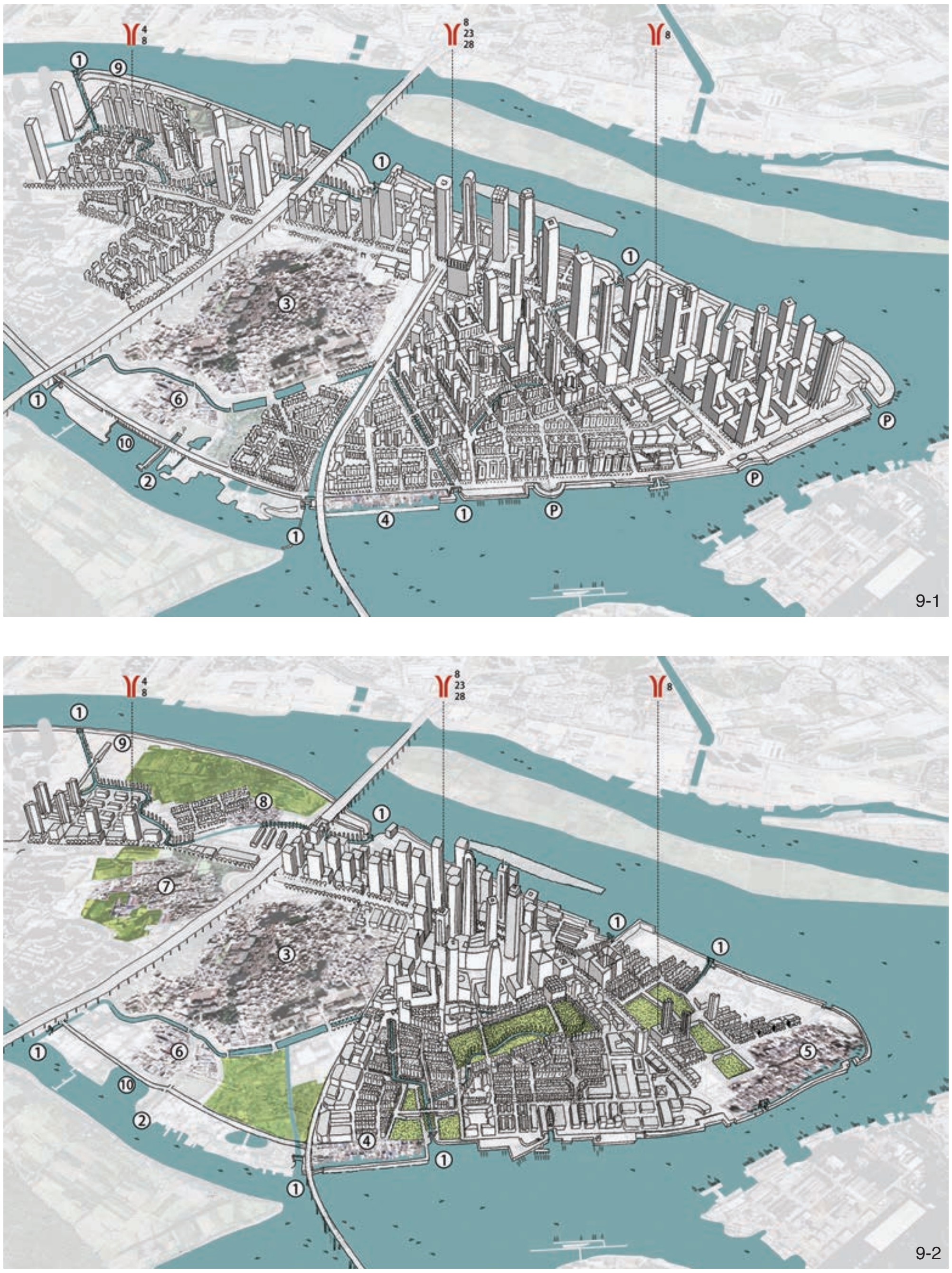
Throughout history floods changed the contours of the island's shore. Records from the Qing Dynasty report 44 major floods from 1736 to 1839[3], an average of a major flood every 2.4 years. These floods carried sediments from the river basin, much of which was deposited in the delta reaches such as Guangzhou. The floodwaters rearranged previously deposited sediments, so that island shapes and extents changed with each large flood. The resulting alluvial islands are low-lying and continue to be subject to flooding.

