

Procesos urbanos,  
dinámicas del agua  
y cambio climático  
Urban processes,  
water dynamics and  
climate change

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Blue-green urban  
infrastructure in Boston  
and Bombay (Mumbai):  
a macro-historical  
geographic comparison

Infraestructura urbana  
azul-verde en Boston  
y Bombay (Mumbai): una  
comparación geográfica  
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## Resumen

Este estudio ofrece una comparación geográfica y macrohistórica de la infraestructura urbana azul-verde en las ciudades costeras de Boston (EE. UU.) y Mumbai (antes Bombay, India). Después de presentar los objetivos y métodos de la geografía histórica comparada, nos enfocamos en las ideas que ofrecen estos dos casos. Sus historias comienzan con antiguos asentamientos pesqueros costeros, seguidos de los primeros procesos de urbanización y fortificación en el siglo XVII. A finales del siglo XVIII, los comerciantes angloamericanos de Boston comerciaban con los comerciantes parsi en Bombay, en un momento en que los bostonianos tenían poco más para vender que hielo a cambio de los finos textiles de la India. Desde principios del siglo XIX en adelante, las dos ciudades marítimas emprendieron procesos sorprendentemente paralelos de recuperación de tierras y desarrollo de agua. Boston encargó propuestas de infraestructura azul-verde a escala urbana, desde Back Bay Fens de Frederick Law Olmsted hasta el Plan del Distrito de Parques Metropolitanos de Charles Eliot, innovaciones que ofrecen más de un siglo de lecciones en desempeño ambiental y resiliencia. Las dos ciudades desarrollaron proyectos paralelos “Esplanade”, “Back Bay” y “Reclamation”. Ninguno de estos proyectos anticipó la magnitud del cambio de tierra, agua e infraestructura del siglo XX. Ambas ciudades han comenzado a abordar los crecientes riesgos de inundaciones urbanas, aumento del nivel del mar y desplazamiento de la población, pero necesitan visiones metropolitanas más audaces de infraestructura urbana azul-verde para abordar el cambio climático emergente y los peligros del agua.

## Palabras clave

Infraestructura verde y azul, Cambio climático, Urbanismo costero

# Blue-green urban infrastructure in Boston and Bombay (Mumbai): a macro-historical geographic comparison

## Infraestructura urbana azul-verde en Boston y Bombay (Mumbai): una comparación geográfica macrohistórica

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### Abstract

This study offers a macro-historical geographic comparison of blue-green urban infrastructure in the coastal cities of Boston, USA and Mumbai (formerly Bombay), India. After introducing the aims and methods of comparative historical geography, we focus on the insights that these two cases offer. Their stories begin with ancient coastal fishing settlements, followed by early processes of urbanization and fortification in the 17<sup>th</sup> century. By the late-18<sup>th</sup> century Anglo-American merchants in Boston were trading with Parsi merchants in Bombay, at a time when Bostonians had little more to sell than ice in exchange for India's fine textiles. From the early-19<sup>th</sup> century onwards, the two maritime cities undertook surprisingly parallel processes of land reclamation and water development. Boston commissioned blue-green infrastructure proposals at the urban scale, from Frederick Law Olmsted's Back Bay Fens to Charles Eliot's Metropolitan Park District Plan—innovations that offer more than a century of lessons in environmental performance and resilience. The two cities developed parallel "Esplanade," "Back Bay," and "Reclamation" projects. None of these projects anticipated the magnitude of 20<sup>th</sup> century land, water, and infrastructure change. Both cities have begun to address the increasing risks of urban flooding, sea level rise, and population displacement, but they need bolder metropolitan visions of blue-green urban infrastructure to address emerging climate change and water hazards.

### Keywords

blue green urban infrastructure, climate change, coastal urbanism

### Introduction

Coastal cities have followed common paths of urban water development, but also witnessed distinct water innovations, as demonstrated in this comparison of Boston and Bombay (now Mumbai) over the past four centuries. Urban flooding and sea level rise have prompted extensive modeling of climate change impacts that, while valuable, rarely consider the historical geography of urban water development or long-term performance of blue-green urban infrastructure like Boston's Emerald



[Fig. 1a and 1b] Source: Google Earth.

Necklace or Mumbai's Sanjay Gandhi National Park.<sup>1</sup> Maritime cities like Boston and Mumbai also have long records of historical exchange that have shaped their development and offer long-term comparative lessons for blue-green infrastructure design.

Boston and Bombay -- before they even had those names -- had striking similarities. Archaeological research documents indigenous fishing communities settled along tidal bays with rich aquatic diets, in what may be regarded as the first era of blue-green urban infrastructure.<sup>2</sup> There were equally striking differences. Upland areas of Mumbai had myriad rock-cut caves that supported medieval Buddhist monastic pilgrims, which had no parallels in coastal North America (unless one compares them with Puritan pilgrims!). Urbanizing lowlands of both regions have witnessed rapid commercial development from the 17th century onwards, which brought together competing local traders, European navies, factories, and fortifications. Commercial settlement in both "Indies" increased pressure on local wells and tanks whose quality deteriorated rapidly, which led to ever more distant sourcing and conveyance of fresh water supplies.<sup>3</sup>

Comparative water urbanism of coastal cities involves long-distance historical *interactions* as well as parallels. Ironically, the British General Charles Cornwallis, defeated in the American Revolution, which originated in the Boston area, received his subsequent assignment as Governor-General of the East India Company where he issued regulations for water improvement in colonial cities and cantonments like Bombay. U.S. cities (and their waters) at that time remained "unclear" about the public role in water improvement.<sup>4</sup> Even commercial trade between the U.S. and India had a water component, as merchants exported ice from New England ponds to tropical cities like Bombay in exchange for fine textiles, ivories, and texts that inspired transcendentalist philosophers.<sup>5</sup> The 20<sup>th</sup> century likewise witnessed fascinating parallels in coastal land reclamation, contamination, and ecological design in the emerging context of climate change. Both cities developed "Esplanade" and "Back Bay Reclamation" projects whose similarities and differences offer fascinating lessons for

