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A Mapping Method for the Exploration of Rapidly Urbanizng Deltas

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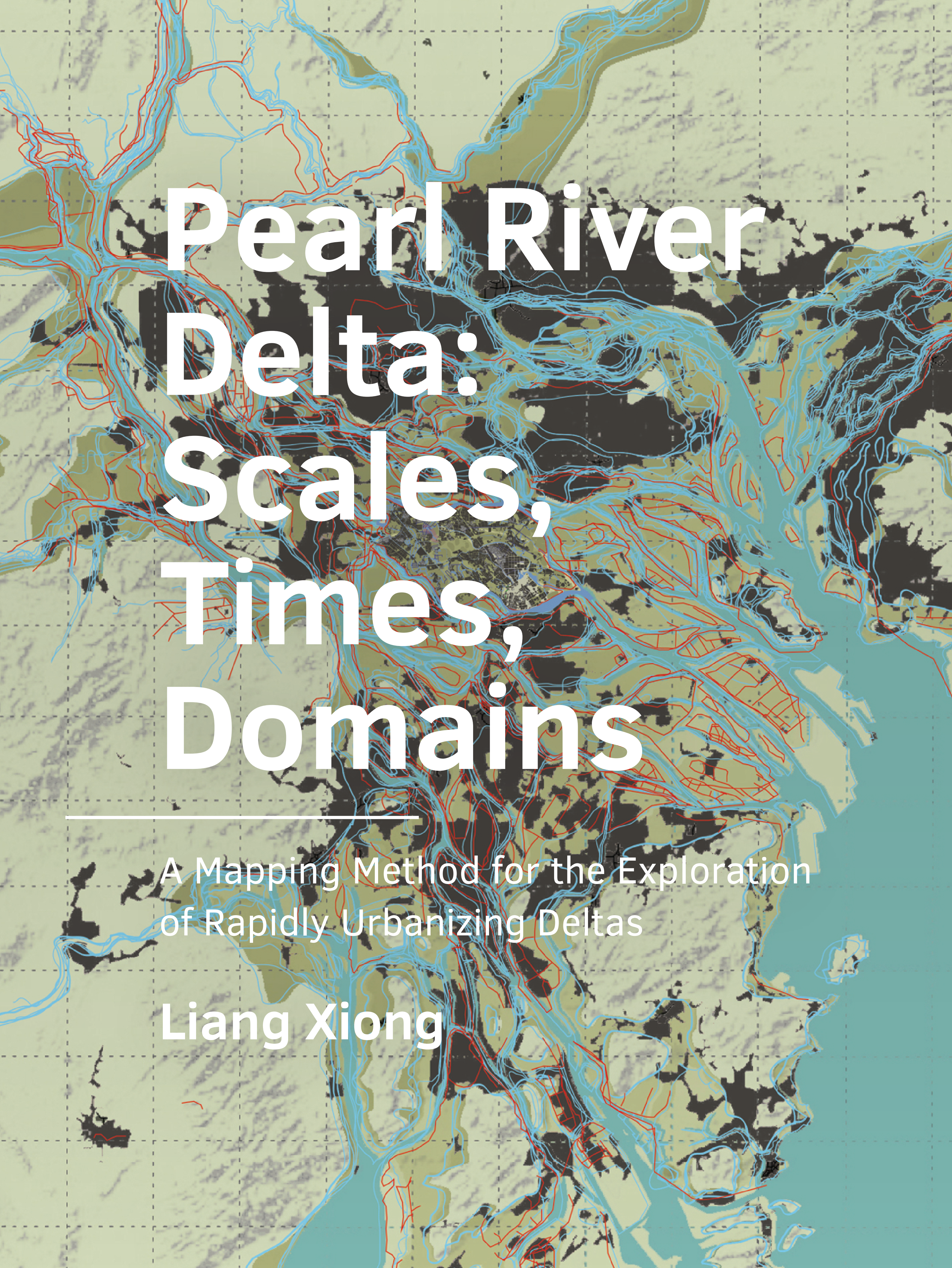
DOI
10.7480/abe.2020.21

Publication date
2020

Document Version
Final published version

Citation (APA)
Xiong, L. (2020). *Pearl River Delta: Scales, Times, Domains: A Mapping Method for the Exploration of Rapidly Urbanizng Deltas*. [Dissertation (TU Delft), Delft University of Technology]. A+BE | Architecture and the Built Environment. https://doi.org/10.7480/abe.2020.21



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Liang Xiong

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TOC

A+BE | Architecture and the Built Environment | TU Delft BK

20#21

Design | Sirene Ontwerpers, Rotterdam

ISBN 978-94-6366-341-0
ISSN 2212-3202

This dissertation is open access at https://doi.org/10.7480/abe.2020.21

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A Mapping Method for the Exploration of Rapidly Urbanizing Deltas

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, prof.dr.ir. T.H.J.J. van der Hagen
chair of the Board for Doctorates
to be defended publicly on
Wednesday, 16 December 2020 at 10:00 o'clock

by

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This research was funded by the special PhD - Program of the China Scholarship Council (CSC) in cooperation with the Delft University of Technology in the field of: Integrated Water Solution and its application towards Urban Deltas (file number 2009601067), and also partially supported by the National Natural Science Foundation of China (NSFC), the Netherlands Organization for Scientific Research (NWO), and the Engineering and Physical Sciences Research Council(EPSRC) of the United Kingdom's Joint Research Project: "Adaptive Urban Transformation (AUT) - Territorial governance, spatial strategy and urban landscape dynamics in the Pearl River Delta" (grant no. ALWSD 2016.013 sustainable delta program).

For my grandparents
For Duoduo, Yu An, Zi An, & Yufang
For Naili

Acknowledgements

I am grateful to God, who helped me through this journey. “Yea, though I walk through the valley of the shadow of death, I will fear no evil: for thou art with me; thy rod and thy staff they comfort me.” I would not make it with the loss of my beloved three grandparents, two children and one mentor. So many times, I thought I was done, you carried me through. Thank you for giving my life, then teaching me how to make good use of it.

I want to express my gratitude to my mentor team: Han Meyer, Steffen Nijhuis, and the late Ina Klaasen. I was fortunate in having Han, who feels like a breeze during my time-consuming exploration, as my promoter. I owe him, not only for the guidance, but also for the wonderful research atmosphere he created in the Delta Urbanism research group. My promoter Steffen helped me to preserve my passion in Landscape Architecture and life with his overflowing optimism and encouragement. With her sharp observation, Ina guided me back on track during our short yet powerful discussions. I am gratefully to have Ana Maria Fernández-Maldonado as external mentor, who took care of my mental health. My special thanks to my unofficial supervisor Prof. Taeke de Jong, who taught me to enjoy the exploration of possibility.

I am grateful to be funded by the special PhD – Program of the China Scholarship Council in cooperation with the Delft University of Technology, and partially supported by the National Natural Science Foundation of China, the Netherlands Organization for Scientific Research, and the Engineering and Physical Sciences Research Council of the United Kingdom’s Joint Research Project: “Adaptive Urban Transformation (AUT) – Territorial governance, spatial strategy and urban landscape dynamics in the Pearl River Delta”. I could not have completed my doctoral study without their financial support. I owe my thanks to Prof. Y. Sun of South China University of Technology (SCUT), Prof. E. Lange of University of Sheffield (UoS), Prof. G. Lin (SCUT), Dr. S. Hehl-Lange (UoS), and Dr. A. Tomkins (UoS) from the AUT team for their critical and constructive comments.

The members of the doctoral committee, Prof. Y. Sun (SCUT), Prof. dr. -Ing. S. Z. Wu (Tongji University), Dr. P.E. Rabé (Erasmus University Rotterdam, University of Leiden), Prof. dr. ir. C. Zevenbergen (IHE Delft, TU Delft), and Prof. dr. W.A.M. Zonneveld (TU Delft) are gratefully acknowledged for their approval without reservation. I doubted if I still have the strength to revise my draft again. Véro Crickx proved me wrong, and helped to turn the draft to a better-designed book.

My sincere gratitude goes to the Foshan Natural Resources and Urban Planning Bureau (FNRUPB), Shunde Bureau of Land Resource, Urban Construction and Water (SLUW), Foshan Water Authority, Bureau of Housing and Urban-rural Development of Foshan, Bureau of Culture, Press, Publication, Radio, Film and Television of Foshan, and Foshan Institute of Urban Planning, Survey and Design for their support and cooperation. I am particularly thankful to Mr. Bihui Li, Vice Director, (FNRUPB), and Mr. Wei Wu, Section Chief (FNRUPB). Mr. Jinkui Li (China Development Institute), Prof. Xiaotao Cheng (China Institute of Water Resource and Hydropower Research), Prof. Hailiang Xu (Wuhan University of Hydraulic and Electrical Engineering), and Dr. Weibing Zhang (China Institute of Water Resource and Hydropower Research) provided me with valuable information. Also, I am thankful to the libraries, archives, exhibition halls, and museums that provided me with essential literatures and maps.

I would miss my fellow PhDs in the Delta Urbanism research group: Chenkun Chung, Yuting Tai, Verónica Zagare, Dieu Quang Pham, Wei Dai, and Daniele Cannatella. Mapping with you has always been inspiring. I enjoyed the accompany of amazing colleagues and visiting scholars in the Chair of Urban Design: Theory and Methods and the Chair of Landscape Architecture for the exploration of design and designerly thinking, in particular Els Bet, Jiaxiu Cai, Sinan Yuan, Teake Bouma, Terrence M Curry, and Mei Liu. Thanks to Astor Huang, Suwanna Rongwiriyaphanich, Jinhuan He, Peiwen Lu, Diego Sepulveda-Carmona, Leo van den Burg, MaartenJan Hoekstra, Nikki Brand, Sitong Luo, Rachel Keeton, and Cinco Yu, you helped me to find a balance between work and coffee time, despite the fact that I cannot drink coffee.

I could not dream for better secretaries like the ones in in my department. I was grateful to be supported by Linda de Vos, Amber Leeuwenburgh, Danielle Hellendoorn, Margo van der Helm, Karin Visser, Astrid Roos-Aukes, Annemieke Klein, and Chiara Termini. Even in the current Covid-19 pandemic, their care, laugh and food reached me as if I just passed by the secretaries'. Life would have been so hard without them.

My gratitude goes to my friends. Thank you for supporting me during my darkest days, and for so many times.

My dear parents in law, Guiyong Zhao and Kaiqin Tan, thank you for the trust and support.

My dear parents, Tongsheng Xiong and Xiaohong Zheng, I love you.

My dear Duoduo, Yu An, Zi An, and Yufang, I love you.

My dear Naili, I love you.

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Summary

An implemented design of an urban area not only imposes long-term conditions on societal processes, but also on natural processes. The urbanization of the Pearl River Delta (PRD) is a highly dynamic process that has interfered with many natural and artificial processes in the complex system. The involved human and natural processes, each with their own scale and speed of change, compose the complex urban delta landscape. The dominance of the efficiency-oriented fast urbanization process and its accompanying infrastructure development have put the deltaic social, cultural, and ecological environments at greater risk. Human activities have caused conflicts of a lack of cooperation with nature and coordination with other human activities during the rapid urbanization. The effectiveness of the related plans and designs depends on their capability to acknowledge and adapt to the nature of urban deltas.

The research aims to provide an understanding of an urbanizing delta in which different scales, times, and domains are related to each other; and to examine how this understanding can be used in a planning and design process in a rapidly urbanizing delta. A mapping method is developed according to the key notions in the understanding of urban deltas, namely its systems, scales, and temporality. The systematic mapping approach was used to organize and analyze both short-term and long-term spatial data during the rapid delta urbanization processes by transforming spatial data via scales, times, and domains. The mapping approach works with insufficient data, which is often the case in a rapidly changing environment, to identify spatial challenges from a long-term perspective.

Applied in the PRD, the knowledge of the development of the urban landscape had been inventoried, synthesized, and presented in its own spatial-temporal model using maps. Three types of processes (landscape formation, infrastructure extension, and urbanization) were identified according to their speeds. Spatial interactions were illustratively explained on both the delta scale and local scale from 4000 BC to the present with a time extent ranging from 2000 years to 50 years. The visualization revealed a transition of the regional pattern from a water-based mode to a land-based mode, during which an unawareness of the landscape and a detached urban pattern were developed. The present flooding issue was revealed by identifying the critical threshold signals, namely sudden changes in the spatial pattern of the dike system. Such trends increased the flood risk in the new urban areas on both the delta and regional scales. The mapping approach provided a probable vision of 2080, and a possible alternative vision. The two visions offered both the options of repair and transformation for the discussion of future planning and design. Both empirical and hypothetical mapping were deployed to provide a comprehensive understanding of the delta. Mapping served as a tool with which to not only represent existing knowledge, but also to seek missing knowledge.

The intervention of this mapping framework was applied and evaluated in terms of design, decision-making, and education, and the insights gained were used to discover new possibilities and strategies for the delta. The systematic spatialization approach provided a spatial analysis-based design and planning alternative. In this approach, evidence-based arguments facilitated the cooperation and collaboration of professionals, stakeholders, and the interested public during the planning and design of the delta. During knowledge gathering and the re-mapping process, current stakeholders from different domains were able to collaborate, new stakeholders (the citizens) became involved, and enough awareness of natural processes was created to spur cooperation during the decision-making process. The systematic mapping across scales, time, and

domains provided the stakeholders with a new mindset during design and planning, in which they were able to collaborate with each other and develop interventions that could cooperate with the natural process in the rapidly urbanizing delta. The mapping approach also directed possibilities of sustainable planning and design process by generating a circulation among the individual design, collective design, and mass awareness of the PRD. The mapping approach thus served as a vehicle that brought awareness to the spatial relationships, exchange of knowledge, and means of collaboration in both the short term and long term, on both small and large scales, and among different domains and stakeholders.

This study contributes to the knowledge of urban delta planning and design from the following five aspects. (1) It extends the understanding of the differences and mutual influences of the urban and natural dynamics to the highest level by investigating the region with the fastest urbanization process in the past four decades. (2) It provides an approach for the analysis, understanding, and evaluation of the rapid change of urban dynamics on a large scale and with an extreme transition stage. (3) It enables the possibility of achieving a more effective, adaptive, and resilient strategy by providing an understanding of spatial knowledge. For the first time, the complexity and uncertainty of urban deltas and essential relationships (such as natural-human, land-water, and spatial-management relationships) on a substantial scale and with a rapid change of speed are explored. Furthermore, (4) this study devises, employs, and tests innovative visualization via multiple spatial and temporal scales. This is required to establish suitable interventions and measures via interactive communication and decision-making during the processes of design, planning, and management with stakeholders. Finally, (5) this study provides an effective data acquisition and analysis method to bypass the issues of data censorship, insufficiency, and inaccuracy in Chinese urban research. In other words, this study provides a strategy to achieve more integrated and resilient delta planning and design. It provides a substantial opportunity via visualization and spatialization to overcome the obstacle of localism among different levels of governments in the decision-making and implementation processes. It also helps to increase public awareness of, and participation in, the planning and design process, which are often lacking in the Chinese context.

Samenvatting

Een geïmplementeerd ontwerp van een stedelijk gebied legt niet alleen langetermijn-voorwaarden op aan maatschappelijke processen, maar ook aan natuurlijke processen. De verstedelijking van de Pearl River Delta (PRD) is een zeer dynamisch proces dat veel natuurlijke en kunstmatige processen in het complexe systeem heeft verstoord. De betrokken menselijke en natuurlijke processen, elk met hun eigen schaal en snelheid van verandering, vormen het complexe stedelijke deltalandschap. De dominantie van het op efficiëntie gerichte snelle verstedelijkingsproces en de bijbehorende infrastructuurontwikkeling hebben de delta-sociale, culturele en ecologische omgevingen in gevaar gebracht. Door een gebrek aan samenwerking met de natuur en onderlinge coördinatie hebben menselijke activiteiten tijdens de snelle verstedelijking conflicten veroorzaakt. De effectiviteit van de gerelateerde plannen en ontwerpen hangt af van hun vermogen om de aard van stedelijke delta's te herkennen en aan te passen.

Het onderzoek beoogt inzicht te geven in het verstedelijken van een delta waarin verschillende schalen, tijden en domeinen met elkaar in verband staan; ook wordt er onderzocht hoe dit begrip gebruikt kan worden in een planning- en ontwerpproces in een snel verstedelijkende delta. Een kaartmethode is ontwikkeld volgens de belangrijkste begrippen in het begrijpen van stedelijke delta's, namelijk de systemen, schalen en tijdelijkheid. De systematische kaartbenadering werd gebruikt om zowel kortetermijn- als langetermijn-ruimtegegevens te ordenen en analyseren tijdens de snelle delta-verstedelijkingsprocessen door ruimtelijke gegevens te transformeren via schalen, tijden en domeinen. De kaartaanpak functioneert ook met onvoldoende gegevens, wat vaak het geval is in een snel veranderende omgeving, om ruimtelijke uitdagingen vanuit een langetermijn-perspectief te identificeren.

De kennis van de ontwikkeling van het stadslandschap (toegepast in de PRD) werd geïnventariseerd, gesynthetiseerd en gepresenteerd in zijn eigen ruimtelijk-temporeel model met behulp van kaarten. Drie soorten processen (landschapsvorming, infrastructuuruitbreiding en verstedelijking) werden geïdentificeerd op basis van hun snelheid. Ruimtelijke interacties werden illustratief uitgelegd op zowel de deltaschaal als de lokale schaal van 4000 v.Chr. Tot heden met een tijdsduur variërend van 2000 jaar tot 50 jaar. De visualisatie vertoont een transitie van het regionale patroon van een watergebaseerde modus naar een landgebaseerde modus, waarbij een onbewustheid van het landschap en een losstaand stedelijk patroon werden ontwikkeld. Door de kritische drempelsignalen te identificeren - namelijk plotselinge veranderingen in het ruimtelijke patroon van het dijksysteem - is het huidige overstromingsprobleem aan het licht gekomen. Dergelijke trends verhoogden het overstromingsrisico in de nieuwe stedelijke gebieden, zowel op de delta als op regionale schaal. De kaartaanpak leverde een waarschijnlijke visie op voor 2080 en een mogelijke alternatieve visie. De twee visies leiden tot zowel de opties voor reparatie als transformatie voor de bespreking van toekomstige planning en ontwerp. Zowel empirische als hypothetische kaarten werden ingezet om een alomvattend begrip van de delta te geven. Mapping was een hulpmiddel om niet alleen bestaande kennis weer te geven, maar ook om ontbrekende kennis te zoeken.

De interventie van dit mappingkader werd toegepast en geëvalueerd in termen van ontwerp, besluitvorming en onderwijs, en de opgedane inzichten werden gebruikt om nieuwe mogelijkheden en strategieën voor de delta te ontdekken. De systematische benadering van ruimtelijke ordening bood een op ruimtelijke analyse gebaseerd ontwerp- en planningsalternatief. In deze

benadering faciliteerden evidence-based argumenten de samenwerking en samenwerking van professionals, stakeholders en het geïnteresseerde publiek tijdens de planning en vormgeving van de delta. Tijdens het vergaren van kennis en het proces van opnieuw in kaart brengen konden huidige belanghebbenden uit verschillende domeinen samenwerken, ook werden er nieuwe belanghebbenden (de burgers) betrokken en werd er voldoende bewustzijn van natuurlijke processen gecreëerd om de samenwerking tijdens het besluitvormingsproces te stimuleren. De systematische mapping over schalen, tijd en domeinen gaf de belanghebbenden nieuwe gedachten tijdens ontwerp en planning, waarin ze met elkaar konden samenwerken en interventies konden ontwikkelen die samen konden functioneren met het natuurlijke proces in de snel verstedelijkende delta. De kaartaanpak richtte ook de mogelijkheden van een duurzaam planning- en ontwerpproces door een circulatie te genereren tussen het individuele ontwerp, het collectieve ontwerp en het massabewustzijn van de PRD. De kaartaanpak diende daarmee als een middel dat de ruimtelijke relaties, kennisuitwisseling en samenwerkingsmiddelen op zowel korte als lange termijn, op zowel kleine als grote schaal en onder verschillende domeinen en stakeholders bewust heeft gemaakt.

Deze studie draagt bij aan de kennis van stedelijke deltaplanning en -ontwerp vanuit de volgende vijf aspecten: (1) Het vergroot het begrip van de verschillen en wederzijdse invloeden van de stedelijke en natuurlijke dynamiek tot het diepste niveau door de regio te onderzoeken met het snelste verstedelijkingsproces van de afgelopen vier decennia. (2) Het biedt een analyse-aanpak, het begrip en de evaluatie van de snelle verandering van stedelijke dynamiek op grote schaal en met een extreme overgangsfase. (3) Het biedt de mogelijkheid om een effectieve, adaptieve en veerkrachtige strategie te bereiken door inzicht te verschaffen in ruimtelijke kennis. Voor het eerst wordt de complexiteit en onzekerheid van stedelijke delta's en essentiële relaties (zoals natuurlijk-mens-, land-water- en ruimtelijk-beheerrelaties) op substantiële schaal en met een snelle snelheidsverandering verkend. (4)Verder werd er tijdens deze studie bedacht en getest met innovatieve visualisatie via meerdere ruimtelijke en temporele schalen. Dit is nodig om geschikte interventies en maatregelen vast te stellen via interactieve communicatie en besluitvorming tijdens de processen van ontwerp, planning en beheer met belanghebbenden. (5) Tenslotte biedt deze studie een effectieve methode voor het verzamelen en analyseren van gegevens om de problemen van gegevenscensuur, insufficiëntie en onnauwkeurigheid in Chinees stedelijk onderzoek te omzeilen. Met andere woorden, deze studie biedt een strategie om tot meer geïntegreerde en veerkrachtige deltaplanning en -ontwerp te komen. Het biedt via visualisatie en ruimtevaart een substantiële kans om het obstakel van lokalisatie tussen verschillende overheidsniveaus in de besluitvormings- en implementatieprocessen te overwinnen. Het helpt ook om het publiek hiervan bewust te maken en moedigt hen aan deel te nemen aan het plannings- en ontwerpproces, wat in de Chinese context vaak ontbreekt.

1 Motivation, research objectives, and approach

1.1 Motivation

An implemented design of an urban area not only imposes long-term conditions on societal processes, but also on natural processes[1].

Deltas have been, and still are, one of the oldest and most prosperous territories for urbanization. Fourteen of the world's nineteen largest cities are located in coastal areas and river deltas (UN-HABITAT, 2012). Their environment has provided a rich habitat for humans, including water, land, food, recreation, aesthetic value, and culture. With the advancements of science, technology, and governance, artificial processes are now having an increasing impact on the development of delta regions. In this sense, urban deltas are some of the most promising regions of the world, considering their large concentrations of population, their important role in the world's ecosystems, and their significance to the world's economy (Costanza et al., 1997). This significant role of urban deltas has raised concerns about their security. Unfortunately, these regions are facing multiple threats and are extremely vulnerable to increasing flood risk, damage to social and ecological values, and substantial economic losses (Gao et al., 2012; Priemus & Rietveld, 2009). The combination of the intensification of urban and economic land use, the related disappearance of deltas' resilience against natural hazards, and climate change are resulting in increases of deadly diseases, poverty, and substantial economic losses (Bradshaw & Weaver, 1995). The urban delta landscape therefore demands interventions.

1 In this dissertation material is used that has previously published in: Xiong, L & Nijhuis, S (2019) 'Exploring Spatial Relationships in the Pearl River Delta' in: X. Ye and X. Liu (eds.), Cities as Spatial and Social Networks, Human Dynamics in Smart Cities, 147-163. Springer Nature.

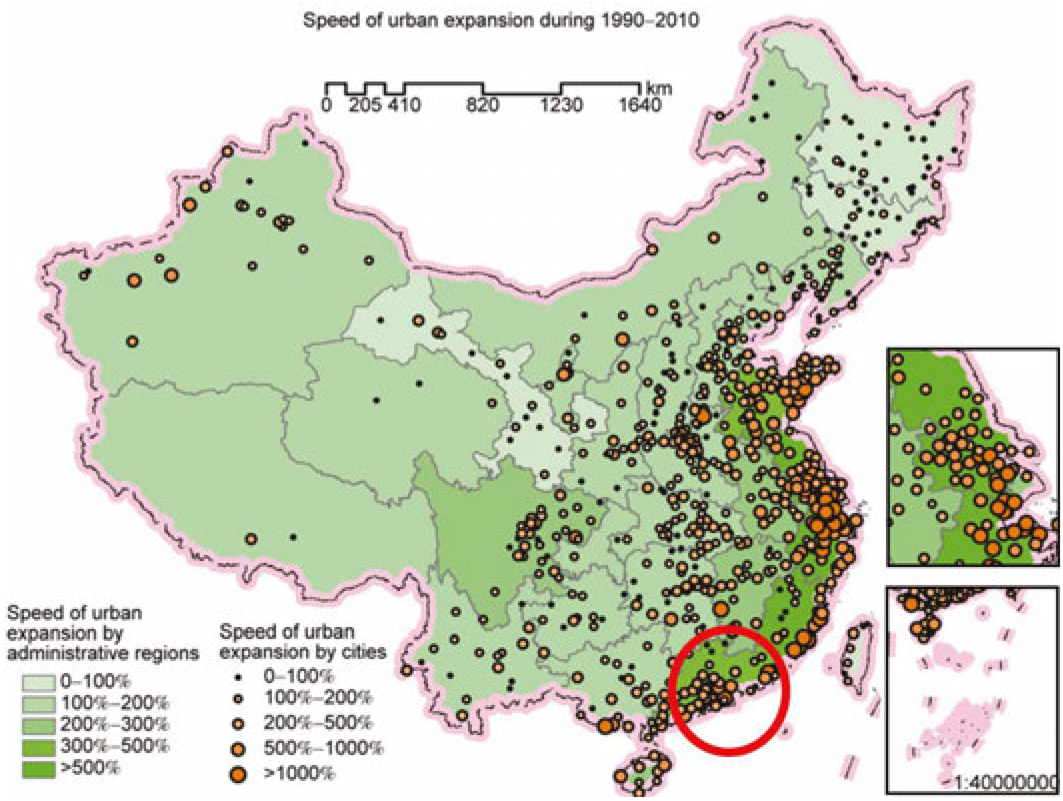

FIG. 1.1 **Speed of Chinese urban expansion during 1990-2010.**
The red circle indicates the Pearl River Delta as one of the quickest-expanding regions. Figure from L. Wang et al. (2012).

Interventions change the landscapes of urban deltas. The Pearl River Delta (PRD) is an extreme case that represents the development of a delta region undergoing a high-speed urbanization process. Ranked as one of the most quickly developing regions in terms of urban expansion (Figure 1.1), it has led Chinese urbanization and socioeconomic transformation with several groundbreaking changes since the 1980s (Lin, 1997; Lo, 1989; X. Xu & Li, 1990; Yeh & Li, 1999). "Time is money, efficiency is life"; there is no other slogan that can better represent the characteristics of the recent urbanization of the PRD. This slogan, introduced in Shenzhen in 1982, has become a national motto for the development speed of the PRD. In the last three decades, the PRD has functioned as one of the key laboratories for the Chinese socioeconomic reform and market economy. Fewer constraints in politics and the economy culminated in a Chinese miracle of industrialization and urbanization. With such a high development speed, the region is also facing challenges that other urban deltas are experiencing, but in an extreme manner.

Not surprisingly, the focus on economic efficiency during the urbanization of the PRD has led to compromises on other aspects. The PRD is known as "the world's factory"; however, an urban delta landscape is not a factory – it is a complex living environment. There is a lack of comprehensive understanding of this rapidly urbanizing delta, as well as a lack of planning and design approach that fits the nature of the delta.

1.2 Research objectives and approach

The objectives of the research described in this book are:

- to provide an understanding of an urbanizing delta in which different scales, times, and domains are related to each other;
- to examine how this understanding can be used in a planning and design process in a rapidly urbanizing delta, in this case, the Pearl River Delta.

The study is based on the hypothesis that a comprehensive understanding of a rapidly urbanizing delta regarding its scales, times, and domains could lead to a solution for the challenges it faces. Therefore, it is necessary to understand the processes that occur in a delta during its rapid urbanization process.

Some important questions that require an answer are:

- What kind of processes are essential to rapidly urbanizing deltas, and how are they related in terms of scale and time?
- How does a systematic analysis contribute to the understanding of the PRD and what are the understandings generated?
- How can these understandings become an instrument in the planning and design processes?

The research is organized into three sections, namely the methodology, application, and conclusion sections. In the methodology section, a theoretical framework of a systematic analysis is developed. In the application section, the method is applied to the PRD on both the individual and collective levels. The method and its implications are then reviewed in the conclusion. Each section is elaborated as follows.

The methodology section is composed of Chapters Two and Three. In **Chapter Two**, the theoretical background of this study is addressed. Three key notions in the understanding of urban deltas, namely its systems, scales, and temporality, are elaborated. With such notions, the state of the PRD urban landscape can be described, leading to the elucidation of the conflicts within and between processes, interventions, and stakeholders. Based on these three key concepts, major elements in the processes, interventions, and stakeholders can be identified. In **Chapter Three**, a mapping method is developed according to the key notions.

The application section is composed of Chapters Four and Five, which describe the application of the cartographic exploration of the urban landscape in the PRD. These two chapters form the heart of the study. **Chapter Four** addresses the research questions of analysis and synthesis on the individual level. Here, the available map sources on the PRD are reviewed, decomposed, and presented as a spatial-temporal model. The derived insights are then used to discover new possibilities and strategies for the PRD. **Chapters Five** addresses the research questions of synthesis and evaluation, and the understanding of the PRD is transferred from the individual level to the cumulative level. Three types of stakeholders, namely designers, the government, and the interested public, were invited to evaluate the knowledge generated by the mapping processes. During the collective mapping process, interventions of different scales were synthesized, different dynamics cooperated, and different domains were coordinated.

Chapter Six concludes this study with a reflection of the approach regarding its formation, analysis, understanding, and evaluation. Feedback and recommendations are then offered to support further research in terms of both methodology and content.

1.3 Relevance and scope

This study contributes to the knowledge of urban delta planning and design from the following five aspects. (1) It extends the understanding of the differences and mutual influences of the urban and natural dynamics to the highest level by investigating the region with the fastest urbanization process in the past four decades. (2) It provides an approach for the analysis, understanding, and evaluation of the rapid change of urban dynamics on a large scale and with an extreme transition stage. (3) It enables the possibility of achieving a more effective, adaptive, and resilient strategy by providing an understanding of spatial knowledge. For the first time, the complexity and uncertainty of urban deltas and essential relationships (such as natural-human, land-water, and spatial-management relationships) on a substantial scale and with a rapid change of speed are explored. Furthermore, (4) this study devises, employs, and tests innovative visualization via multiple spatial and temporal scales. This is required to establish suitable interventions and measures via interactive communication and decision-making during the processes of design, planning, and management with stakeholders. Finally, (5) this study provides an effective data acquisition and analysis method to bypass the issues of data censorship, insufficiency, and inaccuracy in Chinese urban research. In other words, this study provides a strategy to achieve more integrated and resilient delta planning and design. It provides a substantial opportunity via visualization and spatialization to overcome the obstacle of localism among different levels of governments in the decision-making and implementation processes. It also helps to increase public awareness of, and participation in, the planning and design process, which are often lacking in the Chinese context.

This study raises the critical questions of if and how a multi-scale visualization approach would contribute to cooperation among different domains in planning and design. The emphasis of this study is on the application of mapping in planning and design research, not on the implementation of the decision-making process in general; although this study provides related empirical clues, it merely discusses the role of mapping in the planning and design processes. It does not claim that mapping is the only and best solution for adaptive planning and design, but states it to be only one of the tools for knowledge acquisition and intervention. Moreover, this study will raise awareness of the complexity of the relationships among the scales, times, and domains of the PRD by all involved sectors and actors as the most important condition for collaboration and discussion. This study explores the possibilities of mapping as an analytic approach for the research of multi-scale land and water relationships to gain knowledge as a basis for application, intervention, and reflection in the possible desired improbable future of urban delta landscapes. It will also contribute to a new paradigm in the Chinese planning system as an underlying condition for new practices in design, planning, and governance.

2 Urban deltas as dynamic natural and urban systems

2.1 Introduction: The flooding issue in urban deltas

One of the major challenges in urbanizing deltas is flooding. A secured land-river-sea system offers conditions for the development of the accumulated population and socioeconomic structure in delta regions worldwide. However, in rapidly urbanizing deltas, the issue of flooding has become more critical because of (1) higher stakes due to the increasing population and booming economy, (2) the reduction of the stability of the flood defense system due to the strong disturbance of the water cycle and water system, and (3) the existence of more extreme peak discharges and sea-level rise due to climate change, resulting in more pressure on the flood defense system. Unfortunately, the PRD region has experienced all three aspects during its urbanization in the past four decades.

First, the booming of both the population and economy of the PRD is enormous. Vast immigration from the hinterland has occurred, leading to an increase of the population; the population of the PRD region doubled from 20.1 million to 47.9 million between 1982 and 2000 (Tang, 2008), and tripled to 63 million in 2018 (Statistics Bureau of Guangdong Province & Survey Office of the National Bureau of Statistics in Guangdong, 2019). The GDP of the PRD increased by more than 675 times in the 38 years from 1980 to 2018 (Table 1). As the quickest developing and most densified urbanizing delta in the world in the past four decades, the PRD surpassed Tokyo to become the world's largest urban area in terms of both size and population in 2014 (World Bank, 2015). Thus, its security has become more important to both the Chinese and global economies.

TABLE 2.1 **GDP growth in the Pearl River Delta in 1980-2013.**

Year	1980	1990	2000	2010	2018
GDP (Billion CNY)	12	87	737	3837	8105

Data from 1980-2000 was sourced from the (International Statistics Information Center of National Statistics Bureau, 2009) Data from 2010 and 2013 was sourced from the (Statistics Bureau of Guangdong Province & Survey Office of the National Bureau of Statistics in Guangdong, 2011, 2019)

Second, the water cycle and water system have been severely interfered with. First, there is less space for water in the delta. A large amount of agricultural land, primarily fish-pond aqua-agriculture systems, has been transferred into built-up areas (Figure 2.1). Remote sensing (Figure 2.2) has indicated that construction land has grown at the cost of other land-use types, such as natural water and forests (Zhijia Liu et al., 2016). In total, 984.18 km^2 of agricultural land was lost from 1988 to 1993; this land was 13.1% of the total agricultural land or 7.7% of the total area, much more than the land lost during other similar urbanization processes in the world (X. Li & Yeh, 2004). The space for water in the delta, be it flowing, retained, or detained, has been largely decreased.

FIG. 2.1 **Land use in the PRD has changed quickly during the past 40 years of urbanization.**
High-rise housing is replacing agricultural land.

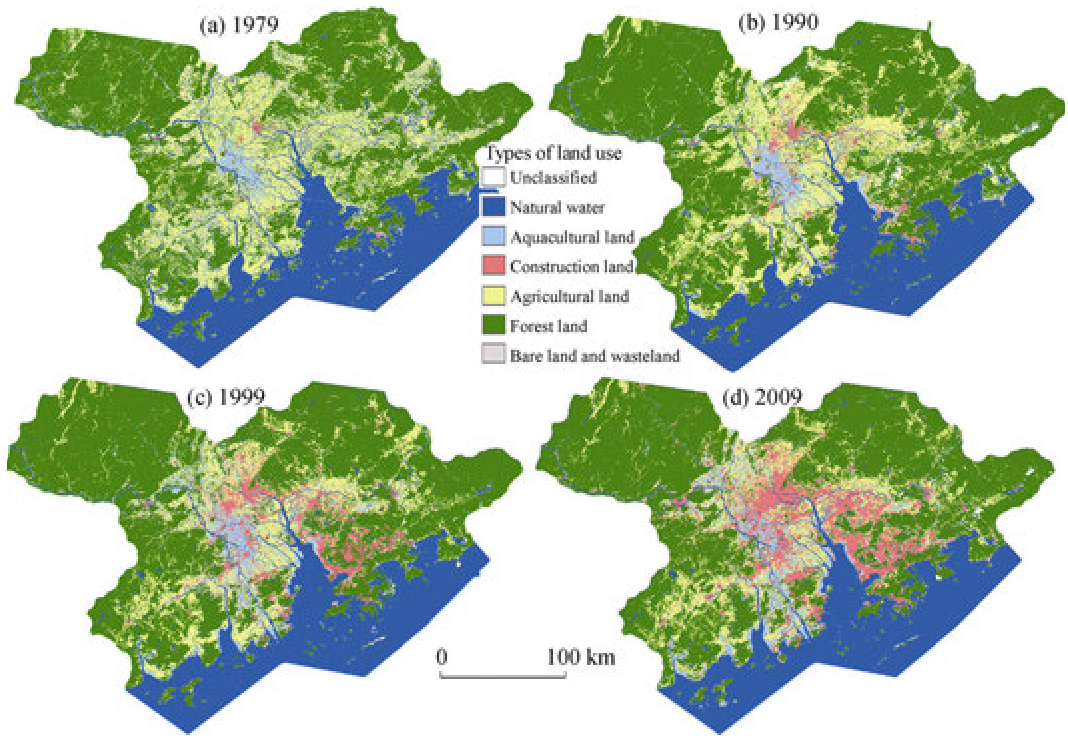

FIG. 2.2 **The land use and cover change in 1979-2009 demonstrates the fast urbanization in the PRD.**
Figure from Liu et al. (2016).

Second, the change of the river network has increased the pressure on the flood defense system. Studies have found that, in the PRD region, activities such as land reclamation and sand dredging have had the greatest impacts on the river network (L. Han et al., 2005; Z. Huang et al., 1983; B. Li & Huang, 2008). By mapping the shoreline transformation (Figure 2.3), it is clear that the extension of the estuaries in the west and middle of the delta has been dominated by land reclamation, and such extension has resulted in increased flood pressure in the river network. As a result, more room for the water is required to flatten the curve during flood season. Unfortunately, there is a lack of publicly accessible information and research on the change in the river network, making it difficult to accurately understand and predict the challenges faced by the flood defense system.

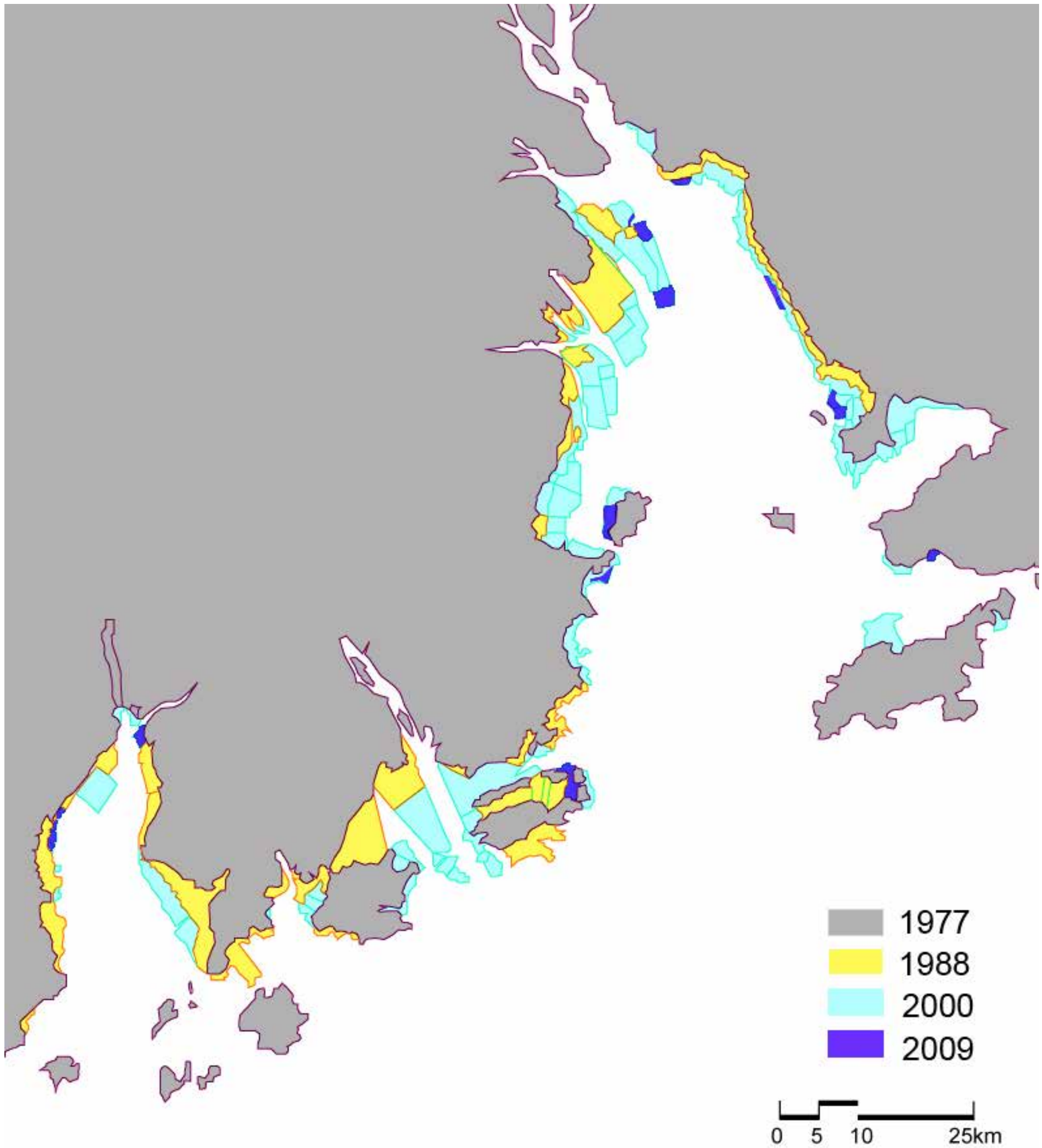

FIG. 2.3 **Shoreline transformation between 1970 and 2009 indicates the trend of land reclamation.**
Before 1988, reclamation generally followed the progression of the natural sediment. There has been a strong trend of land reclamation in the center and eastern parts of the delta, where the urbanization rates are higher. Map by the author. Data from Chen et al.(2010), and Zhao (2010).

Third, climate change will impact the core area of urbanization in the delta. Sea-level rise will affect the majority of the urbanizing area in the flood-prone lowlands (Figure 2.4). One of the largest urban agglomerations, the Guangzhou-Foshan urban metropolitan area in the northwest delta, is the most vulnerable due to its location. In addition to sea-level rise, the impact of climate change will also bring uncertainty to the region in the form of the increasing frequency and intensity of extreme weather.

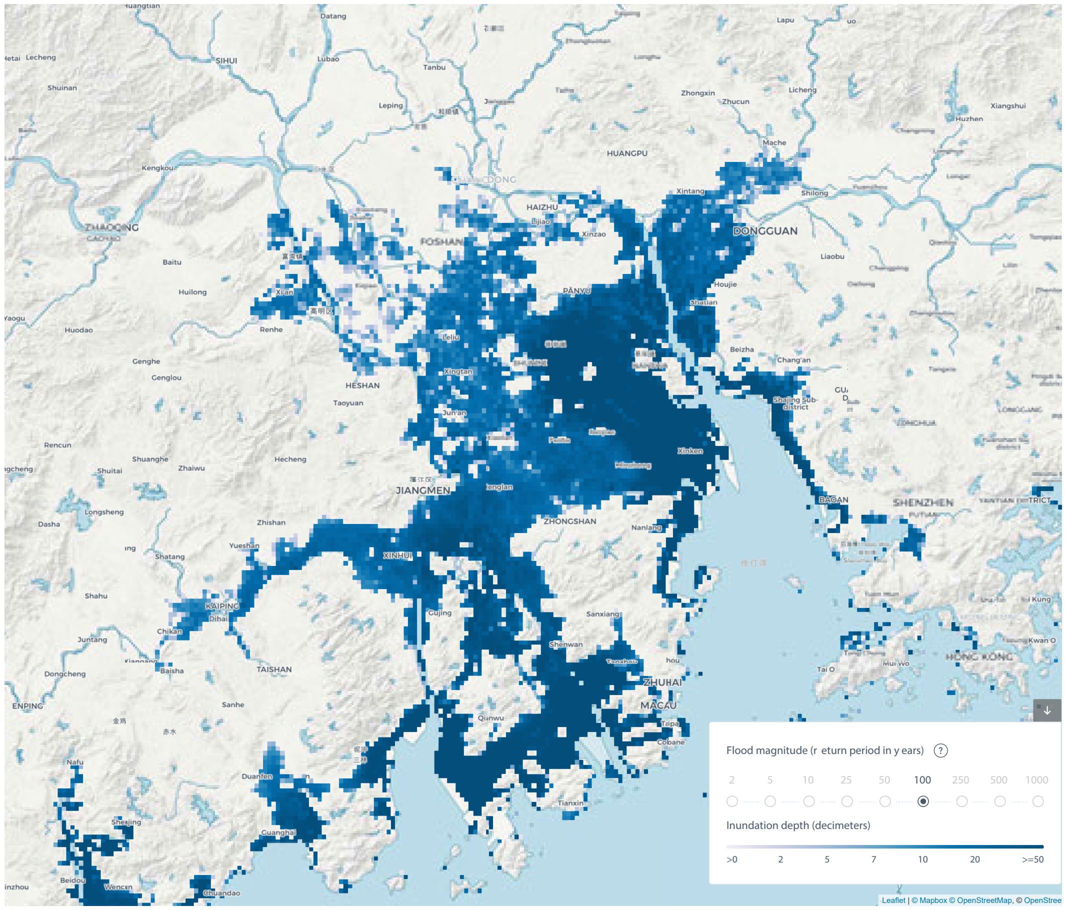

FIG. 2.4 **A map of the coastal flood hazard in 2080.**
Based on the future scenario of “business-as-usual” and the projection model of high sea-level rise, the majority of the PRD will suffer from 100-year floods, which is the highest flood defense level of the region. Map from Ward et al. (2020).

The accumulating population, the decreasing space for water, the need for more space for water, and the uncertainty of extreme weather have all led to potential issues regarding flood defense. However, none of these factors were addressed and connected spatially in the recent plans of the PRD. In the Integration Plan of the PRD (2009-2020), flood defense was limited to the coordination of the upstream dams and the dike rings in the delta ((People’s Government of Guangdong Province, 2010). Considering that none of the factors that threaten flood defense in the PRD were addressed and connected, the water security of the delta is not promising. A deeper conflict regarding the flooding issue is a lack of understanding; the flooding issue is not a challenge of its own, but a component of the challenges in the delta that have yet to be clearly addressed in the space and time domains.

The urbanization of the PRD is a highly dynamic process that has interfered with many natural and artificial processes in the complex system. In fact, several issues that emerged during this quick development suggest blind spots in the highly dynamic process of the development of the delta region. These long-criticized issues include flooding, agricultural land loss, pollution, water shortages, salinization, a low quality of urban life, a loss of identity, and uneven development, among others (Xiaohong Chen & Chen, 2002; Y. Li et al., 2008; Peng et al., 2003; J. Xu & Luo, 2005). Good planning and design cannot be achieved without the awareness of the related scales, times, and domains of these issues. The slow natural process in the river system of the delta region (Figure 2.5) has witnessed the development of various human settlements and ecosystems. The dominance of the efficiency-oriented fast urbanization process and its accompanying infrastructure development have put the deltaic social, cultural, and ecological environments at greater risk. The flooding issue merely represents the tip of the iceberg of the diversity of these conflicts. In fact, flooding is not a collection of conflicts between scales, times, and domains; instead, it represents the interweaving between scales, times, and domains. The involved human and natural processes, each with their own scale and speed of change, compose the complex urban delta. Human activities have caused conflicts of a lack of cooperation with nature and coordination with other human activities during the rapid urbanization. The effectiveness of the related plans and designs depends on their capability to acknowledge and adapt to the nature of urban deltas. Thus, the nature of the conflicts within the urbanization of the PRD is the ignorance of the nature of the urban delta.

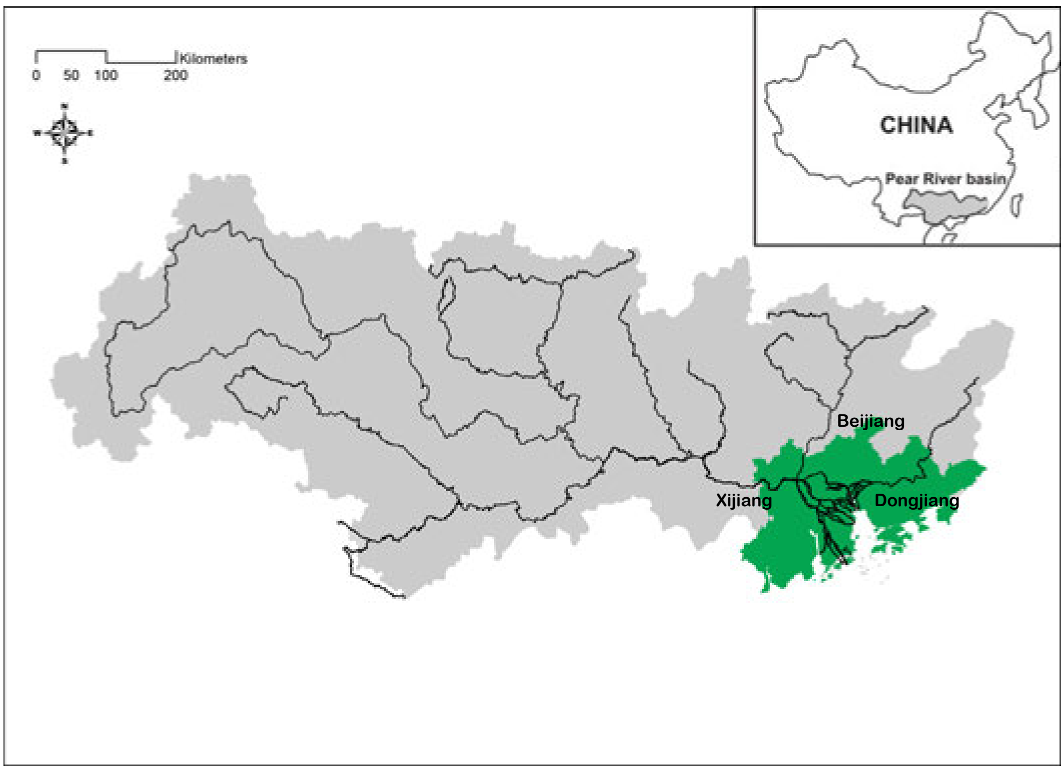

FIG. 2.5 **The Pearl River Basin and Pearl River Delta.**
The delta landscape is complex because of the river network formed by the three main rivers, namely the Xijiang, Beijiang, and Dongjiang rivers, which join in the delta and form eight estuaries. Mapped by author.

2.2 The urban delta as a complex system

The urbanized delta landscape can be regarded as a result of both natural and artificial processes (Meyer & Nijhuis, 2016). Water, wind, sun, fauna, flora, and all kinds of human activities play various roles in shaping the delta landscape. From this perspective, the urban landscape is considered to be a system in which different processes and dynamics influence each other and experience different dynamics of change (Braudel, 1966).

A complex system like an urban delta can only survive in the long term when it has sufficient capacity to recover after disruptions and adapt to changing conditions. Many complex systems are resilient in terms of the ability of the system to recover from external and internal disruptions and maintain its functions. The sustainable design and planning of urban deltas should increase the resilience of deltas. However, as complex systems, urban deltas are not necessarily able to adapt to changes.

As a complex system with various conditions that change at various scales and speeds, the state of the urban delta is less likely to function as a simple model (Figures 2.6a and 2.6b) in which the state of the system responds either smoothly or sharply in a bijective situation, but rather as a complex model, as presented in Figure 2.6c. There are critical thresholds at which the system shifts abruptly from one state to another (Scheffer et al., 2009). For instance, a previous study showed that 91.92% of the tidal flat in the PRD disappeared between 1988 and 2004 (Shugong Wang et al., 2007). Such an ecological disaster urgently demands interventions. Therefore, the sustainable design and planning of urban deltas should also be prepared for these critical thresholds. Once a system has reached its critical threshold, there are two options for human intervention: (1) the implementation of a design and planning approach to avoid or postpone reaching the critical threshold, or (2) the organization of a (controlled) transition of the system toward another stable state, which can be better managed in a sustainable way for a long time.

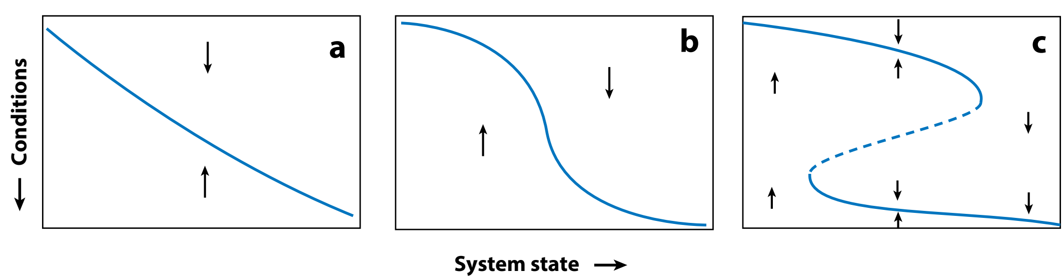

FIG. 2.6 **A classic model of tipping points and resilience.**
The state of the system can be related to the conditions in the following manners: (a) smooth bijection, (b) sharp bijection, and (c) surjection. In type (c), critical transition thresholds exist when there is more than one stable state of the system. Figure from Scheffer et al. (2015).