Like other low-lying alluvial islands in the Pearl River Delta, Pazhou Island is threatened by floods from two sources: local urban floods from intense rains ("in-flooding") and overtopping of protective dikes by high river stage or storm surge ("out-flooding"). Protecting against these two distinct threats requires different strategies. The first type of flood is essentially a matter of more rain falling than can be drained away, resulting in urban "street flooding". During high river stage or high tide, the eastern portion of Pazhou Island functions like a bathtub, protected by levees on the north, east and south sides. Because water levels outside the levees are higher than the land inside the levees, it is not possible to drain out all the accumulating rain water. Pumps can be used, but pumps may not be sized to keep up with the rate of water accumulation during intense rains, and without reliable emergency generator power, pumps become useless in the event of power failure.

During intense rains, run-off from a land-area of approximately 400 hm^2 is now absorbed by six sizeable tidal sloughs that dissect the eastern portion of Pazhou Island (Fig. 5). The sloughs generally run in a diagonal pattern through former and still used agricultural fields. The Nianfeng Tidal Slough in the south east is still lined with trees and shrubs on levees. Depending on tidal action, this slough has a two directional flow to its outlets on both sides of the island, where tidal flow can be controlled by mechanically operated sluice gates. In the past the Xinzhou and Hexing Tidal Sloughs connected to the Whampoa Village perimeter canal. Both sloughs meet the Nianfeng Slough, and together they drain the south facing slope of Whampoa Village. The north facing slope of Whampoa Village drains into the Da Tidal Slough and Sand Tidal Slough, where tidal flow is also controlled at two sluice gates on the island's northern shore. These tidal sloughs work well to drain the island after rains so long as river levels outside the perimeter dikes remain relatively low. However, if flood stage in the river persists, and during tidal surge, rain water cannot drain because the water level outside the dikes remains higher that the water level within.

Thus having the capacity to retain to retain water in low lying areas of the island can be a critically important strategy to survive intense rains without floodwaters damaging buildings. Depending on soil permeability, there could be seepage of water upward from the ground, driven by the hydraulic gradient created by the higher water levels outside the perimeter dikes. We have calculated the water storage needs by multiplying the depth of precipitation expected in an intense storm by the area over which the precipitation falls. For this calculation, we assume infiltration of water into the soil would be negligible, in light of the anticipated high water table and saturated soil conditions. The 37-year record of annual maximum 24-hour rainfalls from 1981 to 2017 (measured at Sun Yat-sen University, Tab. 1, 2) shows that 24-hour rainfall totals have exceeded 210 mm four times, suggesting such rainfalls are roughly decadal in return frequency.

What volumes of rainwater can we expect in this 100-year rainfall? A 24-hour rainfall of 265 mm over eastern Pazhou Island yields 1,077,548 m^3 (Tab.3). Assuming no water lost to infiltration (given the high water table likely during 100-year storm conditions), this full volume of water needs to be stored. We next ask how much room is required to store this water. Spreading this 100-year storm volume over the existing 80 hm^2 of slough and low-lying land would result in an average water depth of 1.34 m. The existing topographic differences between



9

图例 Legend：
1 闸门 Sluice gates
2 黄埔老港遗址 Historic Whampoa pier
3 黄埔村 Whampoa Village
4 渔民新村 New Fisherman's Village
5 新洲村 Xinzhou Village
6 石基村 Shiji Village
7 杨青村 Yangqing Village
8 东围村 Dongwei Village
9 新隧道入口 New tunnel entrance
10 堤道 Causeway

9-1 方案 1：利用 270 hm^2
Scenario ONE utilizing 270 hm^2

9-2 方案 2：利用 170 hm^2
Scenario TWO utilizing 170 hm^2

higher areas and the low-lying lands are sufficient that in most cases the water can be contained by existing topography, elsewhere small berms would be needed around the margins of the wetlands to prevent overflow into built-up areas. Additional storage could be developed in underground galleries beneath roads, parking lots, and buildings, but this storage would be expensive to build and more prone to malfunction in operation. If eastern Pazhou Island were to be fully built out, without preserving the existing 80 hm^2 of wetlands, such underground storage would seem the only remaining option to manage this stormwater. The stormwater cannot be ignored without grave threat to investments on the island.

