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The Largest Megalopolis in the World: Assessing the Urbanization of the Pearl River Delta

世界最大的城市集群：评估珠江三角洲地区的城市化

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娄艾苓女士的教育背景和杰出的职业生涯纵横环太平洋地区，顺应时势需求用自身的国际视角和专业知识去解决该地区快速城市化的各种挑战。作为SOM旧金山办公室的城市设计与规划总监，她主持设计了多个关键大城市核心的开创性发展战略。对创建可持续发展的未来，城市是最大希望。在这样的时代，她的工作实践帮助城市制定利于未来发展的明智规划。娄女士经常受邀到国内外担任演讲嘉宾，并定期向规划官员和开发社区提供咨询服务。

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Abstract | 摘要

With the world's urban population expected to increase by roughly 2.5 billion people by 2050, developing an understanding of megalopolises is critical to understanding and shaping this trend. The Pearl River Delta, with over 55 million people, is one of the most populous urbanized areas in the world. This paper explores its growth, the resulting social and environmental effects, as well as strategies for the region's future. It presents historic and current urbanization facts of the Pearl River Delta, comparing it to other urbanized regions of the world. Questions of scale, growth, social and economic benefits and drawbacks, and the future viability of megalopolises have global applicability, and the authors will summarize key issues and future strategies for the Pearl River Delta.

Keywords: Cities, Environment, Infrastructure, Megalopolis, and Urbanism

世界城市人口到2050年预计增长大约25亿，要理解和引导这一趋势的关键就是对特大城市和城市集群进行透彻的了解。拥有超过5500万人口的珠江三角洲地区是世界上人口最多的城市化地区之一。本文探讨了它的发展、由此带来的社会和环境的影响，以及该地区的未来发展战略。文中介绍了珠三角地区城市化的历史和现况，并与世界其他城市化地区进行比照。特大城市和城市集群的发展规模、增长、对社会和经济发展的正面和负面影响，以及未来可行性等问题具有全球适用性，笔者将总结珠江三角洲地区的主要议题和未来发展策略。

关键词：城市、环境、基础设施、巨型城市、城市化

The Pearl River Delta (PRD) is a unique urban agglomeration formed by the evolution of eight primary cities into a singular "megacity" of 55 million people – by some estimates, the largest city in the world (World Bank, 2015). Emerging from small, separate cities at the beginning of the 20th century, the PRD has evolved into one of the most powerful economic regions across the globe, manufacturing everything from sophisticated electronics to simple household commodities (Figure 1).

This economic and urban evolution has not been without its difficulties, however, especially in the realm of transportation, quality of life, and the natural environment. Today, the PRD is characterized by diminished ecological systems and water and air-quality standards below the global average. For the PRD to prosper as a megacity, it must first act as unified urban entity in comprehensively addressing the issues of urbanization, transportation, and the environment.

Located within the province of Guangdong along the southeastern coast of the People's Republic of China (PRC), the PRD is a vast region of land and water with a total area of 40,000 square kilometers – approximately the same size as the Netherlands. The PRD, as

珠江三角洲地区（珠三角地区）是一个由八大主要城市组成的独特城市集群，预计其将发展为一个拥有5500万人口、世界最大的“巨型城市”（世界银行2015年数据）。珠三角地区兴起于20世纪初分散的小型城市，现已发展为世界上最强大的经济区域之一，该区域内的制造业涉及从精密电子到小家电的各种商品（图1）。

这一地区的经济和城市发展并非一帆风顺，尤其在交通、生活质量及自然环境方面。如今的珠三角地区呈现出生态系统退化以及水质和空气质量低于世界平均标准的特点。为了促进珠三角地区作为全球性巨型城市的蓬勃发展，必须使其形成一个城市统一体，全面地解决城市化、交通和环境问题。

珠三角地区位于中华人民共和国（PRC）广东省境内的东南沿海地区，陆地和水域总面积4万平方公里，大约相当于荷兰整个国家的面积。根据广东省的定义，珠江三角洲地区包括广州、深圳、佛山、东莞、中山、珠海、惠州、江门、肇庆共9个城市。本文中的珠三角地区指大珠江三角洲，包括香港特别行政区、澳门特别行政区，以及广东省境内的9个城市。

珠三角地区发展为巨型城市（经济统一体）的历程可追溯到1978年中国领导人邓小平当政时期。邓小平推动了该地区变

defined by the Guangdong Province, includes nine municipalities: Guanghzou, Shenzhen, Dongguan, Foshan, Jiangmen, Zhongshan, Zhuhai, Huizhou, and Zhaoqing. The term PRD in this paper refers to the Greater Pearl River Delta, which includes the Hong Kong Special Administrative Region (HKSAR), the Macao Special Administrative Region, and the nine municipalities in the Guangdong Province.

The PRD's evolution as a megacity – an economically-unified urban region – can be traced to the rise of Deng Xiaoping, who emerged as the leader of China in 1978. Deng was the catalyst for change in the region, initiating negotiations for the return of Hong Kong to China and establishing the city of Shenzhen as a China's first Special Economic Zone. Deng set into motion many of the concepts and policies that would place the PRD on its new course – a transformation that continues today.

The geography of the PRD is characterized by the intermingling of land and water within an immense topographical basin of over 200 kilometers (124 miles) in diameter that gives the PRD its distinctive physical geography, one which has, in turn, directly influenced its economic and urban evolution. The PRD has a unique estuarine wetland, framed by pronounced ranges of hills and mountains, and is approximately 20 percent water, 10 percent intertidal wetlands and 70 percent land (Figure 2).

Landforms can be characterized by several major systems: first, by a series of rugged eastern coastal ranges that contain the interior rivers, bays, and wetlands; second, by the extensive interior plains on which most cities have emerged; and third, by the hills and mountains in the west, north, and south that frame the delta lowlands. The PRD's hydrology is defined by four major systems including rivers, wetlands, tidal estuaries, and coastal environments. The Pearl River itself is formed by three tributaries that join together near Guangzhou – the North, West, and East Rivers.

The PRD is a unique megacity, and offers many lessons regarding what other large urban agglomerations will be facing as they grow to a similar magnitude. This history and the lessons-learned can be grouped into three main categories for analysis: urbanization and development, transportation, and the environment. As the following assessments and case studies illustrate, there are many important conclusions to be drawn from this distinctive place.