Although it is notably difficult to predict critical transitions in an urban delta before the system reaches its tipping point, certain spatial patterns and dynamics could be recognized as early-warning signals for critical transitions in many complex systems (Scheffer et al., 2009). The phenomena of sudden changes in spatial patterns or a critical slowing down and flickering in a time series have been found before the critical transitions in complex systems, such as the climate (Kump, 2005; Zhonghui Liu et al., 2009; Lüthi et al., 2008; Petit et al., 1999; Tripati et al., 2005), ecosystems (Kéfi et al., 2007; Rietkerk et al., 2004), the human brain (Elger & Lehnertz, 1998; Litt et al., 2001; McSharry et al., 2003), and financial markets (Bates, 1991, 1996). Therefore, in this study, a systematic investigation of the spatial patterns and dynamics of urban deltas is developed in the hope that similar critical transitions can be found for this kind of complex system.

2.3 Key notions for the understanding of urban deltas

Systems are organized entities that are composed of elements and their interactions, and consist of structures and processes (Batty, 2013). The urban delta, as a system, is a constellation of networks and locations with multiple levels of organization (Doxiadis, 1968; Otto, 2011). It is also a part of a larger system within a river basin. Networks are important for social and ecological interactions, communications, and relationships (Xiong & Nijhuis, 2019), and locations are the result of the synthesis of interactions. Networks can be defined as the formal expression of structures for (1) the provision of food, energy, and freshwater, (2) support for transportation, production, and nutrient cycling, (3) social services such as recreation, health, and the arts, and (4) the regulation of the climate, floods, and wastewater (Xiong & Nijhuis, 2019). Locations are the spatial expressions of a locale whose form, function, and meaning are a result of social, ecological, and economic processes (Nijhuis & Jauslin, 2015). Though the relationships between networks and locations are not pre-determined in their outcomes, networks are becoming more dominant as spatial manifestations of power and function in society (Castells, 2000). This shift implies that design domains should focus not only on locations, but also on networks, as they have the potential to gain an operative force in territorial transformation processes (Nijhuis & Jauslin, 2015). In other words, urban landscapes could be considered as complex systems composed of several subsystems (Dammers et al., 2014; Meyer & Nijhuis, 2013, 2016). This way of thinking provides a possible framework for the understanding, analysis, and design of all the natural and artificial dynamics in a delta region. Some notable cases were presented by Yu et al. (2008), who elaborated a landscape planning approach based on linear elements via spatial scales, and Meyer & Nijhuis (2014), who put forward a design and planning approach for the comparison of urban deltas from the perspective of three temporal stages. Important subjects in this framework include how to identify the subsystems, the statuses of the systems, and the interactions among them. All the descriptions of the systems and subsystems are within the context of scale and scaling in space and time.

Scale has been used as an attributor or descriptor of empirical phenomena (Sayre, 2005), and usually refers to the spatial or temporal dimension of a phenomenon; scaling is the transfer of information between scales (J. Wu & Li, 2006). Scale can be defined as comprising both grain and extent. Grain refers to the finest resolution of a phenomenon or a dataset in the space or time domain within which homogeneity is assumed, while extent refers to the expanse of a study in space or time (Turner et al., 1989). Several territory studies have suggested that the effects of both the spatial and temporal scales should be considered (T. de Jong, 2012a; Meentemeyer & Box, 1987; Turner, 1989; Turner et al., 1989). According to the concept of scale, the scaling effect and overlap are two major difficulties in the interpretation of a complex system with multiple spatial and temporal scales; the scaling effect blocks the possibility of investigating systems that are scale-dependent. Evidence has proven that such an effect exists when the characteristics of the behavior of a system can vary under different scales of perspective (Fuhlendorf & Smeins, 1999). On the other hand, there exists the possibility that the extent of a subsystem can overlap with another subsystem. For instance, the extent of the water management, urban development, or political boundary of an urban delta landscape might not be the same, not to mention their grains and resolutions. These two challenges exist in the study of urban delta landscapes. Shreds of evidence in landscape ecology imply that the study of characteristic scales provides effectiveness and potential for the understanding of the dynamics of scale-sensitive patterns and processes (Clark, 1985; Delcourt & Delcourt, 1988; J. Wu, 1999). Therefore, it might also have a function in the study of a combination of both natural and artificial dynamics. The core of the characteristics of the scale concept is the levels of the hierarchical system, which are associated with scale breaks (O'Neill et al., 1991; J. Wu, 1999; J. Wu & Li, 2006). It should be noted that a complex system is not necessarily a hierarchical system (O'Neill et al., 1991). Therefore, in this study, the hierarchies in the temporal and spatial scales serve as a reference for a scaling mapping technique during the analysis of the processes and patterns of delta urbanization. This section addresses how these three aspects, namely the temporal-spatial hierarchy, scaling, and patterns, work together.

2.3.1 Systems

The understanding of a territory as a system was developed in the nineteenth century. Humboldt used the concept of layers to understand a complex ecosystem in his work, *The Kosmos* (GeoMet, 1999). Almost concurrently, Ritter examined the complexity of nature with a similar induction as that of Humboldt (Chung, 2014); he used areal differentiation to organize geographical material in his work, *Die Erdkunde* (*Geography*). Richthofen distinguished three domains in his model, namely the land surface, the flora and fauna, and the human society (Meyer & Nijhuis, 2015). In the late nineteenth century, the concept of layers was adopted in landscape architecture in the United States of America by Eliot and his associates in the office of landscape architect Frederick Law Olmsted. Olmsted and Eliot were the first wave of landscape architects who overlaid, compiled, and mapped information for the understanding of a territory (McHarg, 1998). Tyrwhitt introduced the overlay technique to academic discussion in 1950, and a synthesized interpretation was made based on her maps of relief, hydrology, rock type, and soil drainage, which ultimately formed a land characteristic map (McHarg, 1998; Steinitz et al., 1976). McHarg adopted this map and used it in his ecological planning approach, later summarized as the "layer-cake model," which was an attempt to provide a solid ecological basis for planning and design (McHarg, 1969). This was the first time that such an overlay technique linked theory with sustainability analysis (McHarg, 1998, p. 206). In this model, McHarg identified ten categories of data necessary for ecological planning: climate, geology, surficial geology, groundwater hydrology, physiography, surficial hydrology, soils, vegetation, wildlife, and humans (McHarg, 1998, p. 79). He suggested six elements to overlay those layers into a revealed ecological determined morphology, namely ecosystem inventory, the description of natural processes, the identification of limiting factors, the attribution of value, the determination of prohibitions and permissiveness to change, and the identification of indicators of stability or instability (McHarg, 1998, p. 43). With the assistance of computer science, this ecological-based layer approach has become one of the most popular methods by which to study spatial issues.

McHarg's systematic ecological planning theory has not only greatly influenced ecological planning and design in the United States, but has also spread worldwide. For instance, a layer model was developed in the Netherlands from the late 1980s onwards (Meyer & Nijhuis, 2016). The Dutch layer approach was constructed in a model by De Hoog, Sijmons, and Verschuuren (van Schaick & Klaasen, 2011). The ecological planning approach was also introduced to China in the late 1990s; however, this trend of systematic ecological planning theory has two drawbacks when applied in China. First, such a planning approach cannot effectively address urban issues. Although it is effective in landscape planning and design, most realized plans are for underdeveloped rural regions and relatively isolated areas, such as parks. The connection between the landscape and its surrounding urban pattern is weak. The landscape process has been considered as a secondary process in the planning system, and its capability has been limited because it is not involved in the decision-making process during earlier phases. Second, such a theory would lead to the rational conceptualization of the territory. Dominant in the 1980s and 1990s, rational planning and design seek to identify the causes of urban problems based on scientific study, but the segregation of urban-related knowledge and datasets has limited its effectiveness. It is applied in a top-down manner, leaving less room for communication and collaboration among stakeholders. Therefore, it is difficult for this approach to be used to explain the spontaneous bottom-up, fast urbanization during the absence of top-down planning and design in several areas of the PRD, nor does it have the capability to form a bridge between the top-down and bottom-up urbanization in the delta region. The complex circumstances in the PRD imply that an effective planning theory must consider both the governmental vision and individual demands, and help these actors reach an agreement. The urban delta landscape is not as simple as expected.

There have been increasing doubts about rational planning as increasingly more externalities have been discovered during the urban planning and design process. Rational planning is based on the modern scientific method, which has a dedicated reductionist explanation of all phenomena in terms of fundamental physics (Mitchell, 2009, p. 1); however, the discovery and understanding of chaos have revealed that complete prediction is not possible. From quantum mechanics to weather prediction, increasingly more evidence regarding the chaos principle and phenomenon has indicated that the behavior of some simple, deterministic systems can be impossible to predict in the long term (Mitchell, 2009, p. 38). In the case of an urban delta landscape, it is even impossible to predict its behavior in the short term. Therefore, urbanism theory has been progressively influenced by complex theories that originated in the 1960s (Portugali, 2012); these theories acknowledge that the environment of an urban system follows certain simple rules, but that not every individual's behavior is simple and predictable. The collective behavior of humans makes the urban landscape a complex system, and this complex thinking requires designers and planners to accept the territory as a place that can merely be controlled. A complex system is "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior" (Mitchell, 2009). Such systems are characterized by several similar properties, such as complex collective behavior, signaling and information processing, and adaptation (Mitchell, 2009, pp. 12–13). If urban deltas are considered on an abstract level, each individual component in this large network follows a relatively simple rule, whether it is the daily decision of a citizen or a drop of rainwater. Humans have also adapted their behavior to improve their chances of survival and success in the delta according to information received and processed from both internal and external environments. In this regard, it is worthwhile to perceive the urban system as a complex system.

To understand the urban delta landscape as a complex system, a model is required. Reality can be considered as a system because it is perceived as a composite of parts with spatial and temporal dimensions (Klaasen, 2004, p. 11). In the real world, all systems are open. Therefore, the definition of a system can be interpreted as constituting the following:

- A set of elements identified with some variable attributes of objects;
- A set of relationships between those attributes of objects;
- A set of relationships between those attributes of objects and the environment (Harvey, 1969, p. 451).

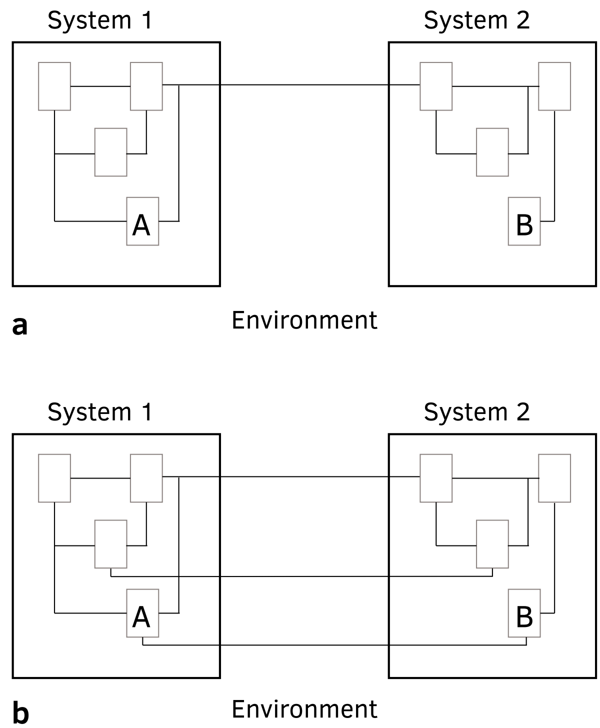

FIG. 2.7 **Interactions between two systems can be perceived differently.**
(a) System 1 and system 2 interact as units with smaller system interactions within each system. Subsystems A and B do not interact directly. (b) System 1 and system 2 interact at two levels. In addition to the primary interaction between the main systems, subsystems A and B interact directly at a lower level. Figure after Harvey (1969), and Klaasen (2004).

Such a definition faces two difficulties in the study of the interaction among systems, namely the scale of the system and the identification of the elements (Harvey, 1969, pp. 450–459). Both difficulties imply that subsystems are possibly embedded in a system and can interact with subsystems within another system (Harvey, 1969, p. 452; Klaasen, 2004, pp. 12–13). Blalock and Blalock (1959) pointed out two different viewpoints from which an element at some higher level in the hierarchy of a system can be perceived, namely an indivisible unit or some loose configuration of lower-order elements. The latter view suggests that interactions exist in subsystems in addition to the main interaction between the main systems, and that these interactions exist in the lower level both in space and in time. These two interpretations are presented in Figure 2.7. The different views of the subsystem can lead to considerable confusion in the subjects that use systemic analysis (Blalock & Blalock, 1959; Harvey, 1969). The present study perceives a complex system as the relationships between forms and processes. The urban delta system implies both spatial patterns and processes (Meyer & Nijhuis, 2015), and social, economic, and environmental processes result in specific spatial patterns. Therefore, such patterns can be viewed as the products of the processes. The physical process of the delta can be regarded as comprising three complex layers (subsystems), namely the natural substratum, the occupation pattern, and the infrastructure network (Meyer & Nijhuis, 2014). Although it influences the other physical layers, the fourth layer of stakeholders is not a physical layer, and serves as a complex addition to the rational planning approach. The stakeholders influence the physical layers via intervention. In this complex layered system, each layer is composed of different subsystems with their own individual levels of spatial and temporal scales, and the subsystems themselves interact on several levels of spatial and temporal scales. The interaction between subsystems at one scale is also relevant in the other levels. In other words, systems, spatial scales, and temporal scales are interrelated in urban deltas. This perspective of systems and subsystems provides a basis for the analysis and understanding of urban deltas.

2.3.2 Spatial scale

From the perspective of a system, urbanized delta landscapes comprise functions with spatial and temporal dimensions (Nijhuis & Pouderoijen, 2014). To comprehend the heterogeneity, this composition in space and time should be viewed as a scale continuum (Nijhuis, 2013). Therefore, the temporal and spatial scales are essential to the understanding of the dynamics of a system. Its elements and interaction with other systems imply that a particular location is always part of a larger context. There are two ways in which to identify the scale in space and time, namely via deductive and inductive reasoning. Taylor (1982) proposed that there are no “natural” (spatial) scales “out there”; instead, different theories invent different scales for different purposes. This idea was supported by Sayre (2005), who drew three deductive conclusions based on a review of scale in existing ecology literature. First, a proper (spatial) scale(s) should be chosen by the researcher to examine the processes. Second, an integrated and unified ecology can only be achieved by addressing inter-scalar and inter-disciplinary phenomena. Third, thresholds of the changes of phenomena exist in certain scales; these thresholds are “an attribute of how one observes something“ (Sayre, 2005). In social sciences, the search for a proper grain and extent that are suitable for understanding a process is no less difficult than it is in natural sciences. Social and natural processes may have widely divergent spatial and temporal scales, and these differences generate significant methodological disparities (Sayre, 2005). This indicates another difficulty of studies on the spatial scale, namely how to combine different scales in different spatial domains. Several scholars have attempted to synthesize scalar issues featured within and across fields to better understand and deal with scale in spatial research (Higgins et al., 2012; Sayre, 2005). Swyngedouw suggested that social and ecological scales exist and have transforming dynamics; he argued that nature and society operate together and usually have nested spatial scales (Swyngedouw, 2004). Based on the central place theory proposed by Christaller (1966), urban designer Doxiadis developed a hierarchical spatial scale series in his model for human settlement (1974). A hexagonal organizational principle is used to build the 20 levels of scale (Table 2.2), and a factor of $\sqrt{7}$ is used between each level of scale. In contrast, De Jong (2004) proposed his inductive spatial scale model based on the analysis of the Netherlands (Table 2.3). The difference between the two models suggests that the deductive model is not applicable to specific cases. However, both models have a similar hierarchical system with a fixed factor. Several fundamental geographical and ecological studies have also indicated the existence of scale hierarchy (Taylor, 1982; Turner et al., 1989). Therefore, a hierarchical model might be a good starting point for an attempt to integrate both social and natural processes. However, none of the mentioned models are unconditionally applied in the present study. Considering that the urban system in the PRD has developed and become much larger and more complex, this study explores the hierarchical spatial system in the urban delta landscape via deductive reasoning to prevent a paradigm bias; in other words, the mentioned hierarchical models are set aside. Instead, a territory-based (in this case, PRD-based) hierarchical model is developed by examining and distinguishing its own morphological characteristics.

TABLE 2.2 **The hierarchical spatial scale in the model of human settlement based on deductive reasoning.**

	Ekistic Territorial Scale	Square meters
18	Biosphere	000,000,000,000,000.000
17	All habitable land	135,750,000,000,000.000
16		19,392,857,000,000.000
15		2,770,408,000,000.000
14		395,772,000,000.000
13		56,538,000,000.000
12		8,077,000,000.000
11		1,153,850,000.000
10		164,836,000.000
9		23,548,000.000
8		3,364,000.000
7		480,570.000
6		9,800.000
4		1,400.000
3	House	200.000
2	Room	28.059
1	Human Bubble	4.084
-1	Standing Person	.583
-2	Squeezed Person	.083

Figure from Doxiadis (1974)

TABLE 2.3 **A spatial scale model including extent, grain, and hierarchy based on inductive reasoning from the case of the Netherlands.**

Frame	Nominal radius (meters)
Global	10,000,000.000
Continental	3,000,000.000
Sub-continental	1,000,000.000
National	300,0000.000
Sub-national	100,000.000
Regional	30,000.000
Sub-regional	10,000.000
Local/ District/ Borough	3,000.000
Area/ Village	1,000.000
Neighborhood/ Hamlet	300.000
Ensemble	100.000
Building complex	30.000
Building	10.000
Building segment	3.000
Building part	1.000
Building component	.300
Superelement	.100
Element	.030
Subelement	.010
Supermaterial	.003
Material	.001
Submaterial	<.001

Figure from de Jong (2004)

2.3.3 Temporal scale

The study of the temporal scale has garnered increasing interest among scholars since the 1980s, especially in the landscape ecology field. The naturalistic, ecosystem science, and landscape ecology approaches are considered to be the three main types of ecological landscape approaches, among which only landscape ecology is focused on the change of the landscape (Baschak & Brown, 1995). In the 2000s, the temporal scale model was put forward by more scholars. Botequilha Leitão and Ahern (2002) suggested the consideration of time during the planning stage. De Hoog et al. (1998) distinguished three layers by the different time scales of spatial dynamics in spatial organization, namely the layers of the substratum, networks, and occupation patterns (Table 2.4). Such a time-oriented approach was then widely accepted in Dutch mainstream spatial planning and in national, provincial, and local planning documents (van Schaick & Klaasen, 2011).

However, this popular Dutch time-oriented approach has been criticized for its two major theoretical limitations, namely a lack of theoretical support for time grains and a lack of consideration of users in a socio-cultural and economic regard (Priemus, 2007; van Schaick & Klaasen, 2011, 2007). Unlike other layer models that focus on spatial classification, the time-oriented model classifies layers by the temporal scale in different dynamics of spatial transformation. The logic of differentiation in the temporal scale remains the same throughout all studied cases; therefore, one would expect a solid theoretical grounding of the concept. However, one study showed an unexpected result that little or no theoretical basis could be found in the application of such a model. Van Schaick and Klaasen (2011) discovered that there is no explicit justification for choosing one time indicator over another (e.g., 5-50 years instead of 5-10 years) in the practical application of a time-oriented model in the Netherlands (Table 2.5). They also found inconsistencies in the definition of the temporal scale in the model; it sometimes refers to a lifespan, planning horizon, or transformation time, and is often an inexplicit mixture of these (van Schaick & Klaasen, 2011). While the manner of temporal identification might glean empirical evidence and practical support in the Netherlands, regarding the PRD, the past four decades provide living evidence that the speed of dynamics might have changed as well. Therefore, a theory that uses a fixed temporal scale for its subsystems is unable to address an important aspect of this complex system: its change of dynamics. Moreover, the current time-oriented layer model has been criticized for its lack of attention to a “user layer” in which socio-cultural and socioeconomic aspects are considered (Priemus, 2007; van Schaick & Klaasen, 2011, 2007). Instead of a time grain of one year or a century in the time-oriented layer model, the time grains for socio-cultural and socioeconomic factors can be relatively small. These aspects, as well as natural daily and weekly processes, are rather cyclic instead of linear (van Schaick & Klaasen, 2011). Without theoretical support, it is difficult to generalize the time-oriented model from the Dutch context. It is suggested that an ontology without scale could solve this difficulty in understanding and explaining socio-spatial transit (Marston et al., 2005).

TABLE 2.4 **The Dutch layer approach distinguishes three layers by the different time scales of spatial dynamics.**

	Design and planning tasks	Approaches
Substratum	Dealing with the physical effects of climate change	Nature engineering
	Modernizing the water management system	Civil engineering
Networks	Strengthening the position of the Netherlands in international networks	Complexes approach (developing nodes for exchange of information and knowledge)
	Control and steer the growth of mobility	Corridor approach (developing mainports and hinterland connections)
Occupation	Accommodating spatial claims and shrinkage in relation to values and attractivity	“Ecology” approach (an ecology defined as a locally characteristic “lifestyle environment”)
		Mould-contramould approach (city vs. landscape)
Coherence	Creating synergy between interventions	Conditioning spatial planning
		Facilitating spatial planning

Source (van Schaick & Klaasen, 2011), after (De Hoog et al., 1998)

TABLE 2.5 **Different temporal scales when applying a time-oriented model in practice without explicit justification.**

Source	Dynamics on the occupation layer	Dynamics on the network layer	Dynamics on the substratum layer
De Hoog *et al.* (1998b)	25-50 years	50-100 years	100-500 years
PRD (2000)	Low rate of change	Moderate rate of change	High rate of change
PRD (2001)	Not mentioned	Not mentioned	50 to > 500
VROM (2001a)	Not mentioned	Not mentioned	Not mentioned
Provincie Noord-Holland (2002)	One generation per cycle on the building market	Faster than substratum	>100 years
Sijmons (2002) on temporal scales	5-10 years	10-30 years	20-200 years
Sijmons (2002) on planning horizons	5-15 years	15-50 years	50-100 years
Werksma (2002)	10-40 years	25-100 years	50-500 years
VROM (2006)	Not mentioned	Not mentioned	Slow/ long term
www.ruimtexmilieu.nl (2006)	10-40 years	20-80 years	>100 years
Senternovem (n/a)	Highly dynamic	Moderately dynamic	Slightly dynamic
Provincie Overijssel (2009b)	5-50 years	50-100 years	>100 years

From (van Schaick & Klaasen, 2011).

A recently implemented project has shed light on the systemic view of the urban delta and its integrated planning and design. The renowned Room for the River program (2012-2016) in the Netherlands has provided a concrete project based on a systematic approach. With the integration of multiple aims, scales, and multi-level governance, it has established integrated plans and designs for 39 projects across the country (Rijke et al., 2012). These projects demonstrate close collaborations in governance among provinces, municipalities, water authorities, and the central government (Rijkswaterstaat Room for the River, 2013). Many of them, such as the Project Room for the Waal Nijmegen (Figure 2.8), also provide good examples of the integration among the domains of flood defense, landscape architecture, and urban planning. Each project was implemented by a special project team that included local stakeholders, who could define how and where the new project would be designed and implemented. The national agency controlled whether every project met the general standards. In this way, the 39 projects collaborated and achieved the designed maximum discharge capacity of 16,000 m^3/sec, which is a 1250-year standard for flood defense. The Room for the River program demonstrated how integrated planning and design works when the processes are coordinated between scales, times, and domains.

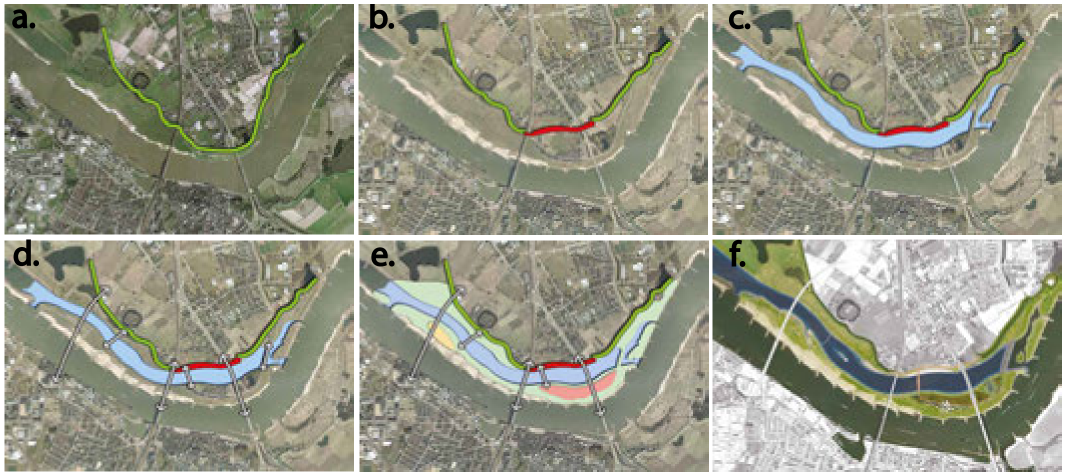

FIG. 2.8 **The construction site of Room for the Waal Nijmegen (2014).**
A sub-project of the Room for the River in the city Nijmegen. Based on the existing dike (a), the relocating of a dike (b), the construction of an ancillary channel (c), the linking of the two sides of the river (d), and the raising of an island (e) were all integrated within a long-term plan (f) of the city to enhance connectivity, recreation, and housing. Figures from Gemeente Nijmegen (2011)

FIG. 2.9 **Satellite views of the PRD (left) and RMSD (right).**
The PRD is located at 22°46'30.16" N 113°40'11.49" E, and the RMSD is located at 51°47'01.30" N 4°45'21.63" E. The view of both regions is from 362.49 km. Source: Google Earth 2019

The Dutch experiences of planning and design in an urban delta could provide a reference for the challenges faced in the PRD. The Rhine-Meuse-Scheldt Delta (RMSD) in the Netherlands and the PRD are comparable in size (Figure 2.9); however, the successful urban design and planning in the RMSD may not be applicable to the PRD given the substantial differences in the natural and urban dynamics of these two deltas (Table 2.6). The two aspects that might lead to different performance levels between the two urban deltas are the scale and time. First, the scales of both the natural and human processes found in the PRD are much larger than those in the RMSD. The mean daily discharge in the PRD is 4 times higher than it is in the RMSD, and the sediment load is 118 times higher. The stronger river dynamic makes diking more difficult, and it is even riskier to reconstruct the dike system. The second influencing aspect is time, as the speeds of many processes are different. The subtropical climate in the PRD results in a much more extreme precipitation pattern, especially when compared with the mild weather in the RMSD. Together with the double-sized river basin, the PRD receives much more water in a shorter response time during the flood season. Therefore, while a peak discharge of 16,000 m^3/s is as rare as once in 1250 years in the RMSD, a peak discharge of 426,000 m^3/s is much more frequently experienced in the PRD. In relation to human processes, the Room for the River projects took advantage of a slower development pace of the urban area due to the impact of the economic crisis of 2008. Moreover, the Room for the River projects were mostly implemented in rural areas (Figure 2.10), where these dynamics are often slower than those in urban areas. In contrast, the PRD managed to maintain a relatively high speed of urban development despite the economic crisis. Human intervention in the river network was also very quick; the hydraulic characteristics of the river networks became invalid due to the fast-changing river conditions. In 2005, a once-in-10-year high water level produced a peak discharge of a 100-year flood (Yue, 2005). In this case, flood prediction failed due to the misinterpretation of the data, resulting in a regional flood throughout the PRD. These two differences at the spatial and temporal scales are the main challenges faced when introducing the Dutch approach to the PRD. Due to the spatial and temporal differences between the two deltas, the same deductive reasoning is applied in this study when exploring the temporal hierarchical system of the PRD, which is applied to the exploration of the spatial hierarchical model. Time periods are identified by the occurrence of significant changes on the spatial scale. In this way, a spatial-temporal model of the PRD is deductively established.

TABLE 2.6 **Comparison of the PRD and RMSD.**

	Pearl River Delta	Rhine-Meuse-Scheldt Delta
River basin (1000 km2)	454[1]	221[3]
River length (km)	2,055[1]	1,320[3]
Mean daily discharge (m3/s)	10.654 (estuaries)[1] 7,233 (Gaoyao, West River)[7]	2,035 (Lobith)[4]
Sediment load (Mt/a)	83.3[7]	0.07
Major agglomerations	Guangzhou-Foshan 22.8 Shenzhen-Dongguan 21.3[5]	Randstad: 8.1[6]
Flood return period (once in X years)	Between 20-50 (2004) and 50-200 (2020) [2]	1,250-10,000
Designed peak discharge (m3/s)	42,600 (Gaoyao station, West River, 1/100 years)	16,000 (Lobith)

Data sources:
1 (National Development and Reform Commission 国家发展与改革委员会, 2004)
2 (National Development and Reform Commissio, 2009)
3 (Vriend, 2009)
4 (The Global Runoff Data Centre, 2018)
5 (Statistics Bureau of Guangdong Province & Survey Office of the National Bureau of Statistics in Guangdong, 2019)
6 (CBS, 2019)
7 (Water Resource Department of Guangdong Province, 2018)
8 (C. Wu et al., 2014)

FIG. 2.10 **Room for the River projects, the majority of which were implemented in rural areas.**
Map from Rijkswaterstaat (2013).

The urban delta landscape is a scale-dependent system. Processes and behaviors can be represented differently or even contradict phenomena in the three networks of hardware, software, and orgware (Xiong & Nijhuis, 2019), the connections between which are essential to the analysis of urbanized deltas. Therefore, an effective spatial-temporal model should be able to adequately address these aspects. In other words, the capability of describing a system with proper spatial and temporal scales would greatly affect the credibility of this type of study. Therefore, in the present analysis, the concepts of spatial and temporal hierarchies in other cases were used as a reference, instead of as a foundation, to avoid possible misinterpretations of their contexts. Therefore, the spatial-temporal hierarchical model should be based only on its own morphological changes, which implies a territory-based model. Urban deltas should be studied as complex systems, within which subsystems interact with each other, with their own territory-based spatial-temporal model.

2.4 The PRD, a state of affairs of the urban delta landscape

An overview of spatial knowledge provides clues for the development of a spatial-temporal model. The spatial information of the delta landscape is clustered by processes, and many maps are presented as part of this knowledge production. With the assistance of numbers and texts, maps represent the knowledge generated from space in an understandable manner. Maps also provide a significant medium with which to communicate spatial knowledge from different domains. With the consideration of a complex system, the processes, interventions, and stakeholders would also seem like complex systems composed of subsystems, each with their own dynamics and relevant spatial scale. Therefore, while the mapping of the knowledge in a spatial-temporal model can show what is known, it also indicates what is unknown. A state of the art of the urban delta landscape can provide clues for possible spatial scales and time periods for the development of a territory-based spatial-temporal model. These clues are further examined via a spatial analysis, the result of which is present within the PRD-based spatial-temporal model.

2.4.1 Blurred Processes

Extreme urbanization and industrialization

The first major process that has taken place in China since the 1980s is extreme urbanization and industrialization. The PRD benefited from less-restrictive planning policies that allowed urbanization and industrialization to flourish in the delta. Such freedom has resulted in massive development, and the urbanization rate rocketed from 16.26% in 1978 to 79.6% in 2006 (Tang, 2008). This high-speed development has created enormous changes in the physical environment. The urbanization and industrialization process could be viewed on several levels of spatial and temporal scale.

On a regional scale, land-use change and land reclamation have been the two primary types of land change during the process of rapid urbanization since the 1980s. The delta used to be one of the most important agricultural regions in China, where the cultivation of rice, sugar cane, banana, and aquaculture took place before economic reform and urbanization (X. Li & Yeh, 2004). During this process, the market-driven economy has greatly changed the landscape of the region, and large areas of land have been altered. Rice paddies have been turned into urban areas, orchards, or fishponds, while wetlands and the shore have been destroyed to create more land. Built-up areas emerged at an average speed of 82.1 km^2 per year between 1989 and 1997 (Weng, 2002). By comparing the four maps from 1979 to 2009 presented in Figure 2.11, this spatial development trend can be visualized. The east wing of the delta witnessed a much more rapid urbanization process than the west wing. Both the form and process witnessed on the regional scale of the PRD suggest a missing spatial scale at the sub-regional level where two types of urbanization processes can be studied more closely.

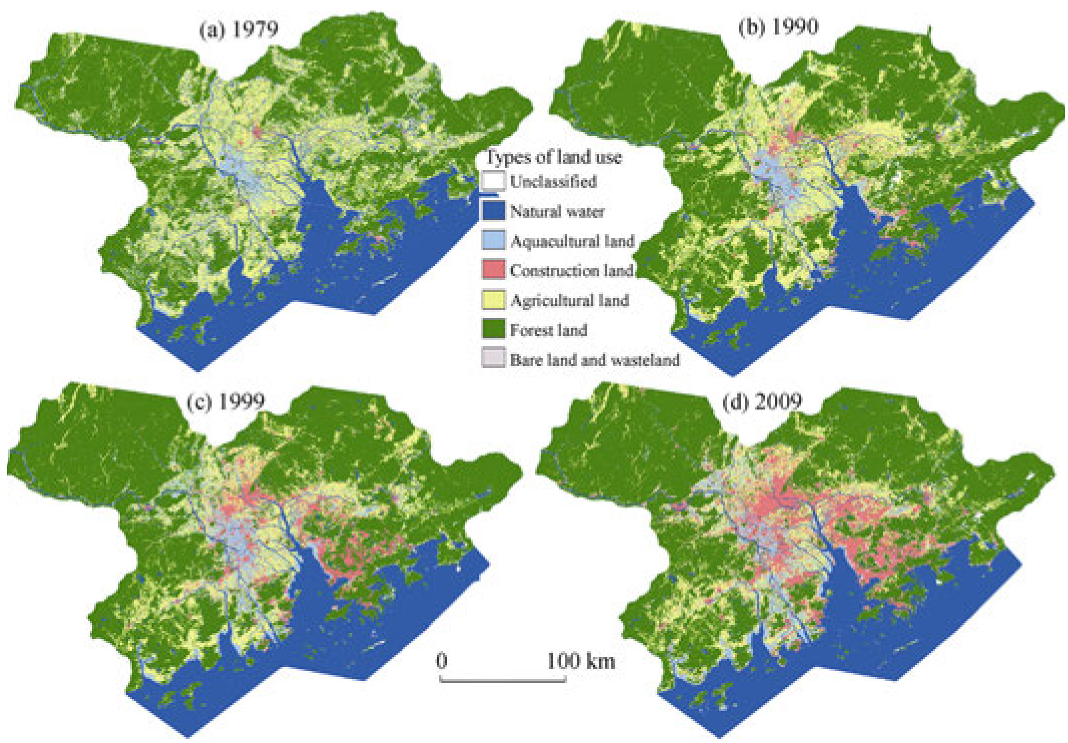

FIG. 2.11 **The land-use and cover changes between 1979 and 2009 reveal the fast urbanization in the PRD.**
Figure from Liu et al. (2016).

At the next level, namely the spatial level, two types of urbanization and industrialization patterns can be recognized on the municipal scale. In addition to the top-down processes that are usually seen in Chinese regional development, a bottom-up process also occurred in the region (Figure 2.12). For example, municipalities such as Foshan, Dongguan, and Zhongshan developed in a bottom-up manner, and urbanization therefore took place at the county and village levels (T. Li & Fu, 2014). In this mode, planning decisions from individuals, families, villages, and counties outweighed the decisions of the municipalities, province, and the central government. In contrast, municipalities such as Guangzhou, Shenzhen, and Zhuhai developed in a top-down manner, and urbanization therefore took place along major infrastructure corridors and around key projects (T. Li & Fu, 2014). The development phases of these cities have been decided by regional or even national governments; thus, their urban regions exhibit more concentrated patterns. Both the top-down and bottom-up modes have shaped the PRD during this rapid urbanization and industrialization process, and the co-existence of the two urbanization modes has been recognized at this spatial scale (e.g., (Smart & Lin, 2007). However, there is a missing link between studies that have focused on the same urbanization and industrialization process on different spatial and temporal scales. The lack of knowledge of the mechanism of the urbanization and industrialization process during its scale change has caused an oversimplified understanding of the developmental model of the region.

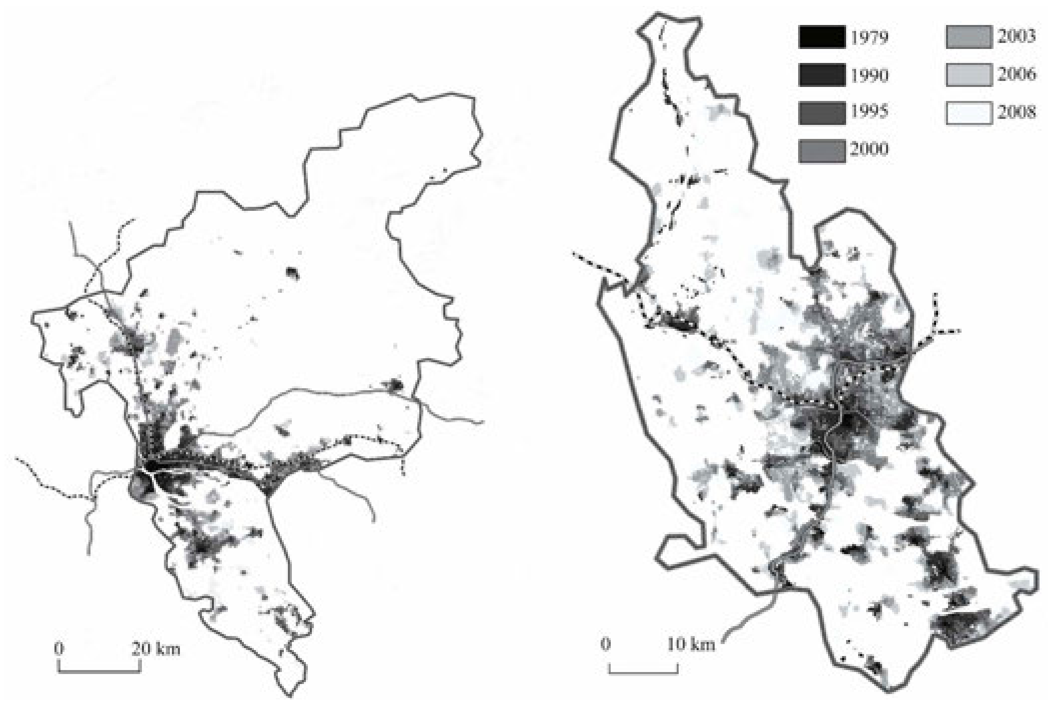

FIG. 2.12 **Two urbanization and industrialization modes in the PRD have resulted in different expansion patterns.** As compared to Guangzhou (left), which experienced top-down planning, Foshan (right), which experienced the bottom-up mode, is characterized by a decentralized expansion pattern that has less co-relation with large-scale traffic infrastructure, but is more related to the original settlements. Maps from Li & Fu (2014).

Infrastructure development

The second major process that has taken place in China is the development of its infrastructure, such as roads, railways, and dikes. The development of infrastructure covers three aspects, namely quantity, quality, and scale. The quantity is the most visible characteristic in the infrastructure development of Guangdong Province, where the PRD is located. From 1978 to 2017, the total length of the roads increased by 4.2 times, the railway length increased by 4.2 times, the port cargo capacity increased by 25.4 times, airport passenger traffic increased by 70.8 times, and airport cargo traffic increased by 47.5 times (Guangdong Provincial Development and Reform Commission, 2017; Statistics Bureau of Guangdong Province, 2008). The quality of the infrastructure also increased concurrently. During the past four decades, the road and railway systems experienced extraordinary development not only in length, but also in speed and connectivity. The percentages of highways and high-speed railways have been steadily increasing across the transportation network; between 2010 and 2015, highways and high-speed railways respectively contributed 7.2% and 73.2% of the total road and railway construction, as compared to nearly 0% in 1978

(Guangdong Provincial Development and Reform Commission & Guangdong Provincial Department of Transportation, 2017). The third development took place on the scale of infrastructure networks. With the increases in the quality and quantity of infrastructure elements, the scales of these networks have also exhibited new trends. Some smaller-scale networks have been linked into larger-scale networks because of increased connectivity; for instance, the development of an intercity railway system has brought the local traffic network of each municipality into a regional traffic network. Conversely, some smaller-scale networks have been replaced by larger-scale structures. For instance, smaller dike rings have generally been replaced by the integration and enhancement of large-scale water infrastructure since the 1950s. These changes in the infrastructure network have placed increasing pressure on the ecosystem, both on land and in the water. In the terrestrial ecosystem, habitat has been separated and isolated by increasing road and railway density, whereas in the water ecosystem, the connectivity of the river network has been reduced by dike integration. The connectivity among economic, social, and ecological functions must be balanced.

Land-water dynamics

The third major process that has taken place in China is the change of the land-water dynamics, which has consisted of both natural processes, such as sedimentation and erosion, and artificial processes, such as reclamation, dredging, and diking. The delta can be divided into two parts by geomorphology, namely a strong fluvial-dominated area in its center and the west, and a tide-dominated area in the east (C. Li et al., 2001). 80.6% of the land in the delta is flat terrain with about 160 hills and 187 islands spreading around the coast (Z. Huang & Zhang, 2004). It starts from the joined point of the Xijiang (West River) and Beijiang (North River) in Sansui (Three Rivers), and Shilong in the Dongjiang (East River). These three major tributaries (Figure 2.5) respectively contribute 77.8%, 10.5%, and 6.6% to the drainage area of the Pearl River (Y. D. Chen et al., 2010), and respectively contribute sediment of 86.9%, 6.2%, and 3.7% to the delta (Yuefeng Liu et al., 1998). Of the sediment, 20% is settled inside the delta and the rest is spread around the estuaries (Z. Wang et al., 2005). Both natural and artificial forces played important roles in the shaping of the delta morphology.

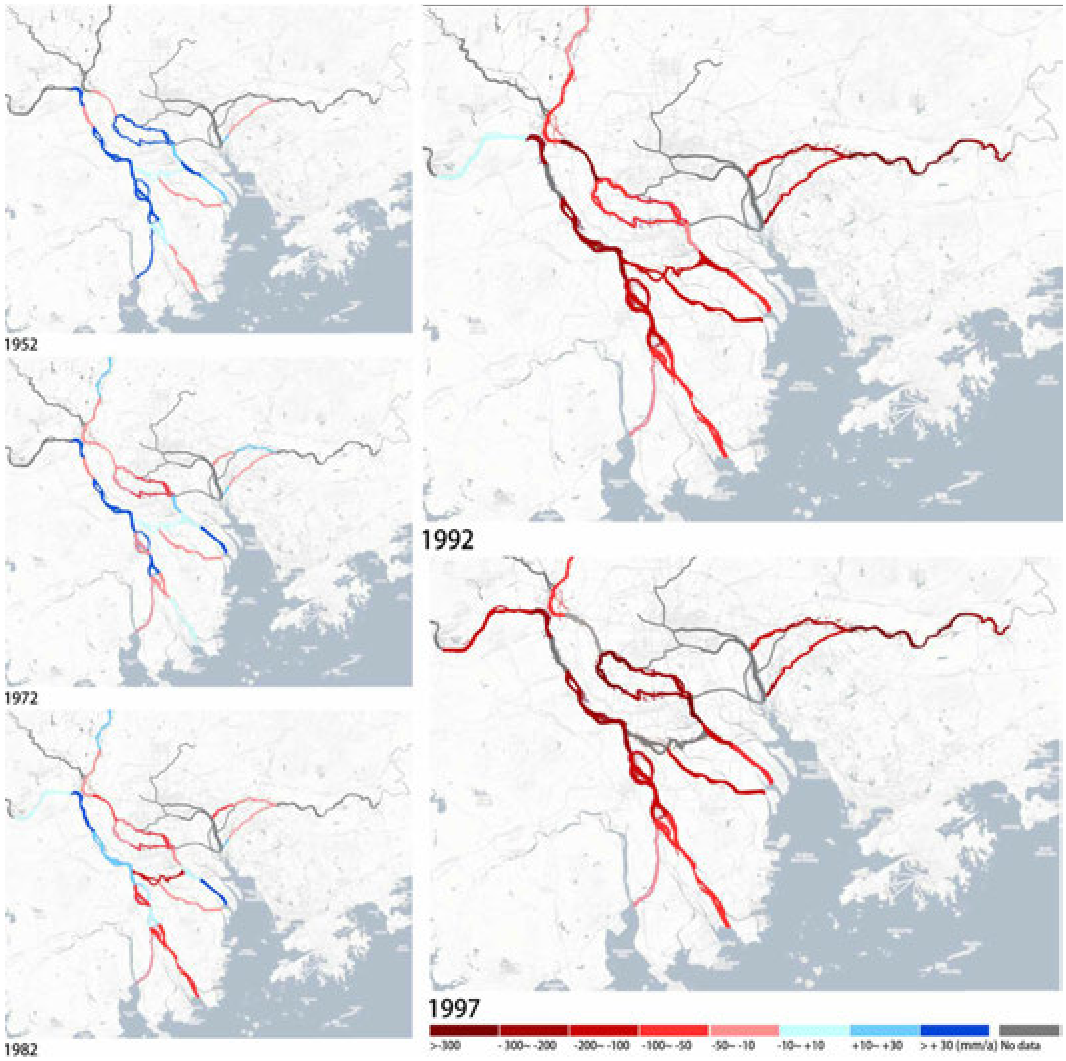

FIG. 2.13 **The average speed of the annual change of the river channel bed (mm/a).**
Data from Lu et al. (2008), mapped by author.

These three processes have influenced each other in shaping the urban and natural systems of the PRD. However, exactly how they interact remains unknown, and it is uncertain what the ultimate result will be in the long term. For instance, in the PRD, increasing river bed erosion has been found to be linked to rapid urbanization processes after twenty years, and the depth of the river channel has gradually decreased since the 1950s (Lu et al. 2008, p.57). By visualizing the change of speed in the river channel, major subsidence from the Beijiang River Network has been noticed since the 1970s. The change later became more severe in the central and upper parts of the Beijiang River Network, and in the lower parts of the Xijiang River Network and Dongjiang River Network in the 1980s. Such decreases mainly resulted from sand dredging activities in the river networks (Lu et al., 2008). The subsidence within the delta river network reached its peak in the 1990s (Lu et al., 2008, pp. 57–81). Between 1992 and 1997, most of the main branches of the delta experienced severe subsidence in the river channel beds; some areas had decreased by more than 300 mm per year (Figure 2.13). Such a change in the river channel bed has had a significant influence on the hydraulic characteristics of the delta. The average depth of the Shunde Watercourse from Zidong to Sancaokou increased by 3.95 meters between 1952 and 1999 (Lu et al., 2008, p. 66). Dongping Watercourse, one of the main river courses of the Beijiang River Network, increased its capacity by 81.13% between the 1980s and 1990s due to the decrease of the river bed (Jing Li, 2006), and this is the primary reason for the decrease in the water level in the upper and central delta regions in recent decades (Jiang et al., 2012; Z. Luo, 2004). Unfortunately, the changes in the river bed and river network were not linked to the demand for construction materials until thirty years after the changes occurred. Moreover, spontaneous and severe sand dredging activities played an intermediary role between the process of urbanization and the change of the river network (Xiaohong Chen & Chen, 2002; Z. Huang & Zhang, 2004; Jiang et al., 2012; Lu et al., 2008). The high rate of sand dredging started at the beginning of the 1980s during the economic growth miracle in Shenzhen, one of the coastal cities in the delta. As a group of cities continued to boom in this region, sand dredging became even more popular in the middle of the 1980s and reached its peak at the beginning of the 1990s (Xiaohong Chen & Chen, 2002; Z. Huang & Zhang, 2004; Jiang et al., 2012; Lu et al., 2008). Considerable artificial disruption has affected the area due to these three major processes during the rapid urbanization process, resulting in the occurrence of highly dynamic and uncertain phenomena in the urban delta landscape.

These highly dynamic and uncertain changes in the river bed have threatened the flood defense system, and flood security levels have become invalid due to the quickly-changing land-water dynamics. The flood in 2005 was misinterpreted as a minor event due to the outdated records, and the once-in-10-year water level turned out to carry a discharge of a 100-year flood (Guo, 2005). The deep cutting of the river bed has reduced the stability of the bottom of the dikes, while the further silting-up of the sediment in the estuary will lead to an increase of the peak water level, thereby threatening the tops of the dikes. These two negative effects are closely related, yet highly unpredictable due to the high intensity of human intervention in the river bed. Therefore, the flood defense system can no longer rely on previous records and experiences.

In addition to flooding, studies have shown that rapid, large-scale urbanization is also closely related to severe challenges such as mangrove disappearance (Y. Zhao, 2010), salinization (P. Li, 1998; Shijun Wang et al., 2006; J. Xu & Luo, 2005; Zhang & Wang, 2007), agricultural land loss (W. Hu et al., 2002; W. Hu & He, 2003), air and water pollution (Chau & Jiang, 2003; X. Han et al., 2010; Y. Li et al., 2008; Ouyang et al., 2006), water storage (Xiaohong Chen & Chen, 2004; P. Li, 1998; Shijun Wang et al., 2006), and decreasing social security (X. Huang, 2003). The urbanized area of the PRD is facing increasing flood pressure, as it has a large area of low-lying land below sea level (Figure 2.14). In 2016, the PRD could have faced massive floods from worst El Niño since 1997/98, which led to chaos caused by a flood of 100-year proportions, as stated by the Pearl River Flood Control and Drought Relief Headquarters Office (Xinhua News Agency, 2016). However, a lack of understanding of the delta has limited the ability of planning and design to develop a more sustainable and adaptive urban delta environment in the PRD.

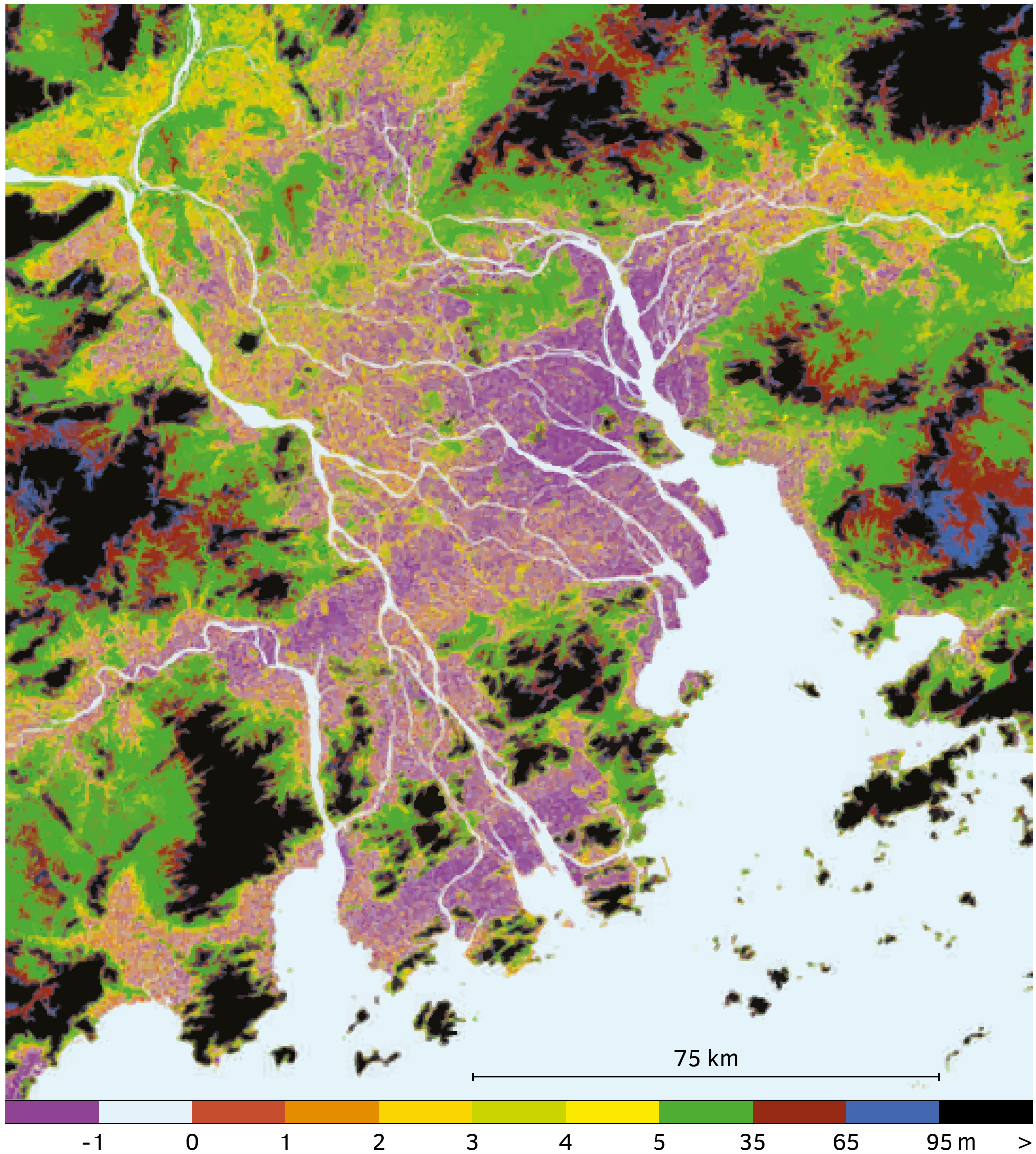

FIG. 2.14 **The area of the PRD below sea level.**
Map from Syvitski et al. (2009).