- 1 Dipesh Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry* 35,2 (2009): 197-222. James L. Wescoat Jr, "Water, Climate, and the Limits of Human Wisdom: Historical-Geographic Analogies between Early Mughal and Modern South Asia," *Professional Geographer*, 66,3 (2013): 382-389. Ramboll Foundation, "Strengthening Blue-Green Infrastructure in our Cities: Enhancing Blue-Green Infrastructure & Social Performance in High-Density Urban Environments, online at: "[https://www.zu.de/lehrstuehle/soziooekonomik/assets/pdf/Ramboll\\_Woerlen-et-al\\_BGI\\_Final-Report\\_small-1.pdf](https://www.zu.de/lehrstuehle/soziooekonomik/assets/pdf/Ramboll_Woerlen-et-al_BGI_Final-Report_small-1.pdf)
- 2 Joseph Bagley, "A Prehistory of Boston Common", *Bulletin of the Massachusetts Archaeological Society*, vol 68,1 (2007):2-11. Mariam Dossal, *Theatre of Conflict, City of Hope – Mumbai – 1660 to Present Times* (New Delhi: Oxford University Press, 2010). Sibananda Senapati, and Vijaya Gupta, "Socio-economic vulnerability due to climate change: Deriving indicators for fishing communities in Mumbai", *Marine Policy* 76 (2017): 90-97.
- 3 Fern L Nesson, *Great Waters: A History of Boston's Water Supply* (Waltham: Brandeis University Press, 1983). Varsha S. Shirgaonkar, *Exploring the Water Heritage of Mumbai* (New Delhi: Aryan Books, 2011).
- 4 Nelson M. Blake, *Water for the Cities: A History of the Urban Water Supply Problem in the United States* (Syracuse: Syracuse University Press, 1956).
- 5 David Dickason, "The 19th century Indo-American ice trade: An hyperborean epic", *Modern Asian Studies* 25, 1 (1991): 53-89. Paul Friedrich, *The Gita Within Walden* (Albany: SUNY Press, 2008).



[Fig. 2] Photo James L. Wescoat Jr.

future urban designers. We begin with a short introduction to comparative aims and methods, and then proceed to the fascinating historical development and performance of blue-green infrastructure in Boston and Bombay.

### **Aims and Methods Macro-Historical Geographic Comparison**

Comparing two urban water systems over a period of four centuries is doubly challenging because it requires the in-depth knowledge of single-city studies and the generalization of multi-city studies. It often involves historical interactions between the two cases.<sup>6</sup> It is more common to compare five to ten cities at a general level using qualitative methods.<sup>7</sup> Beyond 25 cases, one shifts to quantitative statistical methods like cluster analysis to analyze similarities and differences among urban water systems.<sup>8</sup> The total number of coastal cities is vastly larger with one database listing 3,530 port cities worldwide.<sup>9</sup> In a two-city comparison, one thus seeks deep historical insights into the boundless record of water urbanism.

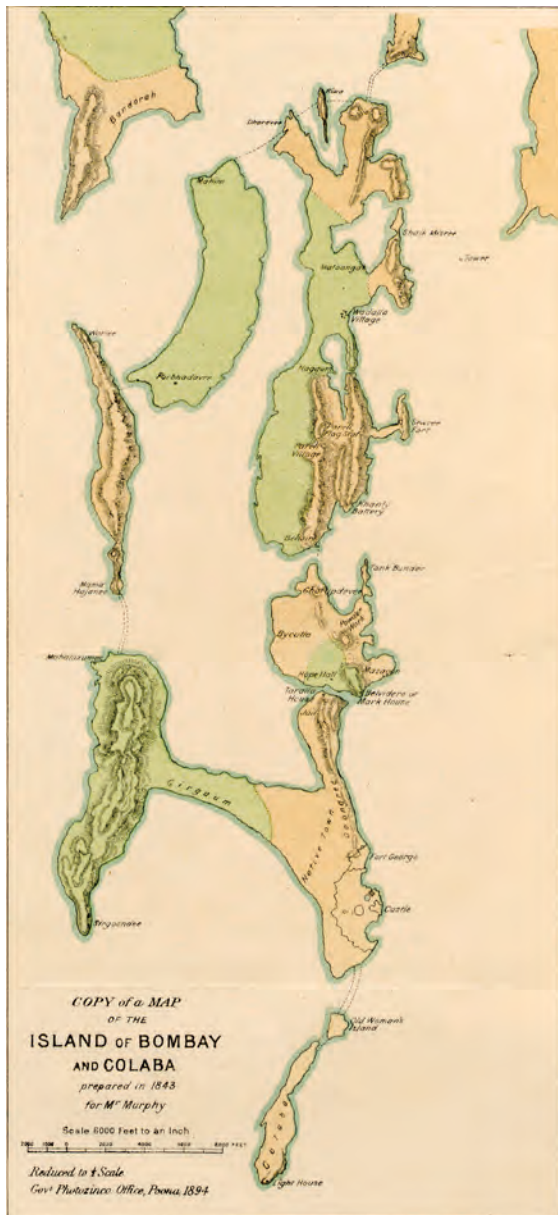
When comparing water urbanisms, it is also important to situate them in relation to comparative urban theory, including debates among the so-called “Chicago School,” “L.A. School,” and “southern”

6 Nelson M. Blake, *Water for the Cities: A History of the Urban Water Supply Problem in the United States*. James L. Wescoat Jr., “Comparative International Water Research”, *Journal of Contemporary Water Research & Education* 142 (2009): 61–6. James L. Wescoat, Jr., “Searching for Comparative International Water Research: Urban and Rural Water Conservation Research in India and the United States”, *Water Alternatives* 7,1 (2014): 199–219. James L. Wescoat Jr. “Comparing Ancient Water Infrastructure for New Cities”, *Landscape Architecture Frontiers* 2,5 (2014): 56-68.

7 Matthew Gandy, *The Fabric of Space: Water, Modernity, and the Urban Imagination* (Cambridge: MIT Press, 2014). Kelly Shannon, and Bruno de Meulder, eds., *Water Urbanisms: East* (Zurich: Park Books, 2014). Vladimir Novotny, et al. *Water Centric Sustainable Communities: Planning, Retrofitting, and Building the Next Urban Environment* (New York: Wiley & Sons, 2010).