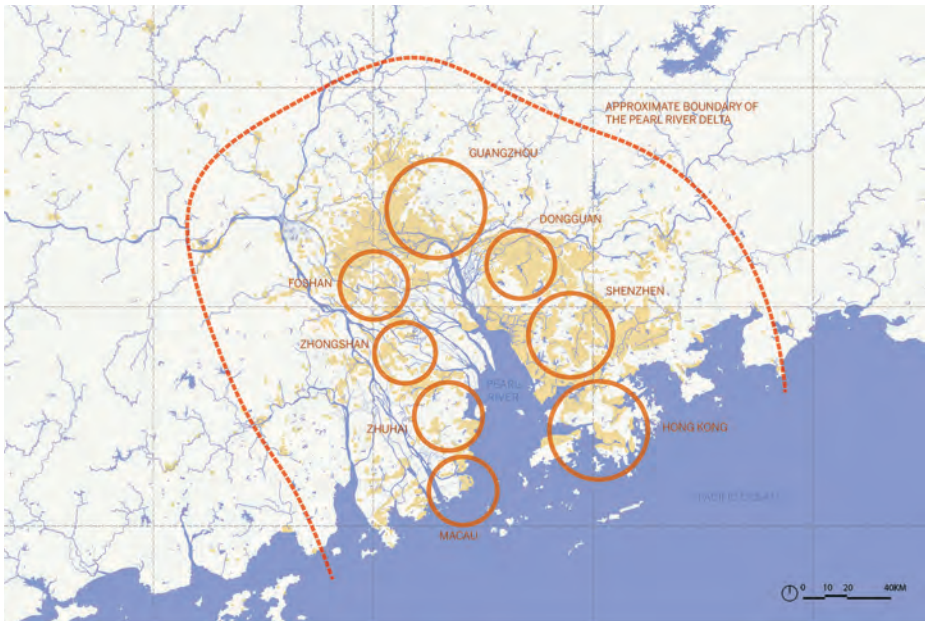

Figure 1. The eight primary cities of the Pearl River Delta and the approximate boundary of urbanized areas. (Source: Skidmore, Owings & Merrill LLP)
图1. 珠三角地区的8大主要城市，以及城市化区域的大致范围。（来源：SOM有限公司）

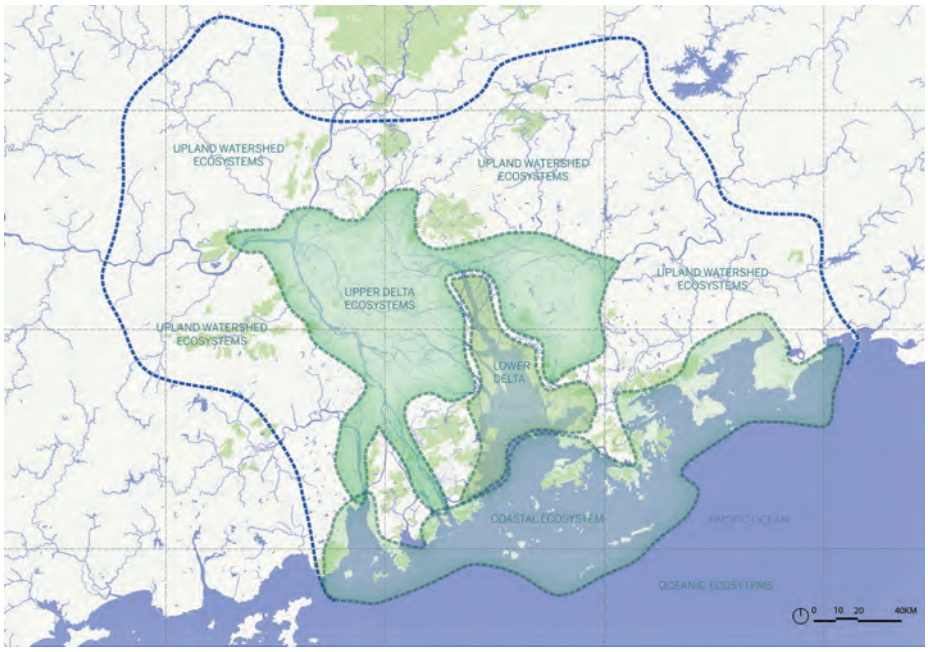

Figure 2. The four primary ecosystems of the Pearl River Delta and the approximate boundary of its immediate watershed. (Source: Skidmore, Owings & Merrill LLP)
图2. 珠三角地区4大主要生态系统，以及其集水区的大致范围。（来源：SOM有限公司）

革，启动香港回归谈判，并在深圳市成立中国的首个经济特区。邓小平同志提出了很多促使珠三角地区转型发展的理念和政策，所触发的影响延续至今。

珠三角地区的地理特点是在直径超过200公里（124英里）的巨大盆地地形内交错分布着陆地和水域，这使得珠三角地区具有独特的自然地理环境，并直接影响其经济和城市发展。珠三角地区拥有由丘陵和山脉围合的独特河口湿地，其中水域面积约占20%、潮间带湿地面积占10%，陆地面积占70%（图2）。

地貌以几大主要系统为特点：首先，东部沿海的一系列崎岖山地作为中央内河、河湾和湿地的围合；第二，孕育了三角洲地区大部分城市的广大的内陆平原；第三，西部、北部和南部的丘陵、山脉界定三角洲的低地。珠三角地区水文分为四个主要系统：河流、湿地、潮汐河口和海岸环境。构成珠江的三条干流和支流在广州附近汇合：北江、西江和东江。

珠三角地区是一个独特的巨型城市，并为其它大型城市集群在达到类似规模的发展过程中将面临的问题提供诸多借鉴。该地区发展历史和经验借鉴可归为三大类进行分析：城市化和发展、交通以及环境。以下评估分析及案例研究显示，这一独特的区域可提供很多重要结论。

Figure 3. Historic map of the Pearl River Delta illustrating the complex intermingling of land and water that defines this unique megacity. (Source: 'Meyers Konversations-Lexikon' (Meyers Konversations-Lexikon, 1890))
图3. 珠江三角洲历史地图，显示了界定珠江三角洲地区的错综复杂相互交织的水陆框架。（来源：'Meyers Konversations-Lexikon'（Meyers Konversations-Lexikon，1890））

Urbanization and Development

Urbanization within the PRD is perhaps one of the most dynamic stories in the history of global city-building. Future analysts may look upon the transformation of the PRD as one of the most momentous periods of urban development in human history. Before 1980, the PRD was a series of relatively small, disconnected cities, small towns, and fishing villages. Hong Kong was the financial capital of Southeast Asia and south China, while Guangzhou was seen primarily as a manufacturing hub. Macau had yet to emerge as the entertainment center it is today; its identity was primarily one of a colonial trading port (Figure 3).

If we consider the PRD megacity as defined by a fifty-year period beginning in 1980, the halfway point in its urbanization process would have been 2005. This fifty year period can be thought of in 10-year increments, each with a distinctive identity: 1980s – Formation; 1990s – Connection; 2000ss – Coalescence; 2010s – Growth; and 2020s – Maturity. After the initial process of formation in the 1980s, during which many of the PRD policies were put into place, the PRD became more than just a series of independent places; it became a connected network of urbanized areas.

With the turn of the millennium in 2000, the region entered a period of intense coalescence. New infrastructure created connections that joined disparate places together, and PRD cities began to expand to meet that infrastructure. Concurrently, the rise of technology industries in Shenzhen and Guangzhou, such as the Foxconn manufacturing facilities for Apple, integrated perfectly with this expanded infrastructure network. The concept of distinct and separate identities for PRD cities began to fade, and the notion of a larger Pearl River Delta identity began to strengthen.