An oversimplified understanding of these multi-leveled, interwoven processes would lead to an inappropriate intervention strategy to address complex urban challenges in the PRD. The central government has enacted a series of regional plans to regulate the urbanization process. Concerning the fragmentation caused by urbanization, the *Pearl River Delta Urban System Planning (1991-2010)* proposed to cluster the urban region. A poly-centric spatial structure was further established by the *Pearl River Delta Economic Zone Urban Clusters Plan (1994)*, but was found insufficiently coherent, thus leading to the *Pearl River Delta Urban Clusters Coherence Development Plan (2004-2020),* which focused on the coherence within the poly-metric structure. During the financial crisis in 2008, the regional integration was enhanced by the *Pearl River Delta Region Reform and Development Plan (2008-2020).* The most recent regional plan is the *Guangdong-Hongkong-Macau Great Bay Area Urban Cluster Development Plan (2018),* in which the concept of the PRD was replaced by the Great Bay Area, aiming at competitiveness, livability, and sustainability in the region. However, urban challenges would be wrongly identified without acknowledging the strong links among the major processes. On a larger scale, fast urbanization and industrialization have brought changes that have led to a sharp increase in flood risk due to an accumulation of consequences on the smaller scale; more people live in areas with a high risk of inundation, yet properties and roads provide less drainage capability. This strong link between scales has been difficult to understand because there were no maps in any of these referenced plans that clearly showed it. Moreover, the further development of this region would be extremely difficult because of the underdeveloped infrastructure network and high density of occupation. The urban village phenomenon is merely one facet in the vast network of the rapidly urbanizing delta. The relatively "free" urbanization and industrialization processes stemming from private initiatives, without clear control by public authorities, have led to a fragmented urbanization pattern, namely rural urbanization. The two types of urbanization and industrialization have experienced different urban challenges within their boundaries. The issue of the "urban village," a new type of urban neighborhood in which historical village centers are surrounded by new urban areas, has been addressed during the urbanization of the PRD. However, the recognition of the urban village as one type of urban neighborhood is oversimplified. When examining the morphologies of urban villages via their development with a finer resolution, one can distinguish different types of urban villages. In a bottom-up mode, the urban region is spread out where the most local economic benefits can be generated, usually around old villages and county centers. This type of rural urbanization expanded so quickly that planners and governments never expected it to occur in this way. Therefore, when bottom-up cities develop to a certain size and higher levels of coordination are required, their urban forms generally become a bottleneck for industry upgrades and regional integration. Moreover, top-down cities also create urban villages. As compared to new urban areas that have a better connection with the village center in the bottom-up mode, these top-down cities tend to have closer connections with remote cities in the major transportation infrastructure network. The segregation between historic village centers and their surrounding urban areas makes it difficult to provide adequate infrastructure and transform them (Yuting Liu et al., 2010; F. Wu et al., 2013). The urban villages in the bottom-up process are different from those in the top-down process in terms of both their development and morphology-associated challenges; therefore, the solutions should also be different. Without seeing through the lenses of proper levels of systems, spatial scales, and temporal scales, the details of the processes in the development of the urban delta landscape will be overlooked.

2.4.2 Segregated interventions

Without seeing through the lenses of proper levels of systems, spatial scales, and temporal scales, developed interventions will also be segregated. In addition to the oversimplification of the three major processes, individual interventions have also been commonly seen in the PRD; it has been difficult to establish connections between different natural and artificial processes due to the high speed of development, and there has also been a lack of cohesion between different authorities. These authorities have each been responsible for a specific scale, sector, domain, and time period of (a part of) the delta. The complexity of the PRD has been approached by dividing the complex system into many different parts. Figure 2.15 provides one example of such a distinction between a traditional spatial organization pattern and a current pattern. In the newer part of the city (right), there are clear divisions between the water infrastructure, green spaces, roads, and housing; in contrast, the separation is much more indistinct in the older part of the city (left). Such divisions in the design, planning, and management of the spatial elements in the territory have brought advantages in both practice and research. However, a side effect is that an overview of the territory is also divided. Among all the involved sectors that have implemented their own design in the region, nobody could foresee the consequences of certain design or planning interventions for other scales and sectors, or in the long term. The segregations of the domains, scales, and speeds of change have led to increasing challenges.

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FIG. 2.15 **Compared to the current urban morphology (right), the traditional morphology (left) has a more complex combination of green spaces, water infrastructure, and settlements.**

Segregation among domains

The first segregation in the PRD is that among the domains of knowledge (such as transportation, housing, telecommunication, gas, water, power, etc.). This type of segregation is due to both the complexity of the science and technology related to urban development and the lack of communication and cooperation during the rapid urbanization process. On the one hand, science and technology have developed to a stage where both the quality and quantity of knowledge have grown into a system of its own. Each branch of this knowledge tree has its own vocabulary and body of knowledge; therefore, it is harder to understand and communicate across the domains. However, to understand and intervene in the urban landscape, it is essential for urban planners and designers to understand and utilize fields of knowledge that influence the physical territory. The skill of collaboration with other domains is missing from the current education of planning and design in China. On the other hand, during the urbanization process, it has been nearly impossible to acquire, digest, and apply the various bodies of knowledge and technology in a comprehensive way. China likely chose the only possible way to shape the urban landscape during this fast-paced development, i.e., the planning and design of the urban landscape were divided by domains into separate tasks, and interaction among the domains was minimized to achieve high-speed development. Each infrastructure sector implemented and maintained its own network according to its own schedule. This means of urban planning and design discouraged potential collaboration and synchronization among the domains, resulting in a separated and uncoordinated agenda in each sector. Uncoordinated agendas in urban planning and design have ultimately led to uncoordinated urban interventions that disturb the function of cities. One of the most criticized consequences has been the “zipper road” phenomenon (Figure 2.16), in which the status of a road is frequently switched between open and closed due to the uncoordinated construction and maintenance of the underground infrastructure networks. For example, the Tonghe Road was opened and closed by various municipal government sectors and companies, each with permits to construct and operate, six times in two months during 2010 (Xinhua News Agency, 2010). The zipper road could have been avoided by communication and integrated planning among the related sectors. In masterplans, separate zones have been set for sectors such as housing, water management, and transportation to ensure that their spatial intervention would not disturb the work of others. For instance, a 50-meter-wide blue line-controlled zone was planned along a dike to ensure the flood prevention in the 2012-2020 Master Plan of Modaomen, Zhuhai City (Zhuhai Institute of Urban Planning & Design, 2014, p. 79). Any change within the blue line required permission from the related authorities. However, in practice, the application for permission was so time-consuming that planners and designers were discouraged to make use of the controlled zone. Possible collaboration among the sectors and the optimization of the space were also limited. Ultimately, both mobility and spatial quality have suffered from segregation between domains.

FIG. 2.16 **A cartoon from the national news critiquing the endless "zipper road" phenomenon caused by uncoordinated sectors during Chinese urbanization.**
Cars complaining endless traffic jams caused by the zipper road. Figure by Zhu, from Xinhua News Agency (2010).

Scale segregation

The second type of segregation is scale segregation, which is closely related to domain segregation. Both the vertical management structure and horizontal multi-plans have contributed to this type of segregation. On the one hand, the spatial structure has experienced negative externalities from a strong culture of competition and ineffective cooperation among local governments. As a national urban laboratory, the PRD has been transformed by many ground-breaking policies and with fewer constraints from the centralized planning system. However, this freedom revealed its weaknesses in shaping regional cooperation and maintaining effective planning and design. The changes in land policy and governance have led to competition among localities (L. A. Zhou, 2007; Zhu, 1999), and the decentralized urban governance has led to short-sighted economic-oriented development, environmental pollution, localism, and overlapping projects (L. A. Zhou, 2007). On the other hand, the horizontal multi-plans made by different sectors have led to unexpected spatial interventions at other scales. The location and size of land reclamation should be considered when planning for flood defense, and the Ministry of Water Resources was once in charge of integrated planning and management between land reclamation and flood defense. However, the land reclamation responsibility was transferred to the Ministry of Land and Resources during a sector re-organization in 1987 (H. Xu, 2011). Land reclamation was considered to be a component of river channel management when it was under the charge of the Ministry of Water Resources, and its function was switched to providing economic benefits under the rule of the Ministry of Land and Resources. The reclamation was no longer a part of the plan for the river basin; instead, the estuaries, which could bring quick economic gains, were prioritized. Therefore, a large area of land near the urbanized region was reclaimed for urban expansion and associated aquaculture (H. Xu, 2011). The urbanization pattern replaced the hydraulic characteristic of the delta as the main mechanism for sedimentation (Figure 2.13). This type of reclamation has put great pressure on the dike system in the delta region and dams upstream of the river basin. Unfortunately, uncertainty in both the governance structure and spatial intervention makes it difficult to develop an effective plan and design to adapt to the quickly-changing dynamics. Without effective communication and collaboration, the entire river basin must pay the price of economic development in the estuaries. The lack of a consistent vision at and between each scale has caused redundant construction and ineffective planning implementation.

Sequential segregation

The third type of segregation regards speed. On the one hand, processes that are related to artificial intervention have accelerated quickly in the delta since the 1980s, and have changed the urban delta landscape at a much more rapid pace than have natural processes. For instance, research has shown that the 15 years of sand dredging between 1985 and 2000 removed the equivalent of 70-125 years' worth of sediment due to natural processes (Jiang et al., 2012). The material was used in the construction of infrastructure and buildings in the region. With such significant changes to the hydrology, morphology, and environment, the consequences have inevitably become obvious. Some of these consequences are directly related to the security of life, and include riverbank erosion, dike weakening, flooding increases, etc. On the other hand, processes related to policy, such as social awareness and ecology, have not accelerated quickly enough in comparison. It took almost two decades until the consequences of sand dredging were brought to the attention of the public, and even longer for the implementation of effective regulation. The 1997 Asian financial crisis slightly subdued the fierce real estate industry in the PRD, but not until then did the local government make a stronger effort to monitor and regulate sand dredging activities. The General Office of the People's Government of Guangdong Province officially announced its decision to transfer the management of sand mining to the lower governments in 2001. Later, in 2005, the Standing Committee of the Guangdong Provincial People's Congress passed *The River Sand Mining Management Regulation of Guangdong Province*, which was the first Chinese regulation for sand mining management on a local government scale (Lu et al., 2008, p. 52). One year later, the Department of Water Resource of Guangdong Province appointed the Guangdong Hydropower Planning & Design Institute and the Guangdong Institute of Water Resource and Hydropower to collaborate on the *Report of Sand Mining Regulatory Planning in Main River Channel of Guangdong Province*. The report was approved by the Guangdong Provincial Government as a regulatory plan for sand mining in 2006, and was the first Chinese spatial regulatory plan to use zone restrictions for mining, monitoring, and inspection to control dredging at the provincial government level (B. Huang et al., 2006). However, these regulations have not been able to meet the significant demand for sand caused by rapid urbanization. It was estimated that 15 million tons of sand could be legally approved to be mined, transported, and traded in the entire PRD in 2005; however, this amount was merely 1.5% of the total sand demand for construction in the same year (J. Wang, 2012). The substantial gap between supply and demand has led to huge profits from illegal sand dredging and trading. The Standing Committee of Guangdong Provincial Government revised *The River Sand Mining Management Regulation of Guangdong Province* in 2012 in the hopes of strengthening the effectiveness of spatial planning and management. However, the revised regulation was altered primarily from the following aspects: it involved more departments such as transportation, ocean, and fishery branches as cooperating departments for the control of sand mining; it focused on the municipality level for monitoring, planning, and implementation; it canceled the application and the use of biding as the only way for license approval; finally, it increased the fines for violating the regulation (R. Chen, 2012). However, the effectiveness of the revised regulation has been questioned due to a corruption scandal worth 20 million CNY (2.4 million EUR or 3.4 million USD) involving the former Deputy Director-General of the Department of Water Resource of Guangdong Province in 2013. The rapid urbanization and industrialization in the delta have demanded large amounts of building material for infrastructure and city development. This business developed so quickly that little could be done in terms of spatial regulation and management before its huge impact could be properly understood. To enhance economic efficiency, little attention was paid to the negative effects on the rivers as a result of sand dredging. The Dongjiang River Network and Beijiang River Network were the most affected areas due to the developing cities in the region, namely Guangzhou, Shenzhen, Hong Kong, Dongguan, Foshan, Shunde, and Nanhai (Lu et al., 2008, p. 50). Before the implementation of the sand dredging policy, a total amount of 7.6×10^8 m^3 of sand had been dug out of the river bed between 1985 and 2000 (Xiaohong Chen & Chen, 2002). The demand for construction materials, the booming sand dredging business, and considerable changes in the river bed all led to a disaster in the water ecosystem, and reactions to this chain of events have not been sufficiently fast due to the segregation between domains. In summary, several artificial activities conducted quickly without proper planning have shaped the delta region because of lags in the governance structure and a lack of public awareness. More alarmingly, natural processes require an even longer time to achieve a balance after such an impact. This segregation in the speed of change has led to unwanted, unexpected, and undertrained outcomes during the rapid urbanization process. However, there has been no effective reaction to deal with this segregation in the speed of change. In the long term, it might result in a total ecological, humanitarian, and economic disaster.

The three types of segregation have limited the adaptivity of the urbanizing delta region not only to future disasters, but also to the promotion of prosperous development. The two major urban clusters of the PRD, namely Guangzhou and Shenzhen, were both listed in the top five coastal cities that will suffer from floods and sea-level rise in 2050 (Hallegatte et al., 2013). Cities in other urban deltas of developing countries face similar challenges; in 2005, 17 of the 20 most-exposed cities were in developing countries (Hallegatte et al., 2013). The fast pace of urbanization will accelerate the negative externalities with less time to react, which makes urbanizing deltas more vulnerable to ecosystem degradation, flooding, climate change, etc. The issues that have emerged from the spatial development in the PRD are similar to those faced by many other urban deltas but on a much larger scale and at a much higher speed. Therefore, research on bridging the segregation of the domains, scales, and speeds of changes in the PRD not only serves as a critical case to gain insights into dealing with a fast-paced, large-scale urbanizing delta, but will also benefit sustainable development in other delta regions.

2.4.3 Isolated stakeholders

The involvement of governments

The central government has made numerous attempts to address these three types of segregation by promoting interdisciplinary pilot projects, such as the Urban Underground Utility Tunnel Construction, the Sponge City, and Multiple Planning Integration. However, these pilot projects have not achieved the expected results. Such initiatives have also tried to address the complex nature of the government itself, namely that the government is also a multi-level system with many subsystems that have their own dynamics and interests.

First, the government, as a complex system, has several levels of authority, and the intentions of the central government are not always necessarily acknowledged by the local government. The "compete and command" approach taken by the central government has certainly discouraged many local initiatives and collaborations. With the fear of losing to their peers, local governments hesitate to test new ideas and new approaches. For instance, when the central government considered flood security as part of the track record for competition between local governments, the first logical priority of the local governments was to prevent the leak of the news of floods. This occurred in the PRD; during a local flood event, instead of securing its citizens or repairing the embankment, one local government tried its best to prevent the information from leaking to the press. It forbade journalists to cover the flood and commanded the local water authority to adjust the water level records. To prevent such fraud, the central government must spread out its resources to implement monitoring. Although competition has persuaded local governments to do things well in their own domains, it has prevented them from collaborating to work on things at larger scales. Too much effort has been wasted at all levels of the government due to a lack of trust and the pursuit of achievement. Moreover, the command from the national government is also often too general to be adopted by local identities. After all, the miracle of the great leap forward in the PRD was largely due to a bold move from both the central government in releasing its power of control and the local governments in risking their track records to test new ideas; the PRD would be in danger without this spirit.

Second, the government has several sectors with several levels of sub-sectors. These governmental sectors have played important roles in shaping the delta in the forms of water management, urban planning, transportation, and environmental protection. Before the great merging of the sectors, the Chinese spatial planning system featured a combination of vertical sectoral management and horizontally-woven multi-plans. There was a collection of plans with overlapping content, cross-management, and varying standards (Y. Hu & Yin, 2016). In this case, when there was a conflict of interest between different sectors of different levels, there existed a lack of communication and cooperation mechanisms among the sub-sectors. For instance, the waterfront of the PRD was in the charge of the provincial water committee, while the local governments could do little to affect the relationship between the city and river; the Foshan City government could not fulfill their wishes of improving the spatial quality along the Beijiang Dike (Figure 2.17), which passes through the provincial water committee, because the dike was regarded as part of the provincial-level flood defense. The wide road on the dike could have contributed to the transportation infrastructure, and the spatial buffer zone could have established a waterfront for the city. Critical thinking was impossible without proper communication between sectors from different levels. Moreover, segregation in both data and knowledge has prevented effective collaboration between sectors within the same level of government. In the PRD, the local hydraulic sector and urban planning sector respectively hold their own territorial data. Although none of the sectors has a full dataset of territorial information (for both land and water), there has been little attempt to achieve this. Because the two sets of data follow different georeferencing and vertical data, it is hard to utilize the data from other sectors. The hydraulic sector follows the Pearl River Datum, the local reference that was applied among the hydraulic sectors under the Pearl River Commission. In contrast, the urban planning sector follows the Yellow Sea 1985 Datum, the national reference for urban planning and design. The two planning and design systems, namely those for water and land, each have their own history and vocabulary. Furthermore, communication between the sectors has been so weak that, for the past 18 years, there have been few successful data transformations and utilization between the two sectors on the local scale. Although the chiefs of the two sectors have both acknowledged the benefits of the planning and design system that would be provided by a complete dataset, they have also admitted that there is currently no way to integrate the datasets. Sometimes, a partial truth is worse than a lie. The inter-disciplinary pilot projects revealed that one of the main difficulties in closing the gap between professions is in the communication between different organizations of the planning system and their respective bodies of knowledge. Even with the assistance of a coordination office and a fund, neither sector has been willing to approach the other for a better plan. There has been a critical demand for the rethinking of the optimization of the communication and collaboration between the sectors of different levels of government, and of the same level of government.

FIG. 2.17 **The wide road on the Beijiang Dike was strictly controlled by the provincial water committee and not publicly accessible.**
The municipality could not intervene to remove the block between the city and waterfront.

In addition to the many incomplete plans that have failed to address the segregation between processes, interventions, and stakeholders, it is even more alarming to recognize the ineffectiveness in the planning system when trying to tackle this challenge. The central government has attempted to address these three types of segregation with two major initiatives, namely the interdisciplinary pilot projects and the reconstruction of the planning system; these experiments have also been implemented in the PRD. Unfortunately, the obstacles have been not cleared; instead, they have become more inconvenient in the planning system.

The interdisciplinary pilot projects were considered to be the first step for the national government to solve the issue of segregation. Major pilot projects, such as the Urban Underground Utility Tunnel Construction, the Sponge City, and Multiple Planning Integration, were promoted with considerable funds for cities across the country. These pilot projects provided an allowance for qualified cities to implement their interdisciplinary plans in the designated fields. For instance, the Urban Underground Utility Tunnel Construction, introduced in 2014, was a project implemented to promote the integration of underground infrastructures such as water, heating, electricity, telecommunication, broadcast, gas, and sewage. Such integration targeted the whole life cycle of planning, design, construction, and management (Ministry of Finance, 2014a). Guangzhou was chosen as the city from the PRD among the 25 pilot cities for this experiment between 2015 and 2016 (Ministry of Finance & Ministry of Housing and Urban-Rural Development, 2015, 2016). The Sponge City pilot project took this attempt at integration a step further by trying to integrate two domains. Introduced at the end of 2014, this initiative aimed to improve the ability of cities to retain, infiltrate, and purify water by enhancing the connection between water resources and urban planning and design. Cities would be awarded special funds if they managed to deliver convincing plans to the three ministries, namely the Ministry of Finance, the Ministry of Housing and Urban-Rural Development, and the Ministry of Water Resources (Ministry of Finance, 2014b). The standard was to retain and reuse rainfall by 70% within the urban boundary. There were 30 cities (Shenzhen and Zhuhai from the PRD) nominated as pilots between 2015 and 2016 (Ministry of Finance et al., 2015, 2016). The third pilot project, Multiple Planning Integration, was even more ambitious in its coverage of domains. It aimed to integrate the four sectoral plans, namely the Plan for Economic and Social Development, the Plan for Urban-rural Development, the Plan for Land Use, and the Plan for Ecology and Environmental Protection, at both the prefectural level and county level (National Development and Reform Commission et al., 2014). Three of the 28 prefectural, county-level pilot units were located in the PRD (National Development and Reform Commission et al., 2014). Complexity in interdisciplinary communication and cooperation soon emerged as an essential component of the pilot projects. For instance, a study has shown that the Sponge City projects have to deal with four sets of management systems and four types of standards, and are implemented by four plans made by different sectors (Che, 2016). The flood defense plan was developed by the river water resource commission, the rainwater runoff pollution plan by the local water authority, and the urban master plan by the Bureau of Urban planning and Design. Although the national government established coordination offices to support the pilot cities, ineffective communication among the sectors was considered to be a major problem for the integrated planning and design solution of the Sponge City program (Yu, 2016). Without changes in the planning system, the interdisciplinary pilot projects could hardly succeed due to the different agendas of the various sectors involved.

Realizing that the dependence on the pilot projects could not achieve its goal of integration, the national government took a second bold move by optimizing the planning system. Spatially-related sections rooted in different governmental sectors were identified and merged into new sectors. This re-organization of the planning system resulted in two new ministries, the Ministry of Natural Resources (MNR) and the Ministry of Ecology and the Environment (MEE). The MNR oversees the management of all the natural resources and urban-rural planning that were merged from 9 ministries, commissions, and bureaus. The MEE was created to manage all ecological and environmental issues such as climate change, water pollution, and nuclear and radiation safety, which were merged from 7 ministries, commissions, and bureaus. As sector segregation has been one of the most criticized obstacles to effective planning, this significant integration of governmental departments was expected to provide a solution. However, new challenges emerged shortly after the elimination of the sector gap. Collaboration and cooperation have not become easier, even without sector segregation. When the gap between agendas was removed, gaps in specialized data, information, and knowledge emerged. The government, planners, designers, and researchers realized that there was a lack of tools available to use these fragmented bodies of knowledge.

Rapid growth in the context of the urban landscape in the PRD calls for a breakthrough in planning and design, both in theory and methodology. Considering that it is one of the largest and densest urban landscapes in the world, the PRD is home to over 56 million permanent residents (Jin Li, 2011), and includes the world's two urban agglomerations with the highest population growth rate since 1970 (United Nations, 2012). Considering that it is a delta landscape, the PRD is the most diverse delta in China's water ecosystem. With 383 phytoplankton species, 410 zooplankton species, and more than 450 species of fish, the Pearl River ranks first in freshwater biodiversity in China (Cui et al., 2005; C. Wang et al., 2013). If it is considered as a laboratory of Chinese planning and design, the PRD represents the most dynamic urbanization process within one of the most centralized planning systems that dare to make changes. This identity makes the study of urbanism in the PRD not only challenging, but also worthwhile.

Finally, aside from the government, there have been other stakeholders involved in the planning system, and their knowledge and support for the plans have also been important for an integrative planning and design approach. The public, researchers, designers, and planners of interests could fill in the knowledge and skill gaps that the government may not be able to. However, their involvement requires an open attitude from the government, together with accessible data and information. The first contact between the government and the other stakeholders requires the help of a carefully monitored design and planning method that should be both practical and consistent. Considering that there are no such cases in the Chinese planning system, learning from foreign cases could be a fruitful starting point. Stakeholder involvement could be a time-consuming process even in the highly-changed PRD because the formation of trust and culture will be much slower and tougher than the construction of buildings and cities.

The involvement of the public

The public involvement in the planning process has been largely controlled, if not prevented, by the government. In the PRD, the public used to able to access in-depth reports from the most critical newspaper, the Southern Weekly. Established in the early 1980s by the Guangdong provincial government, the paper soon achieved influence and a reputation for being the first Chinese newspaper that covered major social events and public opinions. Unfortunately, its coverage of negative governmental actions and revelation of less-considered social facts have gone against the interests of the government in achieving a successful track record. Censorship and the pressure to contain information have led to several rounds of resignations of the chief editor and the editorial board since 2001. The latest event took place in January 2013, when over 50 journalists protested the heavily-altered annual new year editorial imposed by the government; many personal statements posted on the largest online forum by journalists and editors were removed. The relatively calm status of the newspaper after 2013 resulted in less and lighter coverage of sensitive social topics. This restrictive control policy demonstrated that there is a decreasing willingness of the government for the public to be involved in decision-making processes.

Contrary to the expectation of the government, the planning system has suffered from the lack of public involvement. Despite the expectation that planning and design would be more effective with less public involvement, the government realized that such an approach has led to less credit given to their initiatives. Many plans have had to be postponed or canceled due to protests by affected citizens. It did not matter how transparent the government was in providing planning information, nor was science backed by renowned researchers accepted; the public refused to trust the vision provided by the government. For instance, the planning of a p-Xylene plant was protested regardless of the actions of the central government, and protests in 5 cities against the allocation of the plant lasted for ten years from 2006 to 2016. Several terms were banned from social media to prevent the public from expressing their opinion or organizing protests; however, the protests still took place and the local governments had to abandon their plans. The distrust of the public reached its peak in 2015 when a p-Xylene plant exploded in Zhangzhou City. In contrast to the withdrawal of the plan by the local governments in the other 5 cities, Zhangzhou successfully implemented the project with the control of public opinion. Its government, together with all other levels of government, would have probably suffered much more if it did not contain public involvement. Such an event also made it more difficult to justify the construction of future chemical plants in the region. So far, the government has not discovered how to escape the dilemma of sharing restricted information with a distrustful public or the consequences of exposing itself to disagreement. Neither situation would prevent effective planning and design implementation. With the advancements of the techniques of communication, the government has had to spend more energy to control information and public opinion. Radio call-ins, WeChat, newspapers, and even interaction in TV are some new ways in which the government is seeking to communicate and interact with the public. However, doing so only enables the government to be trapped in the same way. Because the controlling of public involvement by restricting information turned out to be a trap, perhaps it works the other way around. To escape difficult and sometimes embarrassing situations, perhaps it is high time to seek a new approach to reestablish communication between the government and the public. The key to reopening this dialogue is to preemptively act instead of react; otherwise, trust could not be reestablished regardless of how excellent the government reacts to questions and criticism from news reporters and the public. The public is only satisfied and cooperative when they share the same vision as the government, which could be achieved by the involvement of professionals, such as planners and designers, on the spatial level.

The involvement of planners and designers

If it is agreed that the conflict between the government and the public is largely due to a lack of trust and skill, then planners and designers should probably be blamed for not working hard enough to act as mediators between the government and the public. People in these spatial professions can provide three types of contribution to the conversation. Their interests are neutral and they are capable of transferring knowledge and opinions, as well as providing ideas for the spatial allocation of interventions and resources. They can also facilitate new spatial ideas that lead to design and plans. First, planners and designers can serve perfectly as a neutral party in the current conflict. It is risky that spatial conflicts might directly lead to criticism of the government, and it is reasonable for the public to be skeptical of the government concerning mistakes that it has made during this fast-paced development. Therefore, it is also wise to introduce academic opinions to this process. Compared to the government, academia is free from the pressure to achieve political success, so they are, by nature and by training, the defenders of long-term public good. Compared to news reporters and the public, academics are expected to be more professional and scientific, and to have a broader picture to share. Additionally, the involvement of planners and designers would also help to solve another challenge between the government and the public, namely that the two sides tend to communicate without the use of a map. Spatial information is hard to acquire and difficult to comprehend without professional training. With a clear map and proper explanation of spatial information, many ambiguities and misunderstandings can be avoided in the communication between the government and the public. In fact, the booming urban planning exhibition halls that emerged in almost every city across the PRD demonstrate that the government is aware of the importance of information visualization. However, the public would be more easily convinced if they could hear another independent, but professional, interpretation of spatial information. Compared to propaganda, communication may be a more effective way to reach a shared vision and knowledge. Unfortunately, there has always been a lack of interaction and feedback in the current Chinese urban planning exhibition halls. Pre-recorded video/audio tours in a huge model room are not helpful for responding to the specific and localized concerns of the public. Moreover, fancy renderings, maps, and videos during the design bid do not help the government to understand and achieve their goals. Advanced technology has led both the government and the public to believe that the best media are always new and "shiny." In fact, the best media are those that ensure a mutual understanding and communicate crucial information and knowledge. Planners and designers must therefore take on the responsibility of communicating spatial issues to the best of their abilities.

Planners and designers must equip themselves with new theories and methods to be able to earn the trust of both the public and the government. They require a planning and design approach that is capable of helping both the government and the public to understand the three major processes (urbanization and industrialization, infrastructure development, and land-water dynamics) so that they can start to communicate and solve the spatial challenges caused by interventions segregated in terms of domains, scales, and changes of speed. To reach a common understanding of the processes in the PRD, this approach should accommodate the different levels of understanding and skills of the three involved stakeholders (Table 4), and should be able to provide a structuralized spatial reference to serve as a basis for segregated datasets, information, and knowledge. This spatial reference should be able to present the essential processes with their own dynamics and spatial scales. It should be easy to understand by the public, the government, and professionals, as well as their subsystems. This approach should not only address the methodology of planning and design at the spatial level, but also in the social realm (such as interactions between governments and the public). With the help of this approach, the role of planners and designers will not be limited to that of a predictor who can foresee the changes and possible futures, but will be extended to that of an interpreter to transfer knowledge among the governments and public to build up a common understanding and agreement of a desired future.

TABLE 2.7 **Data, information, and understanding of the PRD by stakeholders.**

	Subsystems	Scales	Changes in time
Government	Obtain data and information, but segregated among sectors	Obtain data between scales, but with difficulty in inter-scale implementation	Not much data available or well-understood
Public	Lack of overview and organization	Focus on the local or personal scale	Focus on personal experience
Planners and designers	Capable of transferring data and information into knowledge, but require methods and data	Lack of data to develop proper methods and theory for inter-scale issues	Increasing awareness of the topic, though lacking implementation due to a lack of governmental awareness

In summation, the absence of good communication and collaboration within the PRD planning system is not due to a lack of funds, policy, or intelligence. Instead, it is a result of a lack of breakthroughs in methods that are both scientifically sound and publicly understandable to provide an awareness of the urban delta landscape as a complex system. Section 2.4.1 revealed that, even with a fragmented overview of maps and studies of the region, a considerable understanding of the delta can be gained. It would therefore be promising to achieve a more inspiring and fruitful body of knowledge by producing a consistent set of maps that reflects the complex nature of the urban delta landscape. Therefore, this study proposes that a mapping of the delta is essential to the acquisition of knowledge about the spatial mechanisms of urbanization in deltaic circumstances and the problems that they cause. The PRD is presented as a case study to exemplify how mapping can be used for constructing and communicating knowledge as a basis for sustainable regional urban landscape design and planning on different scales.

3 Mapping the complex urban delta landscape

To better address the complexity of the urban delta landscape, the interactions between subsystems, scales, and time should play a core role in mapping. There have been increasing attempts to develop a CAS perspective to address the complexity and uncertainty in speeds, scales, and governance to contribute to the planning and design of urban deltas in recent years. Examples include the Rhine-Meuse-Scheldt Delta in the Netherlands (Meyer, 2009; Meyer & Nijhuis, 2016), the Mississippi River Delta in the USA (Campanella, 2014; Waggonner et al., 2014), the Kaoping River Delta in China (Chung, 2014), the Parana River Delta in Argentina (Zagare, 2014, 2018), and the Mekong River Delta in Vietnam (Marchand et al., 2014; Pham, 2011). These studies suggest a possible benefit from the use of the perspective of CASs in territorial governance, planning, and design (Meyer & Nijhuis, 2013, 2016).

In this CAS perspective, there are three hypotheses of the urban delta:

1. Different subsystems (especially urban systems and natural systems) are related to and influence each other;
2. Different scales are related to and influence each other;
3. Evolution in time takes place in all the subsystems and is related to scale.

The main assumption of this perspective is that the utilization of natural and artificial dynamics in urbanizing deltas, such as processes of landscape and urban transformation, regional development, and renovation cycles of infrastructure, urban blocks, and buildings, offers significant opportunity to generate more benefits with lower costs during sustainable urban planning and design. Such utilization relies on the knowledge of the identification, analysis, and intervention of the related dynamics. While the technical challenges might be considerable, the spatial, governmental, and cultural challenges are by far the greatest. To ensure a sustainable future in urban deltas, new strategies for spatial development are necessary to improve the living conditions and decrease the risk level of all people in delta regions. The implementation of these strategies relies largely on visualization and communication with stakeholders. The knowledge, skill, and management required for design and planning become more complex when more stakeholders are involved (Portugali, 2000). Therefore, to develop an effective planning and design strategy, it is necessary to understand their relationships and properly apply this information according to the participants. It is thus crucial to develop an analytical approach by which the understanding and communication of the complexity and uncertainty of delta urban transformation are possible, and also to steer the planning and design conditions.

A systematic study of urban delta landscapes is essential. This type of study is constituted by description, comparison, and classification as a basis for knowledge-based planning and design (Nijhuis & Pouderoijen, 2014). Cartographic exploration or mapping is important for delta urbanism, the regional design and planning process of urbanized deltas. It is a means to generate knowledge from complex interactions and networks. Mapping serves as an important tool for the systematic study of urbanized delta landscapes in terms of knowledge generation, visualization, experimental design, and decision-making. This study develops a complex system-based mapping approach to serve as a possible solution to the challenges in the PRD, which include blurred processes, segregated interventions, and vague stakeholders. Therefore, this mapping approach has three tasks: to make the blurred processes understood, to generate integrative interventions, and to involve the stakeholders. Accordingly, it should be evaluated by three products: the validity of the set of maps it has created, the integrative nature of the design it has generated, and its effectiveness of involving the stakeholders to share a common vision.

3.1 Mapping technique

The three aspects of the urban deltas outline the essence of the system; it is a complex system with scale sensitivity in both the physical and managerial environments. Therefore, to understand such a system, a tool is needed that is capable of dealing with scaling on both spatial and temporal scales, yet is also able to capture scale breaks in its spatial model.

Mapping serves as an important tool for the systematic study of urban delta landscapes for knowledge generation, visualization, experimental design, and decision-making. It is a means to generate knowledge from complex interactions and networks (Chung, 2014; Marchand et al., 2014; Meyer, 2009; Meyer & Nijhuis, 2013; Zagare, 2014). Maps, as a product, and the process of mapping are important means for both visual thinking and visual communication to understand delta landscapes. Maps help to reflect emerging insights, appraise the landscape in its totality, and observe the relationships between the components and the whole (Nijhuis & Pouderoijen, 2014).

Map dissection and map comparison are useful analytical operations for the understanding of urban delta landscapes as systems. Map dissection concerns the discovery of spatial patterns by selection and reduction and often serves as the basis for spatial association analysis, in which the relationships between different patterns are explored. Techniques for spatial association analysis include overlay analysis and cross-reference mapping. Overlay analysis is employed to derive relationships by applying thematic overlays to geographic locations. Map comparisons are conducted to find similarities and dissimilarities in scales, times, and domains across different urban deltas, as well as within a single delta. Because it is difficult to express spatial dynamics and changes in a static map, different time-slice snapshots must be mapped to delineate the development of a delta landscape (Nijhuis & Pouderoijen, 2014). Via mapping, morphological information is organized, analyzed, and understood in terms of extent, grain, and resolution. Therefore, it might be fruitful to use mapping as a tool to explore the urban delta landscape as a complex multi-scale spatial and temporal system. Mapping offers possibilities to link different levels of spatial and temporal scales while maintaining continuity. This study develops a mapping approach that addresses the following questions:

1. How can mapping contribute to the understanding of urban deltas as complex adaptive systems (CASs)?
2. How can mapping generate information via subsystems, spatial scales, and temporal scales?
3. How can mapping be used to recognize the relevant scales in different layers and construct links between them?

3.1.1 Exploring a CAS approach in delta design

Systems can be classified as homoeostatic, adaptive, dynamic, or controlled (Harvey, 1969, pp. 459–462), and the urban delta landscape can be seen as a CAS (Dammers et al., 2014) in which a set of one or more preferred statuses exist for each possible input. Such preferred statuses might be identified by the link between the elements within the system in both form and process. However, such possible statuses are not necessarily desired for the interest of human beings. It is therefore necessary to understand how a system works in order to avoid undesired probable futures, and designing is the way to explore the desired improbable possibilities (T. de Jong & van der Voordt, 2002). Therefore, a multi-scale cartographic exploration could serve as a vehicle for the identification of the preferred statuses in a complex system by distinguishing the key elements and their links. Such exploration requires the consideration of both the spatial and temporal scales as the key concepts to interpret the data (T. de Jong, 2012a; Meentemeyer & Box, 1987; Turner, 1989; Turner et al., 1989). The aim of such an exploration is to provide a condition for the desired possible, yet improbable, status in the future.

3.1.2 Scaling analysis

The scale dependence of spatial and temporal heterogeneity has been recognized for decades, and plays an important role in describing, manipulating, and understanding spatial patterns (J. Wu, 2004). The framework of scaling in landscape ecology (Figure 3.1) reveals the three types of scaling possibilities, namely the extent, the grain, and the resolution. The scaling effect describes the phenomenon that causes information loss or changes in the scaling process, which are possible in all three types of scaling. De Jong (2012b) used the scale paradox case illustrated in Figure 3.2 to explain how the scaling grain leads to different results when internal homogeneity is combined with external heterogeneity. However, this case is not limited to the scaling of the grain, but also occurs in the scaling of the extent and resolution; any of the three types of scaling would lead to inaccurate information. Such a phenomenon is found not only in ecology (O'Neill, 1977), but also in occupation, governance, and management (T. de Jong, 2012b). Therefore, avoiding the scaling effect is essential when analyzing a multi-scale complex system.

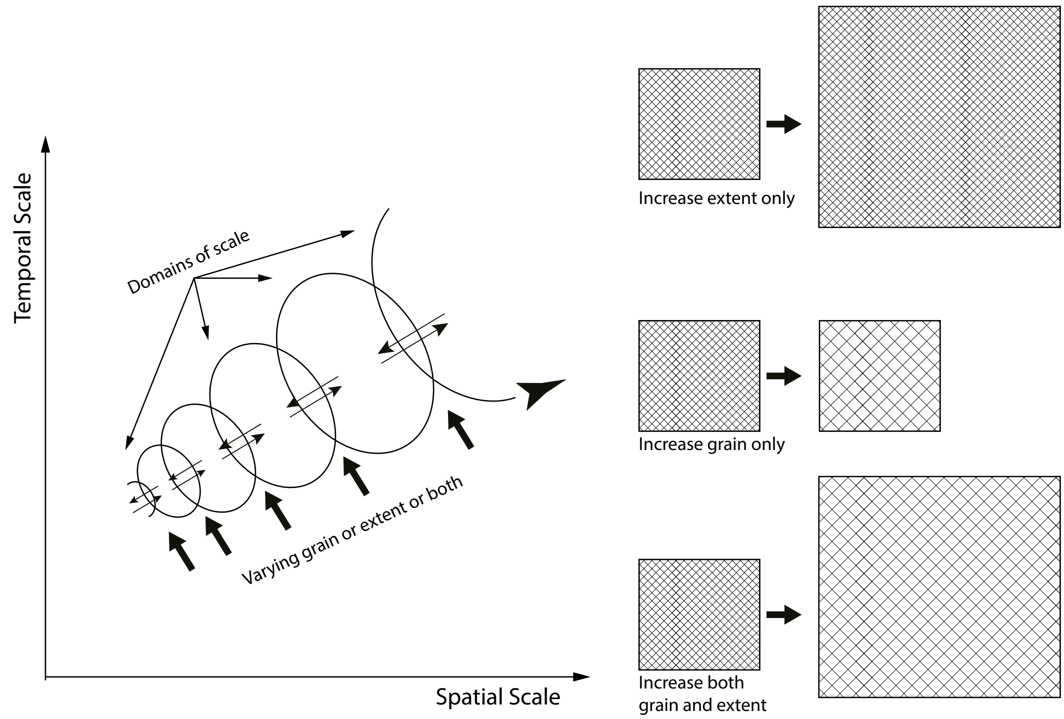

FIG. 3.1 **The three methods of information scaling in a temporal-spatial scale system: extent scaling, grain scaling, and resolution scaling.**
Figure from Wu (1999).

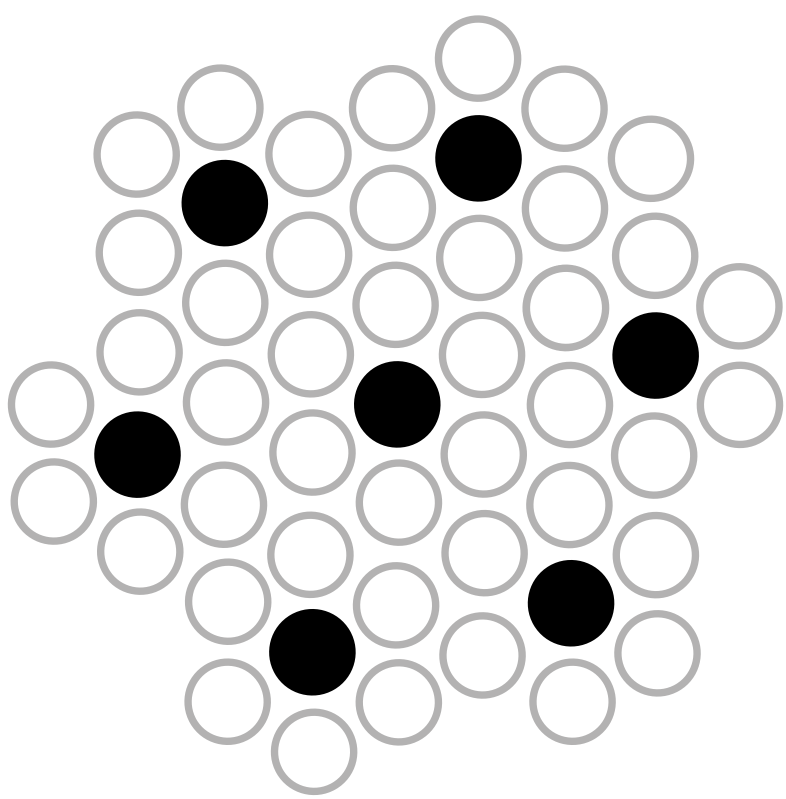

FIG. 3.2 **A scale paradox case for which the result can change due to all three types of scaling.**
Figure from de Jong (2012b)

The scaling effect also influences the descriptive models of urban deltas. There are four types of models that depict the spatial and temporal scales in urbanism, namely verbal models, mathematical models, spatial models, and mechanical models (Klaasen, 2004, p. 18). Among these models, the scaling effect has been proven to have significant effects on mathematical models (J. Wu, 2004), while the reality of a mechanical model can only be depicted as a spatial model (Klaasen, 2004, p. 19). Therefore, two rules are set in this study to minimize the possibility of an unpredictable scaling effect:

- In the analysis phase, a spatial model applies only with the assistance of a verbal model.
- In the concluding phase, a mathematical model can only be built with the results of the spatial and verbal models.

Based on these rules, a method is developed in this study that primarily uses spatial analysis to properly address the spatial relationships in urban deltas across spatial and temporal scales. Specifically, such spatial relationships are represented as various forms and processes in the urban delta landscape.

3.1.3 Scaling the spatial pattern in space and time

To determine the adaptive statuses of the urban delta system, the mapping approach must be able to explore all the possible spatial patterns at each level of spatial and temporal scale. However, the scaling effect and scaling overlap are the two main challenges of the generation of correct spatial patterns via scales. Therefore, two rules are set in this study to avoid the issues of the scaling effect and scaling overlap (Xiong & Nijhuis, 2019). First, only the possibilities that would not cause a discontinuity in the process and structure (Figure 3.3) are considered when scaling; in this way, the problem of the scaling effect can be avoided. Second, a higher priority is placed on the environmental extent during mapping; this limits the overlapping issue to a minimal degree. By exploring the scale change, it is possible to compose, link, and understand different systems and elements under the same temporal and spatial scales.

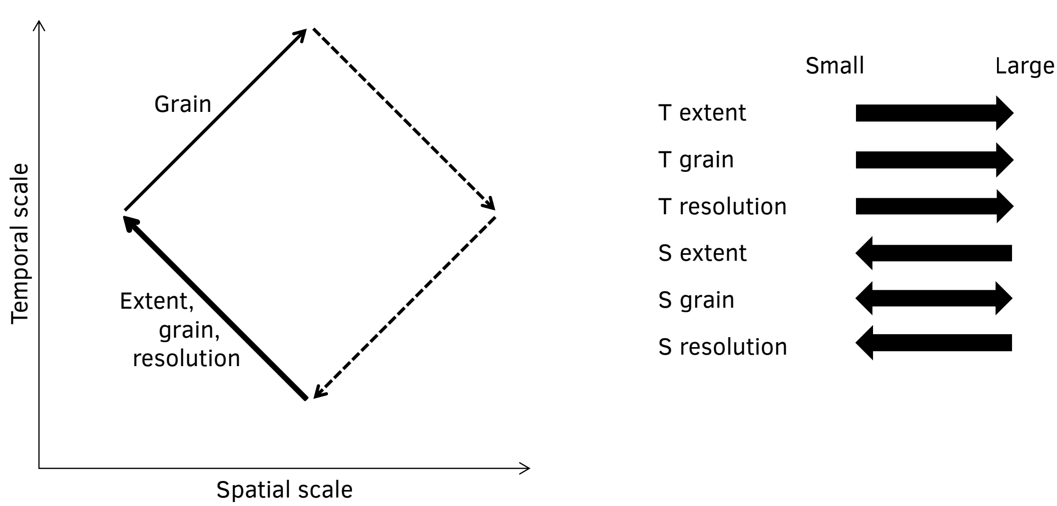

FIG. 3.3 **The spatial and temporal scaling possibilities in the cartographic exploration of urbanized deltas.**
The temporal extent, grain, and resolution can be scaled upward; the spatial extent and resolution can be scaled downward; the spatial grain can be scaled both upward and downward.

3.1.4 Identifying relevant temporal and spatial scales

The core of the identification of the scale change is to recognize the characteristic scales. In the urban delta CAS, the transformation from one adaptive status to another would lead to a change in the spatial pattern; the knowledge of the conditioning of desired improbable possibilities could therefore be generated by analyzing the spatial relationships among the four layers in the past adaptive statuses. In the four layers of an urban delta system, the characteristic scales of physical layers can be well identified by scale breaks (J. Wu, 1999), while the identification of characteristic scales in managerial layers remains questionable. Therefore, in this study, the physical characteristic scale is set as a starting point of all four layers for the spatial model. A descriptive model is attached to the spatial model for the managerial layer. The scale break between the characteristic scales is recognized when significant scale change is witnessed in the spatial patterns of the four layers.

3.2 Evaluation and Validation

When mapping the processes, this approach should be able to provide a structuralized spatial reference to serve as a basis for the segregated datasets, information, and knowledge. To achieve a common understanding of the processes in the PRD, the spatial reference should be able to present the essential processes in terms of their own dynamics and spatial scale. The process mapping is evaluated by the validity of the created map set.

The case study has been employed as the main research method for this mapping exploration, and is “an intensive study of a single unit with an aim to generalize across a larger set of units” (Gerring, 2004). Urbanized deltas are a subject for which the context and object are hard to be separated. The key factors cannot be controlled, manipulated, implemented, tested, or isolated for statistical analysis in an acceptable amount of time (T. de Jong & van der Voordt, 2002; Klaasen, 2004, p. 47; Nijhuis, 2015, p. 87). Moreover, there are only restricted opportunities for experiments due to economic and ethical reasons (Klaasen, 2004, p. 48). Therefore, the focus of the study of delta urbanism lies in two aspects, namely what is possible, and what effects would probably occur under which conditions (Klaasen, 2004, p. 48). The first rational step is to conduct an exploratory case study to approach the possible research questions, propositions, and experimental designs for future inquiry (Nijhuis, 2015, p. 87; Yin, 2009, p. 9).

From the perspective of subsystems, the PRD has experienced various stages of development in all three of its subsystems, namely landscape, infrastructure, and urbanization. The urbanization rate of the PRD reached 84% in 2014 (C. Huang, 2014). The delta could therefore serve as a maximum variation case, which provides the possibility to obtain information about the significance of various circumstances for case processes and outcomes (Flyvbjerg, 2004). From the perspective of the spatial scale, it has the advantages of integration between its natural and political boundaries. The whole delta is within a province; therefore, possible external influences are minimized in the differentiation of the boundaries in its subsystems. From the perspective of the speed of change, it has been the fastest developing and most densified urban delta for the past half-century (World Bank, 2015). The speed of change makes it the most extreme case by which to identify the spatial and temporal dynamics. Extreme cases are beneficial for obtaining information that is especially problematic or especially good in a more closely defined sense (Flyvbjerg, 2004). Moreover, its

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high-speed development started in the 1980s, when remote sensing technologies became available. Therefore, the possible artificial bias for mapping has been reduced.

Two steps of data validation, both accountability and validity, were applied to the morphological data. The accountability of the data was validated by comparing maps of different sources, while the validity check was conducted with other types of data. Both visual and metadata verifications were conducted to evaluate the accountability of the maps (the map quality, coordination system, time frame, and resolution) during the digitalization process. The following criteria were considered as indicating higher accountability: better mapping quality, clear spatial coordination, recent time, and smaller temporal resolution. In the validity check process, numerical and descriptive data were derived from different sources in the existing literature to verify the morphological data. After the two data validation steps, the verified information was sorted by time for later exploration.

With the call for the design of different dynamics in the urban delta (Meyer & Nijhuis, 2016), empirical evidence has been inductively sought to strengthen the theoretical weakness of the spatial-temporal model, and is based on three propositions. First, the characteristic scales of physical and ecological phenomena are considered to be well recorded to be related in space and time (J. Wu & Li, 2006). Second, spatial and temporal scales are fundamentally linked, so complex systems can simultaneously be decomposed in time and space (Courtois, 1985; J. Wu, 1999). Finally, the urban delta landscape is a CAS (Dammers et al., 2014). In this study, inductive reasoning was chosen to identify the levels of spatial and temporal scales via the development of the urban delta landscape.

The cartographic exploration process included both a relational analysis and representation analysis. In the relational analysis, verified morphological data were examined in terms of their tempo-spatial characteristics. The classification of temporal stages was applied when significant changes took place both in morphology and on the spatial scale. Based on the existing studies of the region, the mapping could serve as an open approach to update the understanding of the region once the knowledge is updated. The morphological data were then overlaid within the same temporal stage. During the representation analysis, previous morphological research was studied to explore the proper ways to represent the maps in terms of the layer sequence, color, weight, transparency, line type, etc. The results of the mapping are presented in Chapters 4 and 5. The methods applied in these two chapters are introduced in the subsequent sections.

3.3 Mapping the processes

The main data used in this study (Table 5 and Appendix 1) are the morphological information derived from the natural and human dynamics of the PRD. A description of the data and their location is provided as follows.

TABLE 3.1 **The time ranges and sources of the acquired morphological data.**

Time range	Type of sources	Sources
4000 BC – AD 1980	Geological studies	Zhao 1982; Zeng et al., 1982; Zeng and Huang, 1987; Li et al., 1991
AD 600 – AD 1950	Historical maps	U.S. Army Map Service, 1954; Guangdong Historical Atlas Board, 1995
AD 1900 – AD 2000	Archives	Board of Pearl River Delta Agriculture Gazetteer in Foshan Revolutionary Committee, 1976; Feng, 1990; Wu, Tan and Liang, 1990; Chen et al., 1995; Liu et al., 2001; Mao, 2002
AD 2000 – AD 2015	Master plans	Guangdong Provincial Department of Land and Resources, 2009
AD 2010, 2011, and 2016	Field studies	

The dataset covers the period from 4000 BC to AD 2016, in which all the major natural and human dynamics of the PRD occurred until recently. Sedimentation, river channel change, and coastal line development were considered to be the major natural dynamics. Dike construction, land reclamation, farming, fishpond construction, main road construction, and settlement development were identified as the major human dynamics. The morphological data were collected from geological studies, historical maps, master plans, archives, and GPS-assisted field studies. All data were converted into digital form and rectified with Google Maps as the base maps. The data were then organized in the software environments of ArcGIS 10 and Illustrator CS6.

3.3.1 Identifying the relevant subsystems

The selection of subsystems was based on their significance in shaping the urban delta system over time. Landscape formation, water infrastructure extension, and the urbanization process were considered suitable for analysis. The layer of landscape formation was chosen because of its substantial influence on the entire system as a substratum. The layer of water infrastructure, or dike systems, was chosen for two reasons; first, its long record dates to around AD 1000, and it has functioned as the main intervention tool for the infrastructure between land and water in the delta throughout history. The urbanization process was chosen as the third layer because it was relatively well-recorded before the modernization of the region, and due to its direct connection to the socioeconomic development of the region. All three layers were mapped separately.