8 E.g., Noiva, Fernandez, and Wescoat who analyze 142 cities. Karen Noiva, John E. Fernandez, and James L. Wescoat Jr. “Cluster analysis of urban water supply and demand: Toward large-scale comparative sustainability planning” *Sustainable Cities and Society* 27 (2016): 484-496.

9 National Geospatial-Intelligence Agency, *World Port Index* (Springfield, VA: NGIA, 2019).



[Fig. 3a] Source: British Library. [Fig. 3b] Source: U.S. Library of Congress.

theorists.<sup>10</sup> Three theoretical points have relevance when comparing water urbanism in Boston and Mumbai. The first involves the term urbanism: the *nouveau mot* “urbanisme” of 1780s post-revolutionary France has widely different uses in Europe, the U.S., and India (compare Vidler on Mercier’s Paris with Cerda’s urbanization in Barcelona and Roy’s subaltern urbanism in Mumbai). “Water urbanism” has much more recent origins in water policy studies in the 1960s with later uses in urban landscape research from the 1990s onwards.<sup>11</sup>

A second theoretical issue concerns the relatively shallow historical depth of comparative urbanism, which tends to neglect the archaeological and centuries-long time scales relevant for climate change adaptation.<sup>12</sup> Frederick Law Olmsted’s Back Bay Fens project in Boston now has over 140 years of historical innovation, failure, and renewal--the dynamics of which are vital to water urbanism.<sup>13</sup>

10 Michael Dear, “Comparative Urbanism”, *Urban Geography*, 26:3 (2005): 247-251. Jennifer Robinson, “Comparative Urbanism: New Geographies and Cultures of Theorizing the Urban”, *International Journal of Urban and Regional Research*, 40,1 (2016): 187-199. DOI:10.1111/1468-2427.12273187. Ananya Roy, “Slumdog Cities: Rethinking Subaltern Urbanism”, *International Journal of Urban and Regional Research*, 35,2 (2011): 223-238.

11 Kelly Shannon, and Bruno de Meulder, eds., *Water Urbanisms: East*.

12 Monica L. Smith, *Cities: The First 6,000 Years* (New York: Viking, 2019). James L. Wescoat Jr. “Comparing Ancient Water Infrastructure for New Cities”.

13 Anne W. Spirn, “Constructing Nature: The Legacy of Frederick Law Olmsted”, in *Uncommon Ground: Rethinking the Human Place in Nature*, William Cronin, ed. (New York: W.W. Norton, 1995), 91–113.



[Fig. 4a and 4b] Source: James L. Wescoat Jr.

Third, coastal cities undergo dramatic spatial changes through the combination of land reclamation and geomorphological processes. Mumbai began as an archipelago of seven islands, one of them known as Bombay, that became connected with one another through centuries of reclamation and sedimentation.<sup>14</sup> Boston likewise undertook extensive coastal landfilling to create its Back Bay neighborhood along with the context for Olmsted's Back Bay Fens project.<sup>15</sup> Modern Mumbai eventually developed a spatial structure that we describe as a hub-spokes-and-wheel model of blue-green urban infrastructure, but it was not always so. With these three conceptual points in mind, we proceed to the macro-historical geographic comparison of the two case study cities, before they were cities or had their current names.

#### **Antiquity to the 17th c. – Fisher people, tanks, and wells**

The geological origins of Boston and Mumbai are profoundly different, but their early settlers and settlements have important similarities. Mumbai landforms lie on the western margin of the massive Deccan Volcanic Plateau that erupted some 60 million years ago. The seven main islands that later formed Mumbai were products of coastal erosion and sedimentation from the plateau escarpment that produced mangrove-fringed tidal flats.<sup>16</sup> Boston's landforms, by contrast, were created by receding glaciers whose terminal moraine became a peninsula from the mainland into the ocean with island drumlins extending into harbor.<sup>17</sup>

In each case, however, rainfall collected on the landforms, providing shallow freshwater pools, plant habitat, and aquatic life for ancient fishing cultures. Fishing settlements left stone tools, fish-catching weirs, and pottery dating back five millennia at sites like Frog Pond in what is now the Boston Public Garden.<sup>18</sup> The prehistoric heritage of Mumbai likewise involved local fishing communities (e.g., *Kolis*) who did not engage much in shipbuilding or seafaring.<sup>19</sup>

The early history of Mumbai differs dramatically from Boston, as it includes extensive rock cut Buddhist cave complexes in the headwaters north of the city, carved during the first through tenth

14 Tim Riding, "Making Bombay Island": land reclamation and geographical conceptions of Bombay, 1661-1728", *Journal of Historical Geography* 59 (2018): 27-39.

15 Nancy S. Seasholes, *Gaining Ground: A History of Landmaking in Boston* (Cambridge: The MIT Press, 2003).

16 V.R. Rani et al., "Geomorphology and its implication in urban groundwater environment: case study from Mumbai, India", *Applied Water Science* 5 (2015):137-151. S. F. Sethna, "Geology of Mumbai and surrounding areas and its position in the Deccan Volcanic Stratigraphy, India" *Journal of Geological Society of India* 53 (1999): 359-365.

17 Clifford A. Kaye, "The geology and early history of the Boston area of Massachusetts", *Bulletin 1476* (U.S. Geological Survey, 1976).

18 Joseph Bagley, "A Prehistory of Boston Common". Lawrence Kaplan, Mary B. Smith; and Lesley Sneddon, "The Boylston Street Fishweir: Revisited", *Economic Botany* 44, 4 (1990): 516-528.