The next phase of the PRD's evolution is currently well underway – one of growth. Today, four of the world's 20 tallest buildings are in the PRD. By 2020, it is estimated that three of the world's 20 tallest buildings will be located in the PRD, more than any other city in the world (Figure 4) (CTBUH, 2015). However, if we examine current development within the PRD, it is possible to see both encouraging and discouraging trends.

The positive trends include urban-infill projects in city centers, the expansion of transit networks, and the conversion of low-density industrial sites to higher-density mixed-use

城市化和发展

在全球城市建设的历史中，珠三角地区城市化可能是其中最为生动的故事之一。未来的分析者可能会将珠三角地区的转型看作是人类历史上城市发展最有关键意义的阶段之一。1980年以前，珠三角地区还是一些相对分散、互不连系的小城、小镇和渔村。香港是东南亚和中国南部的金融首府，而当时的广州市则被普遍视为一个制造中心。澳门当时还未发展成如今的娱乐中心：它的主要定位为仍以殖民贸易港之（图3）。

如果我们将珠三角巨型城市的发展定义为一个50年的周期，从1980年算起，其城市化进程的中点在2005年。这50年的周期可按照每10年划分为不同的主题式增长：20世纪80年代——形成；20世纪90年代——连接；2000年代——融合；2010年代——发展；2020年代——成熟。经历了20世纪80年代形成之初，珠三角地区诸多政策落实之后，珠三角地区成为一个相互联系的城市化区域网络，而不仅仅是一些独立的区域。

随着2000年千禧年的到来，该地区进入了一段密集融合时期：新的基础设施创建了不同地区间的连接，随后三角洲城市沿该基础设施开始扩张。与此同时，科技产业在深圳、广州的崛起，如富士康的苹果手机制造厂等，实现了与这一扩展的基础设施网络的完美结合。珠三角地区的城市逐渐不再是明确分离的个体，区域级的珠三角地区的概念开始增强。

珠三角发展的下一个阶段早已开始：这是一个关于增长的阶段。如今，世界上最高的20座的建筑中有4座位于珠三角地区。到2020年，预计世界上最高的20座建筑物仍将有3座建于珠三角地区，这超越了世界上任何其它城市（图4）（CTBUH高层建筑与都市人居环境，2015年）。

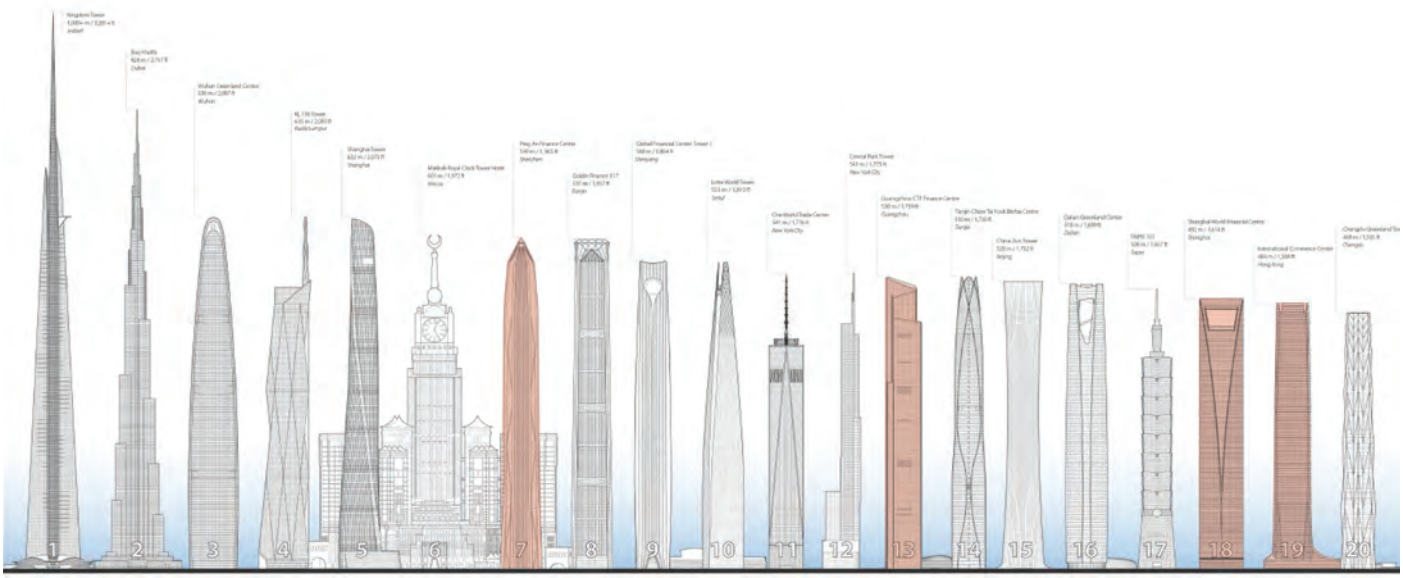

Figure 4. Growth in the Pearl River Delta continues unabated, with four of the world's 20 tallest buildings to be completed there by 2020. (Source: Council on Tall Buildings and Urban Habitat)
图4. 珠三角地区的发展持续不减，到2020年，全球最高的20座建筑当中将有4座建成于此。（来源：世界高层建筑与都市人居学会）

projects. Also evident is the elevation of the standard of living across the PRD and the creation of better amenities within cities.

The negative trends are equally as pronounced, and also have the potential for more substantial longer-term harm. These include the continued development of unsuitable areas (as a recent landslide in Shenzhen illustrated), the degradation of air and water quality throughout the PRD, and the loss of both marine and terrestrial habitat. The amount of urbanized area within the PRD has increased by over 50 percent from the period of 1995 through 2003, as shown by satellite imagery; but, much of this development has taken place in low-lying land with a high exposure to both river flooding and sea-level rise (Figure 5).

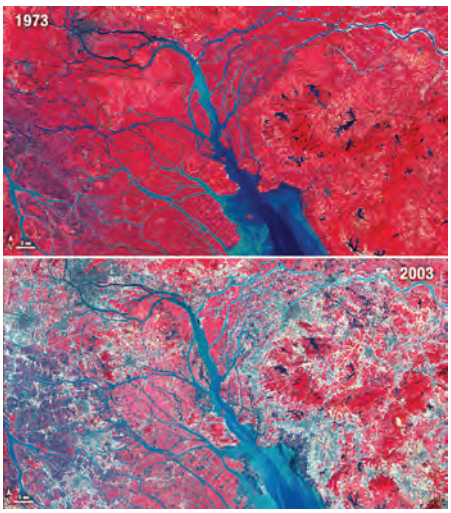

Figure 5. Urbanization in the Pearl River Delta has severely impacted the natural ecology of the region, resulting in environmental quality issues. (Source: Landsat view: Pearl River Delta, China (NASA, 2016))
图5. 珠三角地区城市化已严重影响该地区的自然生态，造成环境质量问题。（来源：卫星图：中国珠江三角洲（NASA，2016））

Case Study: Urban Regeneration in Europe and America as a Model for the Pearl River Delta

For the purposes of visualizing how PRD cities may evolve and mature in the future, it is instructive to look at recent trends in European and American cities. Chinese and PRD cities may see the following trends emerge over the next several years:

- Trend 1) Slowed Suburban Growth: As in the US, the expansion of the suburbs has slowed, as city officials realize the burden of constructing and maintaining infrastructure that is the result of urban sprawl.