The mapping of landscape formation integrated both geological processes and ecosystem development. In delta regions, the following data reflects these two processes: river channel migration, coastline migration, sediment transportation, land subsidence, and land cover change. In this study, data on river channel migration, coastline migration, and elevation were available, whereas data on sedimentation transportation and land cover were not. Therefore, the unavailable data were required to be converted from other available data. The sedimentation transportation on the land was converted by combining the data on the river channel and coastline migration, while

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the underwater sedimentation was intended to be converted from data on water depth; however, at the time of the study, this type of data was not available. Therefore, underwater sedimentation was not included in this research. The process of land subsidence was converted from data on coastline migration. The logic for this conversion is based on the fact that the land subsidence took place when the land was reclaimed. Therefore, the longer time for which the land had been reclaimed, the more it would be subsided. Because the temporal extent of this study was longer than thousands of years, elevation data were utilized to interpret the data of the land cover and ecosystem.

The mapping of water infrastructure extension integrated data on the dike system and channel. The development of the PRD is bound to the dike system and reclamation activities (Xiaowen Chen et al., 2011; Z. Huang & Zhang, 2004). From the first settlements to the fast urbanization in recent decades, residents of the PRD have shaped the land with the force of rivers and sea. By using dikes, people in the PRD have managed to irrigate, cultivate, reclaim, and build a more complex civilization. First built in AD 996, the use of the dike system for flood defense and land reclamation has been well-recorded since its invention. The locations of the dikes, together with their construction data, were used in this study. Although the height information of the dikes was also available, there was a lack of valid historical maps to combine the dike names and their locations. It is unfortunate that the subsidence process varied within the studied temporal extent, as the current elevation could not contribute to the identification of protected areas with dikes to a satisfactory degree. A rough estimation was therefore made to use the boundaries of the dikes and the current elevations to identify the protected areas, the spatial extents of which were then analyzed. Noting that major transportation routes are also important in this layer of infrastructure, there were insufficient data in the spatial extent of the delta. Instead, the transportation routes were more closely examined for a smaller spatial extent. Overall, this series of maps analyzes the development of the dike system in terms of morphology and on the spatial scale.

In the mapping of the urbanization process, both city and village development were included. The urbanization process before 1900 is insignificant to the extent of the delta. Therefore, two pieces of the map were developed to illustrate the spatial development between AD 1950 and 2010 in the map series of urbanization, and were arranged according to similar temporal grains. A local scale of the mapping was developed to further demonstrate developments in both cities and villages.

3.3.2 Identifying relevant scales

The choice of the spatial scale classification system defines the perspective of analysis. There are two main types of spatial scale hierarchies used in the planning and design of the delta region, namely land-based and water-based hierarchies. In the land-based hierarchy, spatial scale levels include the provincial level, prefectural level, county level, township level, and village level. In the water-based hierarchy, the spatial scale is classified by the river basin level, substream level, delta level, dike ring level, and river section level. The series of spatial scale levels in the delta, dike rings, and sections were used in this mapping application. There are three reasons why a water-based hierarchical system, rather than a land-based or political system, was adopted. First, a water-based hierarchical system makes the mapping of the three subsystems in the PRD more consistent in each level of scale (Figure 3.4). Second, there are inconsistencies in the planning and design structures of water-based hierarchies. Apart from the river commission in the river basin scale, there is no comparable water-based institution to plan and design at the delta scale or below. Instead, the provincial government is charged with executing the delta plans. On the other hand, there are already governmental bodies and plans from the land-based hierarchy. Additionally, other classification schemes might not be able to sufficiently identify landscape boundaries.

FIG. 3.4 **Two classifications of spatial scale in the PRD.**
In the land-based system, the water network covers 7 provinces.

3.3.3 Identifying the relevant speed of change

The relevant time stages were used in this study to describe the speed of change, and were identified by the morphological changes of the three subsystems. The starting point of the mapping of landscape formations was the first recorded human intervention in the temporal extent. Archaeology shows the artificial activities in the PRD date back to 4000 B.C (Yang, 2007). The first settlements were along the coast and in natural levees along the rivers. Original citizens made their livings mainly by fishing, hunting, and gathering (Yang, 1982). Therefore, the landscape maps illustrate the progression of delta development from 4000 BC. The construction of dike started from AD 996 in the PRD, introducing a faster change in the delta (Board of Pearl River Delta Agriculture Gazetteer in Foshan Revolutionary Committee, 1976, p. 5). Therefore, three periods of fast change were distinguished from this progress; the first was around AD 1000, the second was around AD 1300, and the third was around AD 1950. Because of such changes in the speed, the temporal grain of the map series was adjusted in each phase. To be more specific, the temporal grain was changed from 2000 years to 1000 years beginning from AD 1000, from 1000 years to 300 years beginning from AD 1300, and from 300 years to 50 years beginning from AD 1950. After AD 1000, the water infrastructure maps followed the same times as the landscape maps. As compared to the two sets of maps of landscape and water infrastructure, the maps of urbanization revealed a significant spatial change in a shorter temporal grain. There was more data available to demonstrate the fast dynamics of the urban layer after 1980. However, with the temporal extent of over 6000 years in this mapping exploration, it is sufficient to identify the current resolution for urban dynamics from the other two slower layers of landscape and water infrastructure.

In this case, nine time stages (4000 BC, 2000 BC, AD 200, AD 1000, AD 1300, AD 1600, AD 1900, AD 1950, and AD 2015) were identified and selected during the mapping process. Although data for landscape development were available for visualization starting from around 8000 BC, the starting time stage was set at around 4000 BC. This decision places focus on the three chosen subsystems and their development. Therefore, the time stages of 4000 BC, 2000 BC, and AD 200 were selected to illustrate the delta landscape when it began to develop in the bay. A finer temporal resolution was chosen when the water infrastructure data became available at around AD 1000. Written urbanization data were available for some of the cities dating back to AD 200; however, the spatial information of both cities and villages were not traceable until 1900, when western cartographic techniques were applied in the region to document it. More spatial data became available after 1950 when more advanced survey technologies were invented and introduced, and therefore a more detailed analysis has become possible since then. However, the time period of 1950-2015 was considered as a single time stage on the delta scale, considering that the dynamics of both the delta development and water infrastructure construction remained stable. Another consideration was the data sensitivity of the Chinese government; many types of spatial information from this time are held by the government or its related institutions. As a researcher from a foreign university, the author encountered stricter local data control policies when acquiring and utilizing the data. Because the data control policy was not clear at the moment, a solution could not be found to legally acquire and publish some of the available data from this time period. For both personal and national safety concerns, published and open access data were utilized at the time of the study to achieve acceptable results. At the time of publication (2020), the sources of this mapping exploration are available and accessible for non-Chinese scholars, so a maximum possibility of falsifiability can be achieved.

Based on these settings, two sets of maps were generated by the three spatial dynamic layers of landscape formation, water infrastructure extension, and urbanization on the scales of the delta and local levels in nine time stages (4000 BC, 2000 BC, AD 200, AD 1000, AD 1300, AD 1600, AD 1900, AD 1950, and AD 2015). On the delta scale, nine temporal stages were identified, while three were identified on the local scale. The development of spatial dynamics in the layers of landscape formation, dike construction, and the urbanization process on the delta scale are first described, and understanding is then generated by linking the management to the change of speed in these three spatial layers. Such understanding on the delta scale is used to understand the spatial mechanism at the local scale with a second set of maps of a part of Shunde District in three time stages (AD 1929, 1992, and 2010). The understanding of the urbanization of the delta in terms of the two scales and in the nine time stages yielded spatial principles for a more sustainable delta plan, which is elaborated in Chapter 4.

3.4 Generating interventions

For the function of generating interventions, this approach should not only address the methodology of planning and design in spatial terms, but also in social terms (such as interaction with governments and the public). The intervention generation was evaluated by the level of integration of the generated design. The proposed mapping approach was tested by applying it to a designer, governments, and the interested public. Three experiments were carried out in different forms to suit the skills and knowledge of the target groups. The outcomes of the experiments are elaborated in Chapter 5.

3.4.1 The designer

The knowledge of the PRD generated by this study was introduced together with the created map set to a designer during his design assignment of the PRD, an individual research and design study for the renewal of the local industrial area. The analysis contributed to a master's graduation project from the Department of Urbanism, Delft University of Technology. The involved designer was from the PRD and had both local knowledge and mapping skills. After choosing the site, the designer was introduced to the maps and methodology of this study. The designer then developed the research and design independently. Therefore, his research and design practice were reliable for the evaluation of whether and how the mapping exploration of this study functions for designers in the creation of a design.

3.4.2 The governments

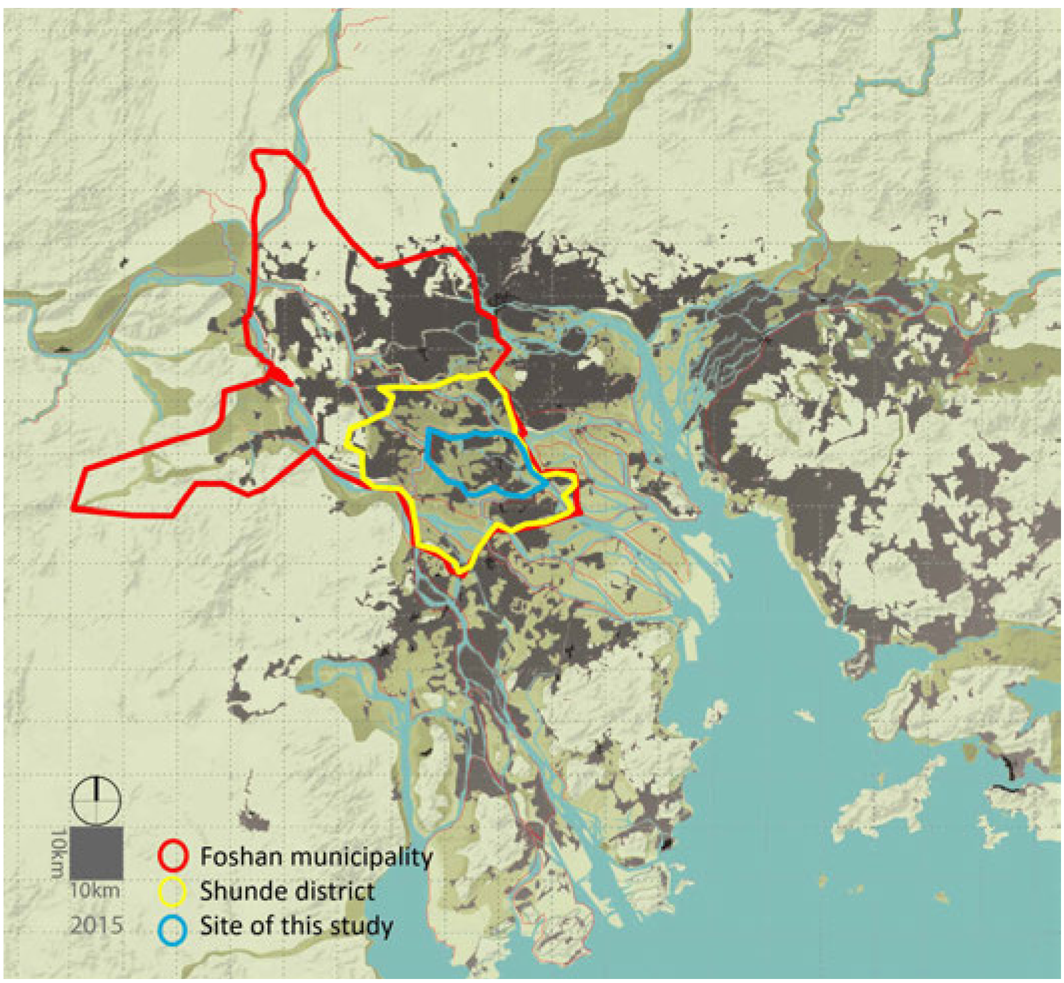


FIG. 3.5 **The application of the proposed mapping approach to collective decision-making took place in the Foshan Municipality and Shunde District.**

The map set was introduced to local governments as a collective decision-making process during two workshops held at the district level and municipality level. The local scale site used in section 4.3 is included in both the Shunde District and Foshan Municipality (Figure 3.5). Therefore, the knowledge generated there could contribute to the decision-making process for the mentioned district and municipality. The decision-makers, including hydrologic engineers and planners, were invited to attend a half-day workshop. The spatial-temporal mapping approach functioned as both an analytical and communicative tool during the workshop. The analytical tool focused on the understanding of the human-nature transformation in the delta region, while the communicative tool targeted the collaboration between specialists of water management and urban-rural planning and design. The participants had local knowledge of either hydrologic engineering or planning. Not all of the participants had mapping skills.

3.4.3 The interested public

The map set was introduced as part of an online course on the human-nature transformation in the delta region, and the interested public was targeted. The course went online in May 2017 and served as an introductory course for people who are interested in urban challenges in developing countries. The course runs annually. The latest count on the registered participants from 2017 to 2020 has surpassed 30,000 people from over 163 countries and regions. In the course, the creation and understanding of the PRD maps were explained with a 7-minute video. The participants were encouraged to use the same technique to identify urban challenges in their own regions. These maps and questions were shared in a forum so that the researcher could further investigate the quality of knowledge acquisition.

4 A cartographic exploration of the PRD

Cartographic exploration is the core of this study. By exercising various map combinations and their indications of the system, mapping contributes to a new strategy of planning and design. Subsystems, scales, and times were the three cornerstones on which this mapping exploration was constructed. Both significance and availability were the main considerations for the settings of this mapping practice. To be specific, this study made use of three subsystems, three scales, and nine time stages to establish a map set of the PRD. The three subsystems included landscape formation, water infrastructure extension, and the urbanization process; the two scales included the delta and local scales; the nine time stages included 4000 BC, 2000 BC, AD 200, AD 1000, AD 1300, AD 1600, AD 1900, AD 1950, and AD 2015. The identification of the elements was conducted in parallel with inventorying the mapping materials and extracting spatial information. The identification of cartographic elements itself became part of the analysis of the spatial information.

4.1 Mapping the urban delta

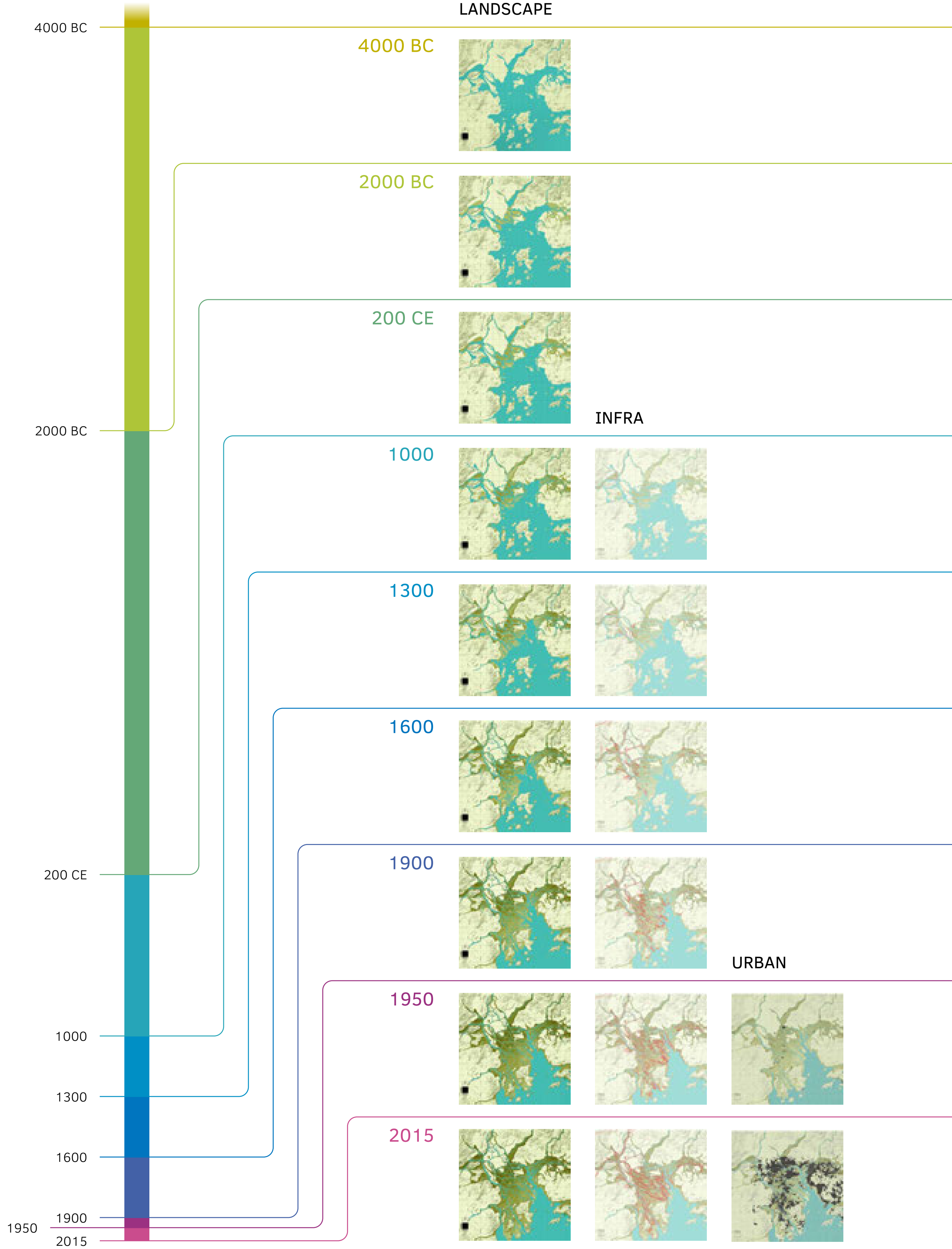
Delta scale

A map series of the landscape, the water infrastructure, and urbanization of the PRD was created in terms of their changes in dynamics from 4000 BC to AD 2015 on the delta scale. An online animation is also available (https://www.dropbox.com/s/a4fqijgpiklvs9z/PRD_1second%3D250years.mp4?dl=0), in which every 250 years is equal to one second. The process of the map creation is explained as follows.

Local scale

A finer resolution in both space and time was introduced to investigate whether spatial development consisted of different scales. It also covered the information that could not be included on the delta scale within the temporal extent of 6000 years. The mapping approach was applied to a part of the Shunde District, Foshan Municipality, Guangdong Province. The spatial extent was set within the current regional dike ring, and the temporal extent was set from 1900 to 2010. With the use of local historical maps, three time periods were identified as 1929, 1992, and 2010.

DELTA SCALE



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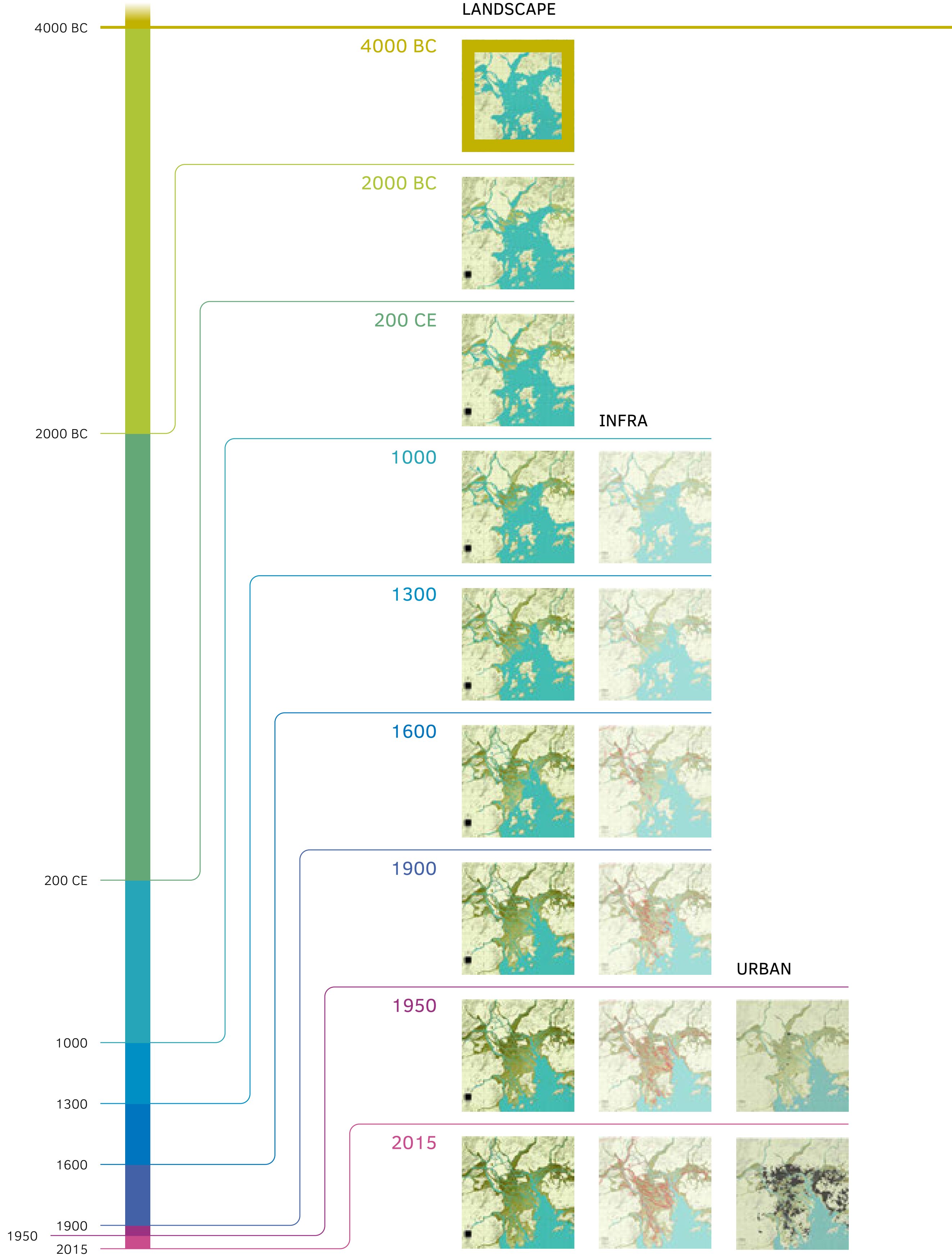
LANDSCAPE	INFRA	URBAN	
• Major part of today's delta was a bay. • West and North River Deltas extended southeastward in the north. • East River had not developed into a delta geomorphology. • Hills surrounding the bay to the east, west and north. • Inside the bay, there are hills and terraces in the islands. • Sediments brought by the three rivers had distributed in the bay.			4000 BC
• Sub-deltas extended significantly due to substantial sea level decline. • West and North Delta developed further in the north. • Floodplain became visible in the East River Delta.			2000 BC
• Another major sea level fall of 4-5 meter took place. • Sub-deltas had extended further. • Average extension rate of the North River Delta is 8.7 m/y, and East River Delta 6.1 m/y.			200 CE
• Delta extended further with a higher speed due to sedimentation. • As the delta continued growing without major change in the sea level, natural levee started develop along rivers due to seasonal flooding. • A few rivers meandered in the floodplain. • Increasing expansion in North River Delta (17% to 10.2 m/a) and East River Delta (by 38% to 8.4 m/a).	• Dikes built mainly near the joint point of the river. • Most dikes are semi-open and built on stabilized land; few located along natural levees to enhance them from the high tide.		1000
• Development speed of delta accelerated again. • Increasing expansion of deltas in North River (83%) and East River (73%). • Many islands to the west and north connected with the mainland. • Strong sedimentation (distributed sand on West coast side). • West River extended southeast in a high speed (68.7 m/a). • Rivers changed courses in the upper part of the three sub-deltas.	• Local scaled dike system began to extend its length and height. • Dike system started to link and upscaling from local homogeneity to sub-regional homogeneity (especially in the north).		1300
• Sub-deltas began to connect. • Speed of acceleration of delta slowed down. • Increasing expansion of deltas in North River (4%) and East River (34%). • More islands in the west were connected. • Significant expanding to the west, noticeable development in the east. • Rivers kept changing courses in the upper-middle of the sub-deltas.	• Dike system spread towards the newly formed part of the delta region in the south, again with sub-regional spatial scale.		1600
• Major expansion of the delta took place in the middle and west. • Speed development of North River Delta of 26.9 m/a and the East River Delta of 15.2 m/a. • No development on east coast. • Tributaries silted up due to increased sand accumulation rate; this resulted in continuously changing courses in the middle of the delta.	• Some relevant information on dike system in 1900.		1900
• Delta continued to develop in a high speed in the west and north. • Lot of of river meanders in the middle and lower part of the delta. • Significant development in the frontier of the East River Delta, but no sign of coastline extension in the neighboring east coast.	• Huge change started when the dike system has been scaling up towards a regional level.	• Some relevant information on urbanization in 1950.	1950
• Frontier of the delta developed in a high speed. • Speed development of east coast of 242.9 m/a since 1978. • West wing the delta expansion focused on the estuaries; some most prominent estuary in Wanqingsha region grew at a speed of 431.8 m/a since 1978.	• Integrated regional dike system.	• Comparing to the former two sets of maps, we witnessed a far more significant spatial change in a shorter temporal grain in the maps of urbanization.	2015

DELTA SCALE



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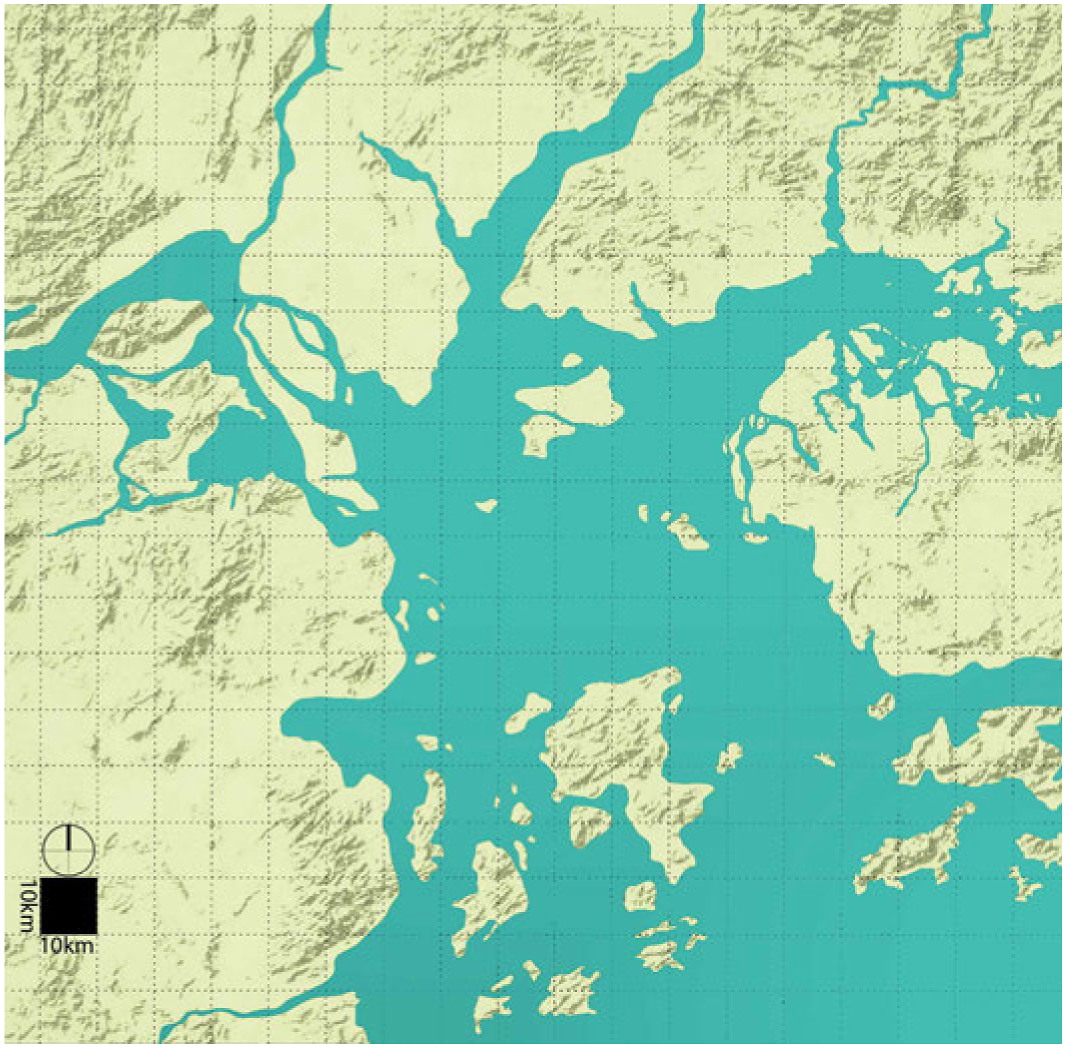
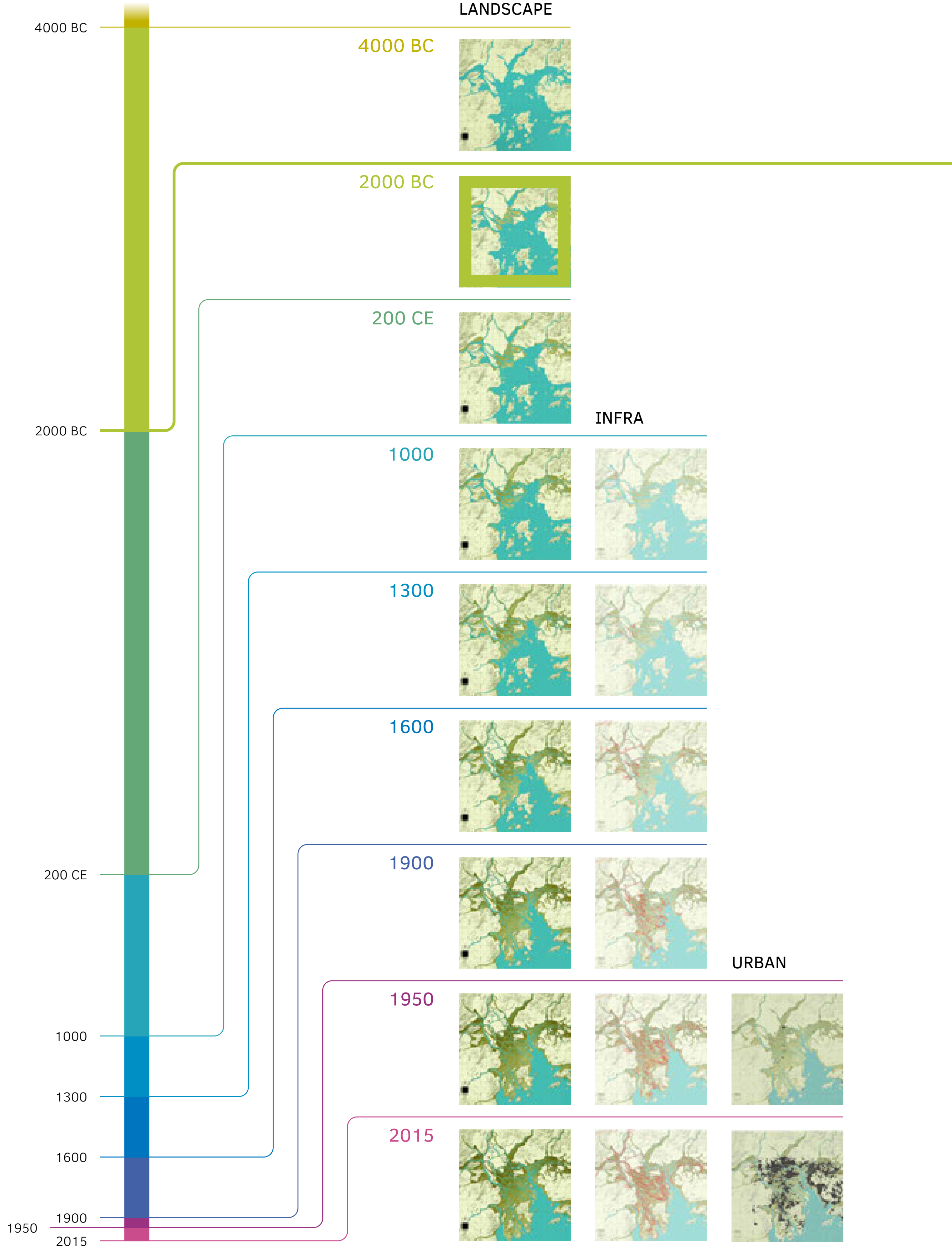
4000 BC



The majority part of the delta today was a bay at the time 4000 BC. The West and North River Deltas had extended southeastward in the north of the region. While the East River had not developed into a delta geomorphology in its estuary. There were hills surrounding the bay to the east, west and north (Weng 2007). Inside the bay, there were hills and terraces in the islands. The sediments brought by the three rivers had distributed in the bay.

DELTA SCALE



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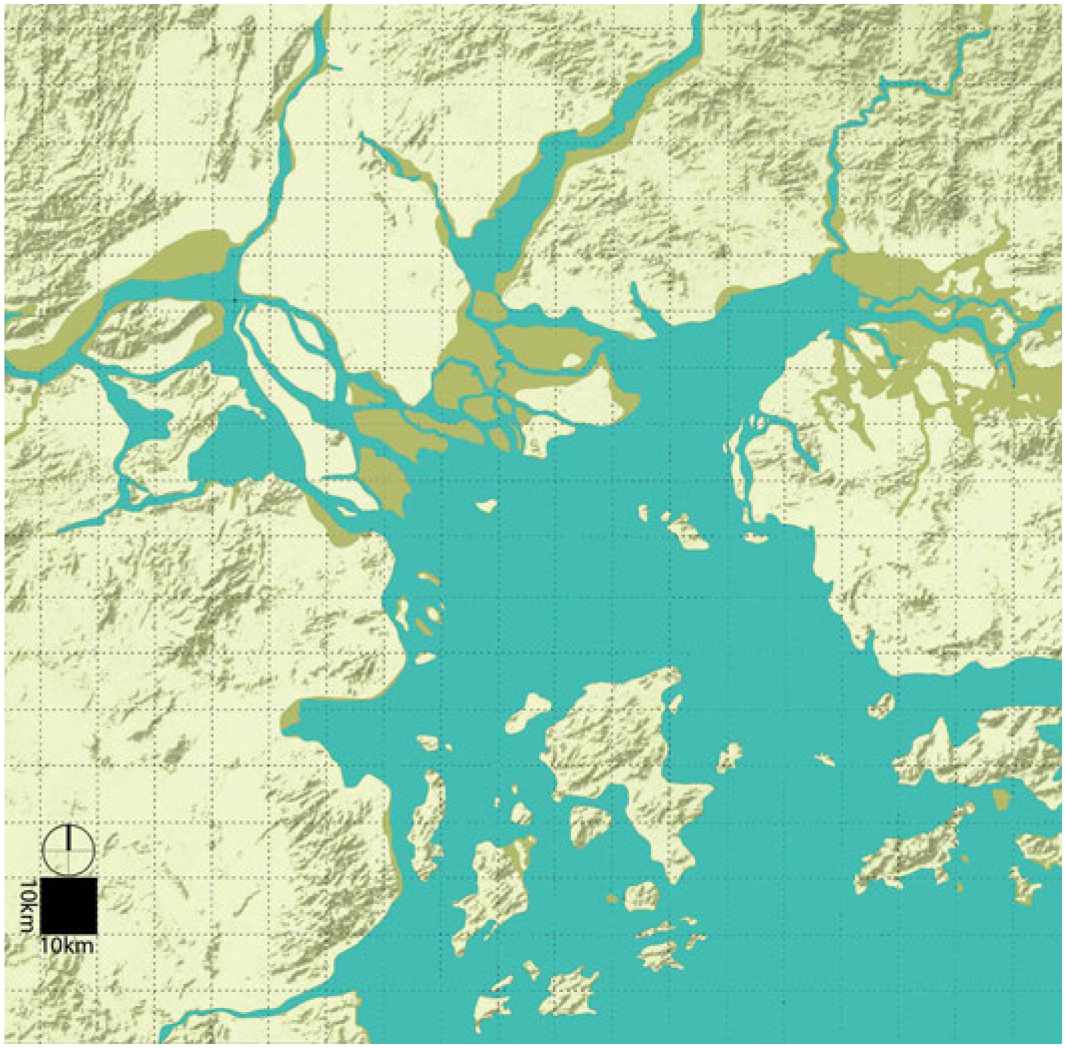
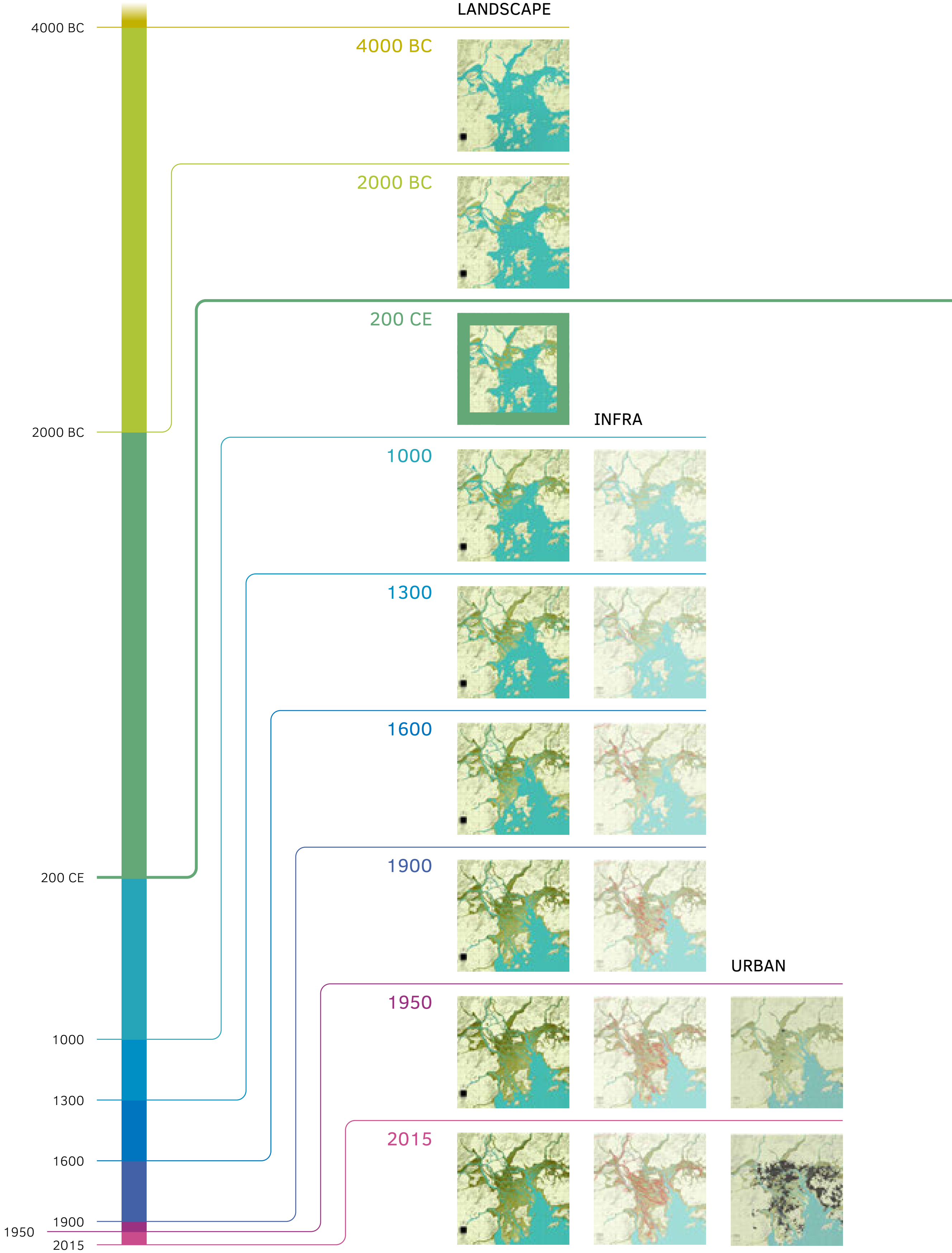
2000 BC



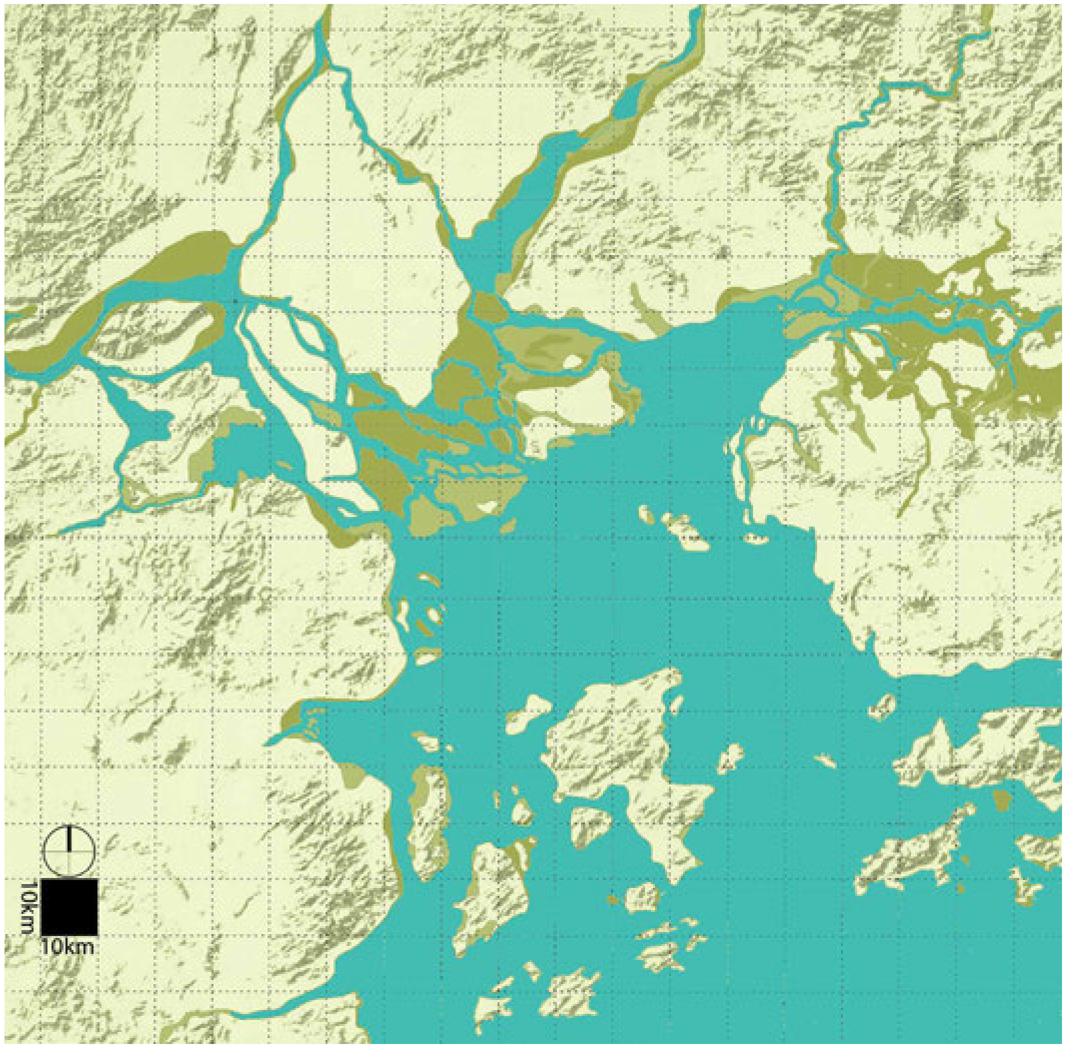
The sub-deltas had extended significantly because of a substantial sea level decline around this time (Li et al. 1991). The West and North Delta had developed further in the north. And the floodplain became visible in the East River Delta.

DELTA SCALE



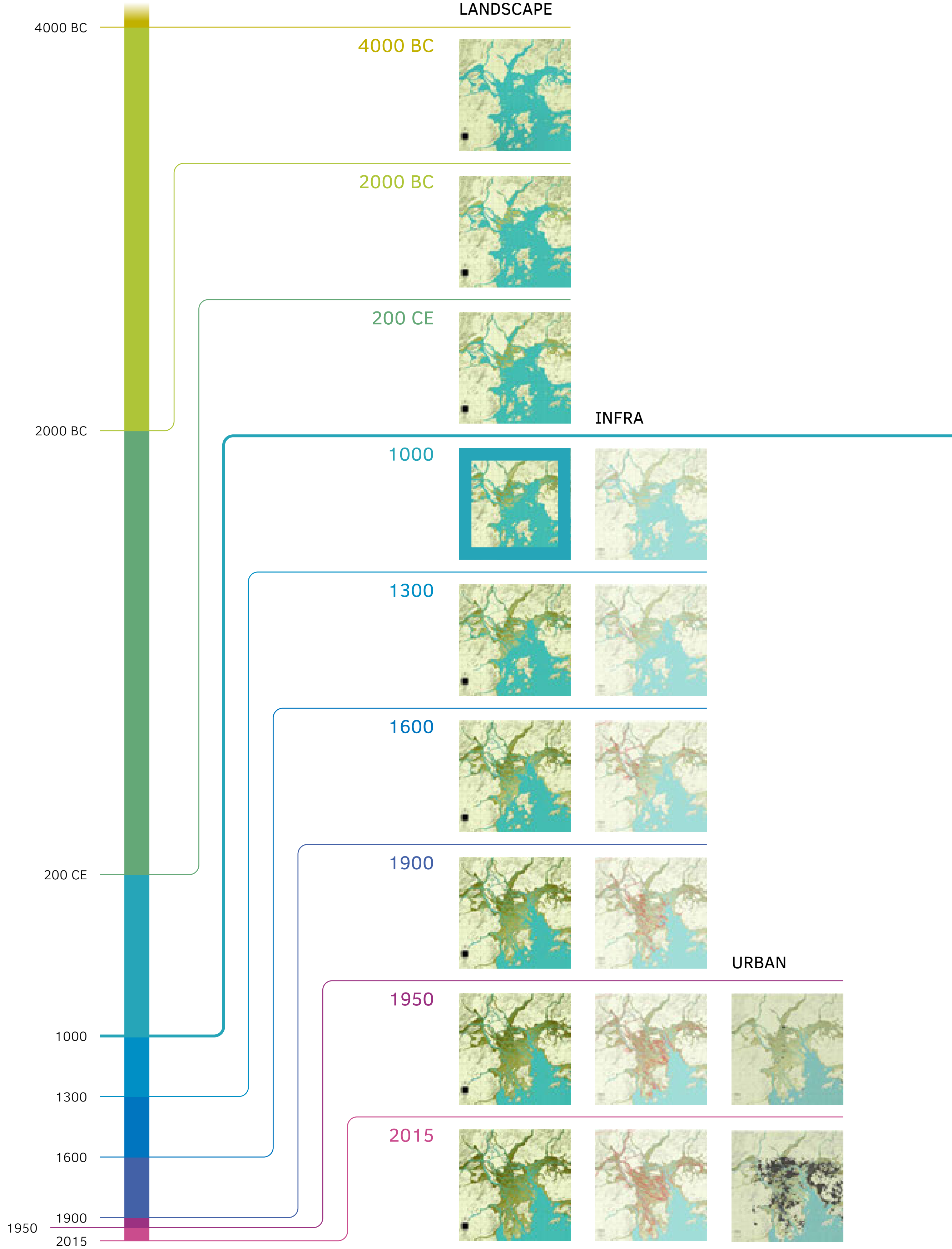
LANDSCAPE
INFRA
URBAN
4000 BC
2000 BC
200 CE
1000
1300
1600
1900
1950
2015

200 CE



Another major sea level fall of 4-5 meter took place during this time (Li et al. 1991). The sub deltas had extended further. The average extension rate of the North River Delta was 8.7 m/a, and East River Delta 6.1 m/a (Huang et al. 1982).

DELTA SCALE



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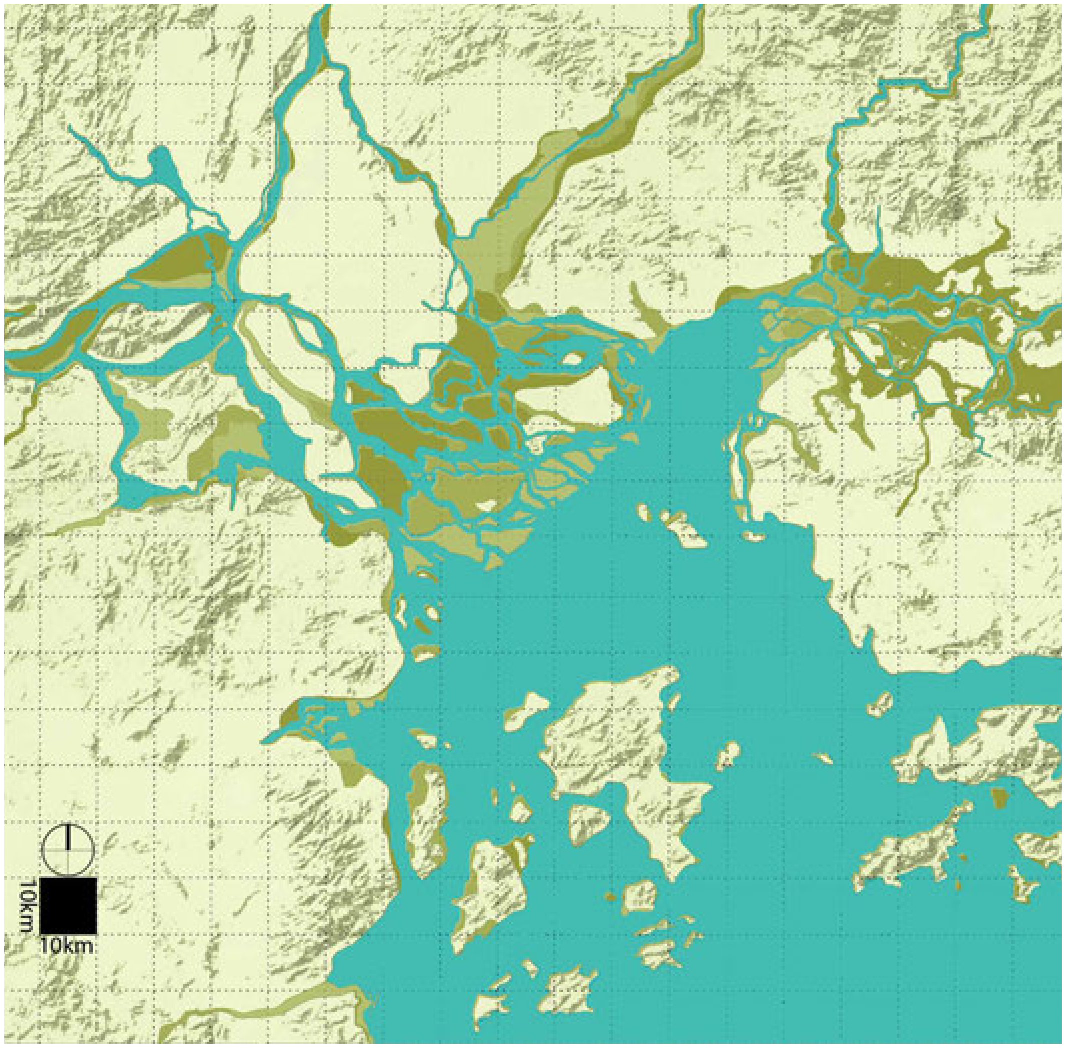
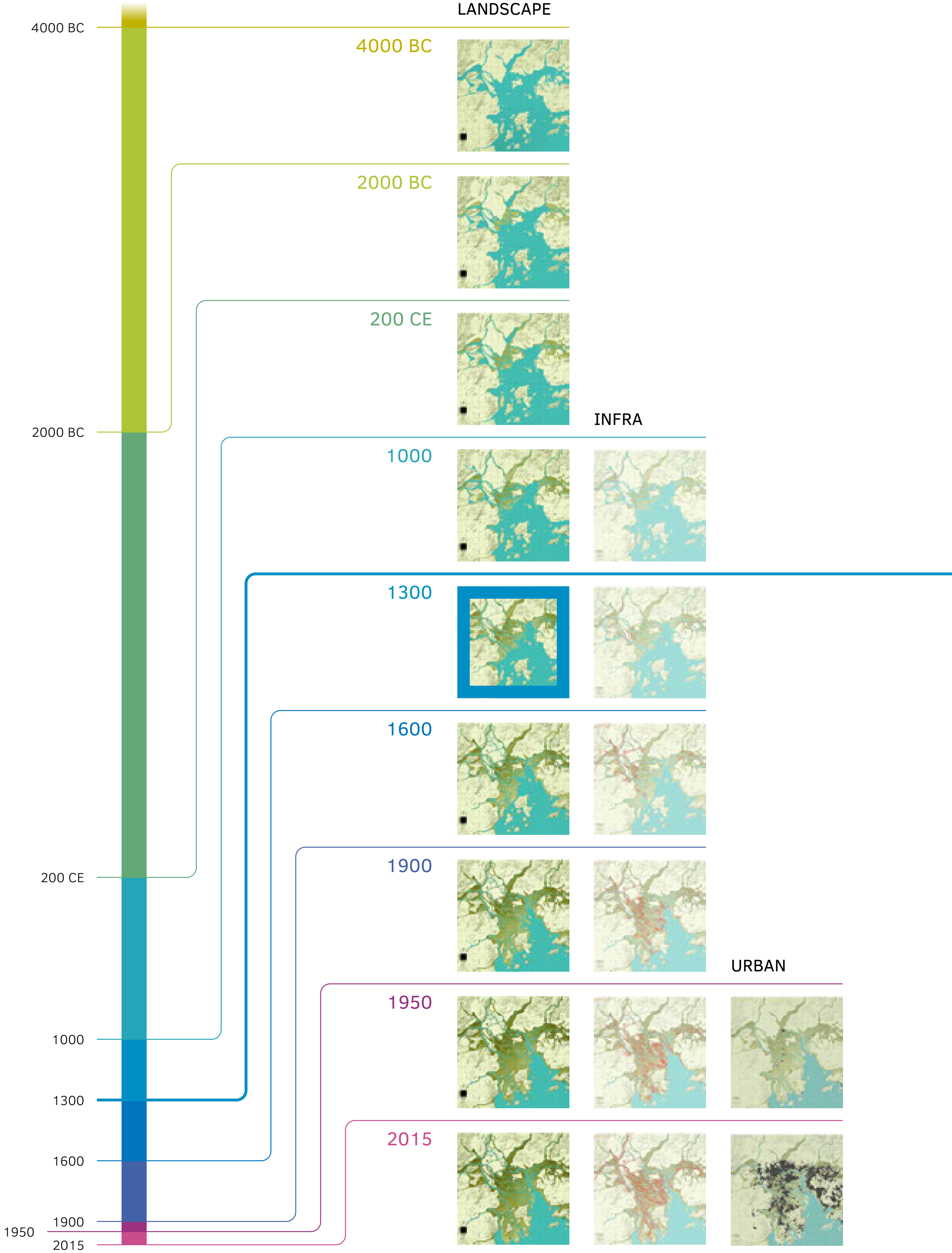


The delta had extended further into the bay with a higher speed. The main driving force during this period was the sedimentation. Because the delta continued its growth without major change in the sea level, natural levee started developing along the rivers due to seasonal flooding. A few rivers meandered in the floodplain. There was a growth in the speed of expansion in both the North River Delta and the East River Delta. In the North River Delta, the speed had grown by 17% to 10.2 m/a, and in the East River Delta by 38% to 8.4 m/a (Huang et al. 1982).