Our analysis of storm water leads to an important implication for future land use on the island. The existing 80 hm^2 of slough and adjacent low-lying wetland, if flooded to an average depth of 1m, should be sufficient to store the 1,077,548 m^3 of rainwater accumulated over a 24-h period in the 100-year storm, with an average depth of 1.34 m. Storing water in underground culverts and reservoirs would be expensive, and would be more prone to failure than preserving wetlands to store water. If we can retain all the runoff in the 80 hm^2 of sloughs and adjacent low-lying land, the greater reliability and decreased costs seem like strong arguments for preserving them. In light of more intense storms anticipated with climate change, it would make sense to build in additional storage, perhaps ensuring that an average depth of 1.3 m of water can be retained on the island.

2 Protecting Against High River Levels and Tidal Surge

The perimeter of eastern Pazhou Island is protected from riverine flooding by dikes, but the perimeter of dikes is incomplete, and in places evidently too low. The water authority's flood control standards call for a levee with an elevation of 8.68 m above sea level. The actual elevation of the flood control dike on the islands northern shore is only 8.05 m. On the south-eastern shore the levee elevations are even lower at 7.10 m, 6.95 m[1]. In some places along the south-eastern shore, dikes do not exist, exposing these areas to flooding in even relatively small, frequent floods. The highest tide during typhoon Mangkhut on September 15, 2018 reached 8.227 m above mean sea-level at the Su Yat-sen University tide-gauge station, about 10 km upstream of eastern Pazhou Island). In a combined tidal surge and typhoonal storm event, with rainfall having nowhere to go except to be pumped up and over dikes into the adjacent flooding river, the dikes could overtop and extensive flooding could result. A critical issue with overtopping dikes is the integrity of the dikes, and the danger of their failing catastrophically, releasing a fast-moving wall of water that would be lethal to human settlements. In recent decades the frequency of so-called "100-year floods" has increased[4], and with acceleration of sea-level rise, even a continuous dike system at 8.68 m elevation would have to designed to be adapted to higher elevations in the future. It is not clear to what extent the water authority's standards for flood control dikes include consideration for run-up of wind driven waves, commonly accounted for by increasing the levee height over the anticipated water level. (Height above the expected water surface is often termed "freeboard" and is commonly set at 0.9 m in the US.). Certainly under future conditions of higher sea level and greater extremes in weather patterns, higher flood levels seem inevitable. We therefor recommend to raise the dikes to at least 9.5 m above mean sea level (Fig. 6).

3 The Villages on Pazhou Island

Whampoa Village is the largest and oldest of the six villages on Pazhou Island. Since the Song Dynasty, the anchorage at Whampoa was well known to mariners around the world. During the Qing Dynasty all foreign ship were forced to terminate their journey to the south-east of Pazhou Island at a natural harbor in the lee of hills located on an island to the Southeast of the Whampoa anchorage. Sailing ships would use the monsoon winds to arrive here between June and September and depart in November to February. During their time at the anchorage cargo was trans-loaded to sampans and taken to Guangzhou. Ships and riggings were repaired locally at Whampoa village. The contact with foreign crews supported a local industry and an openness to the world different from what could be expected in rural villages elsewhere. As a result, the character of Whampoa Village remained distinct and different from the other five villages on Pazhou Island.

Shiji Village to the south is virtually attached to Whampoa. Likewise, across the elevated Guangzhou Beltway, Yangqing Village to the north east is integrated with more recent development. All three villages follow a comb shaped layout with houses constructed in rows, one behind the other. The layout is referred to as combs because the rows are organized in parallel lines following ancestral halls and arranged perpendicular to perpendicular to canals or ponds. The layout follows Chinese geomancy, but also provides improvements to micro-climate by allowing for an ambient wind-flow to move from the cooler surface above water to the lanes, courtyards and homes. The comb structure of Whampoa Village is more complex than in other villages. Ancestral halls with varied orientations to ponds and canals gave shape to the overall structure of the village[5].