- Trend 2) Transformation of City Centers: Many cities, such as New York, have re-invested in their city centers. PRD cities such as Shenzhen and Guangzhou continue to refine their core areas as changing preferences in urban life dictate new land uses and urban amenities.

- Trend 3) Growing Commitment to Walkability and Cycling: As in Europe and now in the US, many PRD cities must evolve from a car and transit-centric model to one where the pedestrian and bicyclist is valued and protected. Too often, in cities such as Macau and Hong Kong, the pedestrian connections at street-level are an afterthought, relegated to second-level walkways (Figure 6).

- Trend 4) A New Generation of Urban Brownfield Sites: As is occurring now in

Figure 6. Cities in the Pearl River Delta, such as Hong Kong, have created some of the most iconic skylines in the world. Innovations in high-rise structural design characterize many new buildings. Meanwhile, pedestrian connections are often separated from the ground level. (Source: Peter J. Kindel AIA)
图6. 珠三角地区的城市，例如香港，拥有世界上最具标志性的天际线之一。许多新建筑以创新的高层结构设计为特色。同时，步行连接常常与地面层脱离在其他高程设置。（来源：Peter J. Kindel AIA）

如果我们审视珠三角地区内目前的发展情况，既可以看到令人鼓舞的趋势，也有不乐观的趋势。正面的趋势包括城市中心的城市填充项目，公共交通网络的扩张，低密度工业用地向高密度多功能综合利用项目的转变。整个珠三角地区生活水平的提高和城市内配套设施的也显而易见。

负面趋势同样明显，且还有可能造成更严重的长期破坏。这些包括在不适宜发展的地区发展建设，深圳最近的一次山体滑坡是其中一个例子，整个珠三角地区的空气质量和水质量普遍下降，以及海洋和陆地栖息地的流失。卫星图显示从1995年到2003年，珠三角范围内城市化地区的面积增加了50%以上。许多新城市化开发集中在低洼地区，河流洪泛和海平面上升的风险很高（图5）。

案例研究：欧美城市再生为珠三角地区提供范例

为了更直观的反映三角洲城市的未来发展可能性，可参考欧美城市的最新趋势。中国和珠三角地区的城市在未来几年里很可能会出现如下趋势：

- 趋势1：郊区发展放缓：美国随着郊区扩张已经放缓，城市官员意识到了城市蔓延造成的基础设施建造和维修的压力。

- 趋势2：城市中心的转型：纽约等许多城市已经重新投入其城市中心的建设。深圳和广州等珠三角城市继续完善其核心区，根据城市生活的不同要求确定新的用地功能和城市设施。

- 趋势3：致力于步行和自行车慢行交通：珠三角城市必须从以机动和公交为中心的模式，转向对于步行和自行车骑行的重视和保护，在欧洲以及当前在美国都可以看到这样的发展动向。而目前香港和澳门等城市，街道层面的行人连接常常是一种事后考虑退而使用二层人行道（图6）。

- 趋势4：新一代城市工业废弃地的开发：在珠三角地区以及美国，许多城市地块正从低密度工业用地转型为高密度多功能综合利用项目。幸运的是，由于中国政府致力于公交设施的建设，使这些以前不理想的地块具备了住宅、办公或多功能综合利用开发的极高价值。

城市交通

珠三角地区最初的各城市分散独立的特点，使覆盖广泛的水上运输系统成为必需且蓬勃发展到今天。该系统在过去由往返

Figure 7. Rail and subway systems in the Pearl River Delta. (Source: Joho Maps; 2007-2014)
图7. 珠三角地区的轨道和地铁系统。（来源：Joho Maps；2007–2014）

the PRD and also in the US, many urban sites are being converted from low-density industrial uses to high-density mixed-use projects. Fortunately, due to the Chinese government's commitment to transit, these previously undesirable sites have an exceptionally high value for residential, office, or mixed-use development.

Mobility

The disparate collection of cities that originally characterized the PRD necessitated an extensive water-borne transportation system that thrives to this day. This system historically consisted of small fishing fleets that plied the estuaries and coastal waterways, supplying a steady food source that had sustained the growing communities. This water-borne transport system also provided ferries that connected the cities and villages, filling the gaps in the roadway network.

Rail systems in the PRD have historically been limited in geographic coverage, especially when compared to similar systems in Europe. While rail travel has always been a major component of China's larger transportation network, the geographic disposition of the PRD with extensive water areas, has limited the expansion of the railway system (Figure 7). The highway system in the PRD has also been limited by the extensive water bodies. Primary arterials were connected by ferries where possible, uniting the PRD into a fairly complete road system.

There are currently 13 ferry routes in operation on any typical day in the Pearl River Delta. This critical transportation mode reduces traffic loads on highways, connects transit hubs, and reduces regional transportation choke points. This strategy allows travelers to bypass immigration at heavily-used entry points, greatly reducing travel times between key PRD hubs (Figure 8).

于河口及沿海航道的小型捕鱼船队组成，为不断增加的社区人口提供稳定的食物来源。这种水上运输系统还提供了连接城市和乡村的渡轮，填补了道路网络的不足。

历史上珠三角地区的铁路系统覆盖范围一直很有限，由其与欧洲的类似系统相比。虽然铁路交通一直是中国较大交通运输网络的重要组成部分，但由于珠三角地区水域宽广，这样的地理特征却限制了其铁路系统的进一步扩展（图7）。珠三角地区的高速公路系统也受到大范围水域的限制。在可能的情况下通过轮渡接驳主干道，将珠三角地区整合至一个相当完善的公路系统。

目前，珠三角地区日常运营的轮渡线路有13条。这一至关重要的运输方式可减少高速公路的交通负担，连接了交通枢纽，并缓解了区域交通瓶颈。这一策略使旅客在人流量大的出入点绕道而行，从而大大缩短了珠三角中心区之间的交通时间（图8）。

珠三角地区的现代化铁路系统得益于高速铁路的持续升级和专项战略投资。近期的高铁投资和超过1100公里的新建轨道都缩短了交通时间，尤其是广州与香港之间的南北交通。随着2020年新九龙高铁站的建成通车，这一连系将进一步得到加强。

在最近20年里，珠三角地区的路网建设得到了全面升级和延伸。截至2012年，已完成3000多公里的高速公路建设，连接区域内的所有主要城市。随着中国城市的新发展，道路规划往往推动着新的城市化开发。然而，路网的规划并未审慎考虑自然地形、水流或自然栖息地。因其往往沿河而建，也因此严重危及了湿地栖息地。

Figure 8. Ports and commercial waterways (indicated by dark lines) in the Pearl River Delta. (Source: Skidmore, Owings & Merrill LLP (2016))
图8. 珠三角地区的港口和商业河道（以黑色线条标示）。（来源：SOM有限公司（2016））

The modern rail system in the PRD has benefited from both continued upgrades and specific strategic investments in high-speed rail. Recent investments in high-speed rail and over 1,100 kilometers of new track have reduced travel times, especially north-south between Guangzhou and Hong Kong. This link will be further strengthened in 2020 with the opening of a new Kowloon high-speed rail station.