19 Himanshu Prabha Ray, "History of Fishing and Sailing Communities in the Western Indian Ocean", *Asian History*, (Dec 2009), DOI: 10.1093/acrefore/9780190277727.013.404

centuries CE.<sup>20</sup> These caves served pilgrimage populations with rainwater harvesting channels and pools. The Buddhist coastal port site at Sopara had a stupa and Ashokan rock edict that may have mentioned the provision of water supplies. The ancient and medieval history of the Mumbai region thus articulated religio-political values associated with water that had no close parallels in Boston.<sup>21</sup>

### Early Urbanization and Water-Related Trade – 17th-19th centuries

Bombay also had earlier mercantile urbanization than Boston in the 16<sup>th</sup> through 19<sup>th</sup> centuries. It faced strong competition from nearby ports like Surat, until political, economic rivalries and siltation led trading communities to shift to the larger port of Bombay.<sup>22</sup> Likewise, Boston faced competition from Salem, Massachusetts, which sent some the first U.S. trading vessels to India.<sup>23</sup> In each case, the initial European settlements were trading posts secured by forts, followed by commercial establishments that soon outgrew both their fortifications and the water tanks and wells that supplied them. Rapid immigration depleted and degraded these local rainfed structures, which were then supplemented by new wells and tanks. However, this process of expansion led in turn to declining water tables, salt water intrusion and leachate from urban pit latrines that rendered the blue-green infrastructure of those times brackish, septic, vector-ridden and, at best, only fit for non-potable uses.

Bombay has always been much larger than Boston, with an estimated 100,000 people compared to Boston's 20,000 in 1790 CE. Although it also has twice as much precipitation, that comes only in the four monsoon months and is difficult to store. Boston's precipitation occurs in roughly equal amounts in each month of the year. A third important difference was that Bombay developed an agrarian landscape alongside its trading and manufacturing economies. Monsoon irrigated rice fields and coconut and date orchards (Portuguese "oarts"), built on reclaimed lands with tanks, constituted the extensive blue-green infrastructure of that era.<sup>24</sup>

The inner geography of the cities also had some similarities. Bombay Fort had a circular green in the center with a well next to it and a circular tank within the ramparts. Just beyond lay its Esplanade, laid out initially for military purposes in 1739. Wells and tanks proliferated in commercial wards beyond the Esplanade. Wells and fountains were a major type of private philanthropy, especially in Bombay, led by successful merchants like Cowasji Jehangir Readymoney.<sup>25</sup> Boston did not have a primary fort or as large a tradition of water philanthropy, but it did have a central Common used for grazing, civic, and recreational functions with the adjacent Frog Pond incorporated into a Public Garden in 1837. These constituted its early core of blue-green urban infrastructure. Boston had poorer glacial soils that mainly supported forest products, some of which were bored out and used as municipal water pipes.

Related to the above, Boston shared with Mumbai two early water infrastructure problems: 1) contamination of local wells and tanks by unregulated sanitary and industrial wastewater discharged into low areas that became stinking toxic pools (e.g., from tanneries); and 2) ineffective discharge of these wastes into tidal waters that washed them back into drains and dwelling spaces on daily and seasonal bases, leading to waterborne disease outbreaks and the degradation of coastal landscapes. Another similarity was their early reclamation histories that excavated hilly areas to create new coastal lands, which they then tried to harden with riprap, pilings, and dredges to improve shipping docks.

20 Himanshu Prabha Ray, "Kanheri: The archaeology of an early Buddhist pilgrimage centre in western India" *World Archaeology* 26, 1 (2010): 35-46. Himanshu Prabha Ray, "History of Fishing and Sailing Communities in the Western Indian Ocean".

21 E.g., the Koli goddess cults, like Mumbadevi, are believed to provide disaster protection. Antonia Marika Vicziany, and Jayant Bhalchandra Bapat, "Mumbādevī and the Other Mother Goddesses in Mumbai", *Modern Asian Studies*, 43,2 (2009): 511-541.

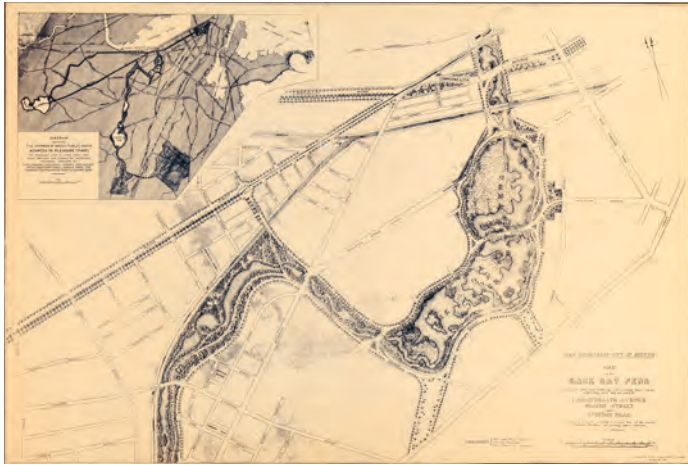
The medieval Banganga tank complex linked legendary accounts of Rama with Shaivite temple pilgrimage on Malabar Hill -- see Rahul Mehrotra and Sharada Dwivedi, *Banganga: Sacred Tank* (Mumbai: Eminence Design, 1996).

22 Sharada Dwivedi and Rahul Mehrotra, *Bombay: The Cities Within* (Mumbai: Eminence Designs, 2001).

23 Susan Bean, *Yankee India: American Commercial and Cultural Encounters with India in the Age of Sail* (Salem and Ahmedabad: Peabody Essex Museum and Mapin Publications, 2001). Jenny Rose, *Between Boston and Bombay: Cultural and Commercial Encounters of Yankees and Parsis, 1771-1865* (London: Palgrave, 2019).

24 Mariam Dossal, *Theatre of Conflict, City of Hope – Mumbai – 1660 to Present Times* (New Delhi: Oxford University Press, 2010).

25 Mariam Dossal, *Theatre of Conflict, City of Hope – Mumbai – 1660 to Present Times*. Varsha S. Shirgaonkar, *Exploring the Water Heritage of Mumbai* (New Delhi: Aryan Books, 2011).



[Fig. 5a] Source: Map reproduction courtesy of the Norman B. Leventhal Map & Education Center at the Boston Public Library.



[Fig. 5b] Courtesy Salem State Archives.

### 19th Century Reclamation Experiments and Early Blue-Green Urban Infrastructure

Land reclamation began early in the history of both cities, but it developed most extensively in the 19<sup>th</sup> century. Both cities built new lands by dredging; excavating hilly areas; importing fill by cart, barge, and rail; and dumping urban waste into low-lying areas.<sup>26</sup> These reclamation projects also improved connectivity between upland and low-lying coastal margins, widening the Boston neck, and establishing causeways and fields between the islands of Mumbai.