In contrast to comb shaped villages, Xinzhou Village on the eastern tip of the island follows a strictly linear layout. This village has a direct relationship to the Zhujiang Back Channel, which is still heavily used by river and ocean going navigation. Dongwei Village to north of Whampoa exist in the historically agricultural setting with vegetable fields to the north. This village also follows the comb structure layout (Fig. 7).

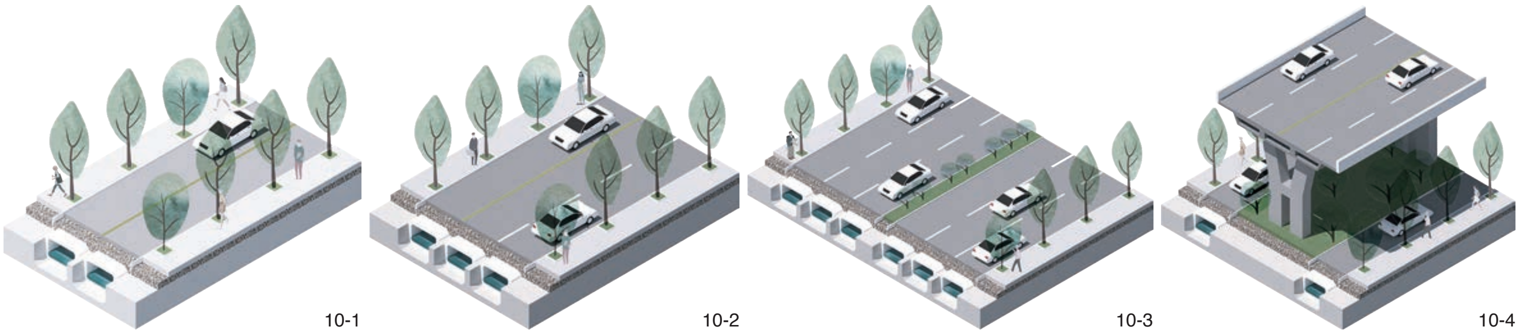
Remarkable for social and physical reasons, the New Fisherman's village does not have a proper name. Located on the south facing shore this village is directly exposed to tidal surge and typhoonal rain events. The villagers live isolated from the communities on Pazhou Island, not connected by formal roads, but connected only by foot-path and water. Structures of up to four stories in height are built on pylons with water flowing below the ground floor. The fishing village has the reputation of being home to Tanka people, a derogatory label used in Cantonese to describe "Boat Dwellers". The prevailing theory considers the Tanka as members of an ethnic minority known as Baiyue who lived in Southern China since prehistoric times. The Baiyue people took refuge in the extensive river system to live on junks and sampans, when Han Chinese migrated to the delta from eastern parts of China during the Song Dynasty[6]. The villagers live now on land but maintain a strong functional and probably also a ritual relationship to the water. Fishing from jetties and boats continues to provide income to the older village members (Fig. 8).

The eastern portion of Pazhou Island included a shipyard where fishing boats were built prior to the opening of China's economy in the late 1970's. The shipyard and the dormitory for its workers stays empty. Some buildings are currently repurposed for new technology industries. Other light manufacturing and logistics installations elsewhere on the island have been demolished or repurposed for design-related or other activities.

An accurate estimate of the current population in all six villages is difficult to obtain because of the large number of residents who rent living space in the villages, but maintain their residency registration in the rural districts from where they migrated to Guangdong Province in search of employment. During our work we used estimates of 30,000 inhabitants on the eastern portion of the island[1]. As a design objective, we propose to preserve (and where possible improve) the livelihood of all villagers, and avoid the relocation of the current rental population. Jobs on the island for lower income residents will become available and the current housing needs for a younger working population require the retention of sufficient rental units. It may not be possible to meet the housing needs of this population if all land available on the island is developed for new commercial land-use. This last observation brings us to the design experiment we conducted in January of 2019.