Within the last 20 years, road networks within the PRD have undergone significant upgrades and expansions. Over 3,000 kilometers of highways have been completed as of 2012, connecting all major cities within the region. As with all new growth in Chinese cities, road planning often drives new urban development; however, these road networks are laid over the land without significant regard for natural topography, water flow, or ecological habitat. Because they are often constructed along river edges, they also severely compromise wetland habitats.

The creation of modern mobility systems within the PRD, whether they are rail, road, air, or water-based systems, has had a significant impact on the environment. Future improvements must be considered as a holistic system that is carefully designed to minimize environmental damage.

Mobility Case Study: Japan's Transportation Networks as a Model for the Pearl River Delta

As the PRD continues to grow and densify, questions remain as to whether the current surface transportation system will provide sufficient service to meet the needs of the PRD megacity. If other large-scale urbanized areas are studied, it becomes evident that the current rail system may be insufficient for continued growth. For the purposes of comparison, the Japanese transportation system, recognized as one of the most efficient in the world, can be examined as a model for the PRD. Japan, like China, has several tiers of train networks, including high-speed rail, intercity express, and local networks, and the spacing and population density of Japanese cities is similar to those of the PRD.

Examining rail utilization at the broadest level, the average Japanese citizen currently travels about three times as many kilometers per year as does the average Chinese citizen (2,000 kilometers per year per person for Japan versus 650 kilometers per year per person in China) (Wikipedia, 2016). Part of this can be explained by China's larger population and smaller per-capita income, but the fact remains that there is, indeed, lower rail utilization per capita.

One of the key differences in the Chinese urbanization and transport model, when compared to the growth of Japanese cities, is the implementation of high-speed rail. Japan's Shinkansen –one of the world's first high-speed rail systems – was designed to connect city-centers together. By contrast, the Chinese model has established new high-speed rail station on the perimeter of their major cities, which pulls development away from city centers, potentially exacerbating urban sprawl.

Based on the above assessment and analysis, the following strategies are recommended to guide mobility planning for the continued evolution of the PRD megacity:

- Strategy 1) Increase Rail and Transit Mode Split: Modal share is an important component in developing sustainable transport within a city or region. Higher transit mode-share reflects a desire for change between modes and usually results in an increase in the proportion of trips made using more sustainable modes.

- Strategy 2) Increase Natural Habitat through Infrastructure Projects: It is recommended that the PRD cities adopt a policy whereby all new infrastructure projects require offsetting conservation areas in proportion to the project's impact (Hayes, 2014).

- Strategy 3) Expand and Enhance Inter-Delta Ferry Systems: A simple way to expand

- mobility within the PRD is to expand ferry service between major cities. This system has less permanent impacts than other systems, can be modified relatively easily, and is convenient to use.

- Strategy 4) Connect Airports with Multi-Modal Systems: Every effort should be made to simplify procedures and facilitate direct access into the rail, subway, and ferry system that links cities, reducing the need for supplemental fossil fuel- based transportation.

The Environment

Deltas and coastal areas are among the most densely populated areas in the world.

珠三角地区的现代交通系统的建立，无论是铁路、公路、空运或是水上系统，都已经对环境产生了的显著影响。今后的改进必须作为一个整体系统加以精心设计，以尽量减少对环境的破坏。

交通案例研究：日本交通网络为珠三角地区提供范例

珠三角地区持续增长和开发强度增高，问题在于目前的地面交通系统是否可以提供足够的服务，以满足珠三角巨型城市的需求。如果对其它大型城市化地区进行研究，显而易见的是目前的铁路系统可能无法满足持续增长的需求。相较之下世界公认效率最高之一的日本运输系统，可作为珠三角地区发展的研究范例。日本和中国一样，铁路网络分为几个层次，包括高速铁路、城际快速铁路和当地铁路支线，日本城市的间距和人口密度与珠三角地区相类似。

在最广泛的层面考察铁路的利用率可发现一般日本公民每年出行交通公里数是一般中国公民的3倍：日本每人每年2000公里，中国人每人每年650公里（维基百科，2016年）。这可以从中国的人口较多和人均收入较低的角度来解释，但人均铁路利用率较低仍是事实。

与日本的城市相比，中国城市化和交通模式的关键差异之一在于高速铁路的实施。作为世界最早的高速铁路系统之一，日本新干线的设计将各个城市中心区联系在一起。而相比之下，中国模式将新高铁站建在主要城市的边缘，导致新开发项目远离城市中心区，从而加剧城市蔓延。

根据上述评估和分析，为了实现珠三角巨型城市的持续增长和发展，建议采用以下交通规划策略：

- 策略1：增加轨道及公交占出行模式的比例公交出行比例是一个城市或地区建设可持续交通系统的重要组成部分。较高的公交出行比例反映了交通模式之间的换乘意愿，从而提高使用更可持续的交通方式出行的比例。

- 策略2：通过基础设施项目来增加自然栖息地建议珠三角城市制定和采用政策，向所有的新建基础设施项目要求一定比例的保护区用地补偿（Hayes，2014年）

- 策略3：扩建并提升三角洲城际轮渡系统的品质珠三角地区扩展交通的一简单方式是扩展主要城市之间的轮渡服务。该系统比其它系统带来的长期影响更小，改建更容易且使用更便捷。