DELTA SCALE



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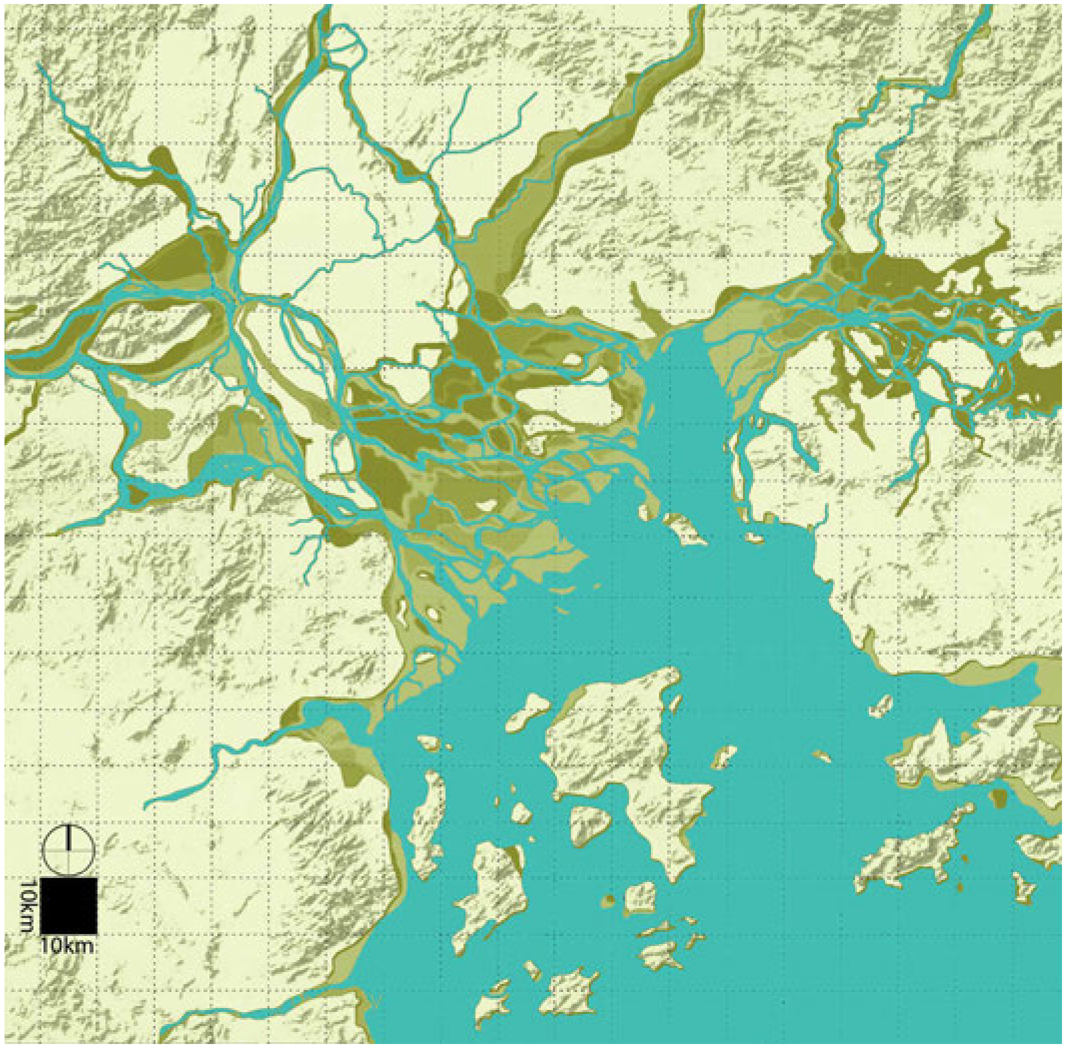
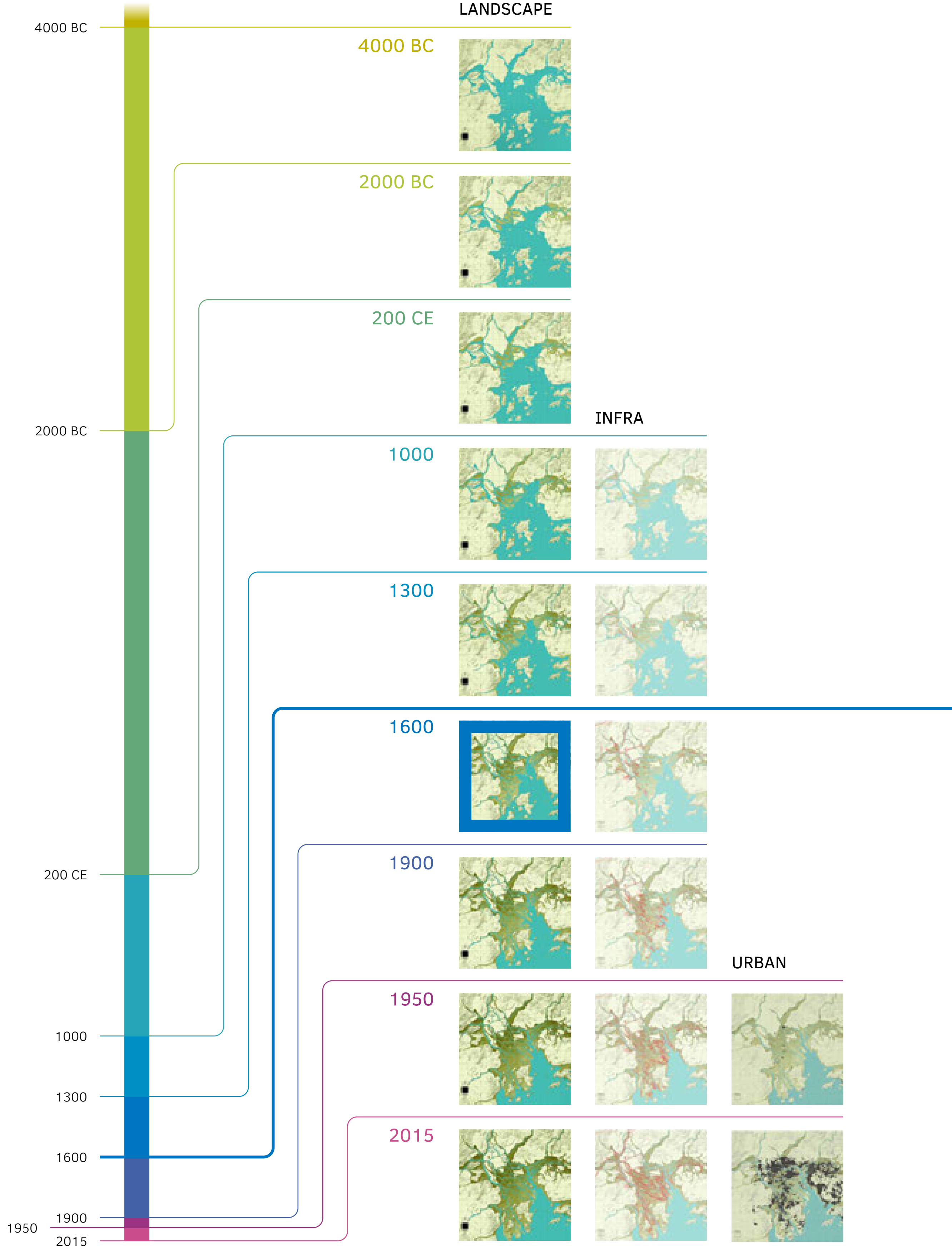
1300



The development of delta accelerated again in this phase. There was an increase in expanding speed by 83% in the North River Delta and 73% in the East River Delta (Huang et al. 1982). Many islands to the west and north of the bay had been connected with the mainland. The sedimentation process was so strong that the west side of the coast had received distributed sand by the West River. The West River extended toward southeast in a high speed of 68.7 m/a during this period (Huang et al. 1982). Rivers kept on changing courses in the upper part of the three sub-deltas.

DELTA SCALE


4000 BC
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LANDSCAPE
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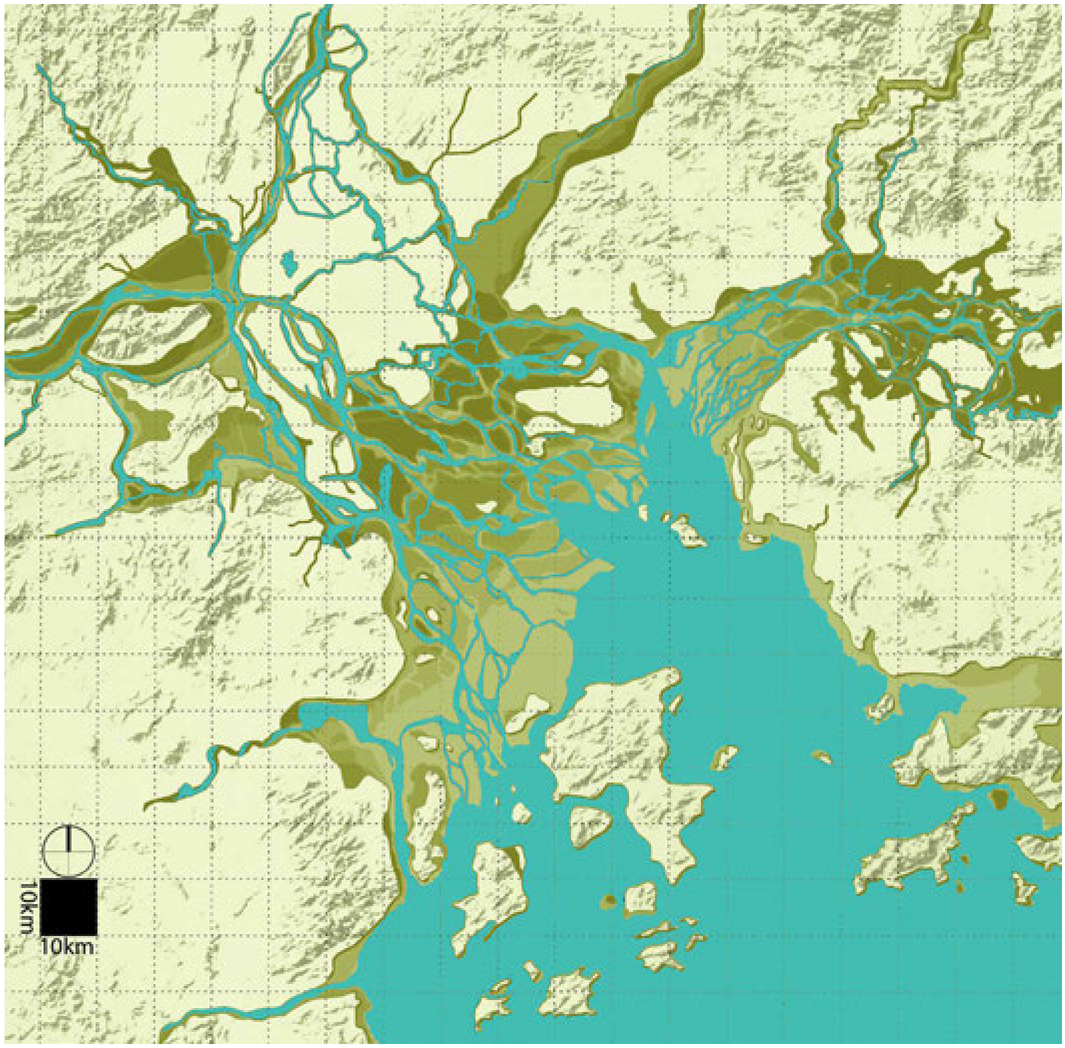
2015

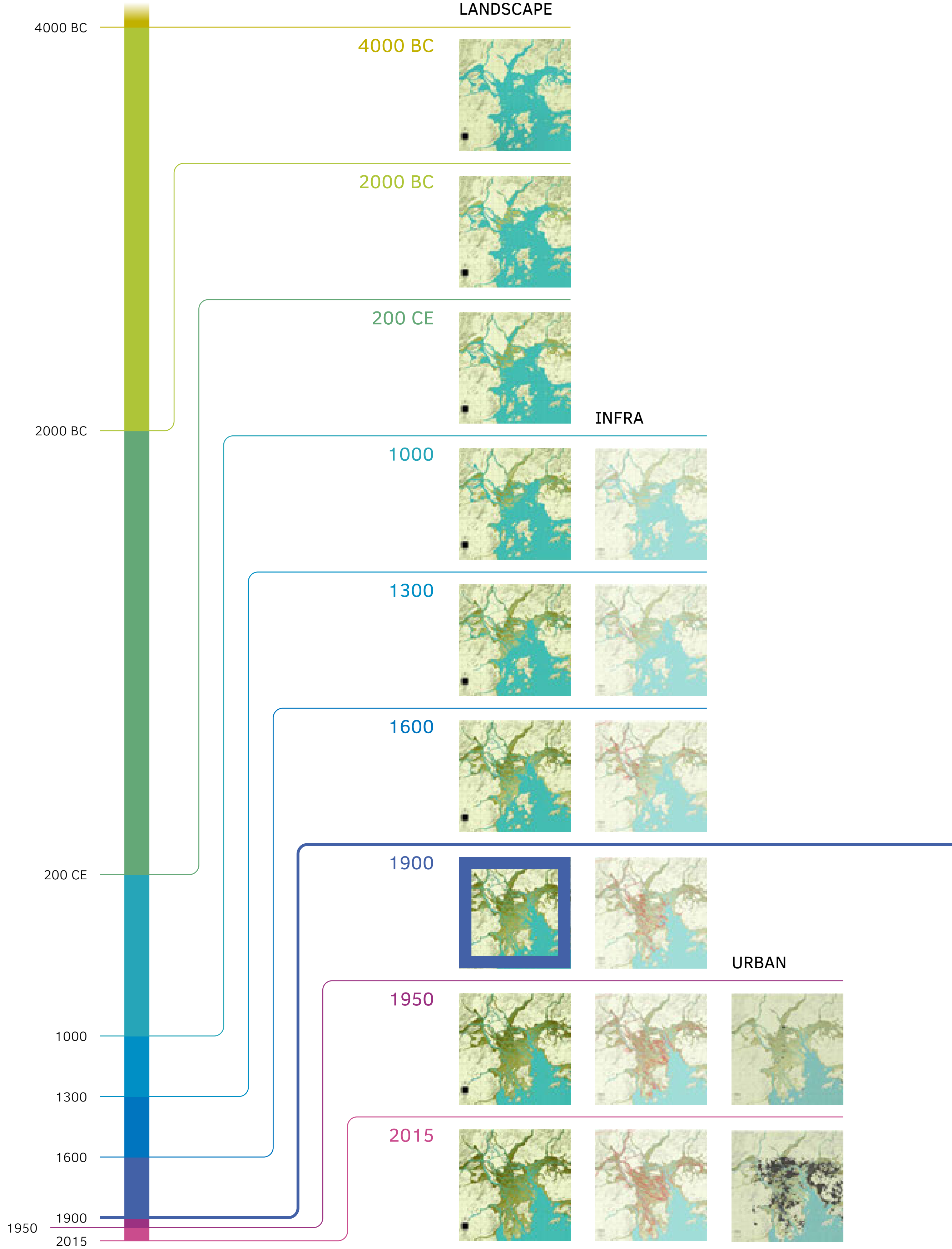
1600



The delta developed in a high speed. The sub-deltas began to connect. While the acceleration slowed down. The expansion of the North River Delta had increased by 4%, and the East River Delta by 34% (Huang et al. 1982). More islands in the west were connected. Besides the significant expanding to the west, there was noticeable development in the east coast as well.

Rivers kept on changing courses in the upper-middle of the sub-deltas.

DELTA SCALE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LANDSCAPE
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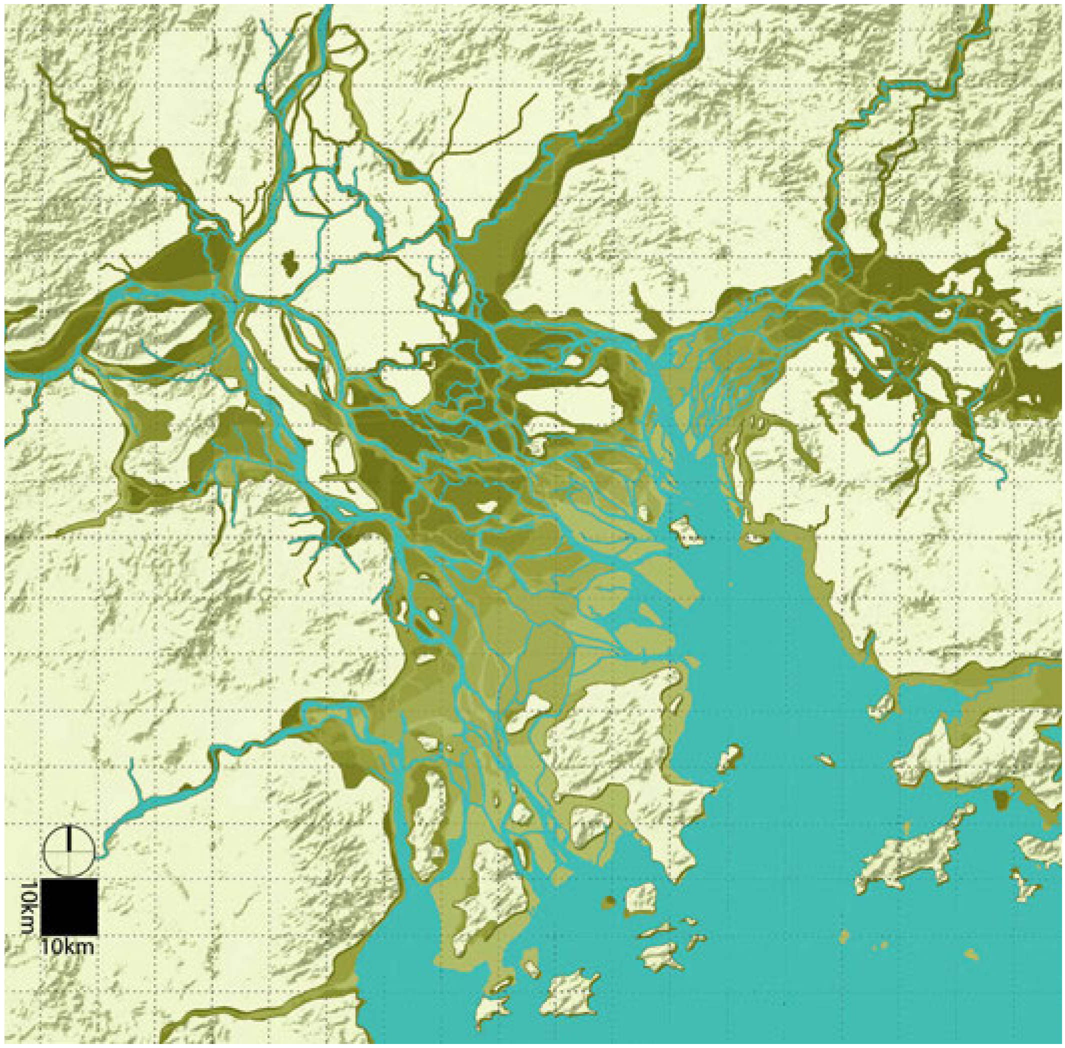
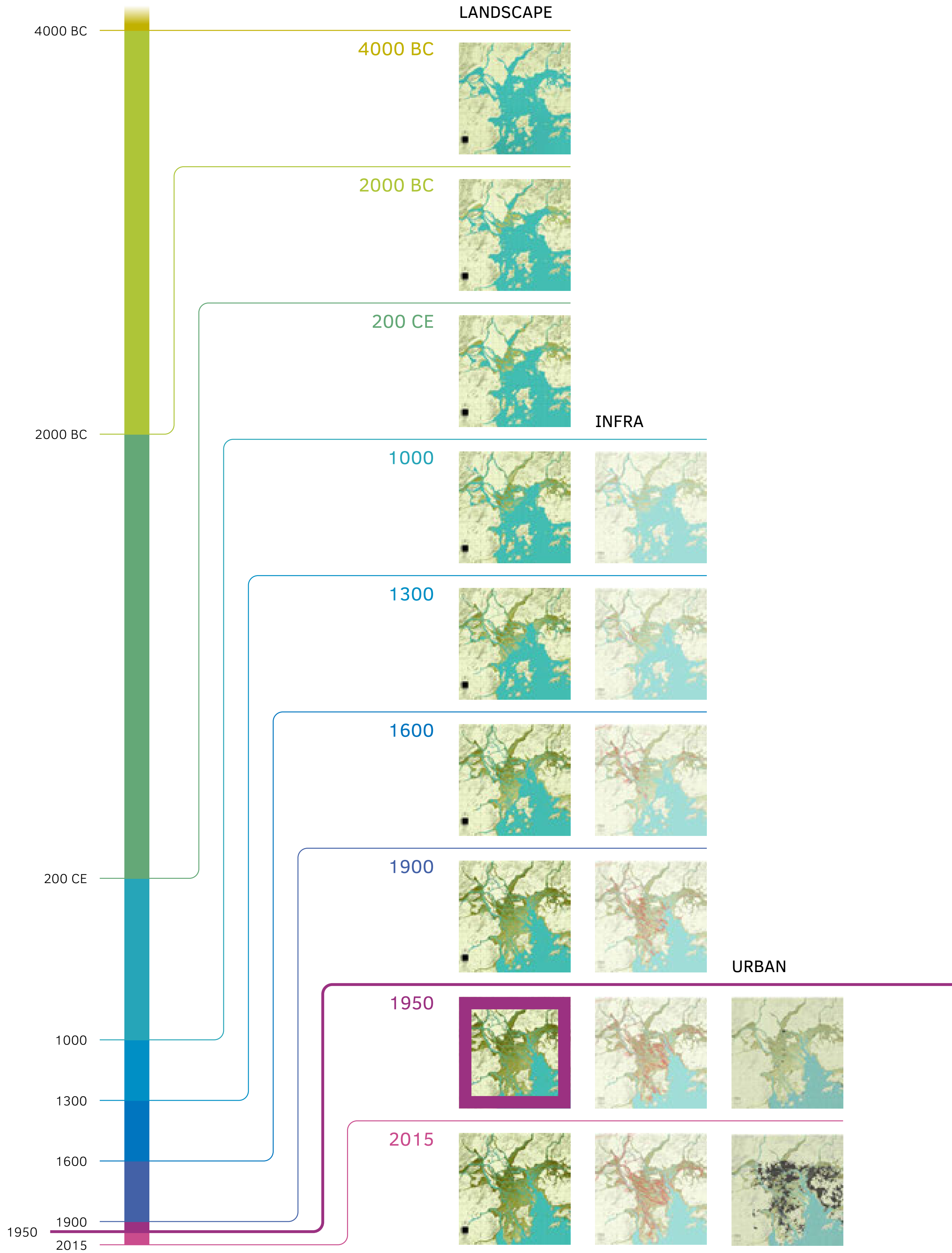
1900



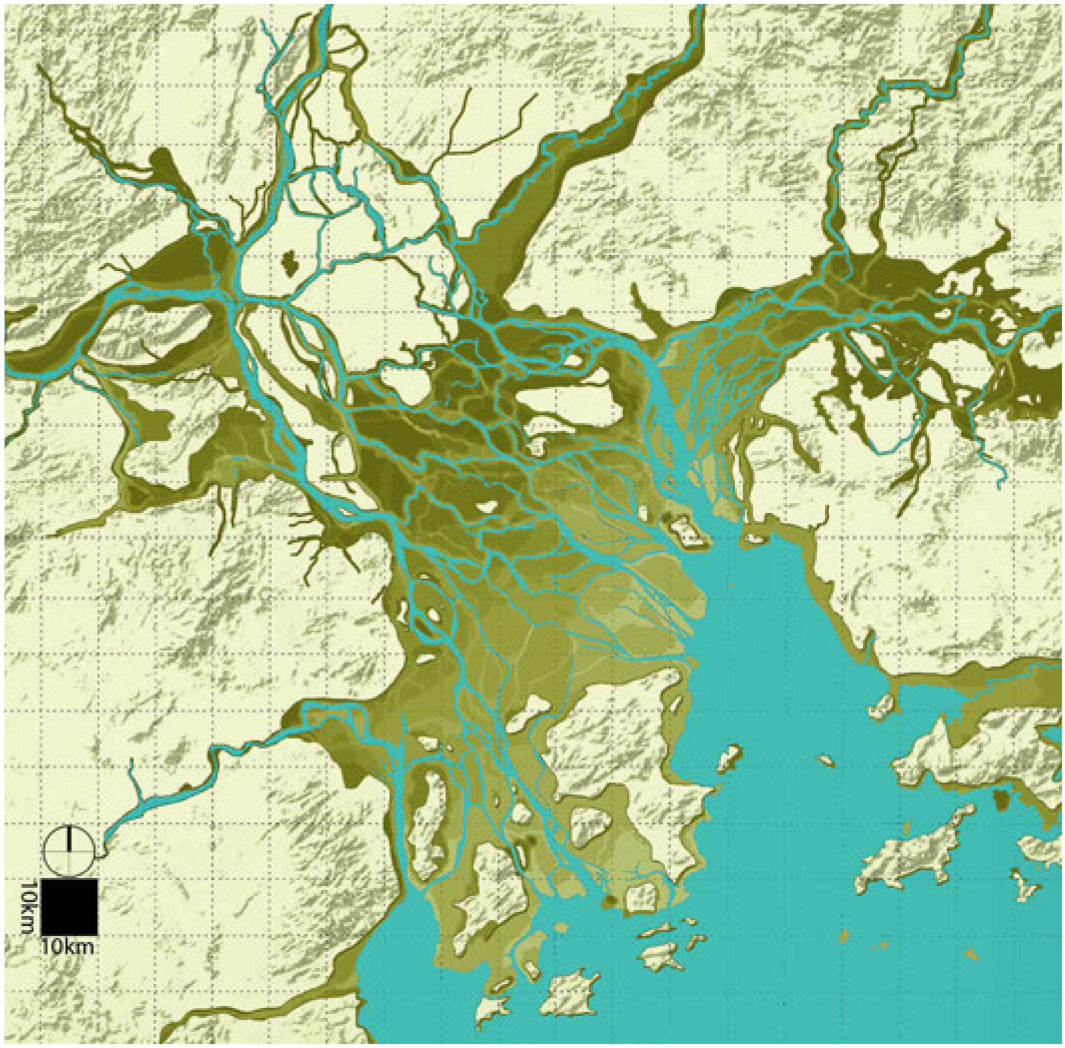
The major expansion of the delta took place in the middle and west part during this period. The North River Delta developed at a speed of 26.9 m/a while the East River Delta 15.2 m/a (Huang et al. 1982). Contrary to the quick development during the previous time, the east coast saw no development. Because of the increased sand accumulation rate, the tributaries were silted up (Weng 2007). This had resulted in continuously changing courses in the middle of the delta.

DELTA SCALE



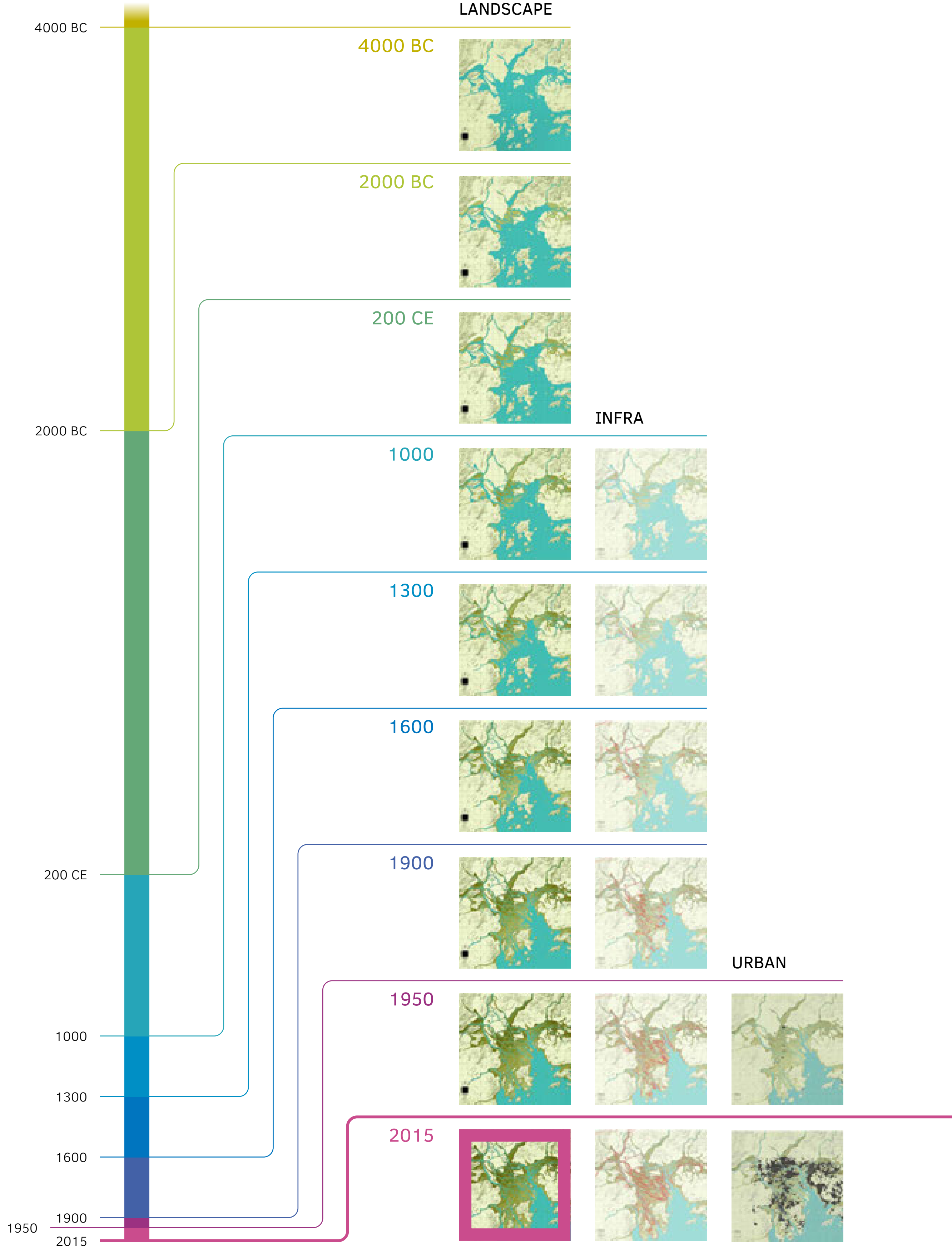
TOC

1950



The delta continued to develop in a high speed in the west and north part. Large amount of river meanders had occurred in the middle and lower part of the delta. Although the significant development in the frontier of the East River Delta, the neighboring east coast had no sign of coastline extension.

DELTA SCALE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LANDSCAPE
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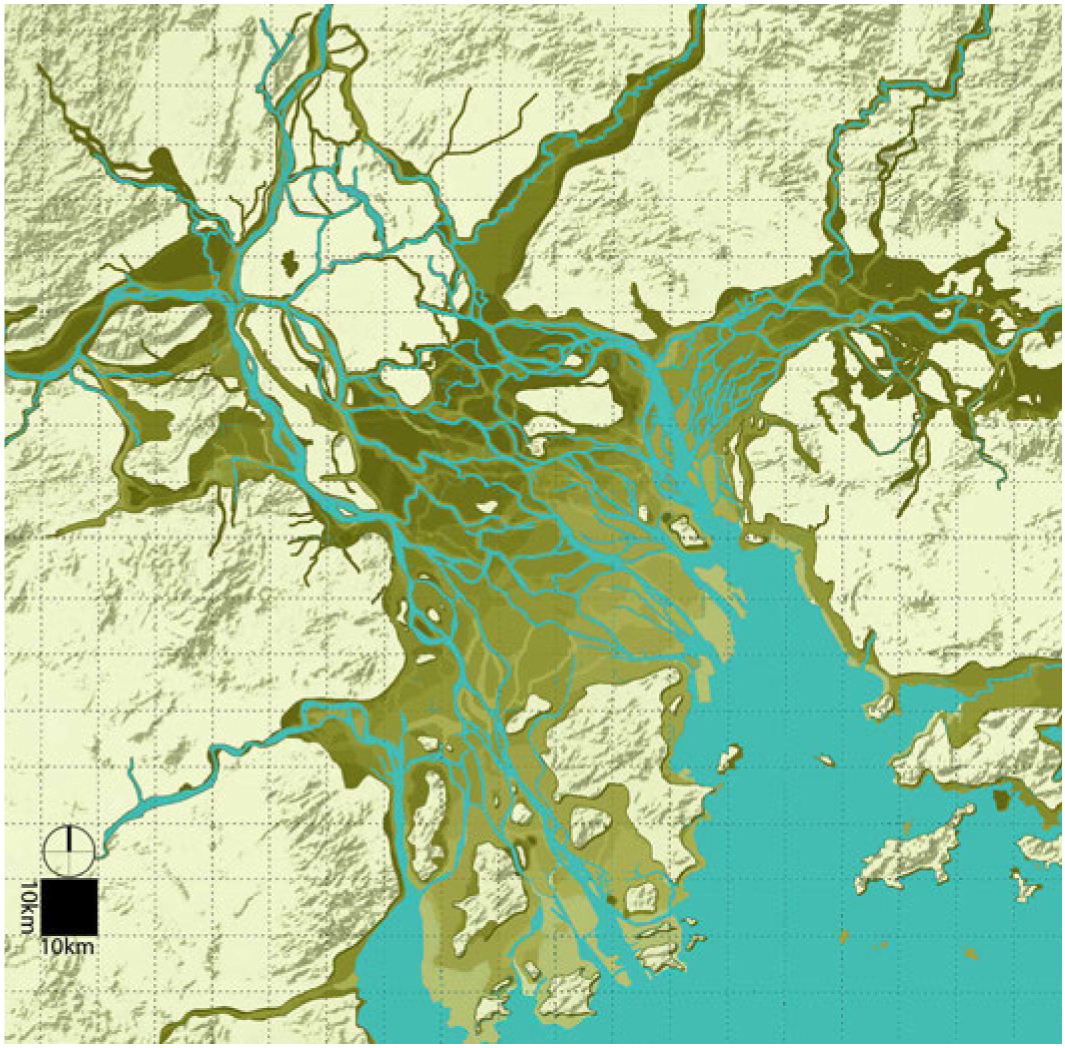
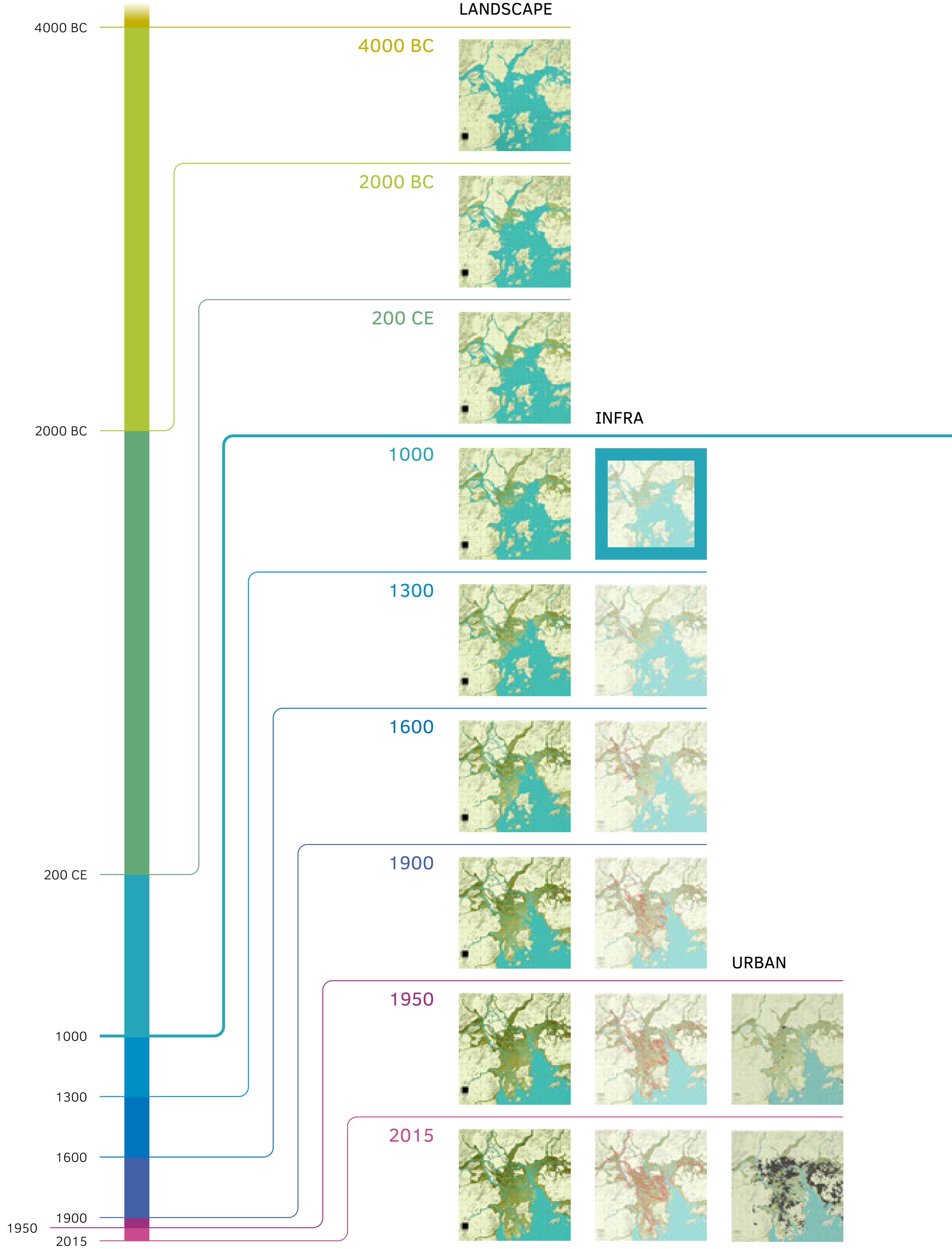
2015



The frontier of the delta developed in a high speed. In the east coast, the delta had developed at a speed of 242.9 m/a since 1978 (Zhao 2017); while the west wing the delta expensed on the estuaries. Some most prominent estuary, Wanqingsha region, grew at a speed of 431.8 m/a since 1978 (Zhao 2017).

DELTA SCALE



LANDSCAPE
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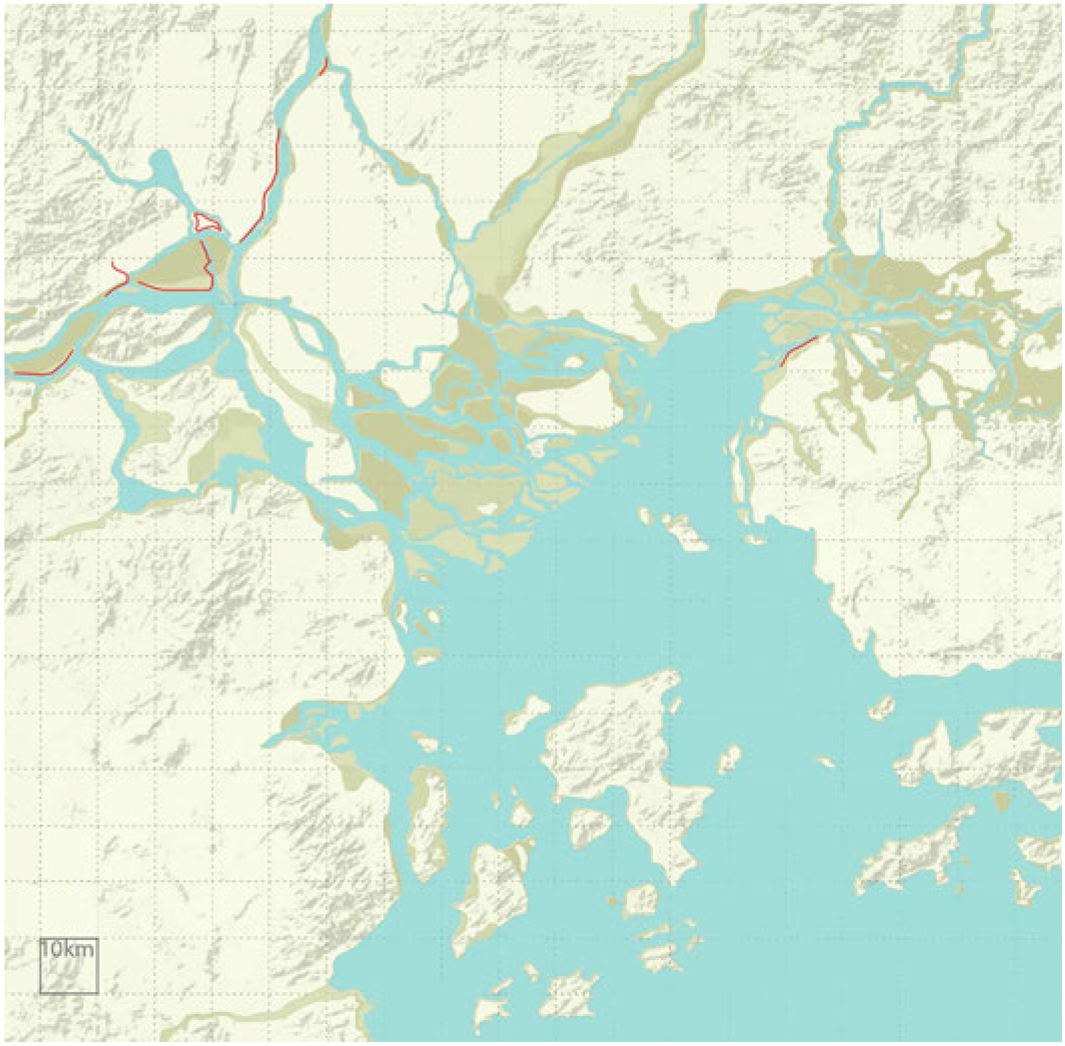
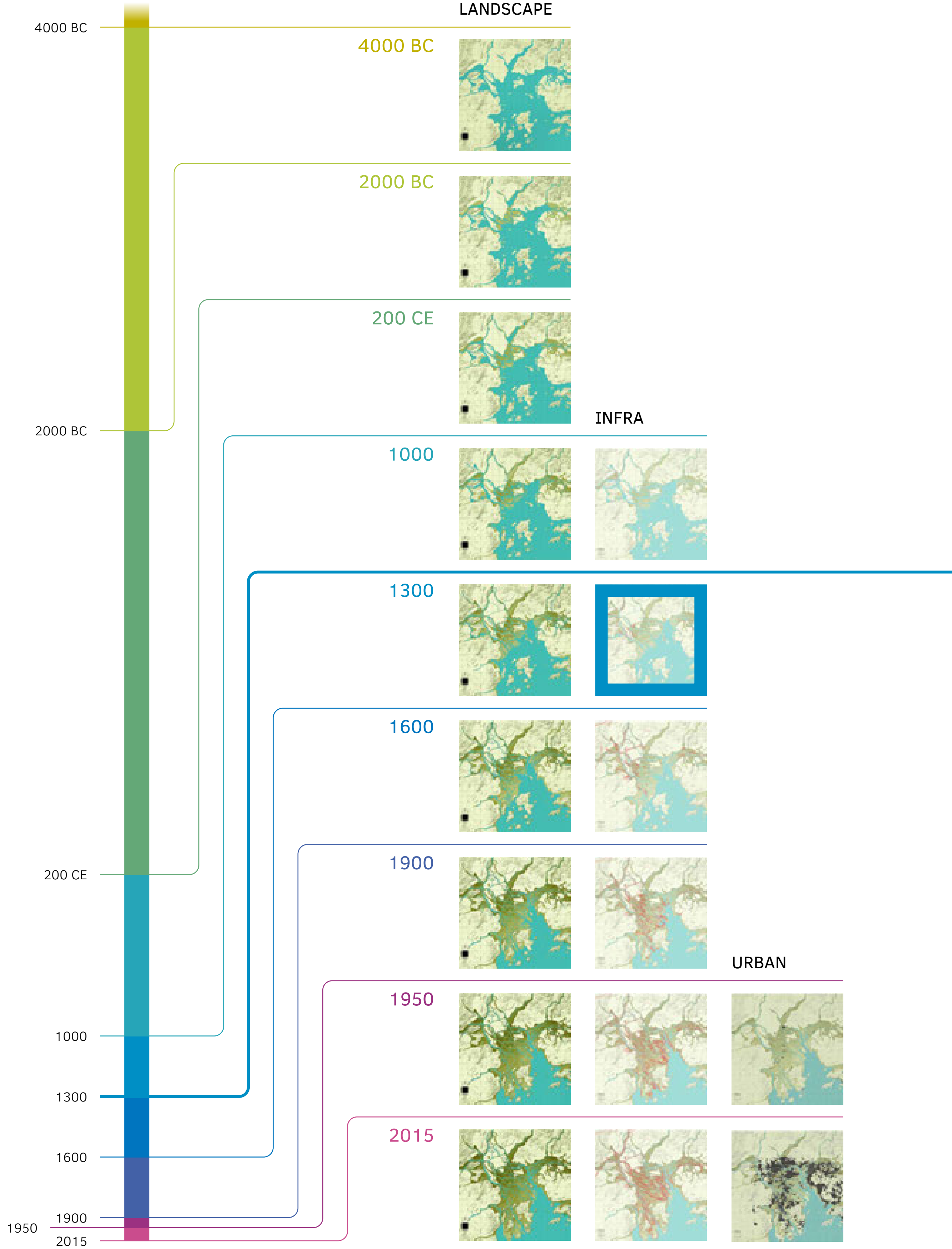


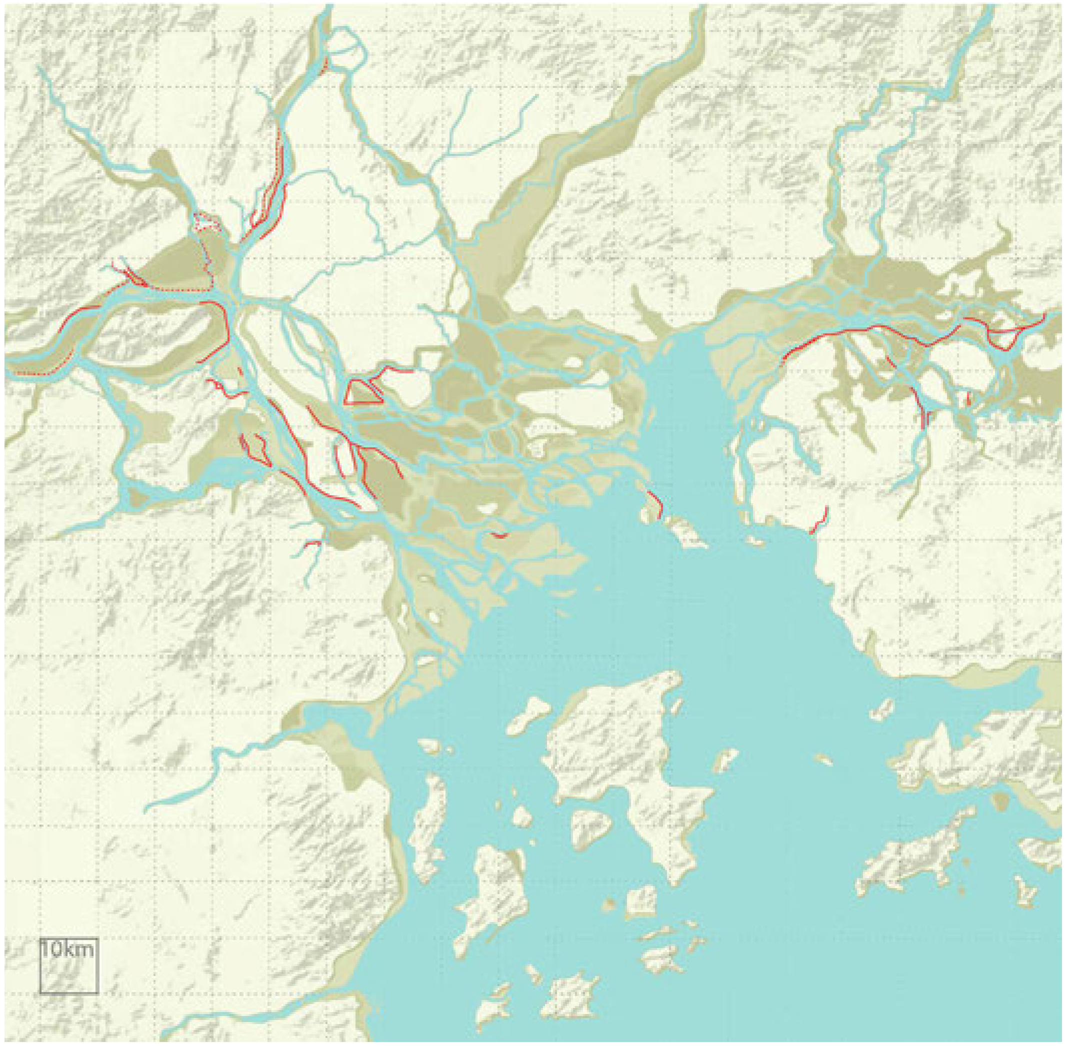
Dikes were built mainly near the joint point of the river. Most dikes located on stabilized land. While the other few located along the natural levees to enhance them from the high tide. Most dikes built at this time were semi open.