Once again, the two cities had striking similarities as well as differences. Both cities developed “Esplanades” (French for “level plain”), Bombay about a century ahead of Boston. Bombay’s Esplanade was located outside the Fort Ramparts and was used initially for defensive surveillance, military drills, and public gatherings. Boston’s Esplanade followed a century later on landfill along the Charles River for recreation and travel. Although both features endured as public open space, Boston’s transportation function exploded with automobile traffic and urban highway development in ways that diminished and severed the Esplanade from the city fabric.

The situation was chronologically reversed in the two cities’ Back Bay reclamation projects, with Boston developing its Back Bay for prosperous residential real estate in the early 19<sup>th</sup> century, and Bombay developing its Back Bay decades later. Boston’s Back Bay lined the Charles River and had a grand boulevard known as Commonwealth Avenue that extended from the Boston Public Garden west. However, when it reached the Muddy River tidal estuary it encountered a sanitary mess of streamflow, urban waste, and tidal currents.

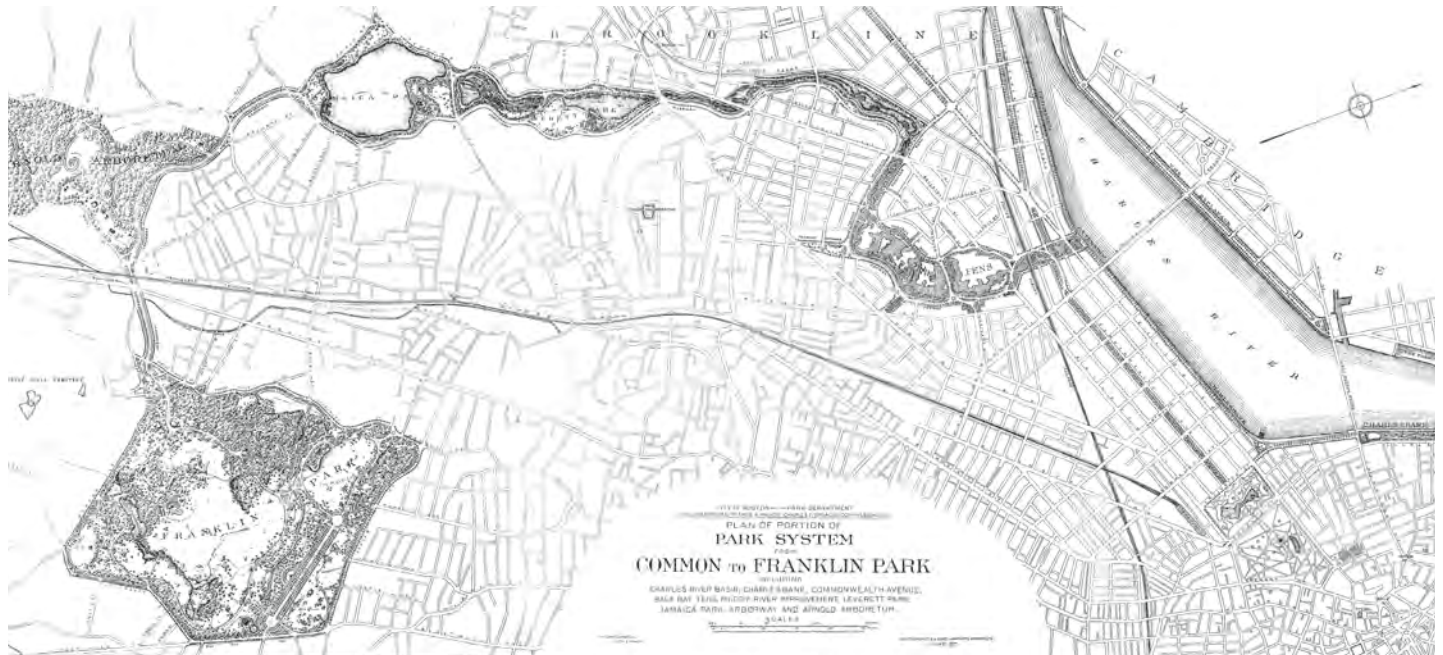
After several failed attempts to deal with the problem through beautification, Boston hired visionary landscape architect Frederick Law Olmsted to develop an alternative approach to urban drainage design. In 1882, Olmsted proposed a broad meandering waterbody to hold stream runoff, flanked by native vegetation, with discharge regulated by tidal gates at the mouth of the Charles River to prevent the backflow of polluted waters. He insisted that the Back Bay Fens, as he called them, were a “sanitary improvement,” and not a “park.”

Olmsted then extended these improvements upstream along an elegant Riverway corridor to a reservoir known as Jamaica Pond. He went further: developing a boulevard to link Jamaica Pond with the new Arnold Arboretum, jointly owned by Harvard University and the City of Boston (which Olmsted helped negotiate *and* design), and from there to Franklin Park which he designed as a true “park” with expansive views and rolling terrain.<sup>27</sup> At an even larger regional scale, Olmsted’s protégé Charles Eliot helped establish Boston’s Metropolitan Park Commission in 1892, which likewise focused on

26 Tim Riding, “‘Making Bombay Island’: land reclamation and geographical conceptions of Bombay, 1661-1728”. Nancy S. Seasholes, *Gaining Ground: A History of Landmaking in Boston* (Cambridge: The MIT Press, 2003).

27 Frederick Law Olmsted, “Tenth Annual Report, Boston Park Commissioners, Report on Back Bay”, in *The Papers of Frederick Law Olmsted: The Early Boston Years, 1882–1890*, vol. 8 (Baltimore: Johns Hopkins University Press, 2014): 228–31. Cynthia Zaitzevsky, *Frederick Law Olmsted and the Boston Park System* (Cambridge: Belknap Press, 1992).





[Fig. 6] Source: Map reproduction courtesy of the Norman B. Leventhal Map & Education Center at the Boston Public Library.

protecting regional pond and stream corridors that flow into Massachusetts Bay. It was one of the most important chapters in the history of water urbanism.