4 Urban Design as the Tool to Tests the Implication of Policy

The current policy of Guandong Province



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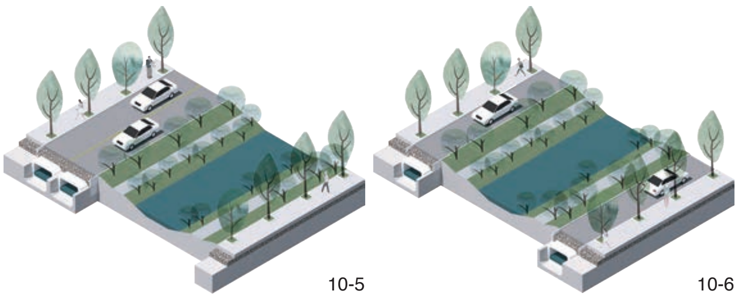

10 一组阐述琶洲岛蓄水策略的详细示意图
A set of detailed drawings that illustrate water-storage strategies on Pazhou Island
10-1 双车道与地下储水箱
Storage vaults under a dual lane road
10-2 三车道与地下储水箱
Storage vaults under a three land road
10-3 六车道与地下储水箱
Storage vaults under a 6-lane road
10-4 抬高的道路
Elevated roadway
10-5 与低洼河涌相邻的双车道
Dual-lane roadway with slough
10-6 河涌两侧的单车道
Two one-way roadways with slough

and the City of Guangzhou is to intensively use the eastern portion of Pazhou as an employment center in the emerging Guangzhou Polycentric Bay Region. Funding is committed for extensions of the Metro and light rail system. Rapid train service is under construction to connect the exhibition pavilions on the island to the airport and to Guangzhou's new South Railroad Station. Several roadway tunnels are also planned to support vehicular access that is currently limited by the capacity of the island's two easternmost bridges.

In our design experiment we recommended that the government not only permit commercial office development, but also include residential use to create a community that is less automobile dependent and more related to the significant transit investments that have already been made and are committed in the future. Distances on the island are manageable for transport that is alternative to single occupancy automobile traffic. For both development scenarios we assumed a 60 to 40 percent split between future commercial and residential floor space.

A total of 306 hm^2 is located to the east of the Guangzhou Beltway. The 37.5 hm^2 that Whampoa Village and the historic port occupy need to be subtracted. Both are protected through heritage conservation. Whampoa Village includes a large number of "immovable cultural relicts", which are subjects to strict preservation rules. The five remaining villages occupy a total of 92 hm^2 of land, but do not necessarily enjoy the same protection. Thus 270 hm^2 could be developed to the east of the Beltway. If we add the 72 hm^2 of Dongwei Village land to the north-west of the Beltway, the total developable land would amount to 340 hm^2. It is realistic to add the Dongwei Village land as the government is currently negotiating with the Dongwei villagers to purchase their collectively owned land. On the other hand, it might be unrealistic that all 340 hm^2 would be developed at once. We therefore decided to compare two development scenarios, one based on 270 hm^2 that would leave 70 hm^2 for "autonomous" upgrading of some villages. The second scenario utilized 170 hm^2 for development and would preserve all villages with their low-lying agricultural land. Informed by our calculation of flooding from torrential rains during the monsoon season, we computed the extent of all low lying land on the eastern portion of the island that is suitable for water storage in the form of waterways, ponds and wetlands. This land includes approximately 80 hm^2 and accounts for the main difference in land area utilization between the two scenarios. The land coverage by buildings and the average floor area ratio of 1∶4 were kept the same for both scenarios.

Both scenarios concentrate commercial development around metro stations. Scenario ONE does so in utilizing the land around all three future station, thus creating a ridge like configuration of high-rise structures. Scenario TWO creates a hill configuration around the central metro station. The proposed surface light rail trolley service will continue to the eastern tip of the island and possibly beyond to form a loop. The light rail will serve the residential communities in both scenarios (Fig. 9).