DELTA SCALE



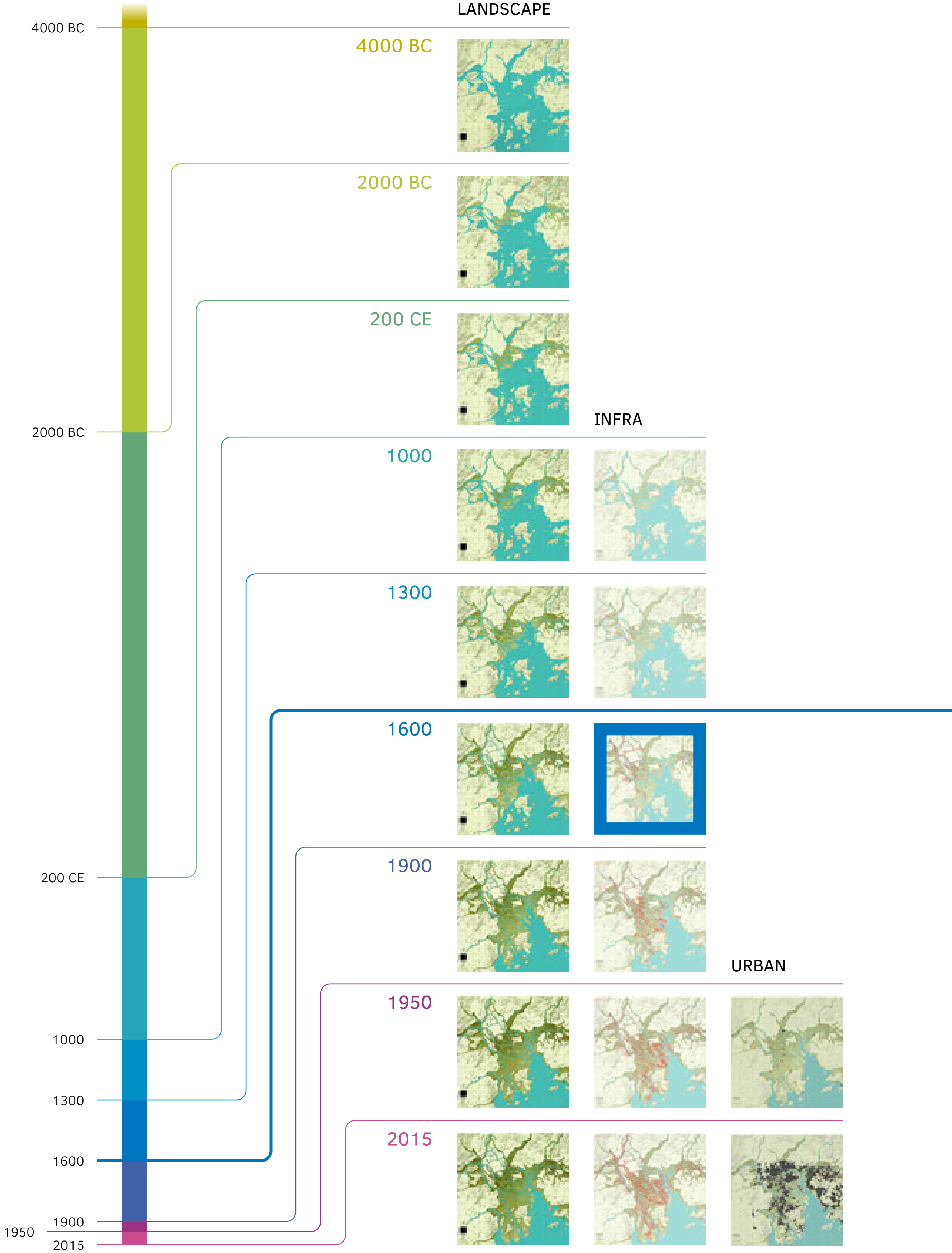
TOC

1300



The local scaled dike system began to extend its length and height. Especially in the north of the delta region, the dike system started to link with each other and upscaling from local homogeneity to sub-regional homogeneity.

DELTA SCALE



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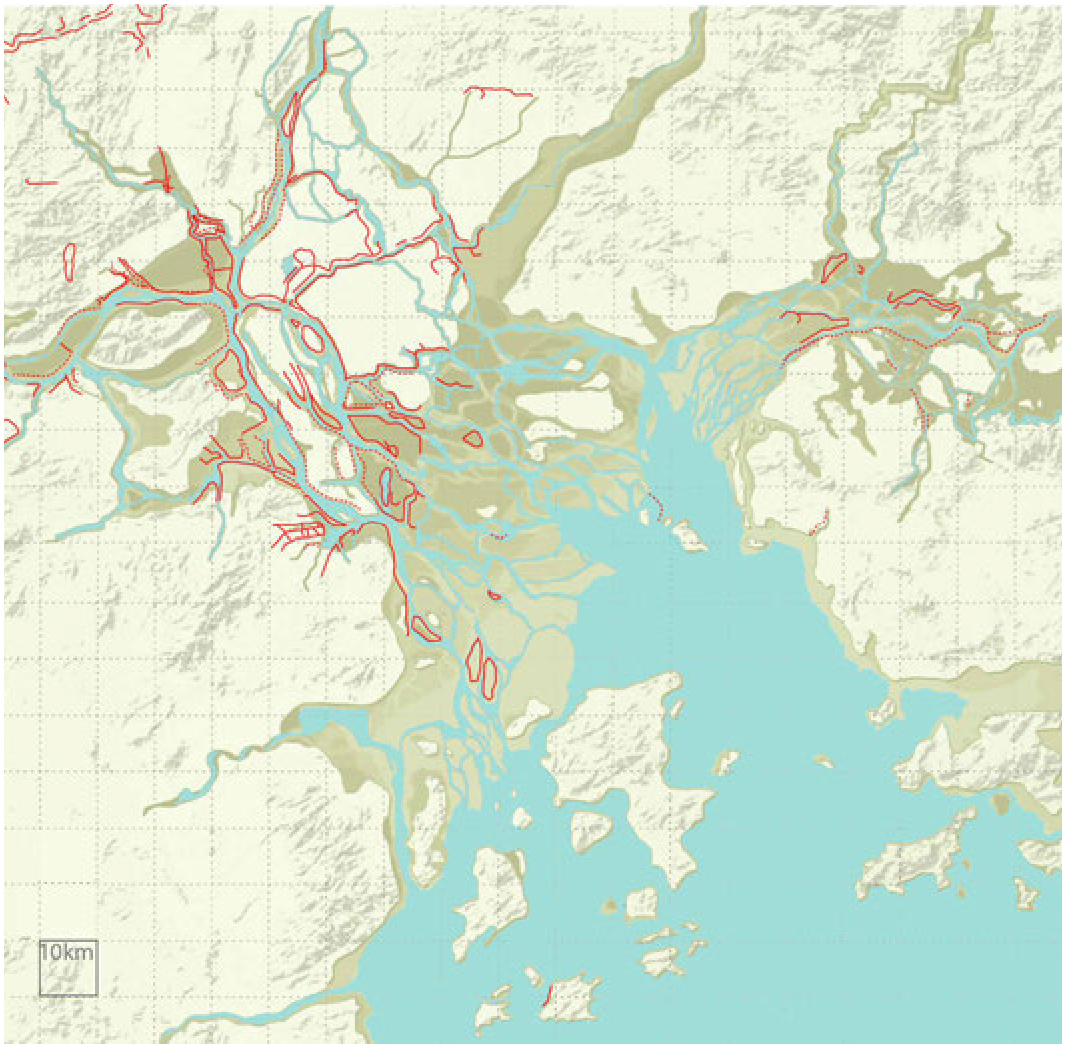
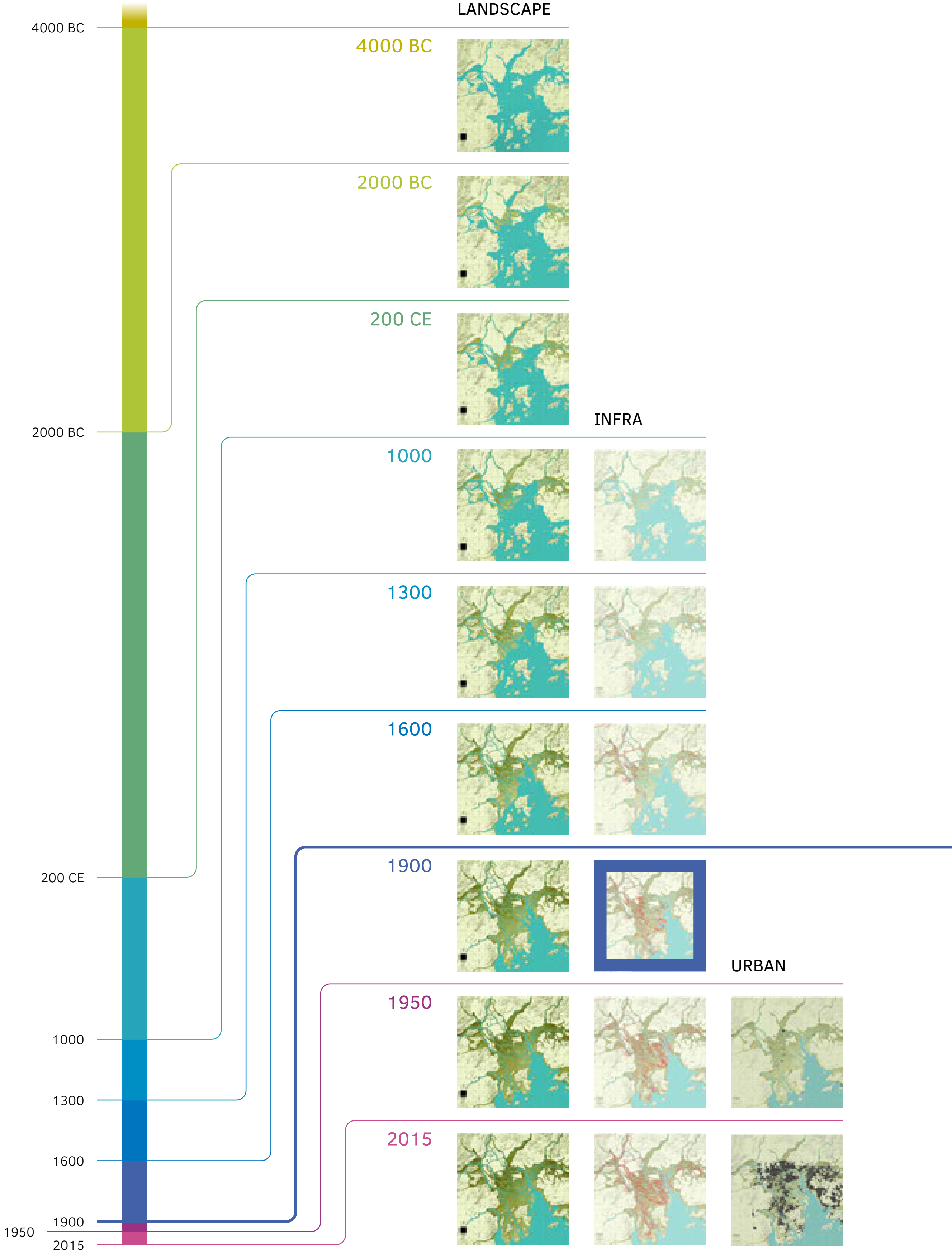
1600



The dike system spread towards the newly formed part of the delta region in the south as it was in the earlier period.

DELTA SCALE

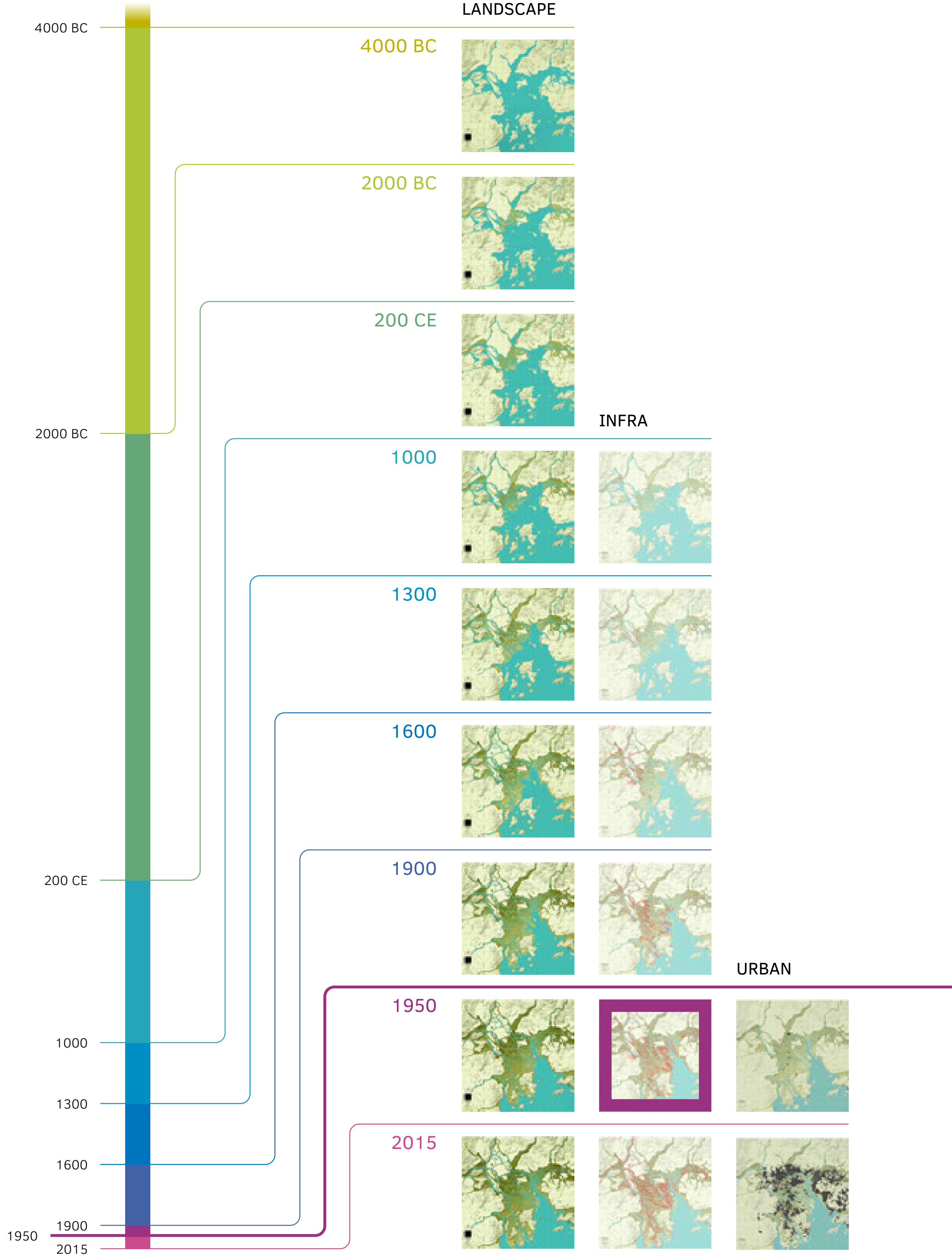


TOC

1900

Small dike rings spread into the delta in a fast pace. The dike rings were built not only in the center of the delta, but also at the coast.

DELTA SCALE



LANDSCAPE
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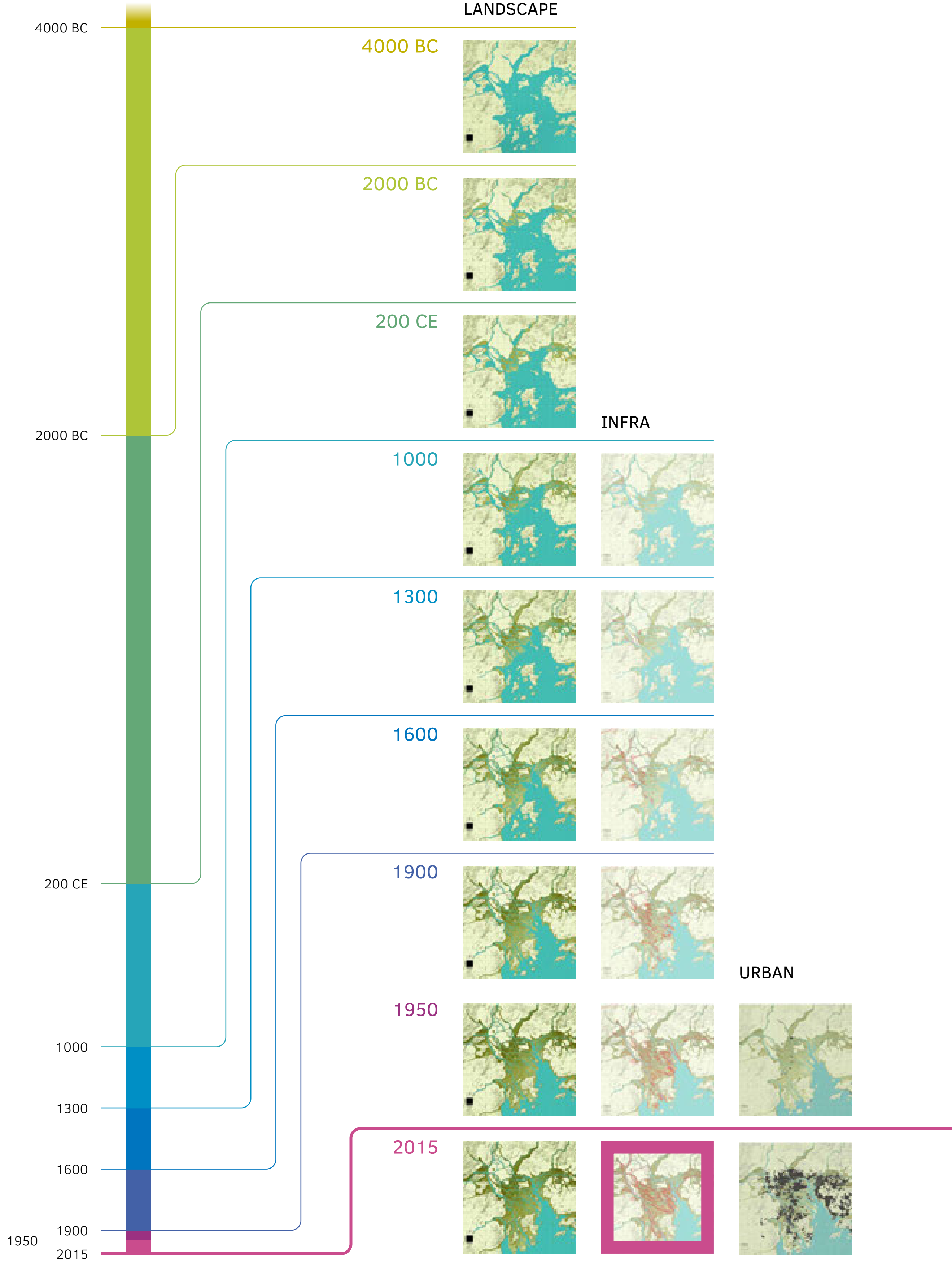
1950

The dike system began to scaling up towards a regional level.

DELTA SCALE



4000 BC
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LANDSCAPE
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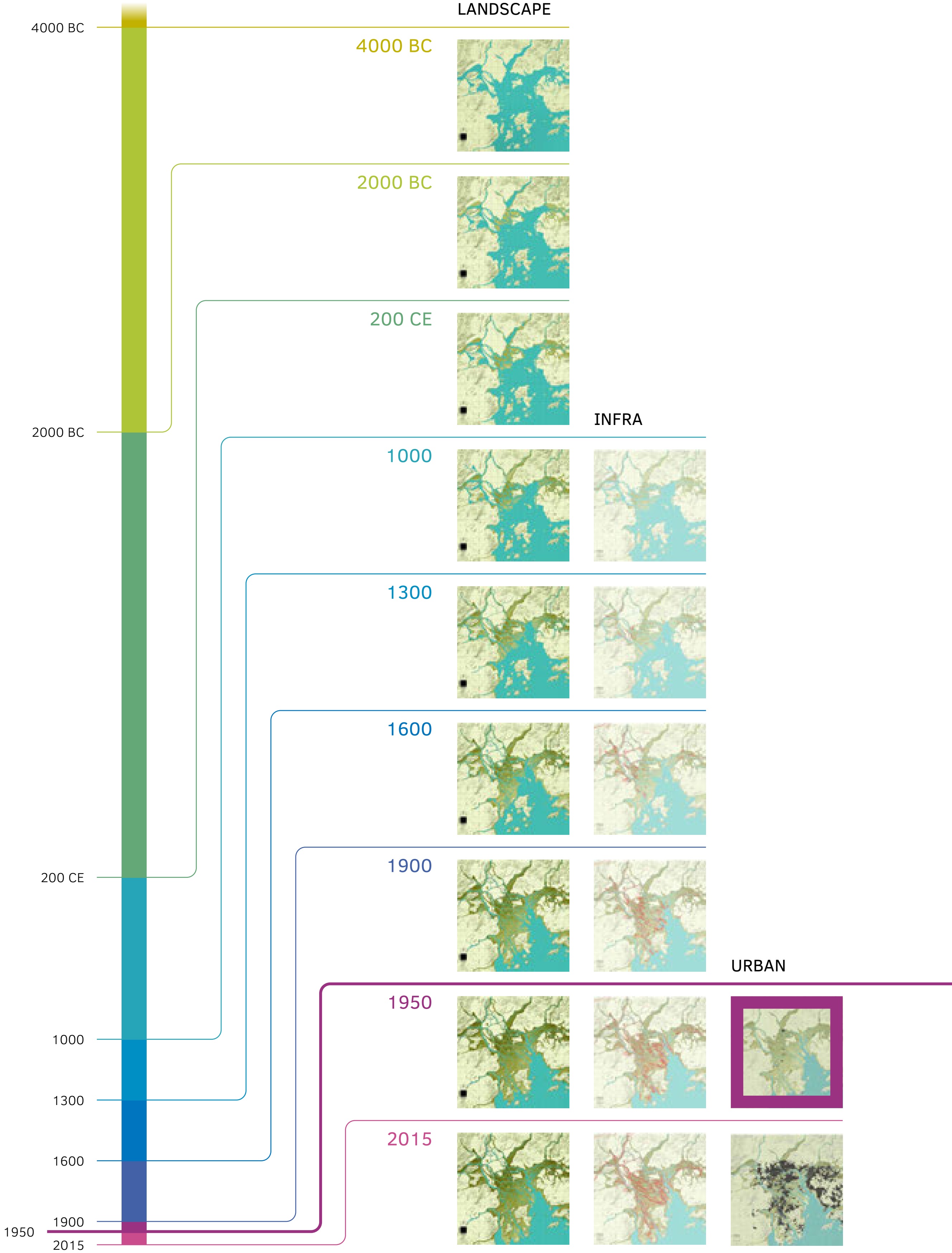
2015

The integration of the dike rings was finished. Several regional scale dike rings took the place of the smaller scale dike rings in the 1900.

DELTA SCALE

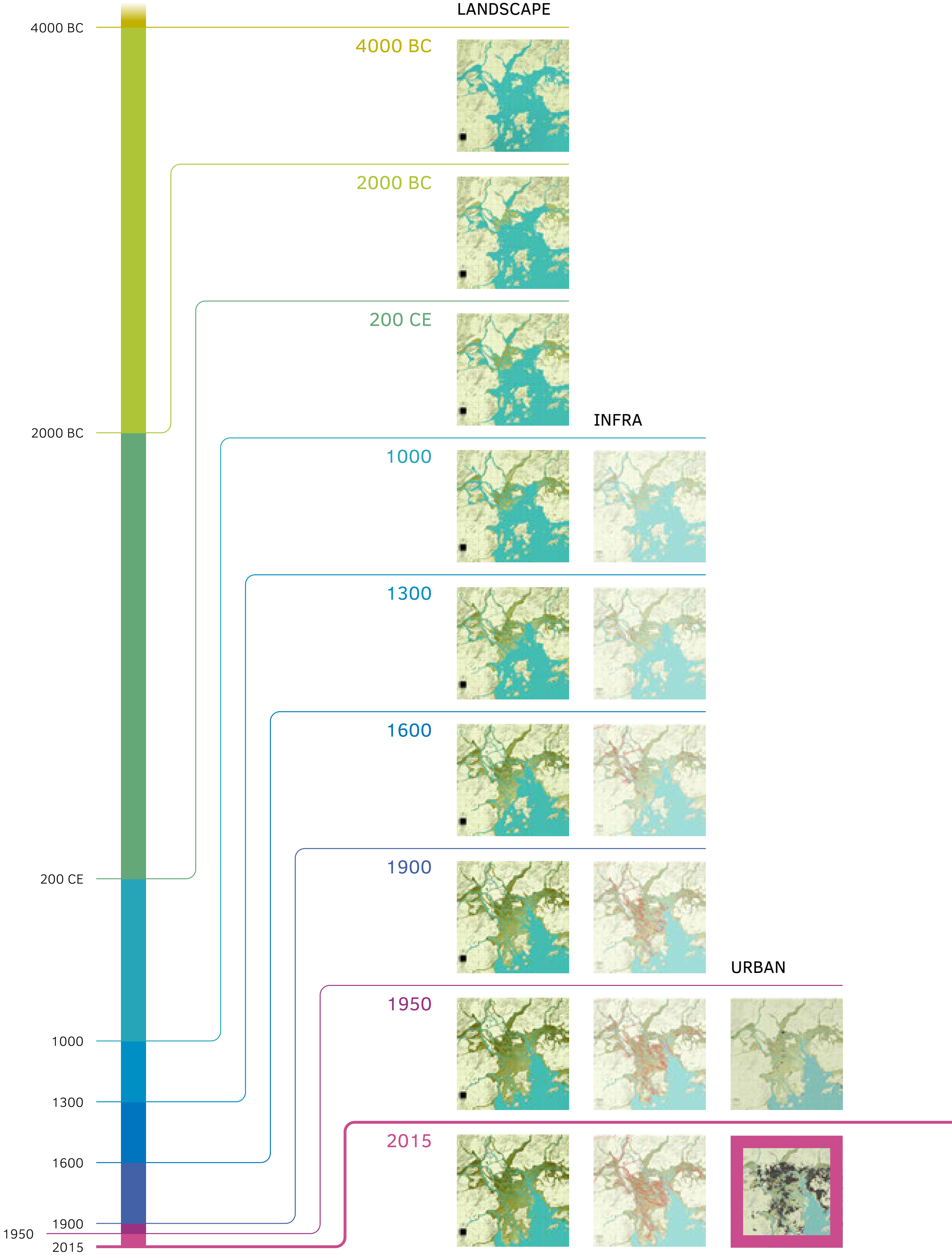


TOC

1950

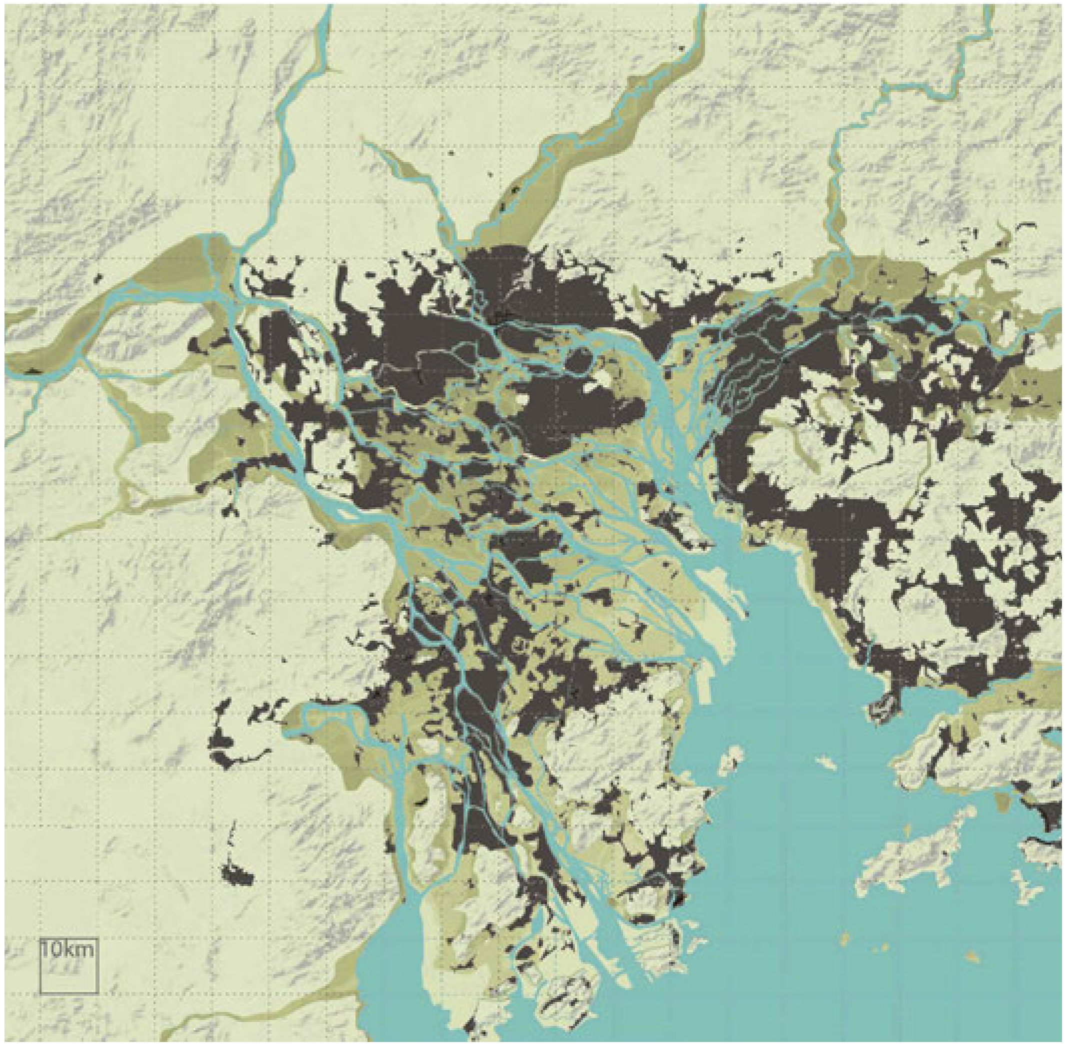
Urbanization mostly took place in the elevated ground, either in islands or near the hills. Near the dike there were also some settlements.

DELTA SCALE



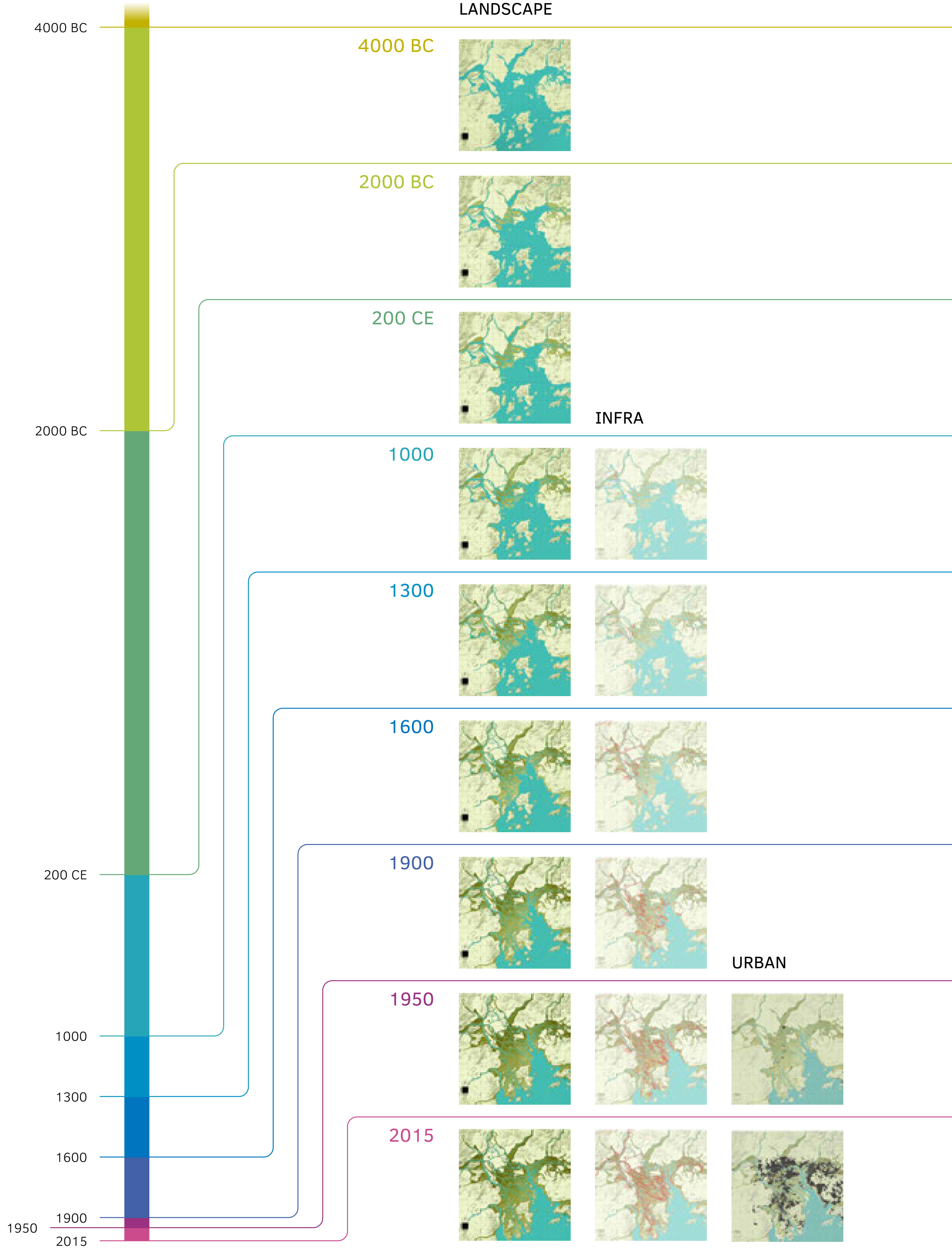
TOC

2015



Urbanization sprawl took place without recognizable pattern. Only a few newly reclaimed parts of the delta had not been urbanized.

LOCAL SCALE



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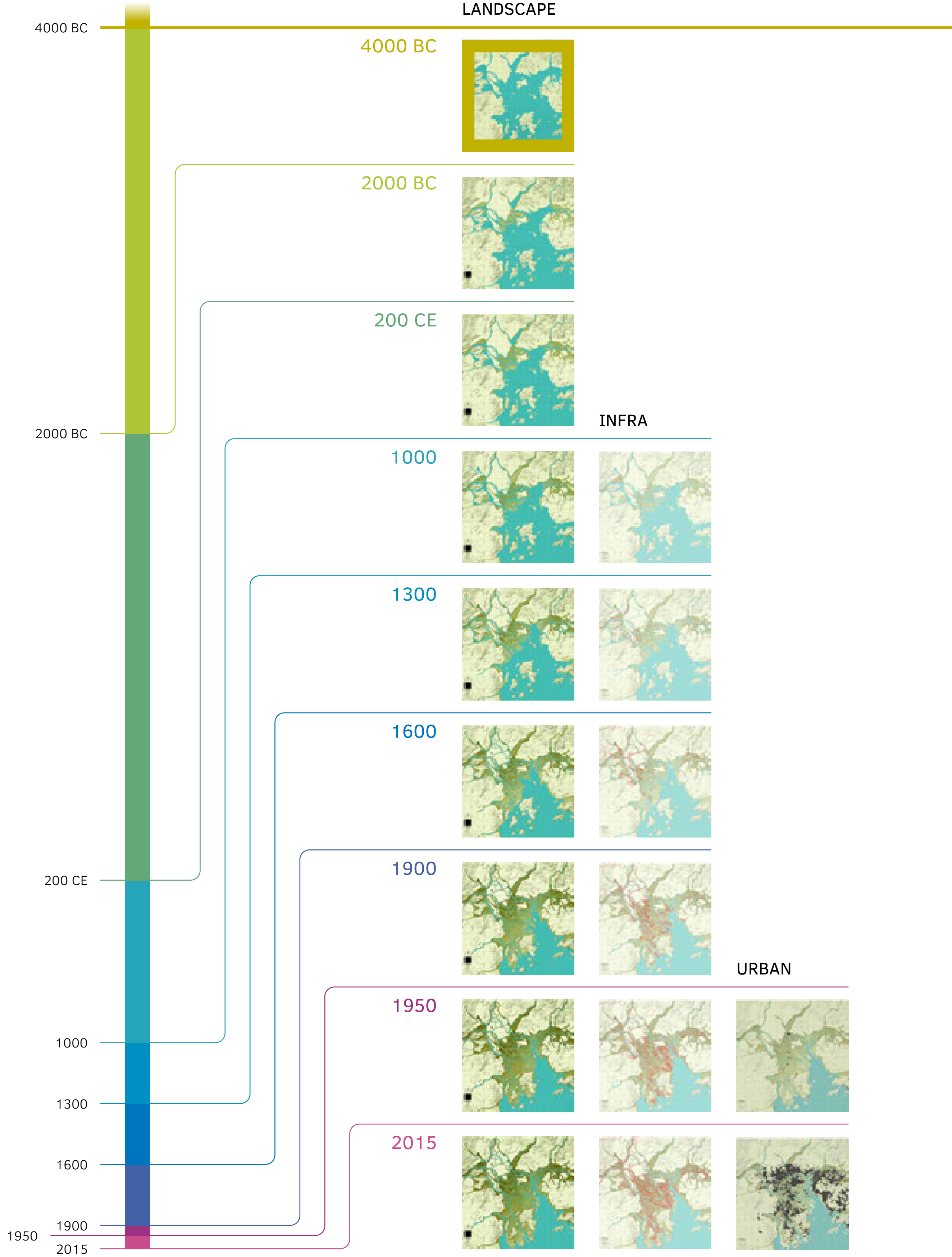
LANDSCAPE	INFRA	URBAN	
• Major part of today's delta was an island surrounded by the sea. • There were hills and terraces in the islands. • Sediments brought by the rivers had distributed in the coast.			4000 BC
• The island started to get extended in its shore. • The river estuaries developed from the west and north.			2000 BC
• The frontier of the delta occupied the surrounding sea of the island. • The water environment changed from salt to freshwater.			200 CE
• The frontier of the delta developed further towards southeast. • The water environment of the local scale became more stable. • Because of the land subsidence, the inner older land became lower than the coast.			1000
• The main island was connected to the western island. • The east part of the main islands got cut through by a new river. • In the surrounding, smaller islands were connected in both northeast and southwest.			1300
• River meandered frequently. • The main island became larger because of the merge to the north.	• The first dike was built along the coast in the southeast of the main island.		1600
• The north part of the main island has been cut through by rivers. • The lower inland was opened to the water in the north. • The south edge of the island got protected by elevated levees.	• Dike rings appeared in large area of the islands.		1900
• The main island was connected towards the west. • As the delta continued to develop towards southeast, now the island was not at the frontier of the delta anymore. • The tidal difference was higher, and the inland was easier to be flooded.	• A larger dike ring emerged. Canals appeared as a new water infrastructure. • A better-connected road network was established within the dike ring.	• New settlement emerged along the new linear infrastructure: road & canals. • Regional roads were developed. While not all of them attracted enough urbanization.	1950
• The island was facing increasing tidal difference and land subsidence.	• Stabilized dike ring encouraged canal network development. • Smaller creeks merged into the canal network or disappeared. • The water cycle were more depended on the artificial water management system. • The water cycle within the islands were more depended on the artificial water management system.	• Large area of farmland was urbanized and industrialized. • Landscape and infrastructure became irrelevant to the urbanization pattern. • Urban sprawl in lowland, leading to serious pluvial flooding.	2015

LOCAL SCALE



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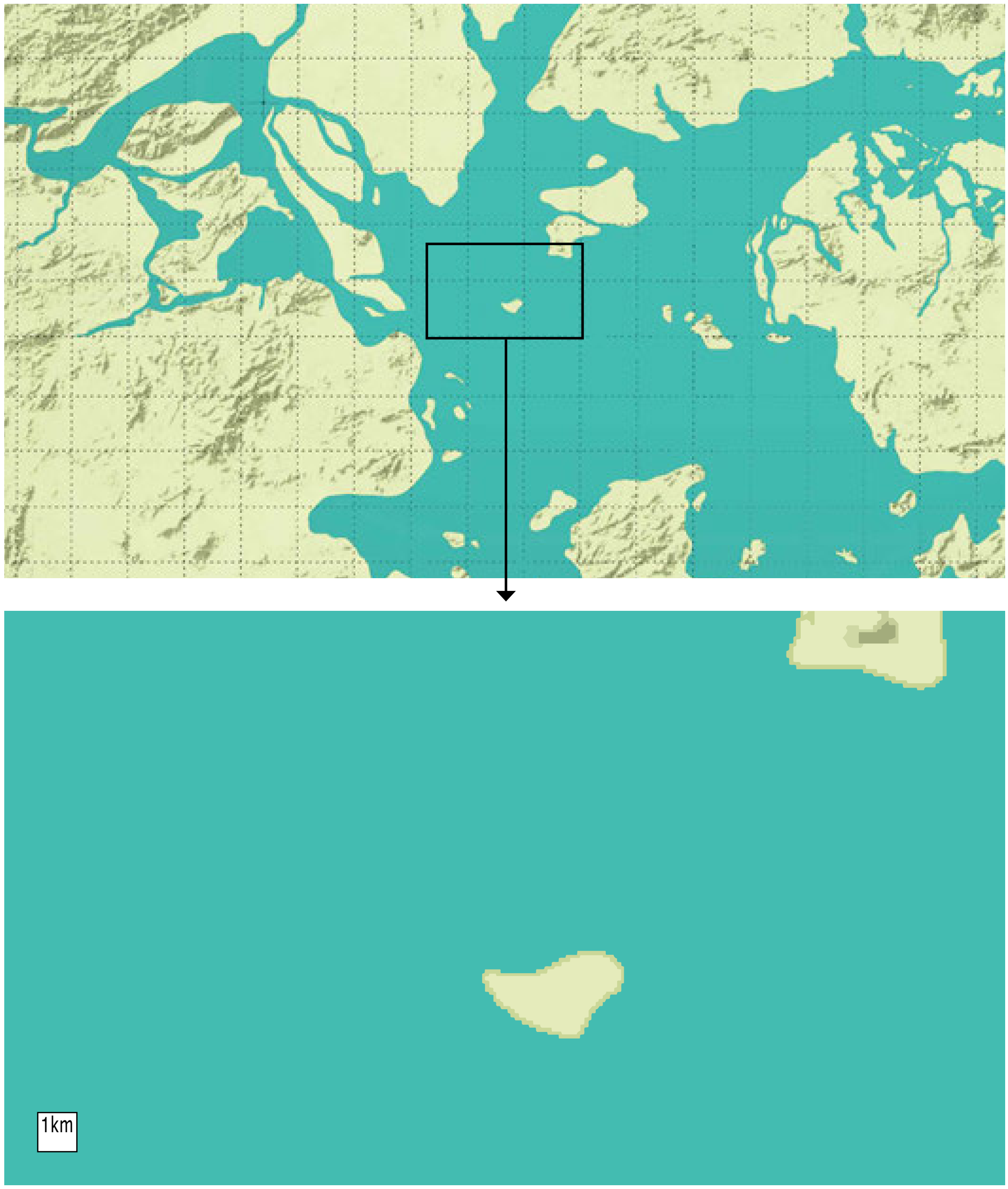
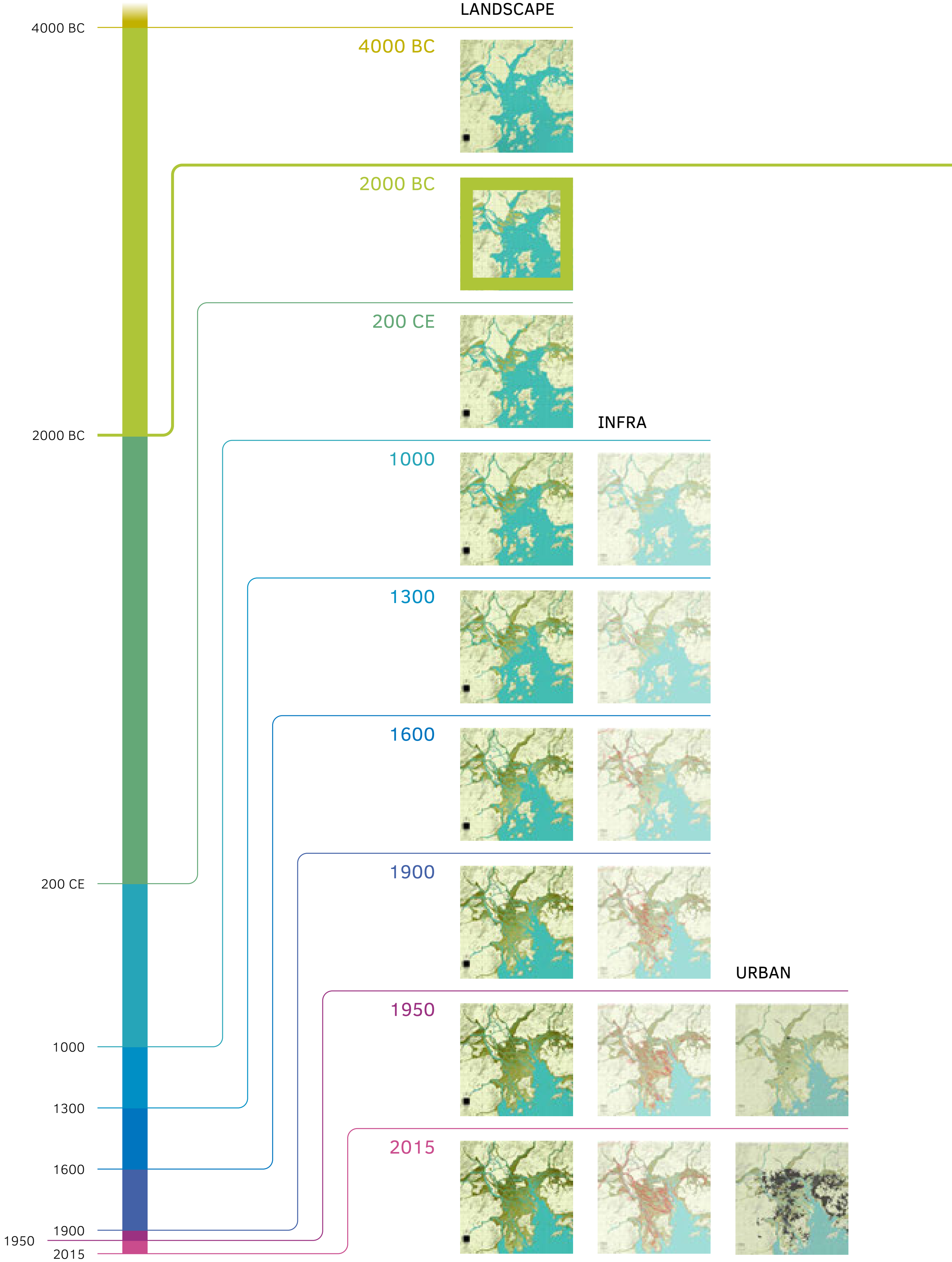
4000 BC



A finer resolution was applied in the middle of the bay. More local maps and evidence were studied in the smaller scale. Two levels of link were established by comparing and linking between the local scale and the delta scale. First, the spatial findings in smaller scale had resulted in adjustment of the maps in larger scale. Second, the delta scale helped to explain some spatial phenomenon that could not be explained in the local scale.

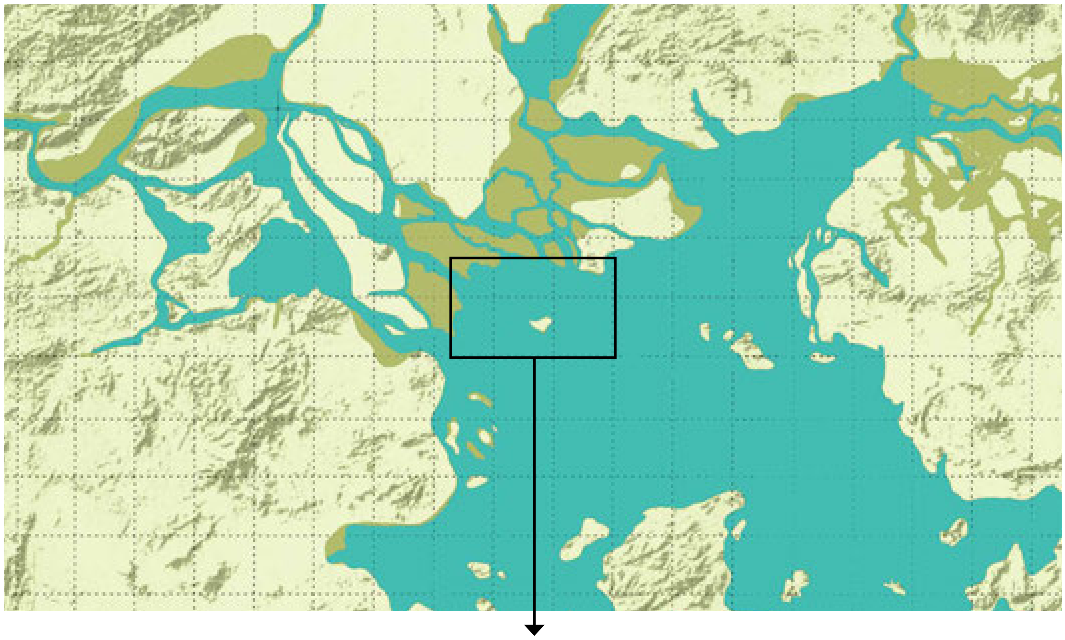
No additional information in the local scale could be found to contribute to the maps. The Shunde District was an island surrounded by the sea.

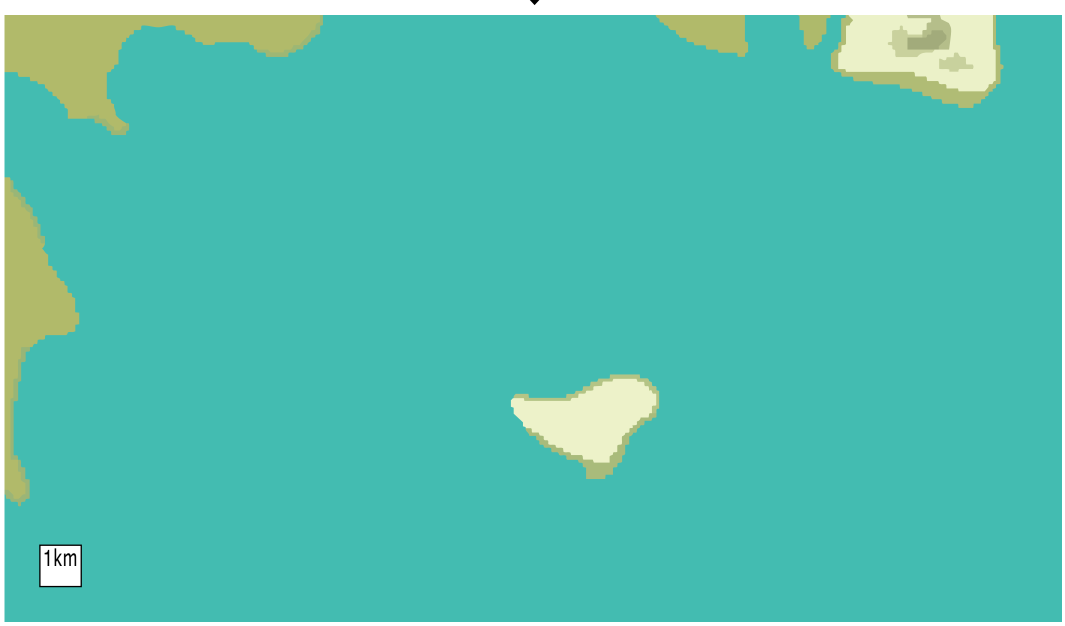
LOCAL SCALE



TOC

2000 BC

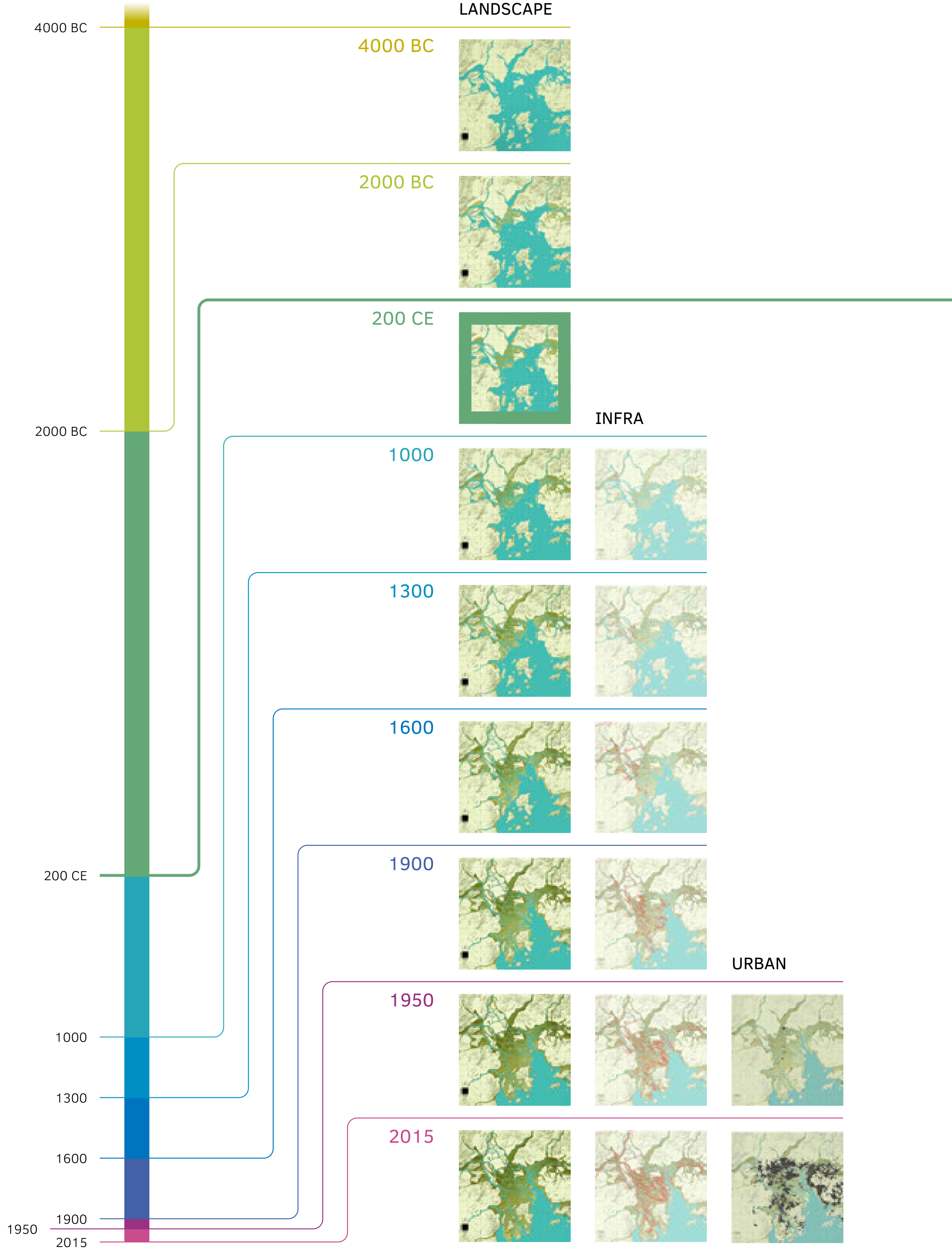




The island started to get extended in its shore. In the west and north, the river estuaries developed into the frame of the local scale.