Olmsted's masterful array of 19th century blue-green infrastructure in Boston later came to be known as the "Emerald Necklace," which bears comparison with Mumbai's Marine Drive, formerly known as the "Queens Necklace," along its Back Bay reclamation project. Bombay's Back Bay reclamation project developed fitfully over many decades due to financial and political problems. Development of the popular Chowpatty Beach was followed by landfill in adjacent areas for commercial, residential, and recreational development.<sup>28</sup> Residual drainageways to the north, like the Mithi River, had to discharge monsoon runoff from large developing areas on a scale that could not be controlled by locks. The tidal flux supported mangrove ecosystems that have been channelized in all but the lowermost reaches.

Both Back Bay projects had waterfront parks, flanked by high-end real estate development, that were diminished over time by widening coastal roads, paved surfaces, and coastal armoring that left little in the way of blue-green infrastructure a half century later. The initial reclamation plans failed to anticipate these processes of urbanization or address the combined discharge of sanitary, stormwater, and solid wastes into coastal waters. But this is to leap ahead to the 20th century.

Urban water demand expanded concurrently with drainage projects in both cities, and in each case, they responded by damming upstream reservoirs in the second half of the 19th century. In Bombay, water engineers first developed Vihar Reservoir (1860) then Tulsi (1897) and Powai (1891) lakes on the upper Mithi River. Boston created the Wachusett Reservoir (1897-1905) in an adjacent upstream watershed. These reservoirs supplied water by gravity to distribution reservoirs and then through pipe networks within the city, which constituted a major infrastructural shift from blue-green to networked gray infrastructure. The cities knew that watershed protection was crucial for maintaining reservoir water quality, but land use controls were weak. One of the most important lessons from these projects is that even the most innovative urban water design projects of the 19th century did not receive adequate protection, maintenance, or design improvement over the long-term.

The three most important parallels of the 19th century were thus: 1) reclamation of tidal lands that created valuable but vulnerable real estate; 2) design of new waterscapes based on the fabric of watersheds, stream corridors, and coastal inlets; and 3) construction of remote water supply projects and distribution networks to meet the needs of burgeoning populations. Each of these improvements would begin to encounter limitations, encroachments, and deterioration in the 20th century that now



[Fig. 7] Source: Map reproduction courtesy of the Norman B. Leventhal Map & Education Center at the Boston Public Library.

pose significant threats for the 21<sup>st</sup> century, as both cities face joint vulnerability to storms and sea level rise aggravated by impervious patterns of urban development.<sup>29</sup>

### 20th Century Innovations and Failings

The 20th century witnessed increasingly ambitious regional reservoirs and long-distance water pipelines, but arguably less innovative urban environmental design, perhaps because increasingly distant water sources and waste disposal relied on underground piping to meet evolving needs. Olmsted's original vision for the Back Bay Fens did not fare well. The Charles River was dammed in 1910, converting its tidal regime into a freshwater reservoir that rendered the tidal locks useless. Carriageways shifted to asphalt roads for automobile traffic, and later urban highways sliced through the Emerald Necklace. An analysis of City expenditures during the 20th century indicates limited investment in blue-green park improvements (with the exception of quasi-private Arnold Arboretum).

29 Anuradha Mathur and Dilip da Cunha, *SOAK! Mumbai in an Estuary* (New Delhi: Rupa Publications, 2009). Vladimir Novotny, et al. *Water Centric Sustainable Communities: Planning, Retrofitting, and Building the Next Urban Environment*.



[Fig. 8a and 8b] Photo James L. Wescoat Jr.

Instead, the city placed increasing emphasis on sports fields, war memorials, and rose gardens.<sup>30</sup> Powai Lake watershed was encroached upon by urban institutions that competed with recreational and environmental uses.

Both cities quickly outgrew their nearby reservoirs, which led to much longer distance regional water appropriation. Boston and its suburbs created a Metropolitan Water Resources Authority that developed the massive Quabbin Reservoir (1930-39), and even envisioned an inter-basin diversion from the Connecticut River that environmentalists and downstream states blocked. Eventually, leak detection and repair of aging pipes saved 30% of the city's losses. Bombay extended its reach to the Tansa River (1892) and Vaitarna River (1957) fed by large monsoon flows from the Western Ghats that receive over 2000 mm of monsoon rainfall per year. But it is still not enough to meet the rising demands of population growth, seasonal shortage, unknown leakages, wastewater disposal, and mismanagement of intermittent and inequitable water deliveries.<sup>31</sup>

Both cities faced two other mounting problems in the 20th century: wastewater disposal and flooding. Boston's combined sanitary, industrial, and stormwater sewers contaminated coastal waters in its harbor to a point that required strict legal intervention. The Boston Harbor clean-up took 20 years and was only completed in 2016 through intense monthly monitoring by the U.S. Environmental Protection Agency. The city then began a long-term program of sewer separation, which reduces raw wastewater discharge into the rivers during major rainstorms, which now go to a facility that treats and discharges them offshore. However, without careful waterscape planning, sewer separation will increase discharge of untreated stormwater directly into streams. A recent consent decree with Boston led to new blue-green infrastructure experiments that will increase infiltration in alleys and bioswales, but the scale is modest.<sup>32</sup>

Olmsted's obsolete stormwater management system failed in the flood in 1996 that inundated neighborhoods, roads, and subways surrounding the Back Bay Fens. This led to an urban watershed management plan and a stream restoration project, recently completed, that built upon Olmsted's vision of blue-green infrastructure with ecohydrologic design methods.<sup>33</sup> The most successful water urbanism program in the Boston region is that of the Charles River Watershed Association (CRWA). This NGO combined citizen water quality sampling with public education, mobilization and lawsuits

30 Ramboll Foundation, "Enhancing Blue-Green and Social Performance in High Density Urban Environments".

31 Nikhil Anand, *Hydraulic City: Water and the Infrastructures of Citizenship in Mumbai* (Durham: Duke University Press, 2017). Lisa Björkman, *Pipe Politics, Contested Waters: Embedded Infrastructures of Millennial Mumbai* (Durham: Duke University Press, 2015).

32 Alex Marks, *Stormwater management in Boston: to what extent are demonstration projects likely to enable citywide use of green infrastructure?*, Master of City Planning thesis (Cambridge: Massachusetts Institute of Technology, 2014).