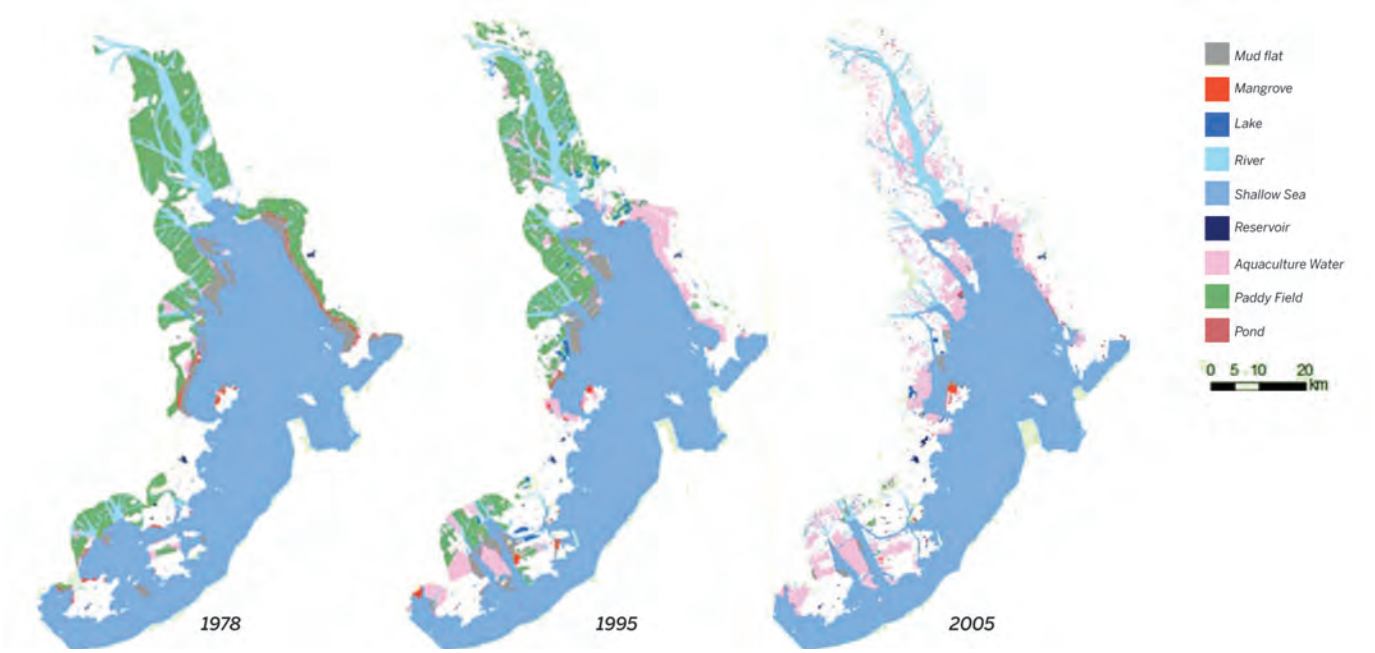

Figure 9. The spatial distribution of coastal wetlands in the Pearl River Delta in years 1978, 1995 and 2005. (Source: 'Research of Spatial and Temporal Variations of Wetland in Pearl River Estuary (1978 ~ 2005)' (Gao et al, 2010))

图9. 1978年、1995年及2005年珠三角地区沿海湿地的空间分布。（来源：'Research of Spatial and Temporal Variations of Wetland in Pearl River Estuary (1978 ~ 2005)' (Gao et al, 2010))

Concurrently, deltas and estuaries are home to incredibly diverse and delicate ecosystems, making them exceptionally vulnerable to urbanization. The PRD, as one of the most rapidly growing delta regions in the world, is facing severe and complex environmental problems.

Between 2000 and 2010, the urbanized area in the PRD grew from 4,500 square kilometers to 7,000 (World Bank Group, 2015). 519 square kilometers of natural wetlands in the Pearl River Estuary were converted to urban land between 1979 and 2009 (Zhao et al. 2010) – that is over eight times the size of Manhattan's land area. 261 square kilometers of natural coastal wetlands were lost between 1978 and 2005 (Figure 9) (Gao et al, 2010).

The drastic increase in impervious surfaces and corresponding decrease in the permeability of the land is causing large amounts of fast-flowing storm water runoff, with frequent flooding, worsening erosion, and increasing sediment and pollution in the water system (Figure 10). Dredging, in addition to the construction of dams, dikes, and channels, is changing sediment patterns, allowing saltwater to penetrate up streams, threatening freshwater resources and causing further habitat degradation.

The PRD's more than 55 million people, and accompanying industries and agriculture, rely on the freshwater systems, causing serious water quality issues and water shortages. Ground water supply in Guangdong has decreased by 512 million cubic meters between the years 2000 and 2014 (PRWRC, 2000, 2010). The chance of flooding and saline intrusion is further increased by land subsidence from ground-water depletion. The water quality of about 25 percent of the streams and rivers in the PRD was ranked "unusable" in 2011 (PRWRC, 2011).

In addition to local and regional environmental problems in the PRD, global climate change has induced sea-level rise and worsened saline intrusion, brought about more intense droughts and heat waves, changed precipitation patterns, and increased the number of extreme floods. Coastline and riverbank erosion, land subsidence, and increased population on reclaimed land all add to flood hazards (Figure 11). However, the PRD is not alone in these struggles. Many delta regions in the world have experienced, and continue to experience, similar environmental challenges. The following case study of the San Francisco Bay Area provides lessons and mitigation measures that could be shared with similar regions.

Environmental Case Study: San Francisco Bay Area

The San Francisco Bay watershed drains over 40 percent of the state of California and supports a diversity of habitats. Surrounding the bay and part of the delta, the nine-county San Francisco Bay Area is one of the largest urban areas in the US with approximately 8 million residents. Throughout the 20th Century, the Bay Area had prioritized development at the expense of the environment; however, in recent years, significant efforts have been made to understand and restore it.

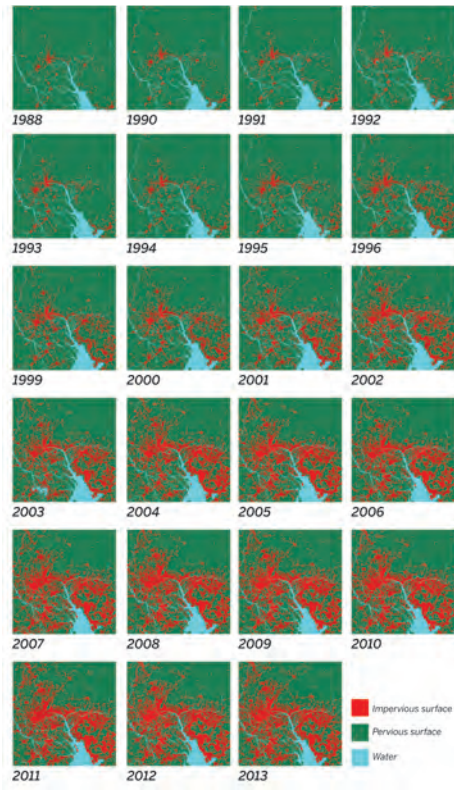

Figure 10. The annual impervious surface maps of the Pearl River Delta, China, 1988–2013. (Source: 'Annual Dynamics of Impervious Surface in the Pearl River Delta, China, from 1988 to 2013, Using Time series Landsat Imagery' (Zhang et al, 2016))

图10. 1988–2013年中国珠三角地区每年不透水面图。（来源：'Annual Dynamics of Impervious Surface in the Pearl River Delta, China, from 1988 to 2013, Using Time series Landsat Imagery' (Zhang et al, 2016))