TOC

LOCAL SCALE



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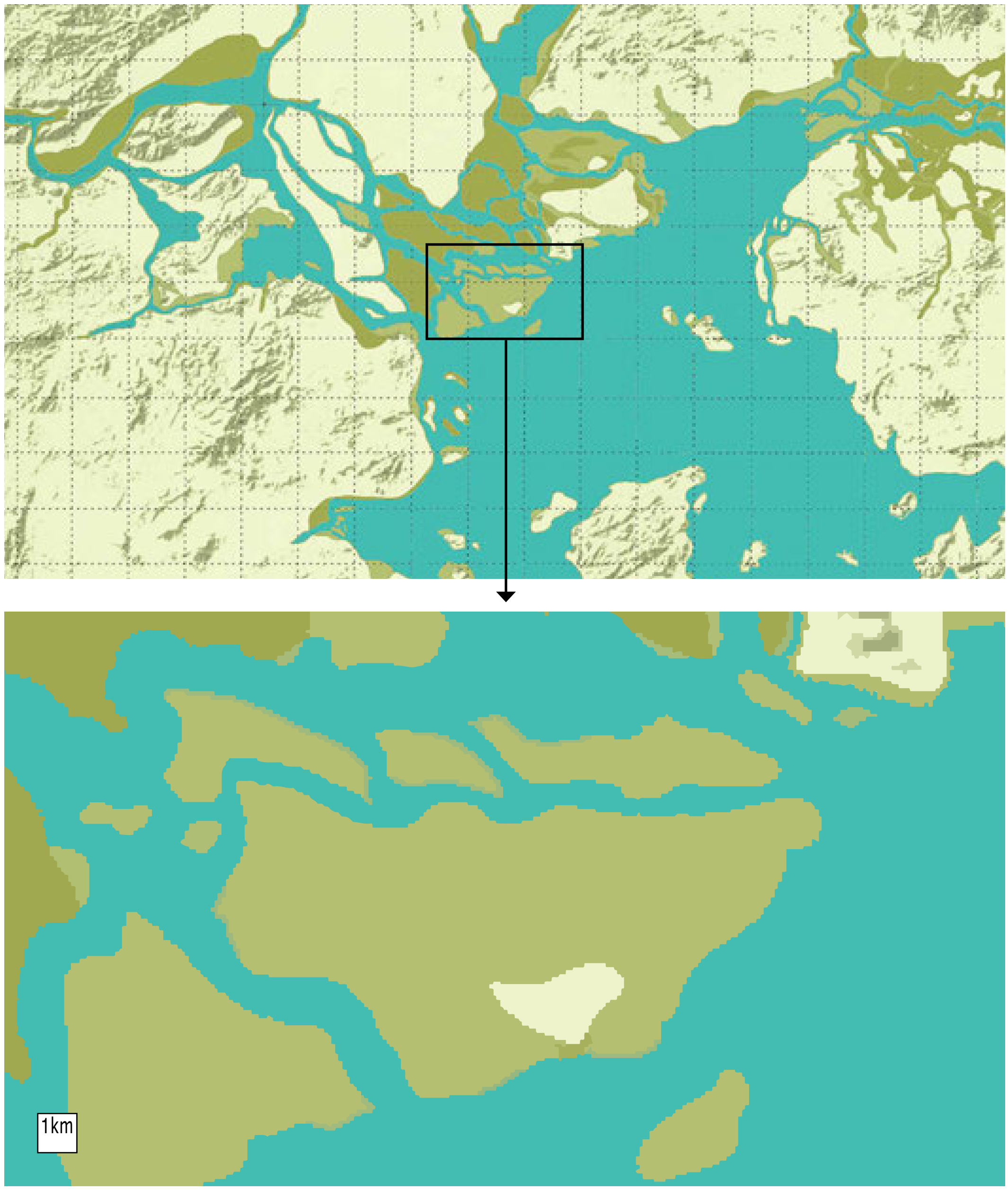
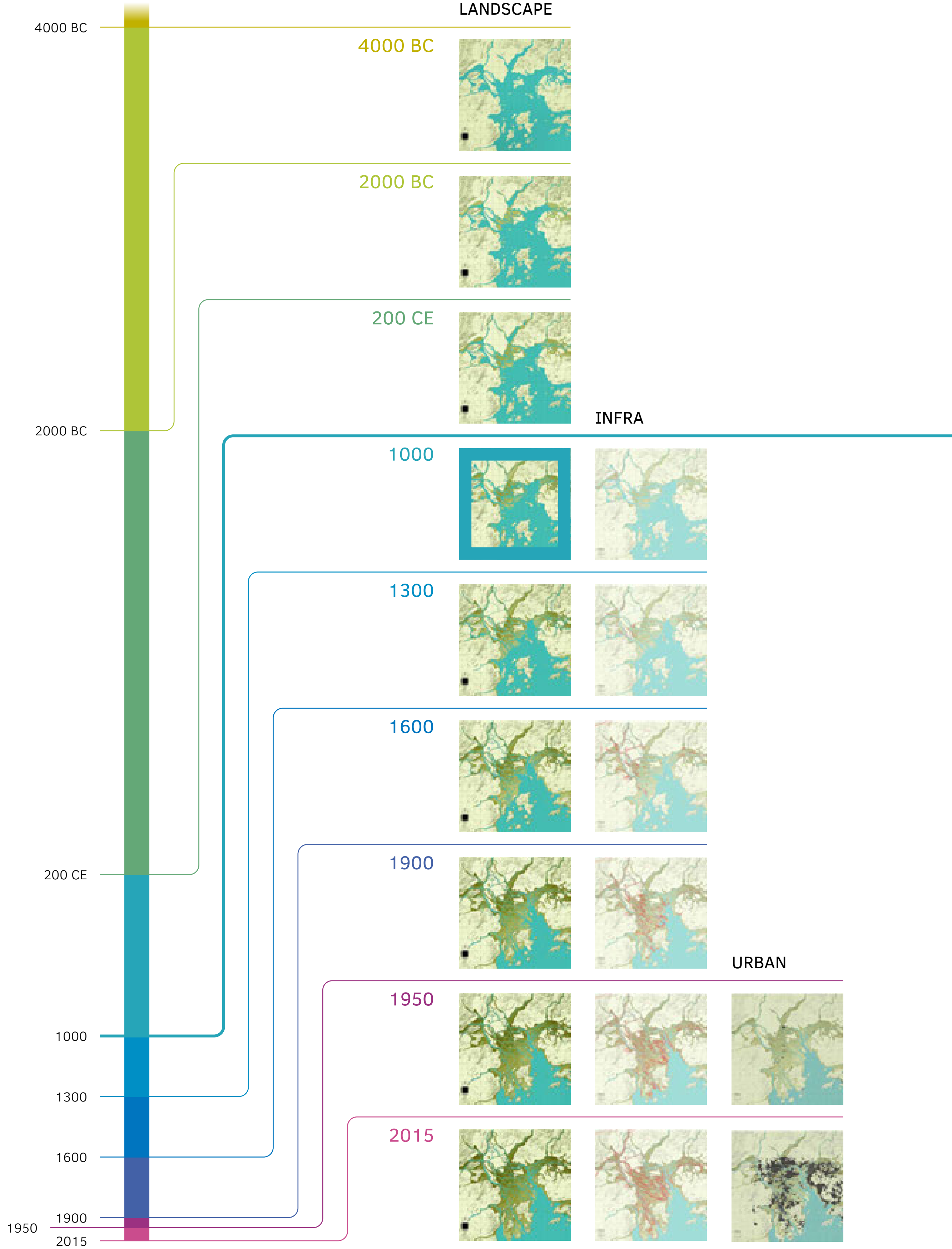
200 CE



The frontier of the delta occupied the surrounding sea of the island. The water environment changed from salt water to freshwater.

LOCAL SCALE



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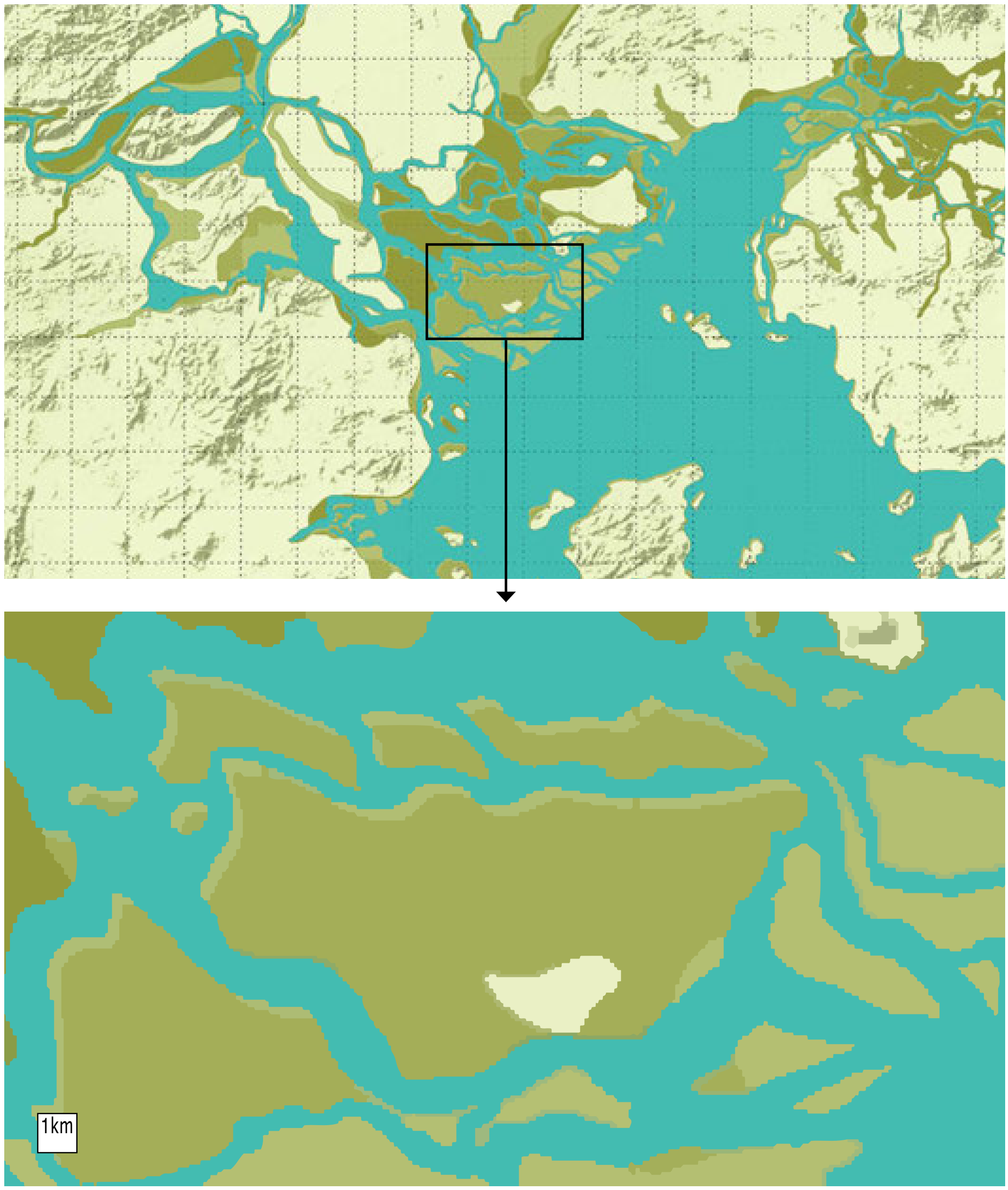
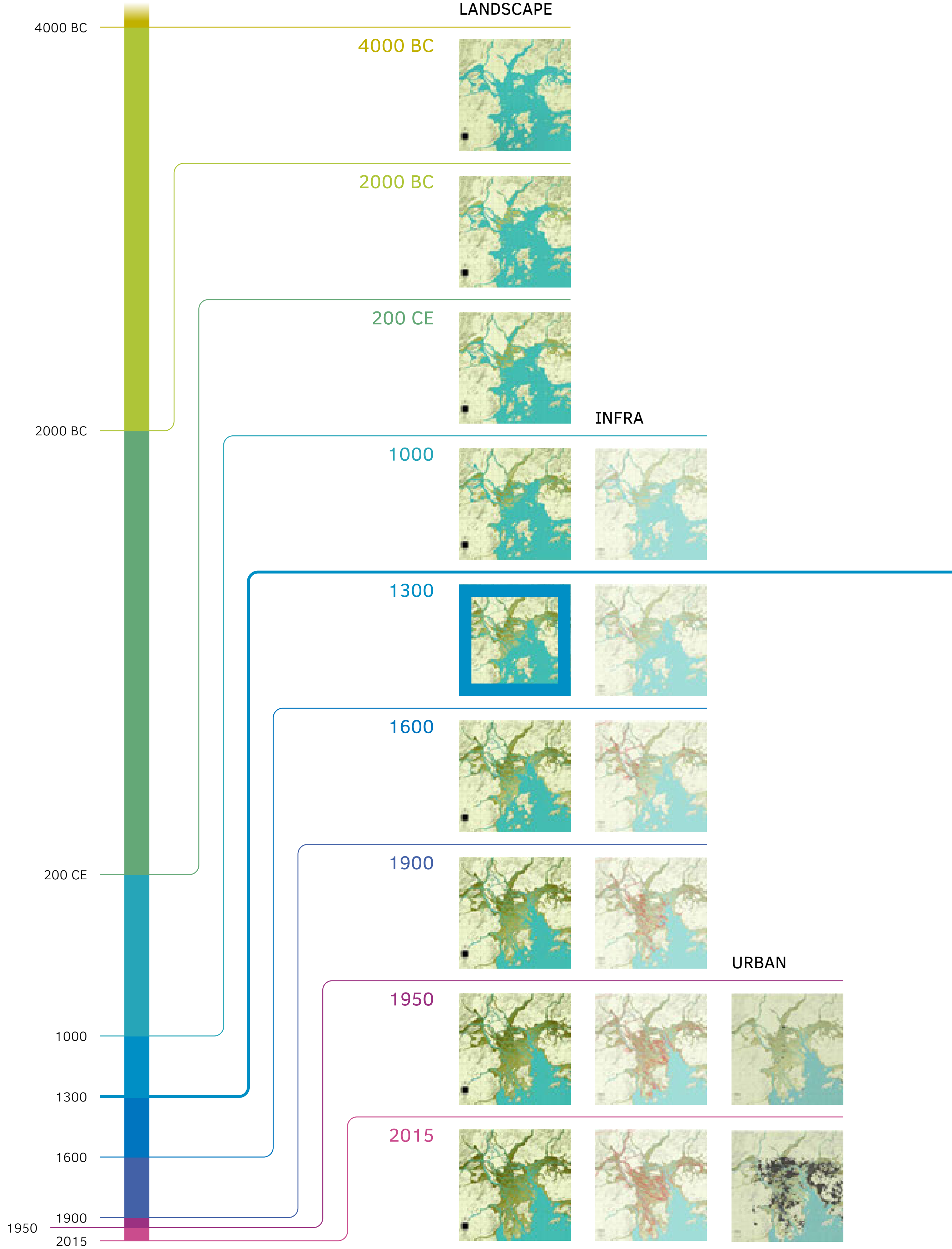
1000



The frontier of the delta developed further towards southeast. The water environment of the local scale became more stable. Because of the land's subsidence, the inner older land (dark green) became lower than the coast (light green).

LOCAL SCALE



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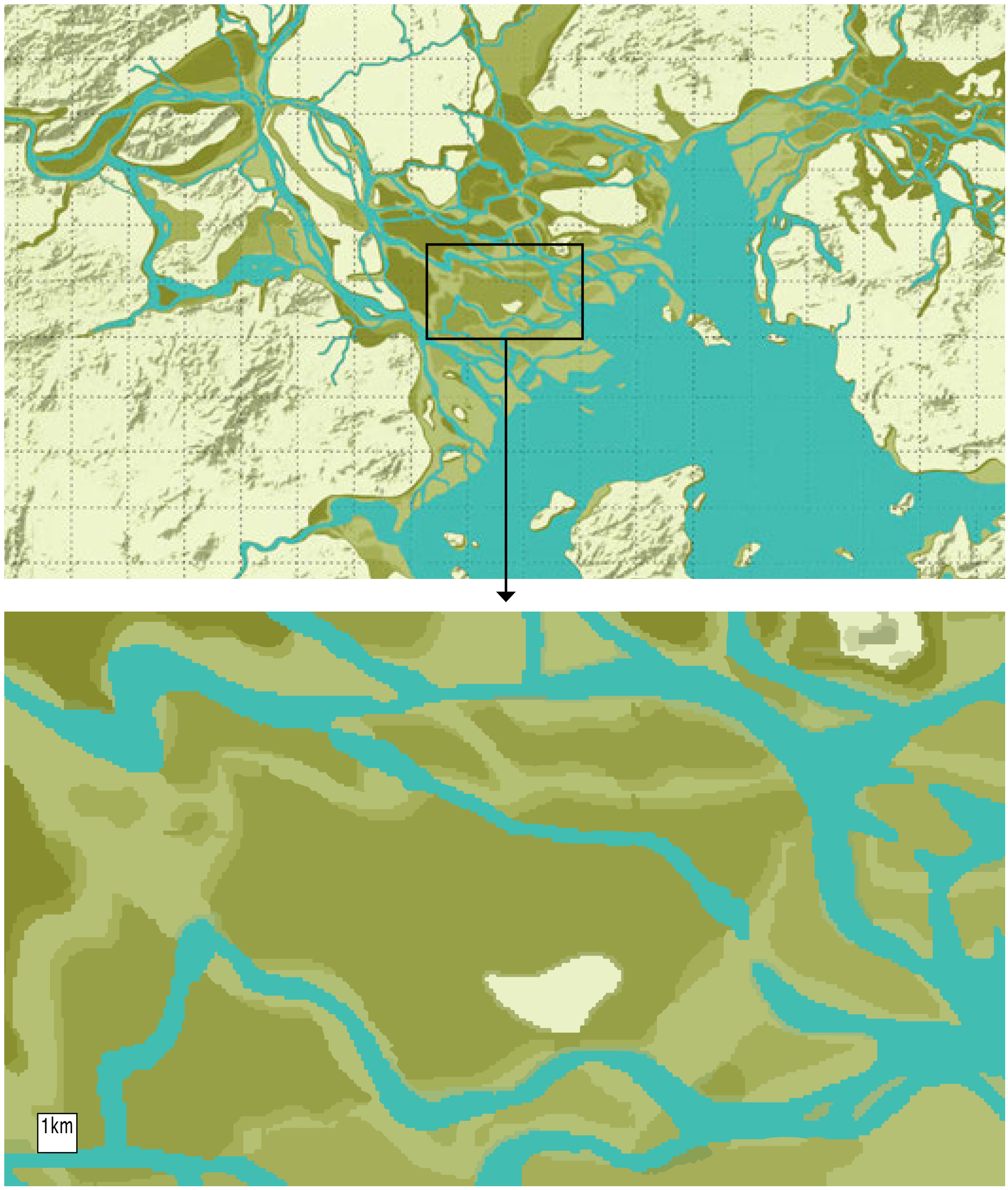
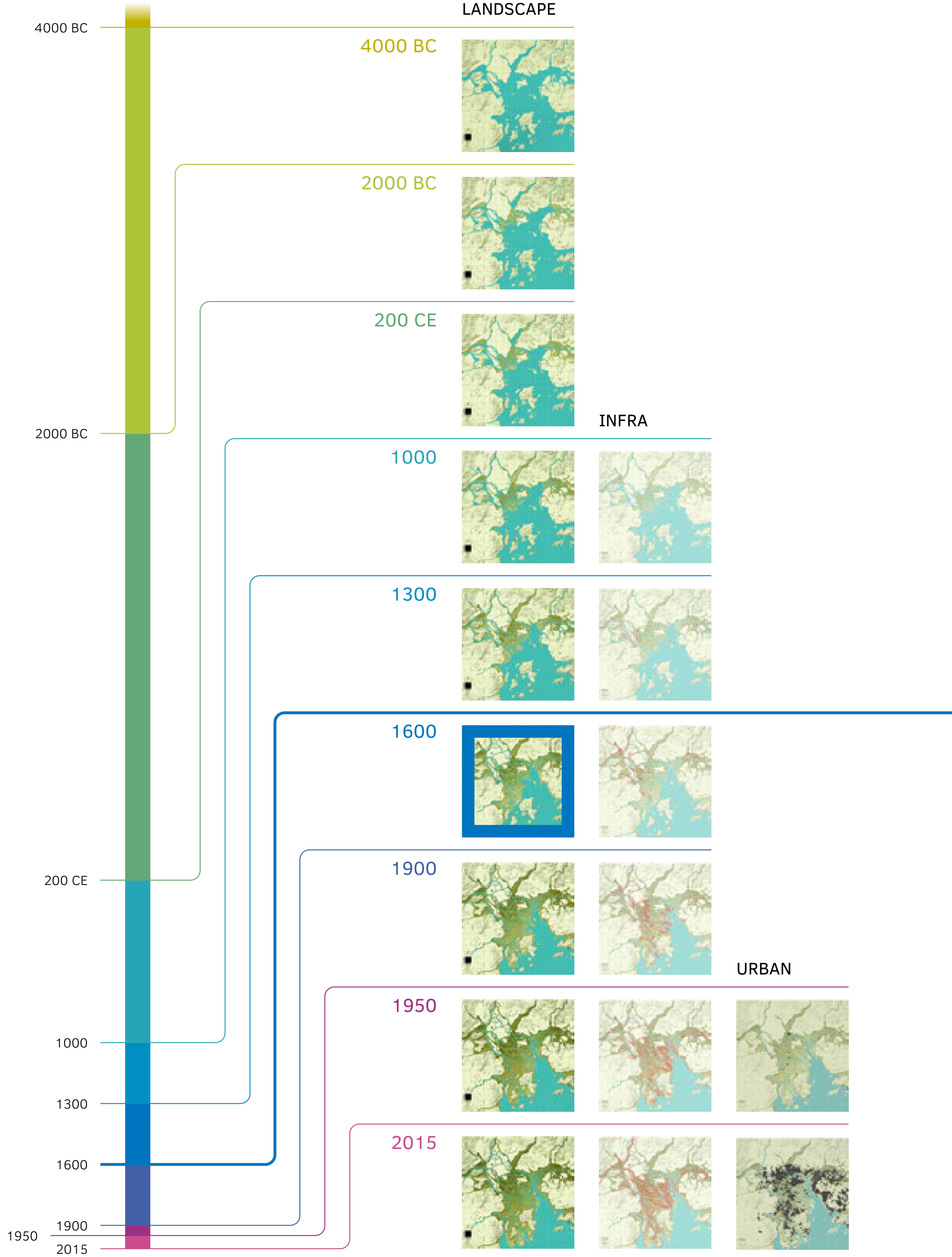
1300



The mainland was connected to the western island as the river meandered frequently at this period. The east part of the main islands got cut through by a new river that changed its course through the older and lower part of the area. In the surrounding, smaller islands were connected in both northeast and southwest.

LOCAL SCALE



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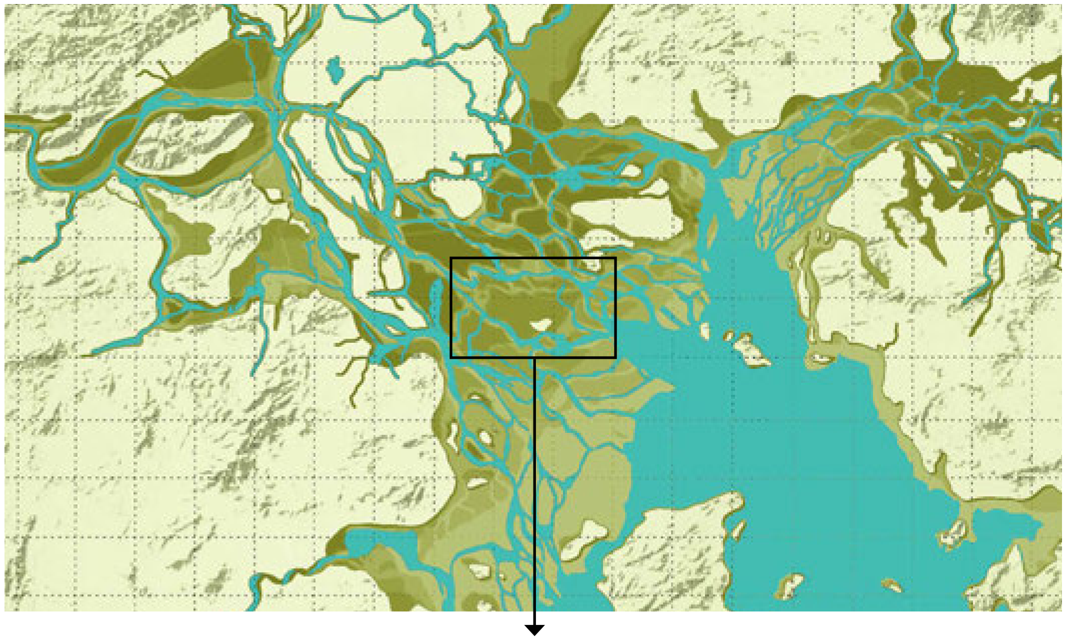
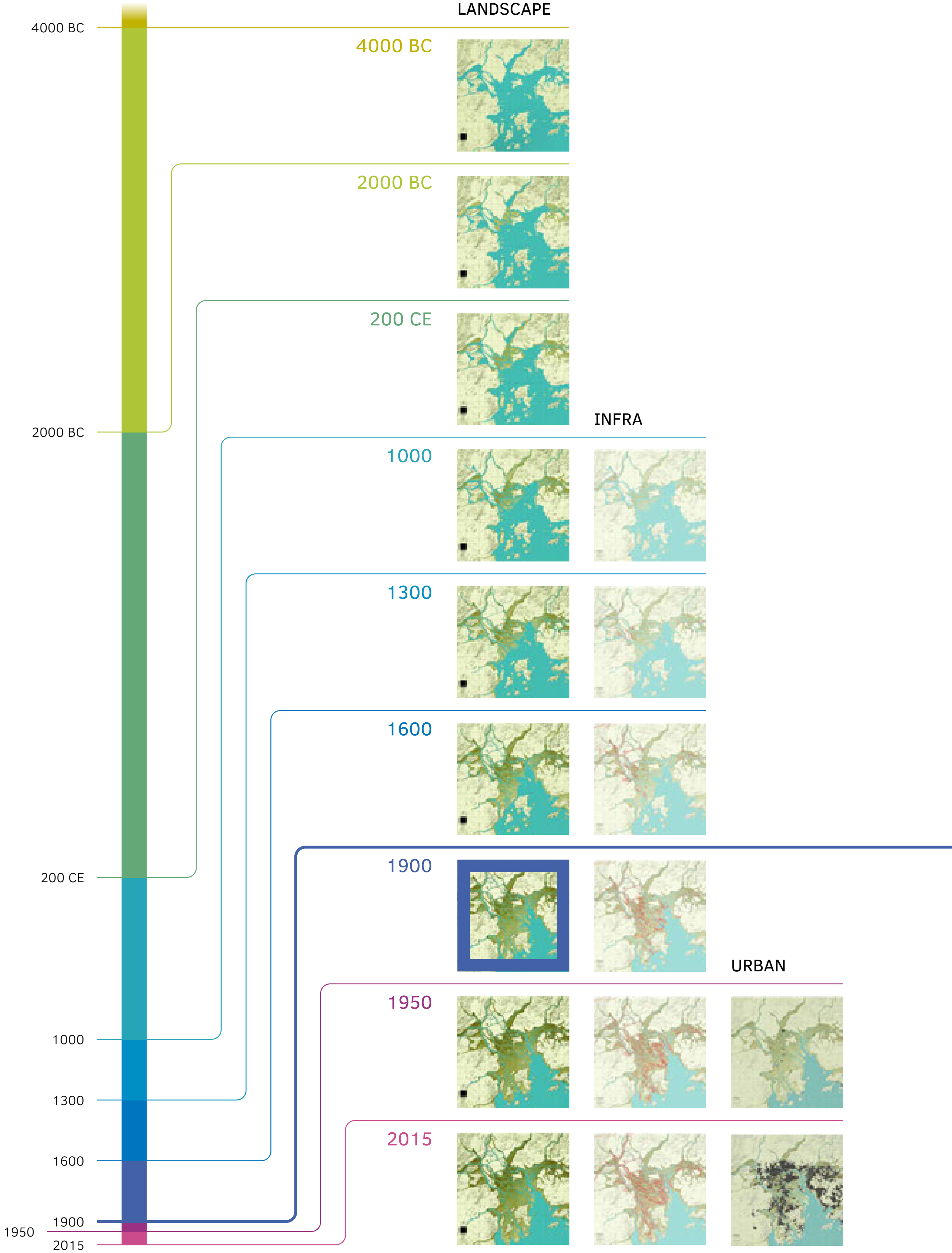
1600



River meandered frequently in this period. The main island became larger because of the merge to the north. Higher elevation existed in the northern part of the main island, while the southern part was lower.

LOCAL SCALE



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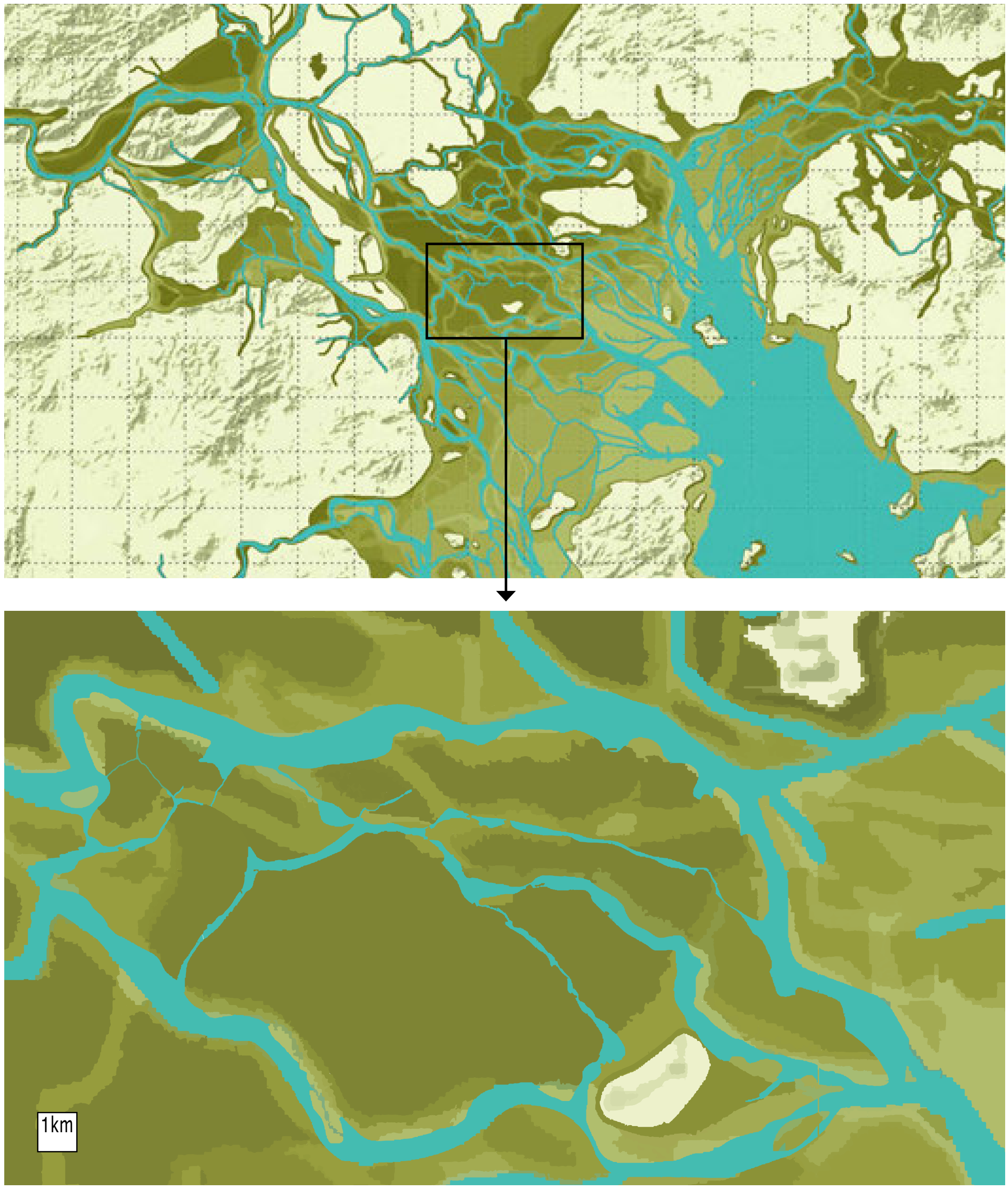
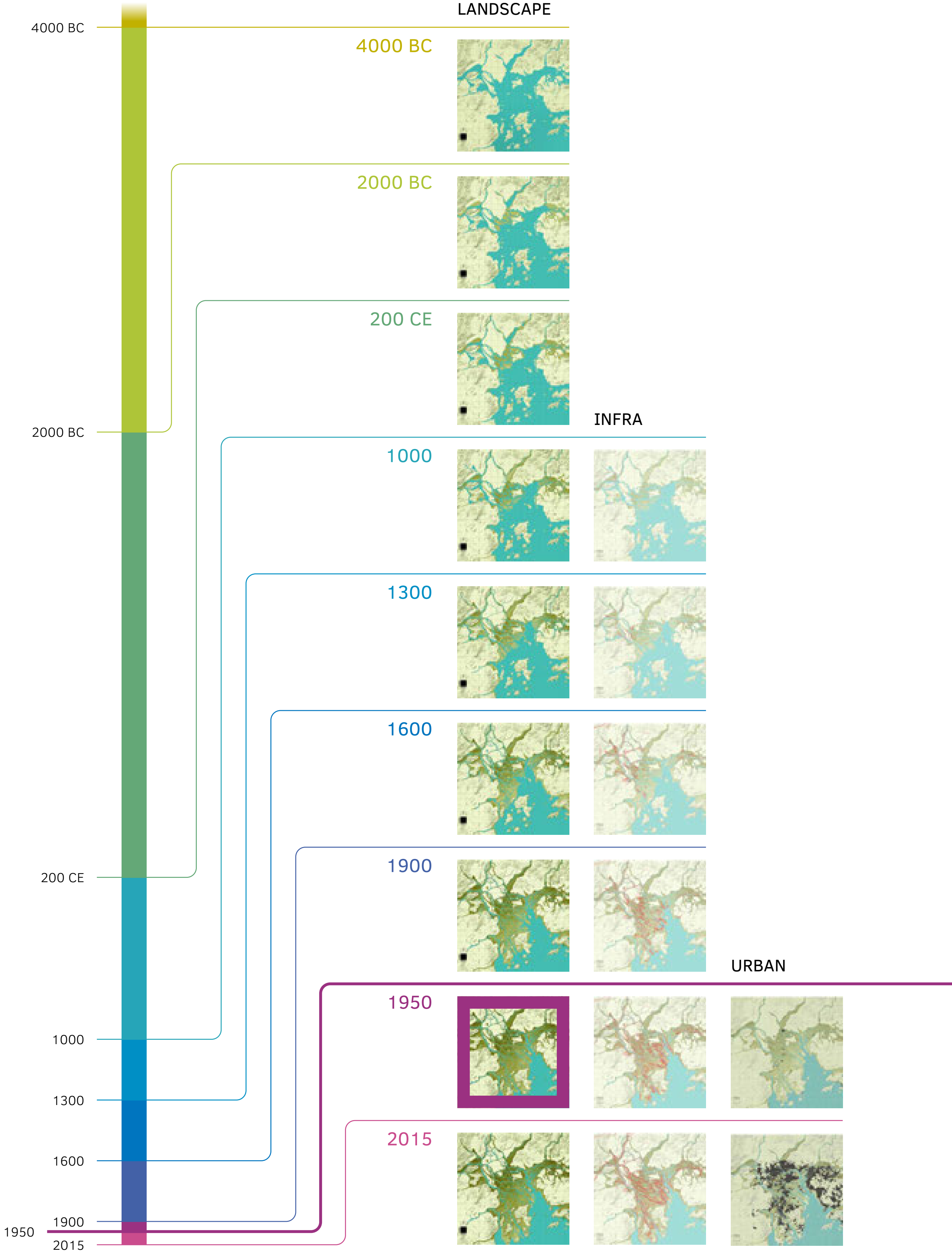
1900



In combination with the local maps, a more precise landscape layer in the lower scale was developed. The north part of the main island has been cut through by rivers. The lower inland was opened to water in the north. On the contrary, the south edge of the island was protected by elevated levees. The relief of the landscape lead to the mapping of the settlement and the dike.

LOCAL SCALE

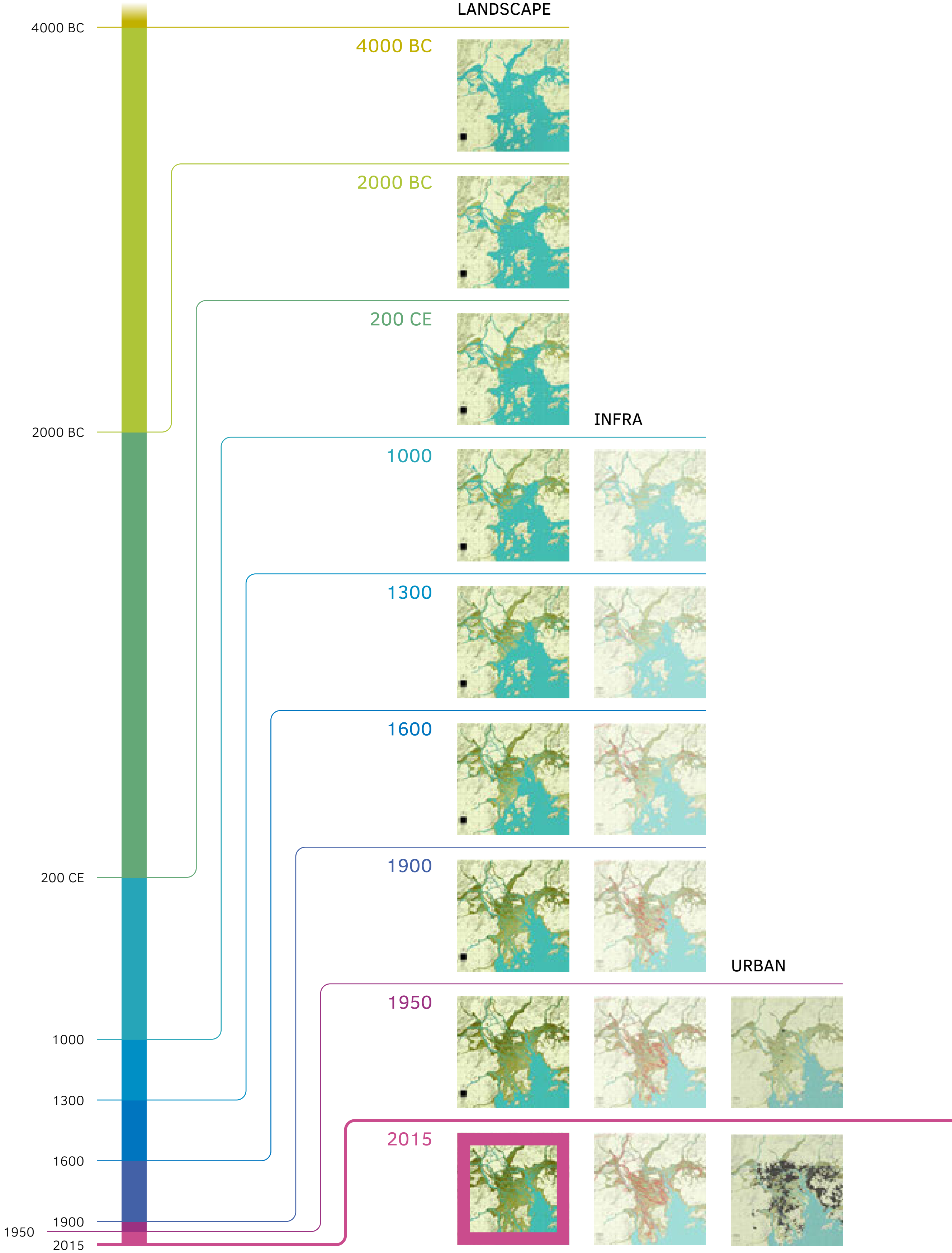


TOC

1950

The main island was connected towards the west. As the delta continued to develop towards southeast, now the island was not at the frontier of the delta anymore. The tidal difference was higher; thus, the inlands was easier to be flooded.

LOCAL SCALE



LANDSCAPE
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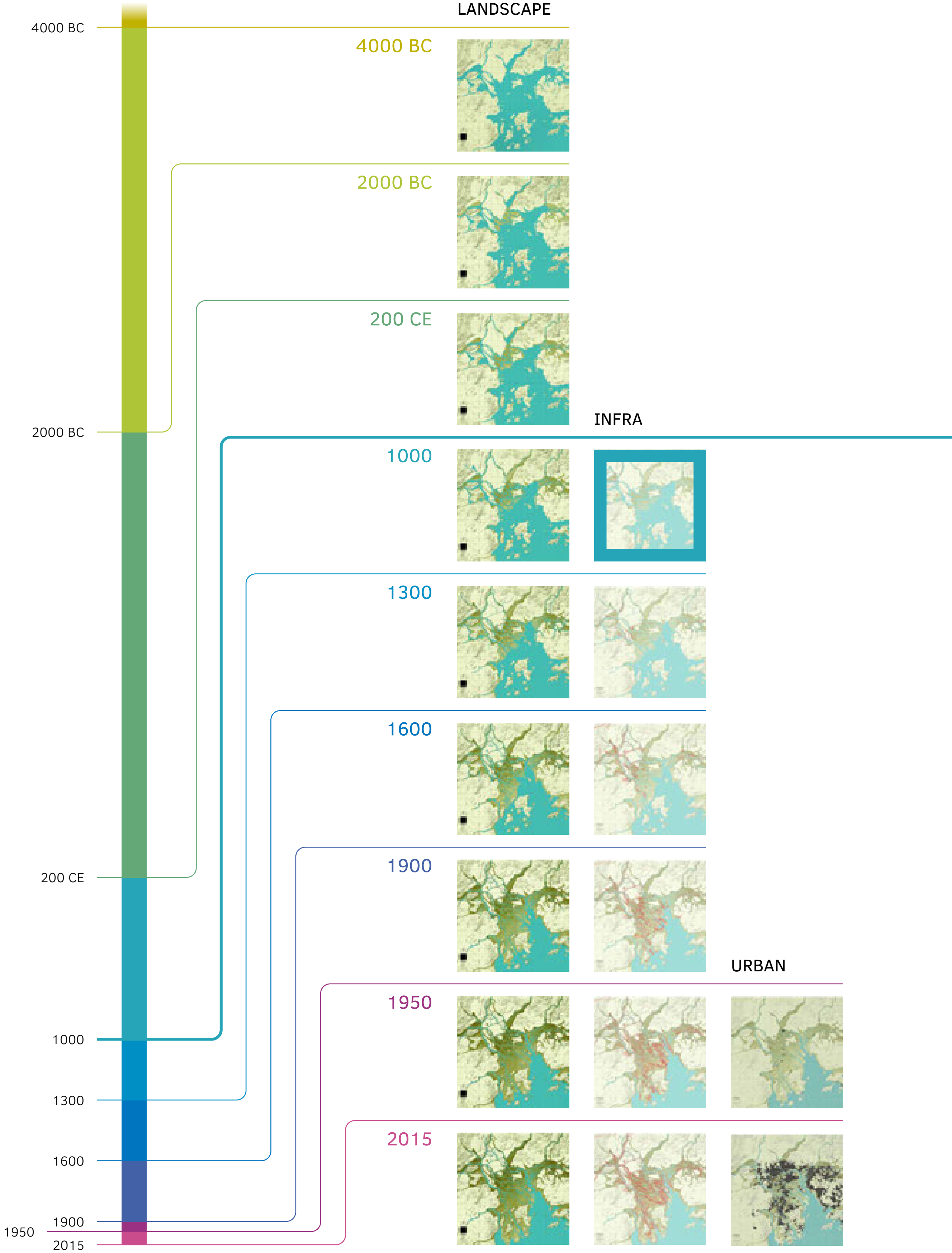
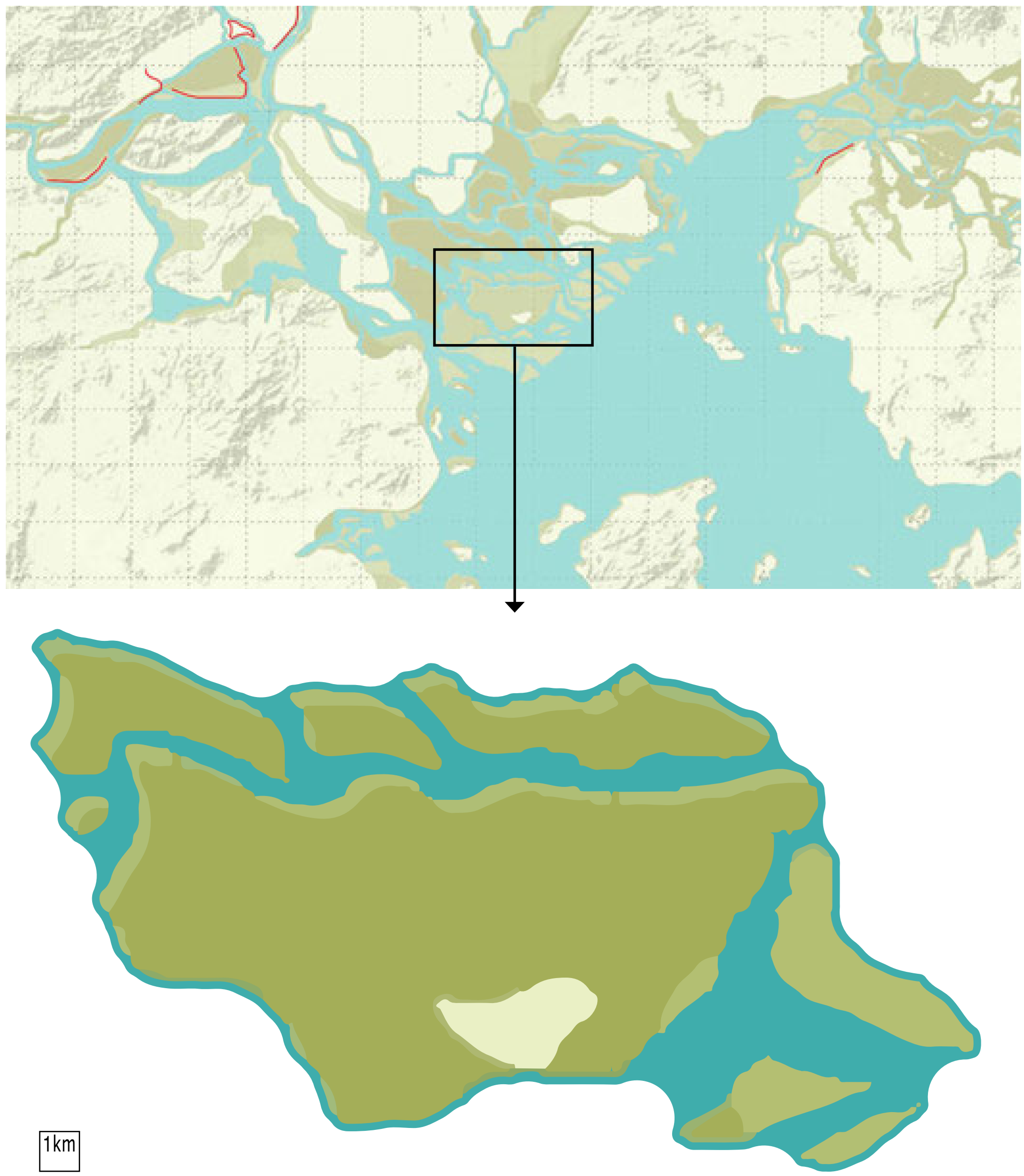
The island experienced an increasing tidal difference and land subsidence. Both factors had led to higher flood risk.

LOCAL SCALE



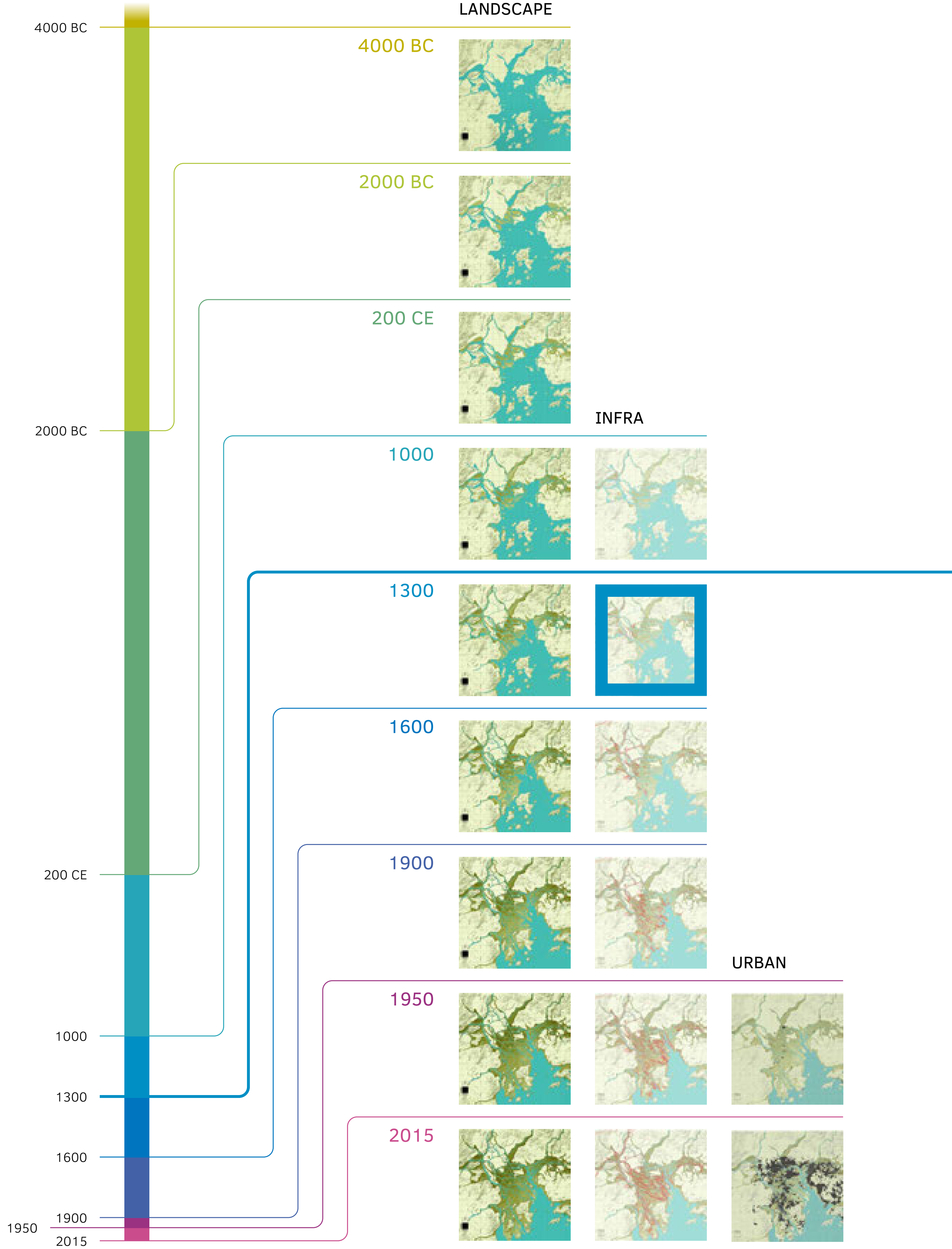
TOC

1000



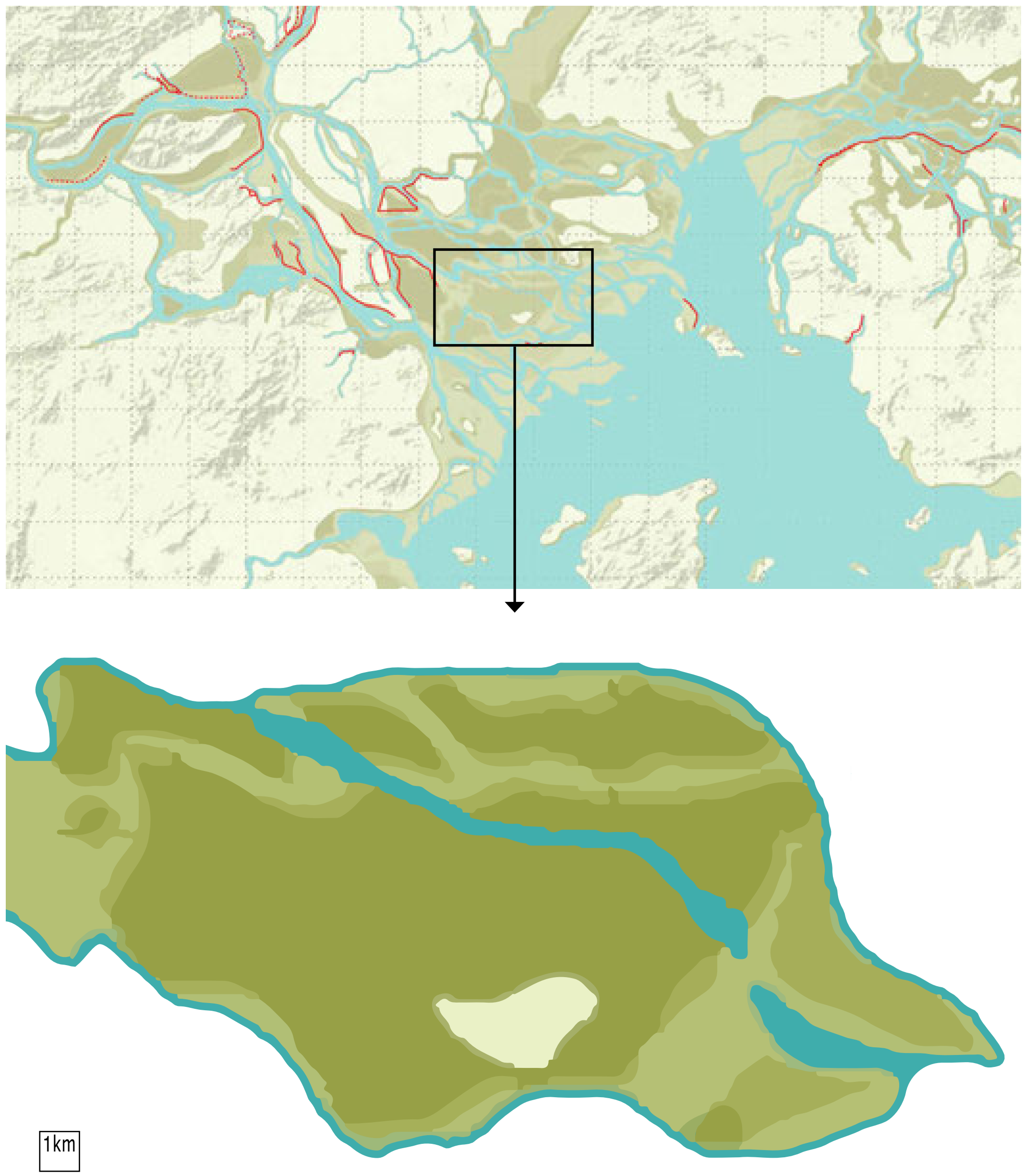
At this period there was no dike build in the islands. A few people started to migrated to the surrounding islands (Li. et al 2001). Because of the natural levees round the coast, flood was not a serious issue at the time.