33 MMOC. Maintenance and Management Oversight Committee, *Muddy River Restoration Project*, [www.muddyriverm-moc.org/](http://www.muddyriverm-moc.org/) (accessed on July 22, 2020).



[Fig. 9a and 9b] Photos James L. Wescoat Jr.

to bring Charles River water quality from a D- to A- rating. CRWA's Blue Cities program integrates urban water infiltration design innovations with porous paving, bioswales, land use planning, and "smart sewers".

Mumbai's urban water and wastewater problems remain staggering. Developed parts of the city have primary wastewater treatment, but huge informal settlements discharge sanitary wastewater and solid waste directly into streams known as *nallahs* that flow into coastal waters. Choked *nallahs* and their surroundings contributed to a perfect storm of intense rainfall and high tides that generated catastrophic flooding in 2005.<sup>34</sup> A more dense network of hydrometeorological stations was established in the Mumbai uplands to measure the high variability in monsoon storm cells and provide real-time warning.<sup>35</sup> The upper Mithi River was channelized with conventional gray infrastructure engineering methods while various proposals sought to protect floodplain mangroves in the lower basin. Historical research compared newspaper damage reports with synoptic climatology records, which showed that the direction of storm tracks as well as their coincidence with high tides accounted for the most damaging events.<sup>36</sup> Recent research underscores that design innovation must consider the socio-political complexities of managing piped water infrastructure systems in cities like Boston and Mumbai.<sup>37</sup> To date, however, there have been limited connections between these lines of academic research and blue-green infrastructure proposals.

### 21st Century – Blue-Green Infrastructure Design in an Era of Climate Change

Some design studies have tried to creatively address the macro-historical geographic challenges of water urbanism. For example, the Ramboll Blue-Green Urban Infrastructure study<sup>38</sup> posited an evolving hub-spokes-and-wheel model that links upland watershed management with stream restoration and coastal zone management in Mumbai that is applicable in Boston and other cities.<sup>39</sup> In the Mumbai context, the Sanjay Gandhi National Park and Buddhist period caves in the headwaters have provided

34 Kapil Gupta, "Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India", *Urban Water Journal* 4, 3 (2007): 183-194. Anuradha Mathur and Dilip da Cunha, *SOAK! Mumbai in an Estuary*.

35 Kapil Gupta, "Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India".

36 Marco Lomazzi, et al., "Synoptic Preconditions for Extreme Flooding during the Summer Asian Monsoon in the Mumbai Area", *Journal of Hydrometeorology* 15(1):229-242.

37 E.g., Anand and Bjorkman. Nikhil Anand, *Hydraulic City: Water and the Infrastructures of Citizenship in Mumbai*. Lisa Björkman, *Pipe Politics, Contested Waters: Embedded Infrastructures of Millennial Mumbai*.

38 Ramboll Foundation, "Enhancing Blue-Green and Social Performance in High Density Urban Environments".

39 Anne Rademacher, *Building Green: Environmental Architects and the Struggle for Sustainability in Mumbai* (Berkeley: University of California Press, 2018).

a “hub” of forest canopy and habitat protection for downstream areas for centuries. The “wheel” of coastal zone management has had a mixed record of protection and degradation. The “spokes” of stream corridors have deteriorated badly.<sup>40</sup> Mathur and Da Cunha propose broader strategies of water urbanism that extend beyond the concept of “spokes” to what da Cunha has called “rain terrain,” which regards the entire landscape as inherently aqueous.<sup>41</sup>

Coastal cities like Boston, and even more so Mumbai, have long records of urban design adjustment to climate variability, sometimes effective, often not, especially on time scales of the decades to centuries involved in climate change. Scientific research on coastal climate change and sea level rise has been underway for more than three decades, but applications to blue-green urban infrastructure design have been relatively slow.

For example, Boston only undertook detailed studies of climate impacts some decades after the advent of research on sea level rise. An early study by Kirshen and Hennesey assessed the implications of climate change for the Metropolitan Water Resource Authority water system, finding wide variation in global climate models and offsetting effects of temperature and precipitation scenarios.<sup>42</sup> A decade later, Kirshen, Ruth, and Anderson and others turned to infrastructure impacts of climate change and the linkages between adaptation strategies and estimated costs.<sup>43</sup> Another decade later, emphasis finally shifted to the urban design implications of sea level rise.<sup>44</sup> However, high value coastal real estate along the Boston Seaport continues to develop despite federal mapping that indicates increasing flood risks.<sup>45</sup> Even low-lying universities like MIT are just beginning to undertake detailed studies of flood risk reduction, floodproofing, and sustainable landscape design.<sup>46</sup>

The lessons from historical geography are important. Recall the early historical research in the Mumbai region that indicated sedimentation and abandonment of the prosperous Buddhist port at Sopara.<sup>47</sup> Modeling flood exposure and vulnerability along the Mithi River underscores the long-term benefits of mangrove protection, coupled with innovative drainage, non-structural warning and insurance interventions, and fundamental water governance reforms.<sup>48</sup>

In summary, the prospect of global climate change, sea level rise, and extreme storm events pose existential challenges for major areas of coastal cities like Boston and Mumbai. The geographic dimension of urban climate adaptation on long time scales is crucial. Kelly Shannon has emphasized the “agency of mapping” for changing consciousness of urban water history.<sup>49</sup> Mathur and da Cunha have developed highly innovative landscape mapping methods for both the Mumbai and New Orleans

40 Monalisa Chatterjee, and James K Mitchell, “The Scope for Broadening Climate-Related Disaster Risk Reduction Policies in Mumbai”, *Professional Geographer* 66,3 (2014): 363-371.

41 Anuradha Mathur and Dilip da Cunha, *SOAK! Mumbai in an Estuary*.

42 Paul H. Kirshen and Neil M. Fennessey, “Possible Climate-Change Impacts on the Water Supply of Metropolitan Boston.” *Journal of Water Resources Planning and Management* 121,1 (1995): 61-70.

43 Paul Kirshen, Matthias Ruth and William Anderson, “Interdependencies of urban climate change impacts and adaptation strategies: a case study of Metropolitan Boston USA”, *Climatic Change* 86 (2008): 105–122.