The two scenarios differ with regard to water management strategies. The 100-year rainstorm of 265 mm (over 24 h) would yield 1,077,548m^3 of water over the eastern Pazhou Island. Storing such volumes under roads, parking lots, and buildings (Scenario ONE) would be a massive and expensive undertaking. More sustainable and less prone to failure would be Scenario TWO, which would retain the existing 80 hm^2 of sloughs and low-lying land to store stormwater. The entire volume of the 100-year, 24-hour storm could be accommodated by the

80 hm^2 of low-lying land with an average depth of 1.34 m. However, the likely flow paths would need to be modeled to properly account for actual accumulations of water, which might require some constructed storage in some areas that could not drain to the sloughs quickly enough. Road runoff could be directed to sand filters into the -sloughs.

5 Conclusion: Responding to the Causes and Consequences of Climate Change

Both development scenarios for the eastern portion of Pazhou Island will be met with skepticism by the permitting authorities. Only commercial office development and no new residential development is currently envisioned for the eastern portion of Pazhou Island. Both scenarios shown here include new residential communities. Likewise, the street oriented urban form illustrated here is not consistent with the contemporary development process in China. Our urban blocks with their street oriented urban form ignore the customary open-space around a single high-rise tower on a given urban block. In our view, however the active use of streets around the perimeter of urban blocks is necessary in support of pedestrian activities on sidewalks. The designs illustrated here encourage walking along tree-lined streets that have an active frontage with entrances to residences and commercial activities. The inclusion of residential uses with office development and greater walkability will lower automobile dependency; both together will reduce the carbon footprint of new urban development on Pazhou Island.

Skepticism will go further: the low-lying lands near villages are currently viewed as opportunity sites for future urban development. The preservation of all low- lying land for water storage purposes, as shown in the second scenario, contradict current development strategies. During our work, we were reminded that future development of Pazhou Island should meet world-class standards. In delta regions world-wide, development strategies are changing in ways that have not been considered in the past[7]. Climate change will call for adaptability of designs to anticipate flooding conditions. These conditions, once considered extreme and rare, are now more frequently occurring. A world-class design of Pazhou Island would take a long range view that prepares urban districts for catastrophic events, simply because such foresight will help prevent physical and social disasters.

Throughout history, the extremely low gradient of the Pearl River system towards the South China Sea[3] allowed ocean going vessels to reach Guangzhou, 120 km inland from the sea. The twice daily incoming tide made that ascent possible, and the anchorage at Whampoa harbor thrived. In the future high tides will continue to reach Guangzhou, but rising tides due to sea-level rise will turn this historic advantage into a liability. Higher water-levels in the river-system will require substantial water storage capacities after storm events. The first scenario that makes 270 hm^2 available for development would depend on extensive storage vaults below all streets which are costly to construct and to maintain. The second scenario would only allow development on 170 hm^2 and preserve 80 hm^2 of low-lying lands on Pazhou Island to serve to store run-off water until it can be discharged after the water level in the river-system outside the levees recedes.

As a result of our experiment we recommend the following water management policies for consideration:

1) Manage Water Storage Needs Locally on the Eastern Portion of Pazhou Island.

Implied in this policy is the preservation of all existing low-lying land that is currently used as farmland. In the future this land will be needed as wet-lands to be designed for water storage after typhoonal storm events. The work will imply a redesign of the sluicegates around the island perimeter and a redesign of tidal slough cross-sections.

2) Protect the Perimeter of Pazhou Island from Tidal Surges and the Associated Over-Topping of Levees, Sea-walls or Embankments.

Implied in this policy is the raising of the perimeter elevation from the currently mandatory 8.69 to 9.5 m above sea-level. A variety of perimeter designs are possible, and they have been illustrated in this article (Fig.10).

Acknowledgments:
The work described in this article received generous support from the International Conceptual Urban Design Workshop for Pazhou Area, Professor Sun Yimin's Studio, South China University of Technology.
Co-authors: Eleni Oikonomaki, Andrew Salmon, SHI Desong, Preeti Shrinivasan, SUN Sihan, CHEN Bilin, WANG Dengyue, XUE Mingqi, ZHU Mingxi, HUAI Lu, LUO Wanqing, LU Peijun, LI Fanshu, CAI Ziyu, and image processing by LI Shiyao

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(Editor / WANG Yilan)