- 策略4：提供机场与多模式城市交通系统的连接应尽量简化换乘程序，便于旅客直接连接城际铁 路、地铁及轮渡系统，以降低对依赖矿物燃料的交通系统的需求。

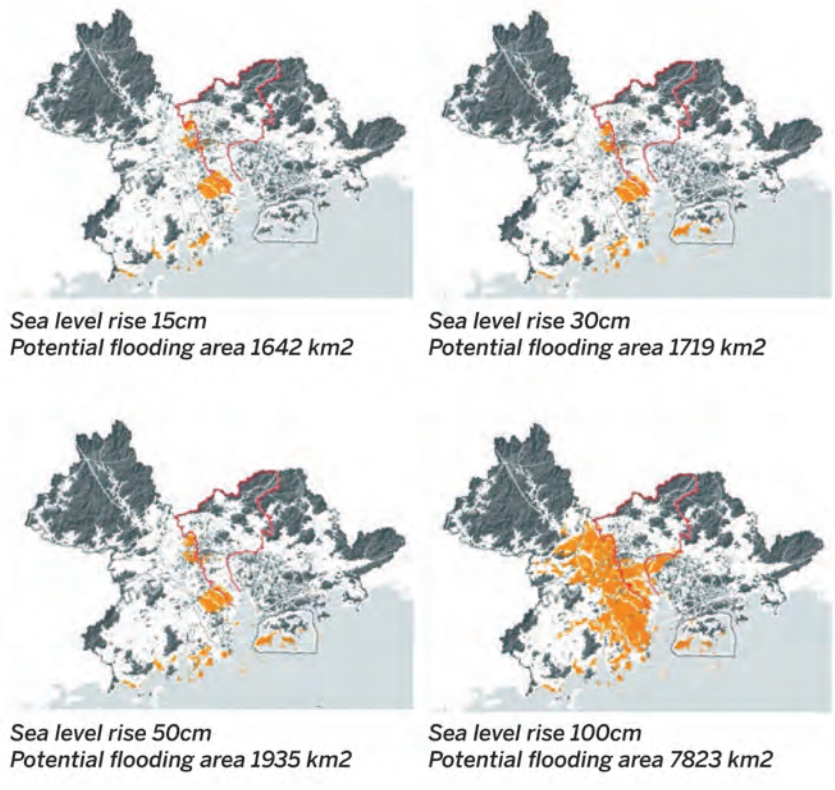

Figure 11. Potential flooding areas of the Pearl River Delta with current flood defense (return period of 100 years) (Source: 'Towards a Livable Urbanized Delta Region. Spatial Challenges and Opportunities of the Pearl River Delta' (Carmona et al, 2014))

图11. 当前防洪设施条件下的珠三角地区100年一遇洪水区。（来源：'Towards a Livable Urbanized Delta Region. Spatial Challenges and Opportunities of the Pearl River Delta' (Carmona et al, 2014)）

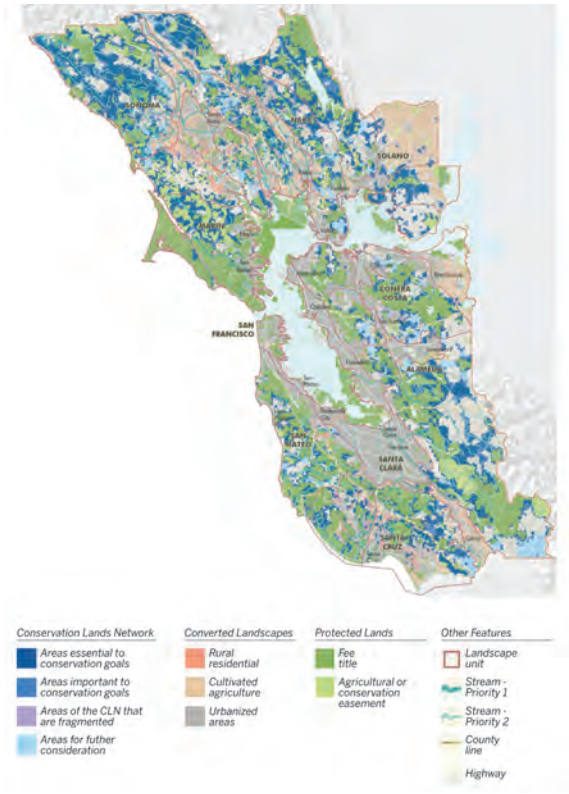

Figure 12. The conservation lands network in the San Francisco Bay area. (Source: Conservation Lands Network (Bay Area Open Space Council, 2014))

图12. 旧金山湾区的土地保育网络。（来源：Conservation Lands Network (Bay Area Open Space Council, 2014)）

By 1961, 90 percent of the Bay's wetlands had been destroyed (Save the Bay, n.d.). Regional agencies such as the San Francisco Bay Conservation and Development Commission (BCDC) and the Coastal Conservancy were established with the legislational support to protect the Bay and other regionally significant habitats, corridors, watersheds, scenic areas, and agricultural lands (Figure 12). With these programs in place, large areas of habitats were restored and urban growth around the Bay became focused to a zone between the Bay and the greenbelt of ridgelines. Coupled with regional land use planning, a similar system can be used to regulate urban growth in the PRD.

In order to effectively address water resource, ecology, and resiliency challenges in a river delta, urban planners must recognize the entire watershed as an interconnected system, and respect and draw on the intrinsic ecology of the system when future development is considered. The state and regional Water Resources Control Boards and the US Environmental Protection Agency (EPA) use similar watershed management approaches to improve the health of the ecosystem watershed-wide. Rather than focusing on an isolated problem at a city level or site level, water quality and ecosystem problems are best addressed at the watershed level (Water Boards, 2016). Watershed management coordinates all the activities that affect a watershed's natural resources and water quality, including storm water, streams and wetlands, land fill, and water supply.

Environmental Strategies

Based on the above assessment, the following strategies are recommended for the PRD:

- Strategy 1) Multi-Jurisdictional Watershed-Wide Management: Integrated watershed management requires a holistic multi-disciplinary approach, and a partnership between different municipalities and entities

- in the Pearl River Basin. The Pearl River Watershed Management Agency should be established and supported by legislation. A comprehensive master plan, renewed periodically based on data analysis, is needed to prioritize and coordinate projects and programs across regions. Funding can then be distributed based on evaluation.

- Strategy 2) Preserve Room for Nature and Environmental Restoration: Room must be made for natural systems to reestablish balance in the Delta. Floodplains should be reestablished to

环境

三角洲和沿海地区是世界上人口最稠密的地区。同时，三角洲和河口地区的生态环境极为多样和复杂，使其对于城市化开发异常敏感。珠三角地区作为世界上发展最快的三角洲地区之一，正面临着严峻而复杂的环境问题。

从2000年到2010年期间，珠三角地区的城市化面积从4500平方公里增加到7000平方公里（世界银行集团，2015年）。1979年至2009年间，珠江河口519平方公里的自然湿地被改造为城市用地（Zhao等人，2010年）；超过曼哈顿面积的8倍。1978年至2005年间，261平方公里自然沿海湿地被填平（图9）（Gao等人，2010年）。

不透水表面的急剧增加相应减少了土地的渗透性，造成大量快速流动的雨水径流，经常性洪水泛滥，加剧水土流失并增加水系统内的沉积物和污染（图10）。疏浚和堤坝沟渠的建设正在改变沉积物分布格局，使海水入侵溪流，威胁淡水资源并加剧栖息地退化。

珠三角地区超过5500万的人口以及工业和农业的发展都依靠淡水系统，也因此造成严重的水质问题和水资源短缺。广东地下水供应量在2000年和2014年之间减少了5.12亿立方米（珠江委，2000年，2010年）。地下水枯竭导致地面沉降，从而进一步增加洪水和海水入侵的机会。2011

allow rivers to expand, slow down, and in the process, deposit the sediment necessary to replenish wetlands. Wetlands should be restored to store water temporarily, purify water, recharge ground water, and stabilize shorelines. Coastal wetlands should be maintained to act as natural buffers to storm surge and sea-level rise. Urban green corridors should be planned to slow down, purify, and absorb storm water, and connect wildlife populations, and forests should be conserved and restored to perform as carbon sinks and improve biodiversity. The implementation of these actions would involve mobilizing an enormous amount of resources, but it is crucial for the health and safety of the PRD, and urgent given impending sea-level rise.