44 Ellen M. Douglas; et al., “Coastal flooding, climate change and environmental justice: identifying obstacles and incentives for adaptation in two metropolitan Boston Massachusetts communities”, *Mitigation and Adaptation Strategies for Global Change* 17, 5 (2012): 537-562.

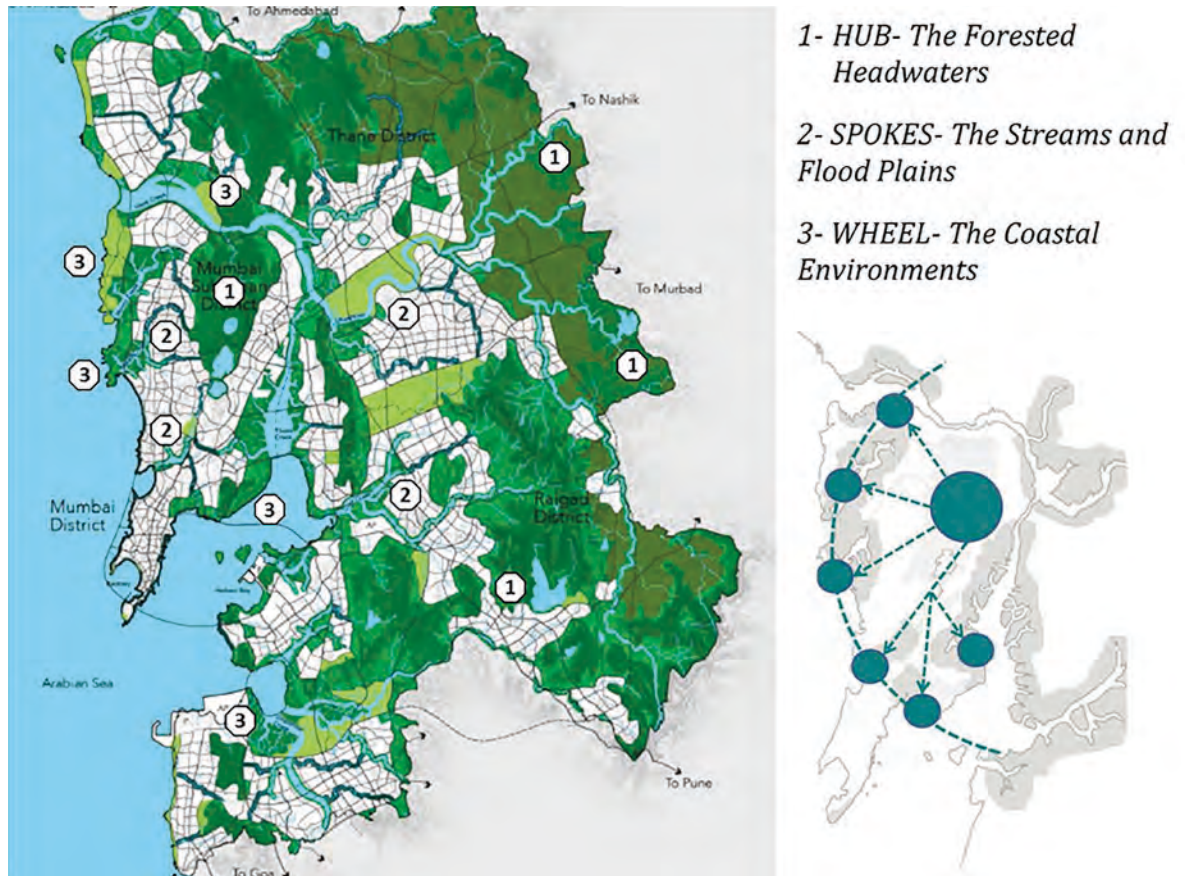
45 E.g., Chingwen Cheng, et al., “Assessing climate change-induced flooding mitigation for adaptation in Boston’s Charles River watershed, USA”, *Landscape and Urban Planning* 167 (2017): 25-36.

46 Kenneth Strzepek, et. al, “MIT Climate Resilience Planning: Flood Vulnerability Study”, Report 326 (Cambridge: MIT Joint Program on the Science and Policy of Global Change, 2018).

47 Savita Ghate, “Sea level fluctuations of North Konkan with special reference to Sopara”, *Current Science* 57, 24 (1988): 1317-1320.

48 Emily Boyd, and Aditya Ghosh, “Innovations for enabling urban climate governance: evidence from Mumbai”, *Environment and Planning C-Government and Policy* 31, 5 (2013): 926-945. Kapil Gupta, “Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India”. Hallegatte, et. al., “*Flood risks, climate change impacts and adaptation benefits in Mumbai: an initial assessment of socio-economic consequences of present and climate change induced flood risks and of possible adaptation options*” (Paris: OECD, 2010). Nicola Ranger, et al., “An assessment of the potential impact of climate change on flood risk in Mumbai”, *Climatic Change* 104 (2011): 139–167.

49 Kelly Shannon, “The Agency of Mapping in South Asia: Galle-Matara (Sri Lanka), Mumbai (India) and Khulna (Bangladesh)” *Footprint: Delft Architecture Theory Journal* 2 (Spring 2008): 105-119.



[Fig. 10] Base map from Concept Plan for the Mumbai Metropolitan Region. Photos James L. Wescoat Jr.

contexts.<sup>50</sup> Berger and Mehrotra have led urban design studios that map Mumbai’s urban “edges” of mangroves, beaches, rivers, and industrial belts to identify adaptive strategies.<sup>51</sup> Berger, Susskind, and Zeckhauser have introduced the concept of mapping resilient districts in Boston that down-zone and wet floodproof low-lying coastal edges, up-zone higher elevation areas (hubs), and provide a transition zone in between.<sup>52</sup> Renewal of Olmsted and Eliot’s urban riparian corridor vision using ecological and equitable principles could address the weak link (spokes) that connect these zones.<sup>53</sup> Macro-historical comparisons of cities like Mumbai and Boston help explain these urban design challenges, assess long-term blue-green infrastructure performance, and imagine a broader range of water urbanism alternatives for the future.

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50 Anuradha Mathur and Dilip da Cunha, *SOAK! Mumbai in an Estuary*.

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