- Strategy 3) Promote Low-Impact Development: In this context, Low-Impact Development (LID) is defined as "development that, through its low negative environmental impact, either enhances or does not significantly diminish environmental quality" (Pickerill 2009). Clean energy, water reuse, storm water and waste management, public transportation, sustainable materials, and compact development are some of the typical LID approaches encouraged to reduce the urban demand on natural resources and alleviate the impact on the PRD's ecosystems.

- Strategy 4) Mitigation Banking/ Compensation for Development Impact: "Mitigation-banking" creates a mechanism to provide a financial incentive for conservation. It requires developments causing negative impacts to compensate for them and contribute to the preservation and restoration of ecologically sensitive areas, creating a more effective conservation effort across the watershed.

Conclusion

If we look to the future and imagine a sustainable Pearl River Delta in 2030, what will we see? Extrapolating current population growth forward, the PRD may see a population close to 75 million people. To adapt to growth, PRD development will need to radically change its course to a sustainable model that achieves economic goals while accommodating and encouraging ecological restoration.

年，珠三角约25%的河流水系的水质被评为劣五类 （珠江委，2011年）。

除了珠三角地区地方性和地区性环境问题，全球气候变化已引起海平面上升，加剧了海水入侵，带来了更强烈的干旱和热浪，改变了降水模式，以及越来越多的极端洪涝灾害。海岸与河岸的侵蚀、地面沉降、以及在填海土地上增加的人口都增加了洪灾带来的风险（图11）。珠三角地区并非个案。全球很多三角洲地区都经历过类似的环境挑战。以下旧金山湾区案例研究提供了值得类似地区借鉴的经验教训和解决措施。

环境案例研究：旧金山湾区

旧金山海湾的汇水区占加利福尼亚州面积的40%以上，支撑多种类型的栖息地。海湾周边和部分三角洲地区，旧金山湾区9个县是美国最大的城市化地区之一，居民人口约800万。整个20世纪，湾区牺牲了环境质量，以发展建设为优先考虑。近些年来，该地区为了了解和修复环境做出了重大努力。

到1961年，湾区90%的湿地已遭破坏（"保护海湾"，日期不详）。旧金山海湾保护和发展委员会（BCDC）和沿海保护协会等地区机构先后建立，并通过立法支持海湾及地区内其它重要栖息地、走廊、汇水区、景区和农业用地的保护（图12） 。有了这些项目的支持，大面积的栖息地得以恢复，海湾周边的城市开发集中在海湾与山脊绿地带之间的区域。结合地区用地功能规划，类似体系可用来规范珠三角地区的城市发展。

为了有效解决河流三角洲地区的水资源、生态及环境可适应性等挑战，城市规划者必须将整个流域视为一个相互联系的系统，并在今后的开发中对其核心的生态系统加以尊重和借鉴。美国国家和地区水资源控制委员会和美国环境保护署（EPA）使用类似的流域管理办法来改善整个流域的生态系统健康状况。水质和生态系统问题最好在流域层面解决，而不应孤立于流域，聚焦在城市或场地层面（水务局，2016年）。流域管理协调所有影响流域自然资源和水质的活动，包括雨水、河流和湿地、开垦地、水质和供水。

环保策略

根据上述评估，建议珠三角地区采用以下策略：

- 建议1：多方管辖的全流域管理策略

- 整合式流域管理需要一个全面的多学科系统方法，以及珠江流域不同城市和机构的相互合作。应建立珠江流域管理机构，并提供立法支持。需要发展一个全面综合的定期依数据分析更新的总体规划来优先考虑和跨区域协调各项目和功能配置。然后，可根据评估来确定项目间的资金分配。

- 策略2：为自然和环境的修复创造条件为了重建三角洲的生态平衡，我们必须为自然系统创造空间。应重新划定和保护洪泛区，以为河流扩展减速提供空间，并在这一过程中分布沉积物以补充湿地。应修复湿地以发挥其临时储水、净化水质、补充地下水和稳定岸线的作用。应保养沿海湿地以作为天然缓冲区，对风暴潮和海平面上升起缓冲调节的作用。应规划城市绿色廊道来实现雨水的减速、净化和吸收，并用以连系野生动物群体。应保护和恢复森林，作为碳汇并提高生物多样性。实施将涉及大量资源的调度，然而这对于珠三角地区的安全和健康至关重要，且在全球海平面上升的背景下是迫切的要求。

- 策略3：提倡低影响开发低影响开发（LID）在本文使用的定义是"通过对环境的低负面影响来提升或不显著降低环境质量的开发"（Pickerill，2009年）。清洁能源、水资源再利用、雨水 管理、废弃物管理、公共交通、可持续材料和紧凑发展都是低影响开发的一些典型途径。鼓励采用这些途径以减少珠三角地区的城市化对自然资源的需求，并缓解对生态环境的影响。

- 策略4：缓解开发影响的生态敏感地补还和经济补偿机制建立"缓解开发影响的生态敏感地补还和经济补偿机制"，为自然保育提供财务奖励，提供机制让造成负面影响的开发补偿其造成的影响并为生态敏感区的保护和修复做出贡献。这将使整个流域范围的保护工作更高效。

结论

展望2030年，一个可持续发展的珠三角地区会是什么样的呢？根据目前人口增长推算，珠三角地区的人口数量将接近7500万。为了适应这种增长，珠三角地区的发展将需从根本上转变为可持续发展的模式，在实现经济目标的同时，鼓励生态修复并为其提供条件。

由珠三角地区的发展证明，以巨型城市为形态的相互连通的城市化模式具有显著的经济效益，协调分配的基础设施投资可大大提高交通效率。然而，尽管大型城市群

As is demonstrated by the evolution of the PRD, interconnected urbanization in the form of megacities has significant economic benefits, and coordinated infrastructure investment can provide major efficiencies in transportation. However, while large urban agglomerations generally offer heightened social and economic benefits, if not planned carefully, they can have significant negative environmental impacts.

将整体提升社会效益和经济效益，如不加以精心策划，会造成严重的负面环境影响。

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