LOCAL SCALE



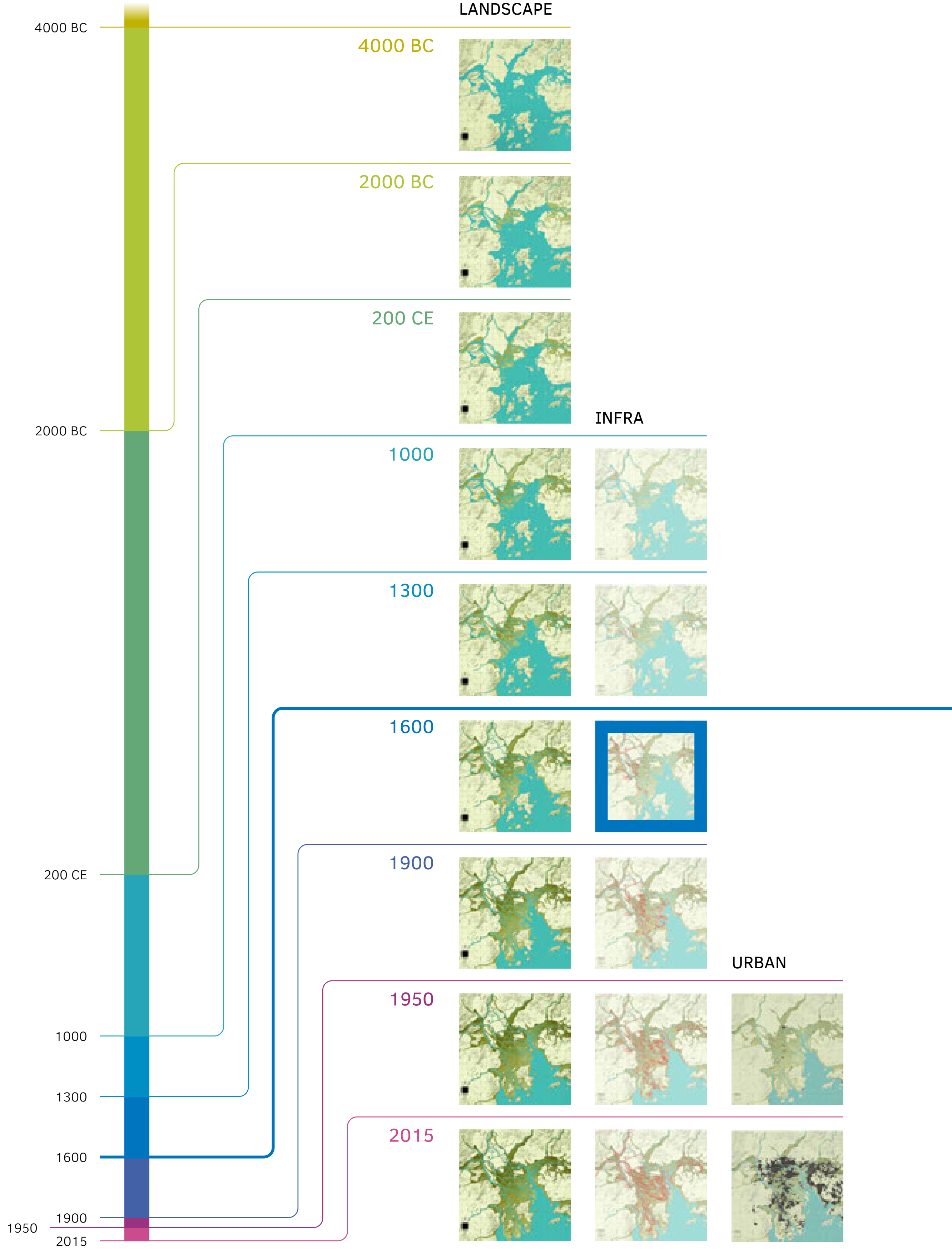
TOC

1300



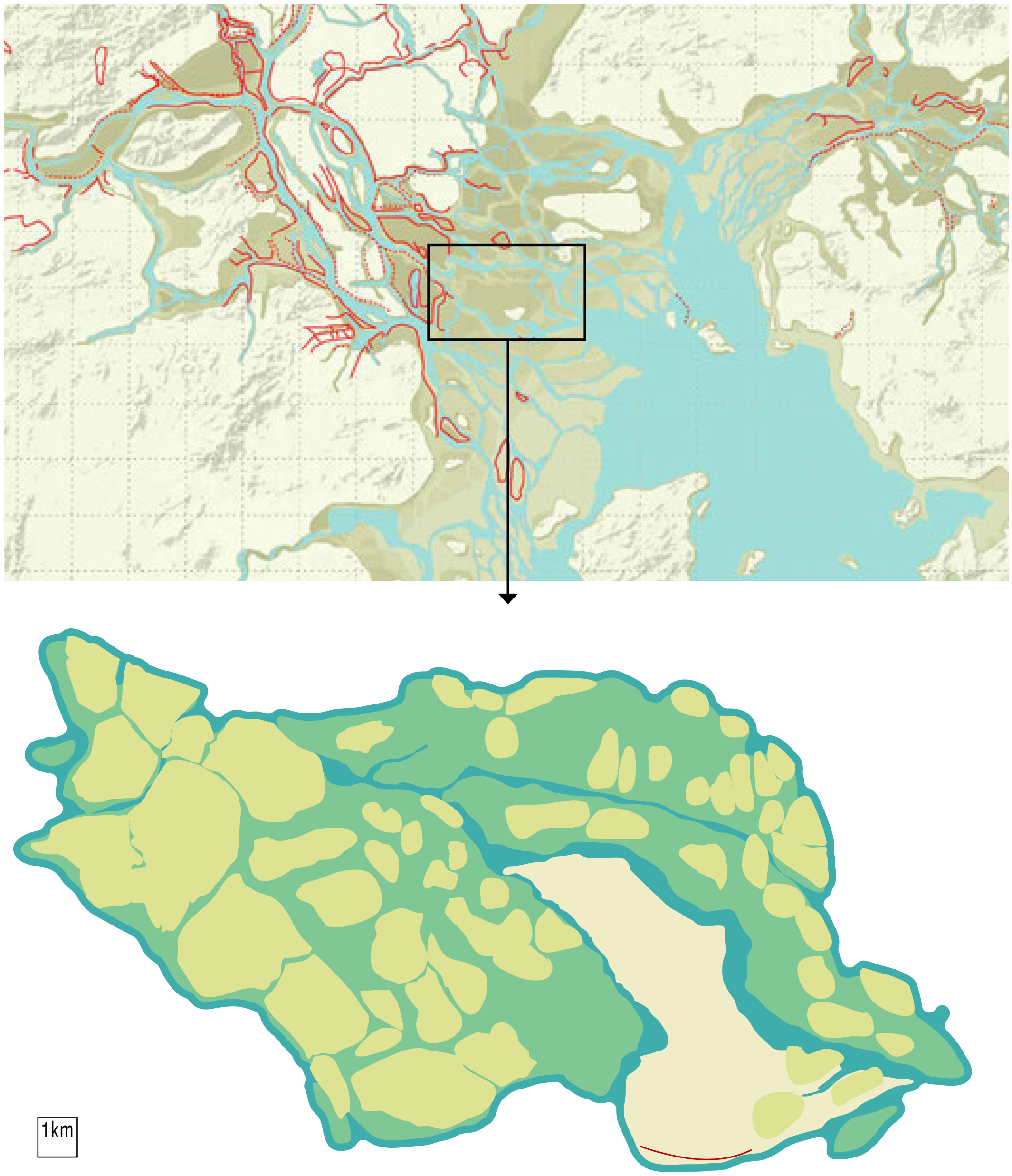
No dike was built in the islands at this time.

LOCAL SCALE



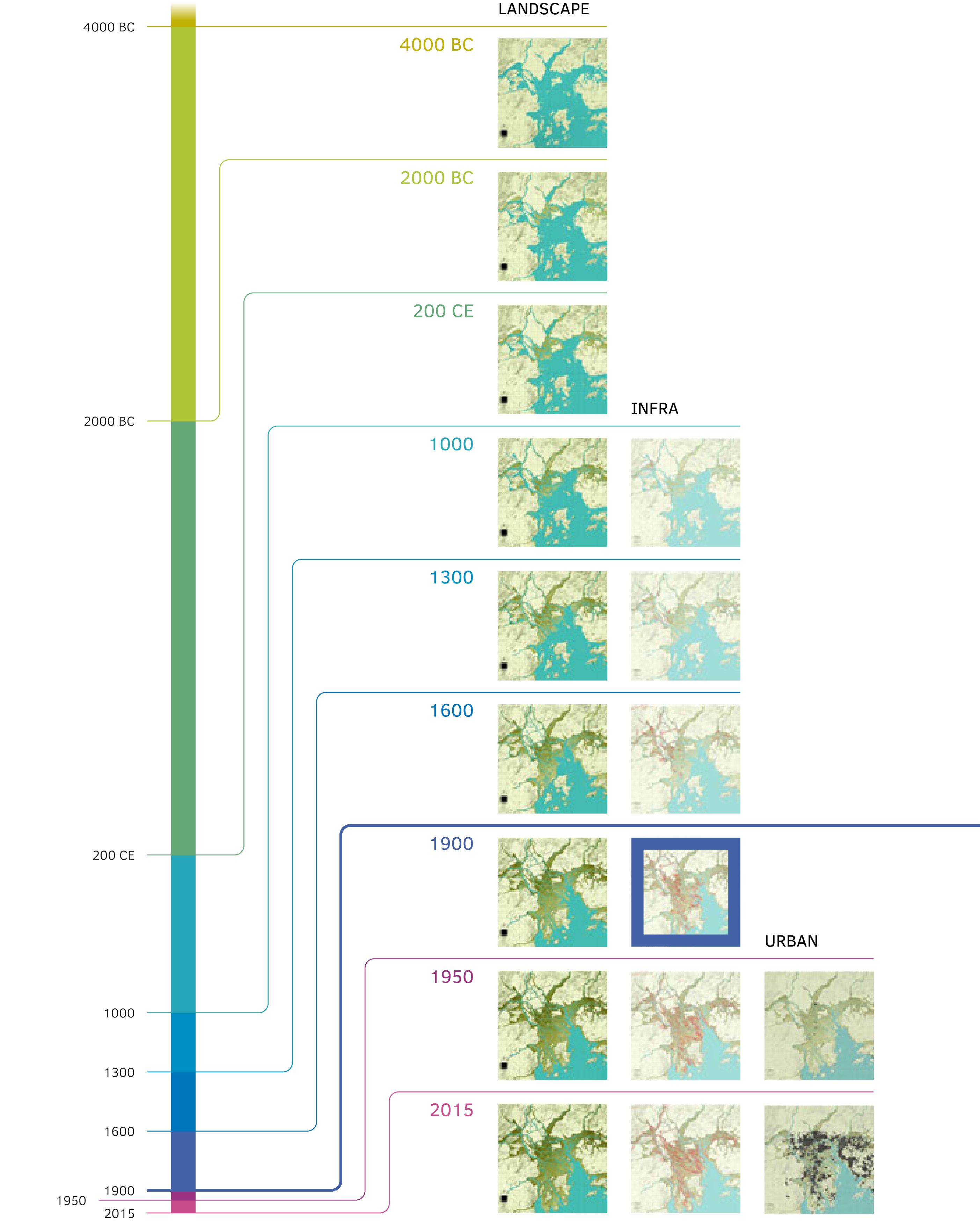
TOC

1600



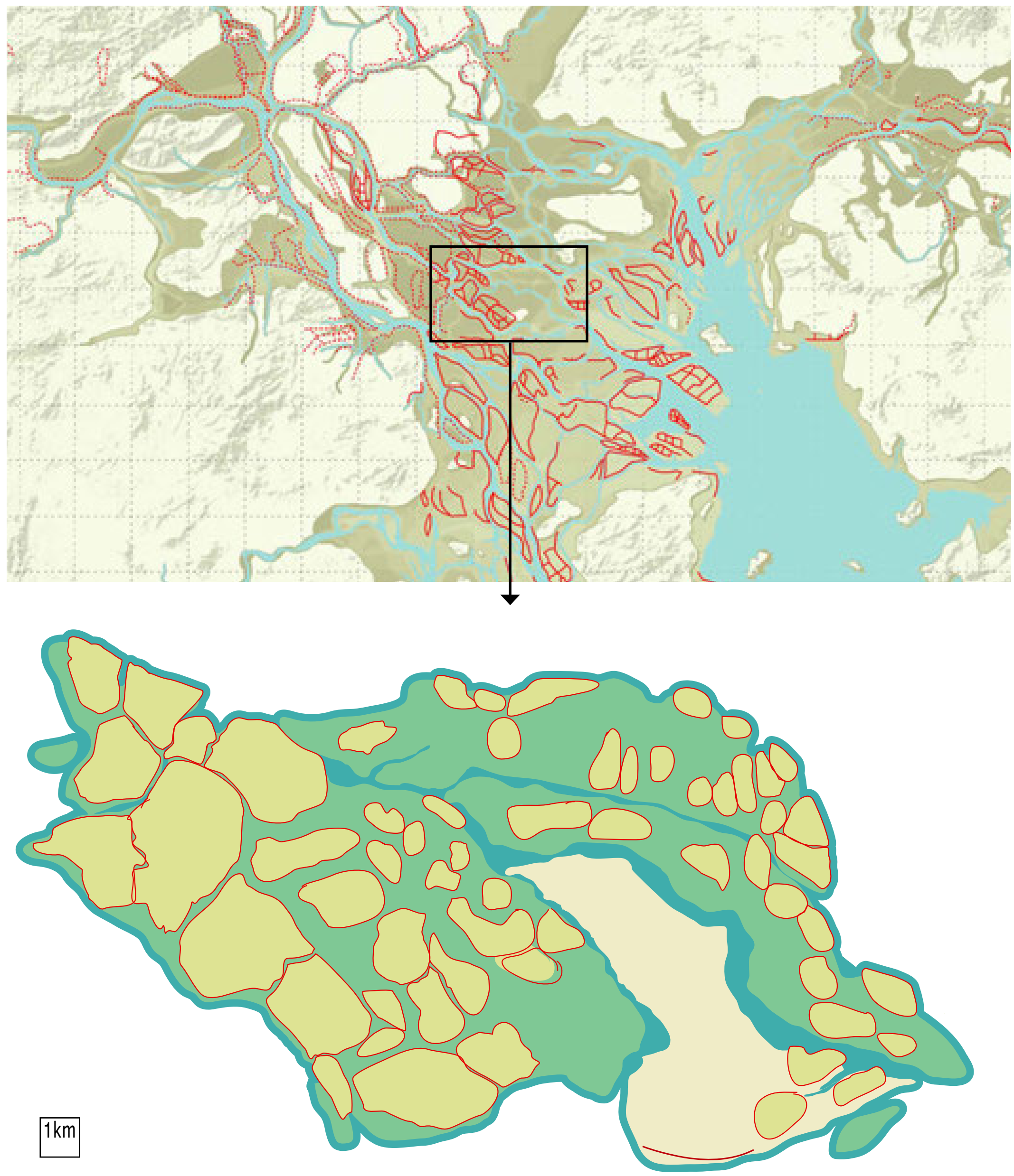
The first dike was built in the island. The dike was built along the coast in the southwest of the island that connects to the hill, which was the highest island in the area. The dike indicated one or more important settlements in this island. It also showed an increase of flood risk, which was cased by the development of the delta to the southeast.

LOCAL SCALE



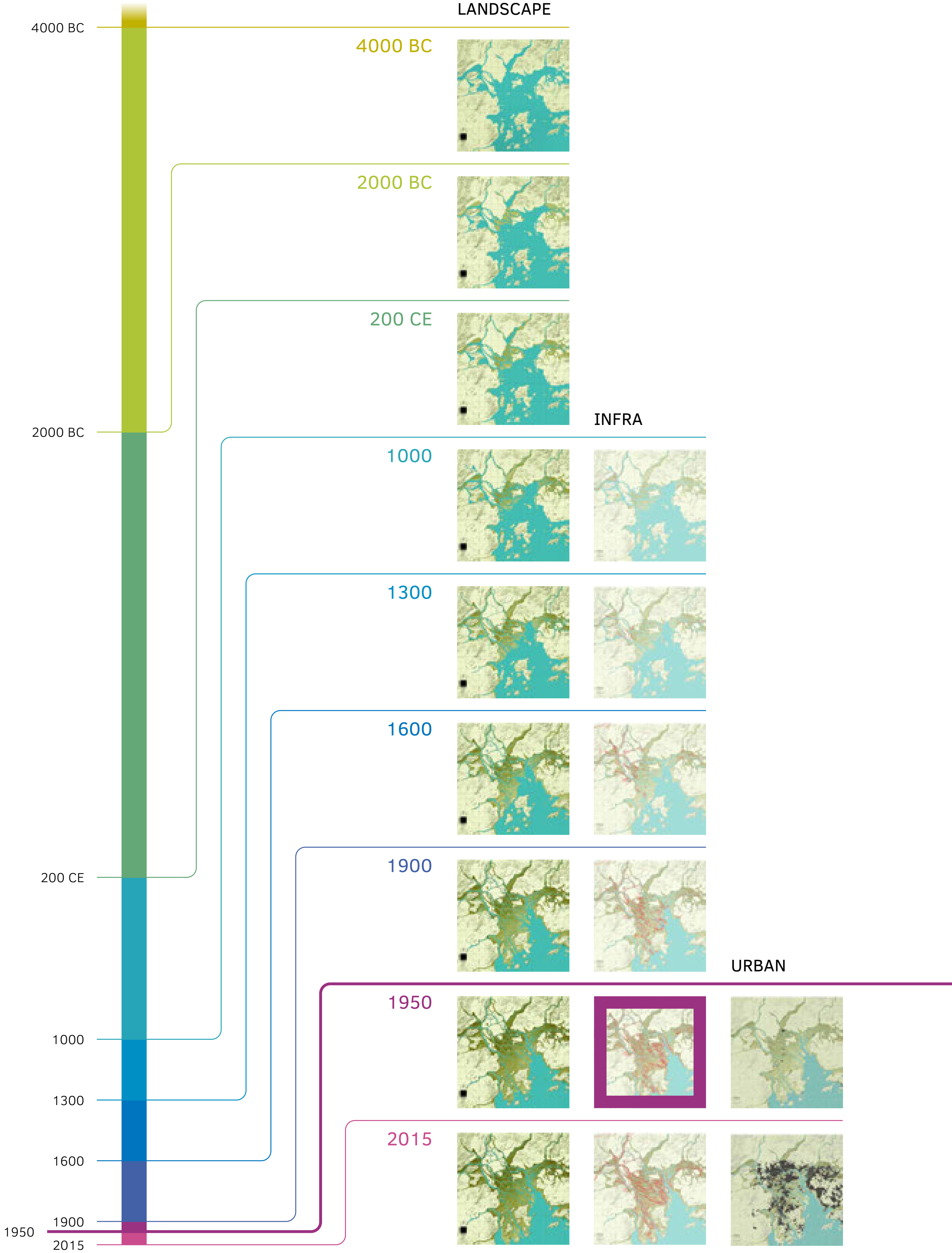
TOC

1900



Dike rings appeared in large area of the islands. It indicated a sharp increase of flood risk in local scale. The cause of the increasing flood risk could be identified from the delta scale map (top). Dike construction took place in all the estuaries that connected with the studied island. The heavy reclamation towards the sea and the blockage of the waterway in the delta frontier resulted in the increase of the height difference of the water around the studied island. The island therefore required additional flood defense in the form of scattered dike rings.

LOCAL SCALE



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LANDSCAPE
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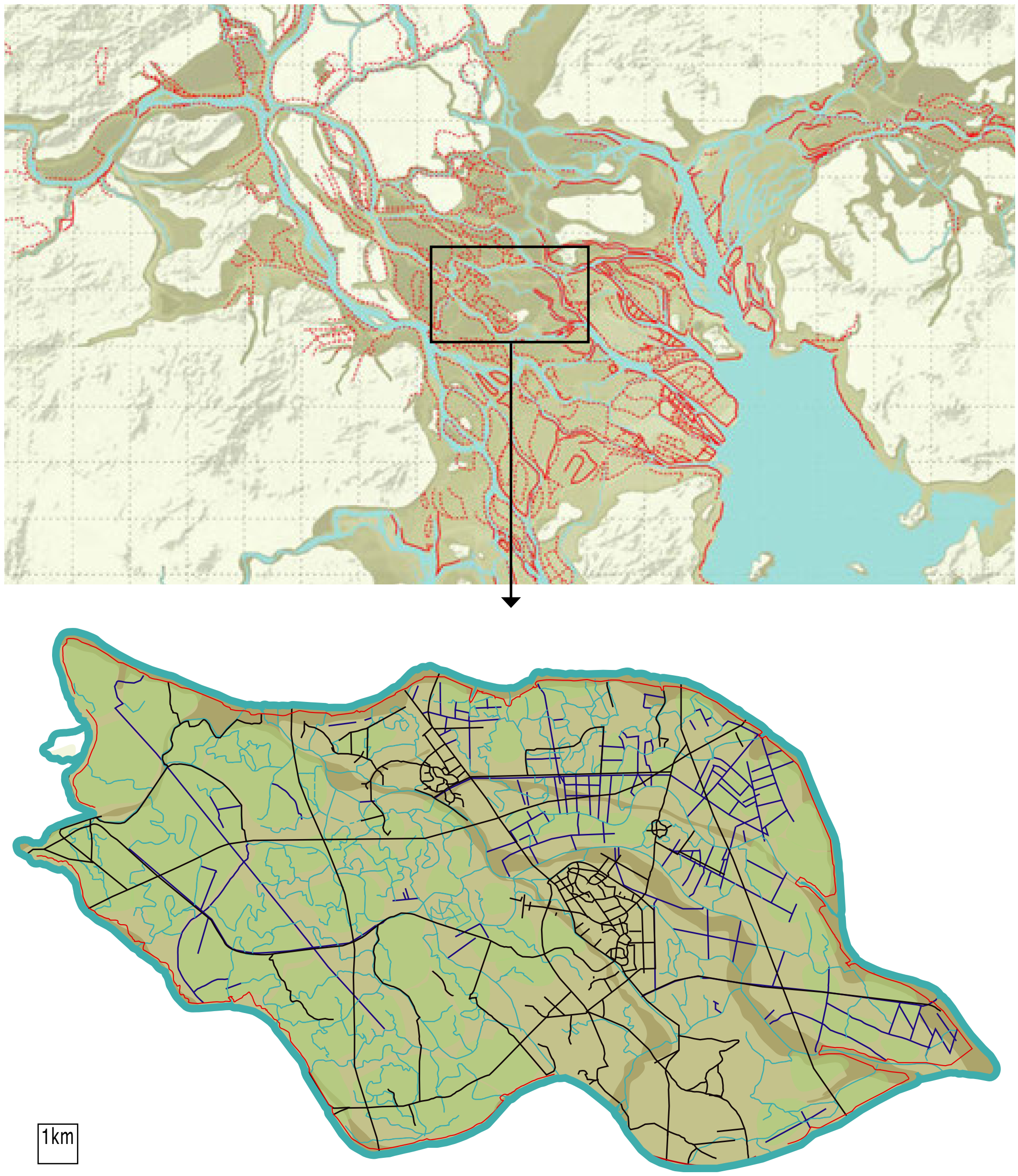
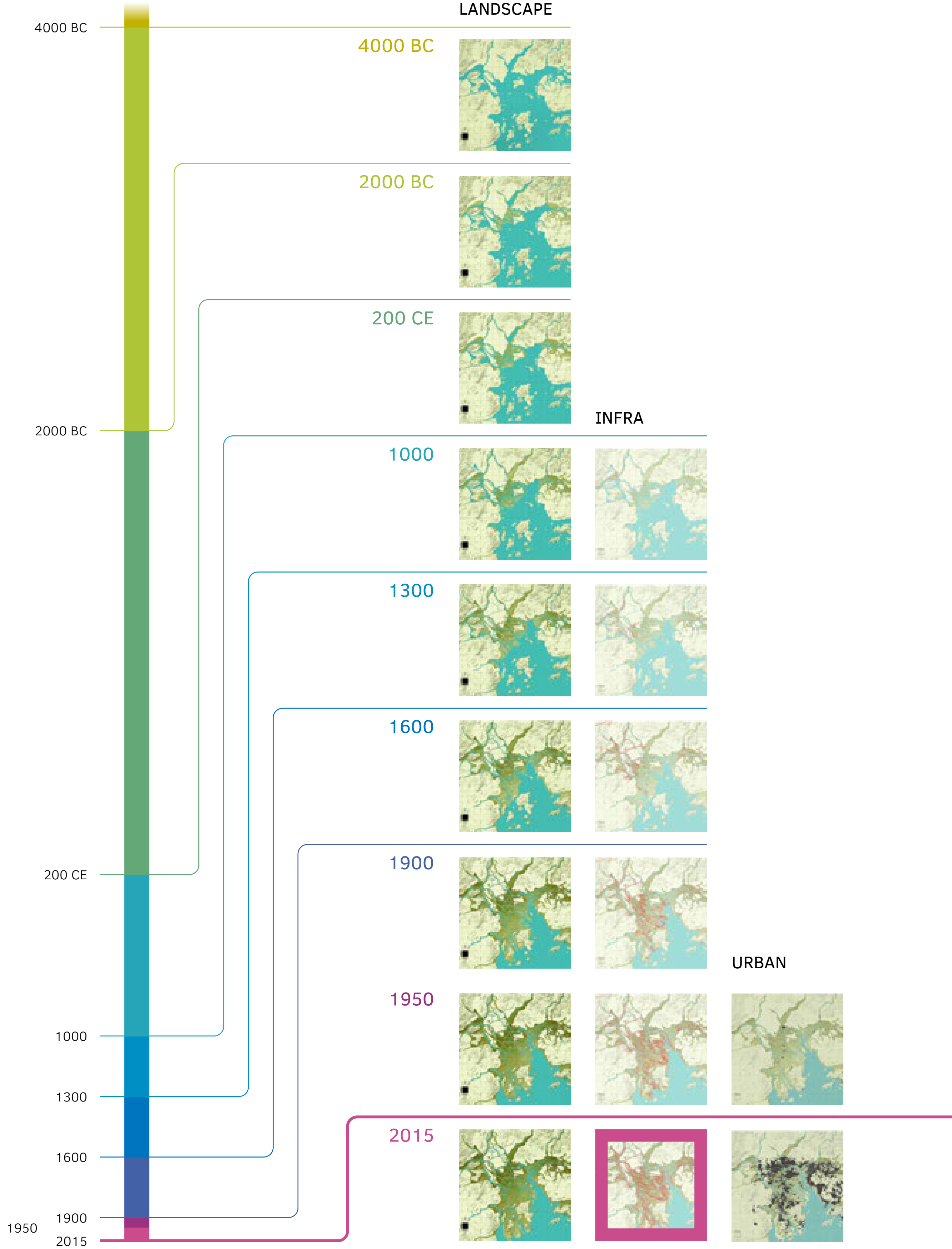


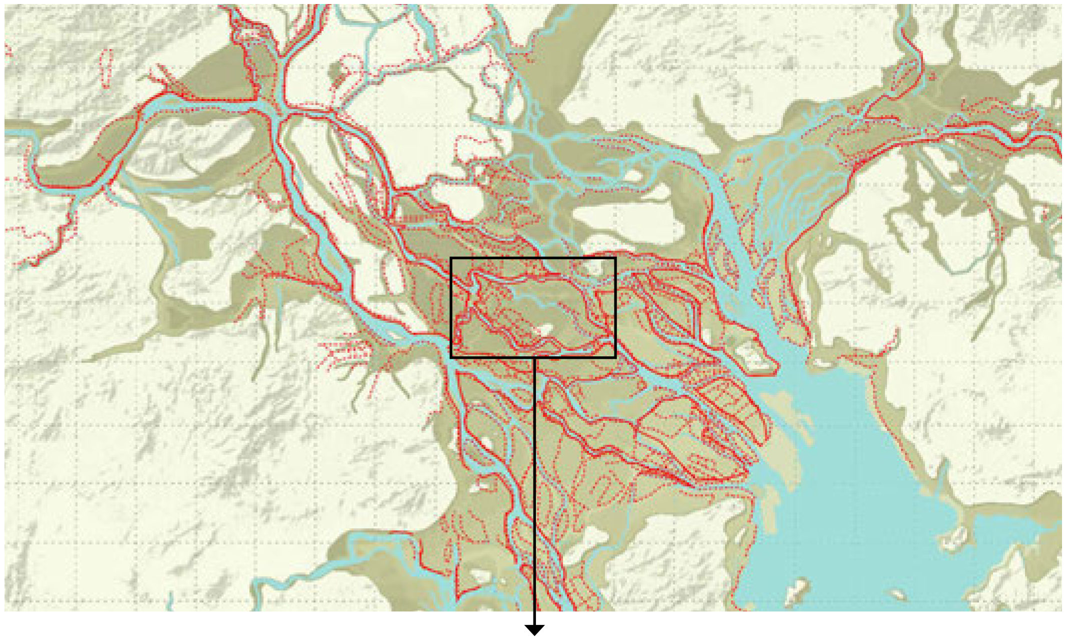
A larger dike ring took placed with the scattered smaller ones. The changed water environment within the island had resulted in a new form of water infrastructure network: the canals. A more connected road network, which connected to the neighboring islands, was also established within the dike ring. The water transportation gradually changed to road transportation. In the delta scale, similar spatial transition has taken place in the east wing. The intense artificial merge of smaller islands started.

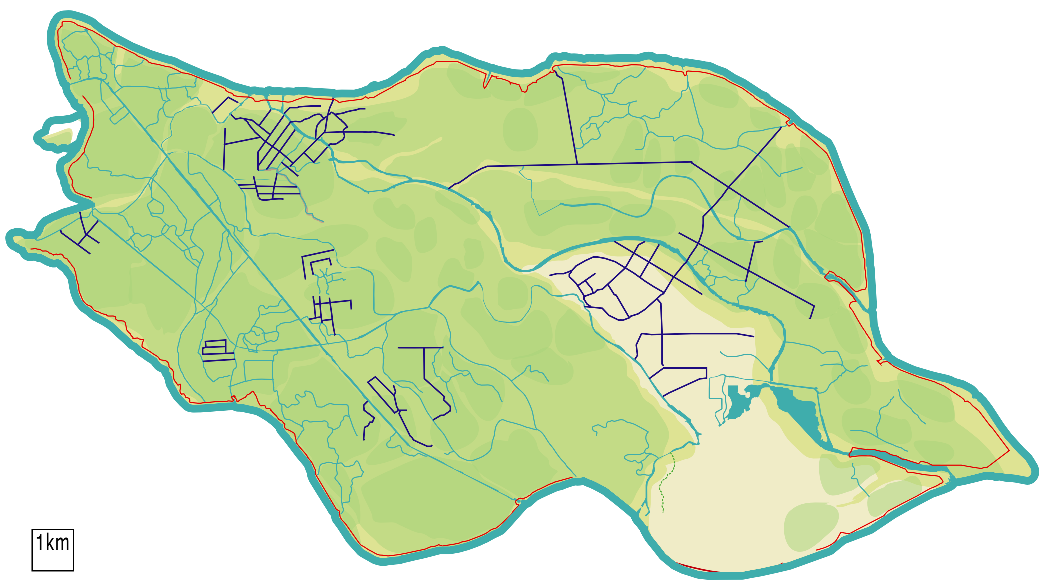
LOCAL SCALE



TOC

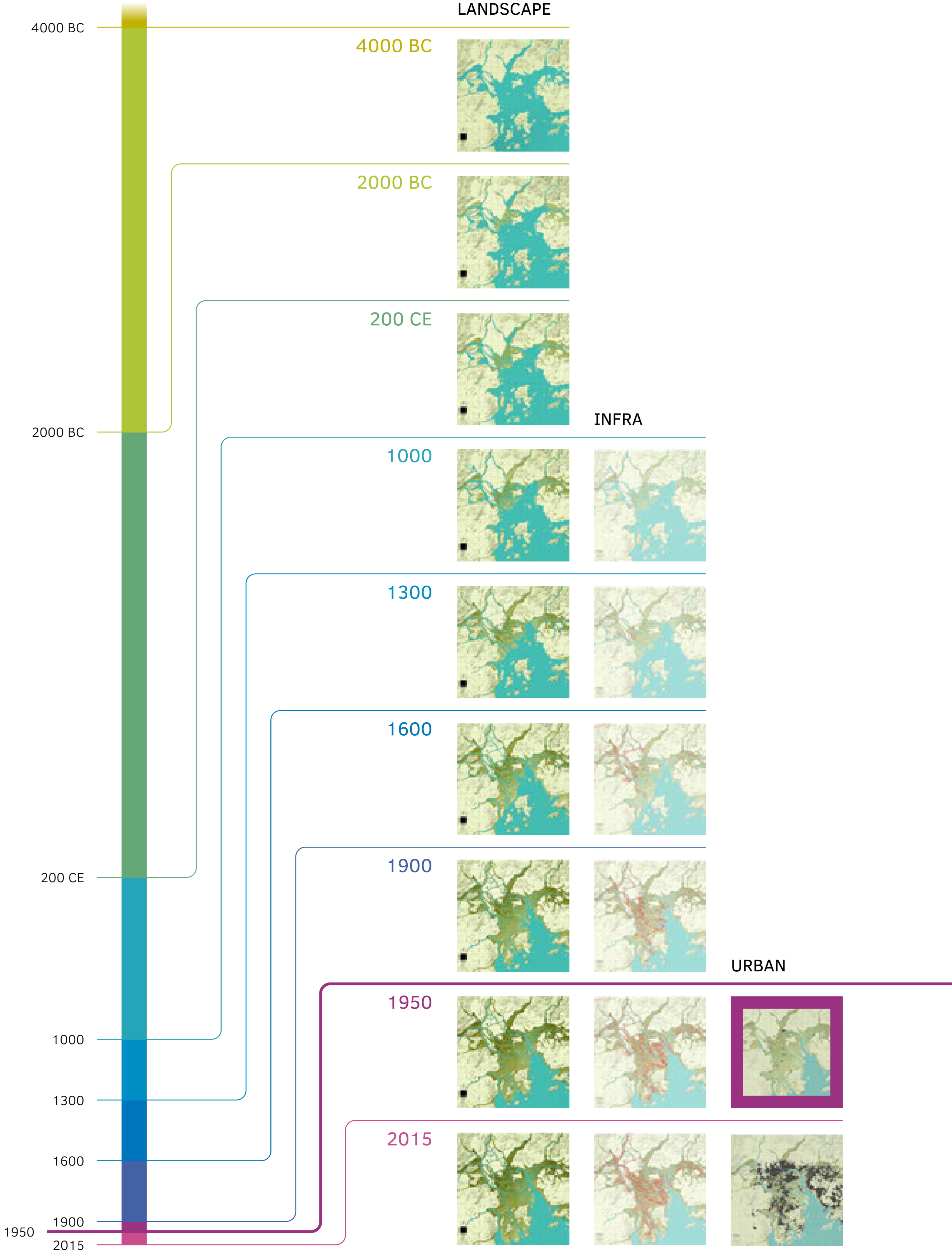
2015





The merge of the dike rings finished in the delta scale. Several regional dike rings had replaced the smaller dike rings. In the local scale, the stabilized larger dike ring encouraged further development of canal network. Creeks were merged into the canal network. The water cycle within the island became more depended on the artificial water management system.

LOCAL SCALE



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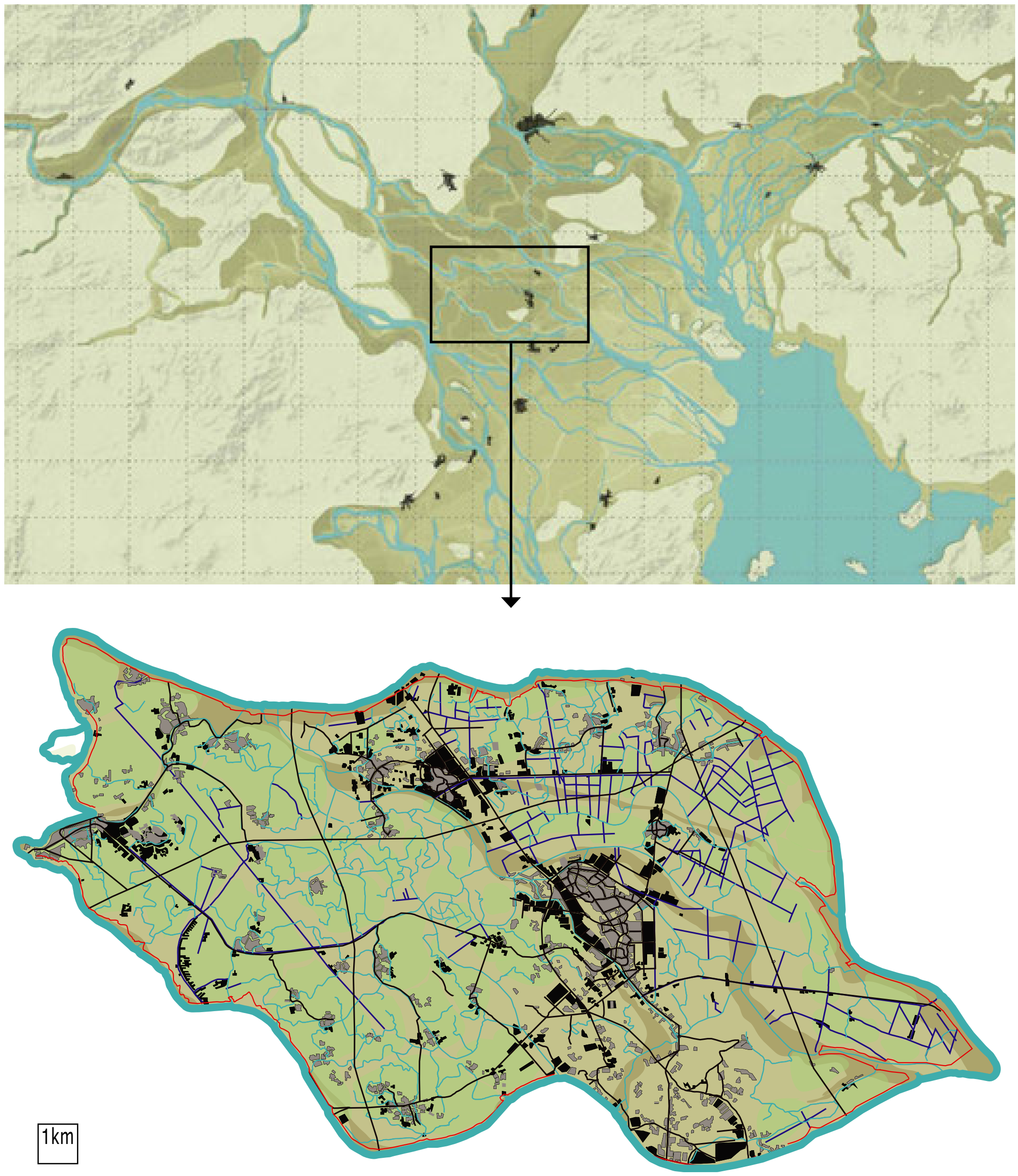
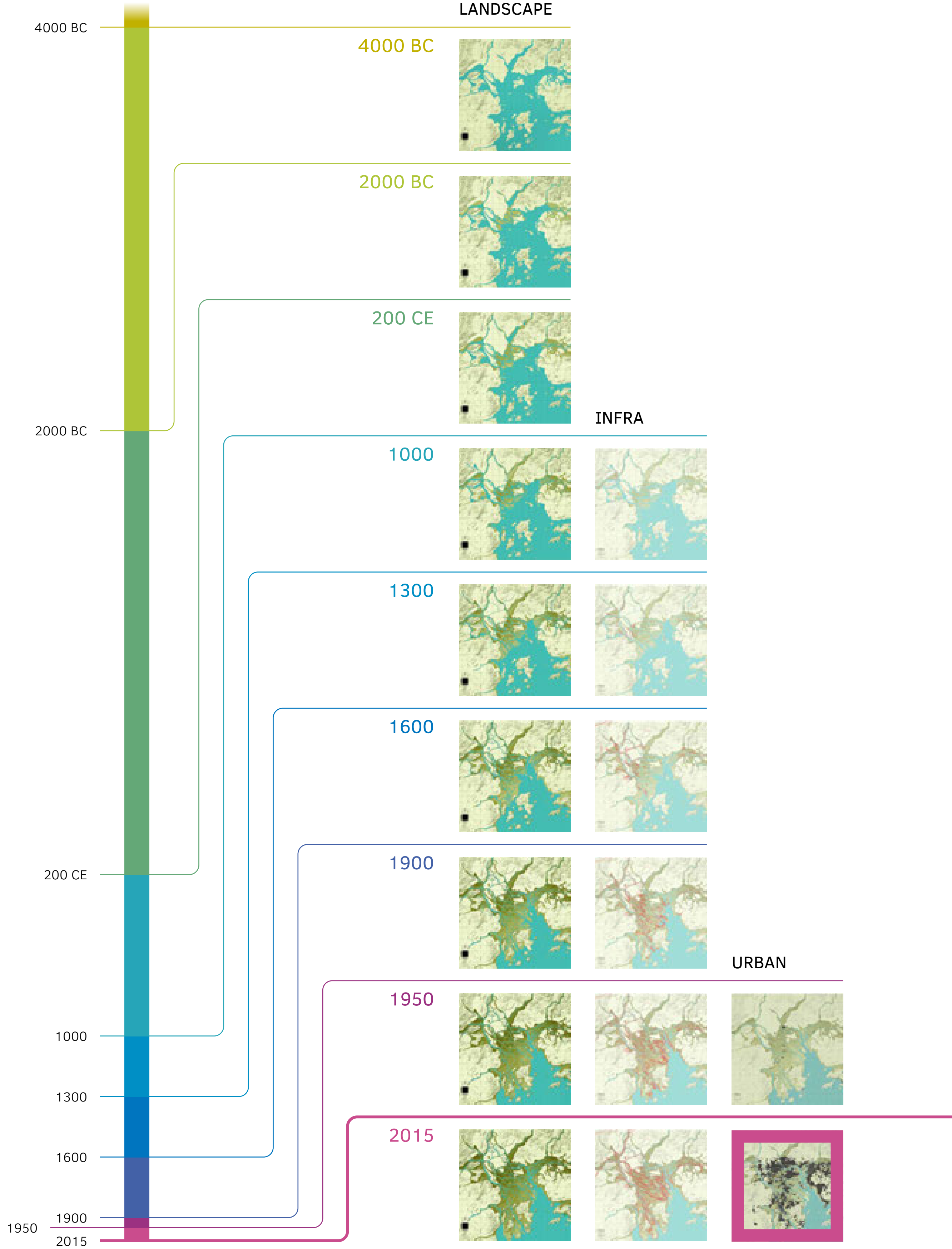
1950



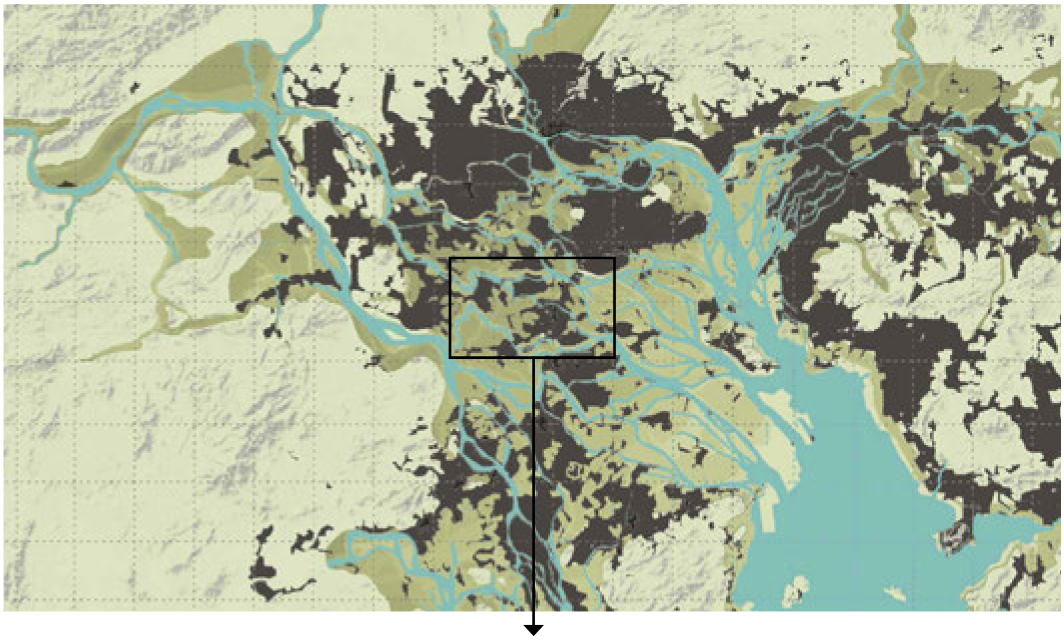
The urbanization took place around the former settlements in the local scale. New settlements emerged along the fresh linear infrastructure, such as canals and roads. Not all the regional roads had attracted enough urbanization along them. But the trend was clear: the waterways have been taken placed by the motorways. The urban system was heavily depending on the new transportation infrastructure network.

LOCAL SCALE



4000 BC
2000 BC
200 CE
1000
1300
1600
1900
1950
2015
LANDSCAPE
INFRA
URBAN
4000 BC
2000 BC
200 CE
1000
1300
1600
1900
1950
2015

2015



In both scales, an urbanization pattern could be recognized, in which the large area of farmland became urbanized and industrialized. The landscape and water infrastructure were no longer relevant to the urbanization pattern. The major urbanization taking place within the former fish pond area, indicated that the fluvial flood risk was not a major concern during the planning and design. Instead, the urban sprawl within the low-lying area had led to more serious pluvial floods. In the delta scale, the delta developed further into the bay, leading to a higher water level difference. The changes in the two scales had increased the fluvial flood risk. However, the current planning and design had not been fully aware of the trend, neither in delta scale nor local scale.

4.2 Analyzing the maps

With the aid of the two sets of maps, it is possible to systematically analyze the spatial relationships in the PRD. This investigation is aimed at phenomena that have been found as early-warning signs of critical transitions in other complex systems. These phenomena include sudden changes in the spatial pattern, or critical slowing down and flickering in the time series. According to the three hypotheses of complex systems presented in section 2.4, the maps should be able to help the reader identify and understand three groups of two-dimensional spatial relationships, namely (1) interactions between large and small scales, (2) interactions between fast and slow speeds of change, and (3) interactions among subsystems (landscapes, infrastructures, and urban areas). Therefore, the maps were analyzed in two steps. First, a two-dimensional investigation was conducted to compare maps with different scales, speeds of change, and subsystems. Then, a three-dimensional investigation was conducted based on the knowledge of the preceding two-dimensional investigation. The systematic analysis revealed the spatial information in the maps.

4.2.1 Two-dimensional spatial relationships

The two-dimensional investigation provided a basic understanding of the spatial relationships in the delta. This approach aimed at one of the three basic attributes of the spatial pattern, namely the scale, speed of change, and subsystems. To be specific, the differences and trends of the three attributes among the maps were investigated. Two cases of the two-dimensional analysis were provided to demonstrate how this type of mapping supports the understanding and inquiry of knowledge. The first case demonstrates how processes with different speeds are inter-related, while the second case indicates spatial linkages between two subsystems. It was not possible for all the findings in the map comparison to be explained by the maps; on the contrary, the analysis provided more questions than answers. By revealing the missing links in the understanding of the PRD, the two-dimensional analysis stimulated further study and collaboration among the stakeholders.

Interactions between fast and slow speeds of change

Processes with different speeds could be spatially related, and their interactions are based on two circumstances, namely acting at different speeds and reacting at different speeds. This study presents a case of the spatial interaction between a fast process (dike construction) and a slower process (coastline development). The dikes protected several locations in the delta from flooding, and these protected locations were the places where a portion of the sedimentation from upstream was supposed to deposit during flood events (Figure 4.1). Once the dikes were built, the frequency of flood events was reduced, leading to less deposition of the sediment in the region. This resulted in an increase of the transfer of sedimentation to the estuary area, leading to the accelerated development of the estuary area and coastline. With the assistance of an analytical map (Figure 4.2) that illustrates the hypothetical and empirical coastline, the impact of dike construction on the landscape development was revealed. Of the two kinds of coastline development in 1300-1600, the hypothetical coastline was based on the assumption of the sedimentation process to be the same speed as it was in 1000-1300, whereas the empirical coastline was derived from a historical map. The comparison between the empirical and hypothetical coastlines revealed that the development speed of the coastline doubled due to the external intervention of dike construction. The analytical map illustrates this spatial connection between the two processes of different speeds.

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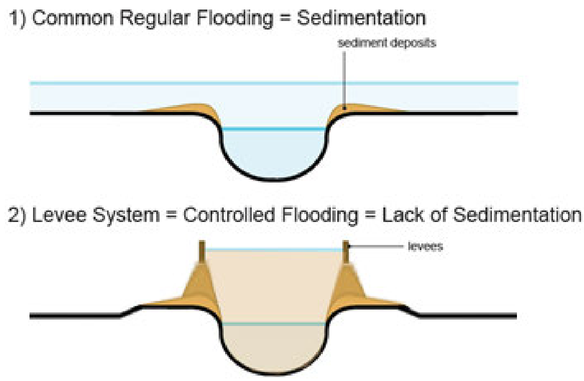

FIG. 4.1 **Sedimentation before and after diking.**
(1) During common regular flooding, sedimentation is deposited along the river, leading to the transport of less sedimentation into the estuary area. (2) After diking, less flooding occurs in the protected locations, forcing more sedimentation deposits in the estuary area and accelerating coastline development.

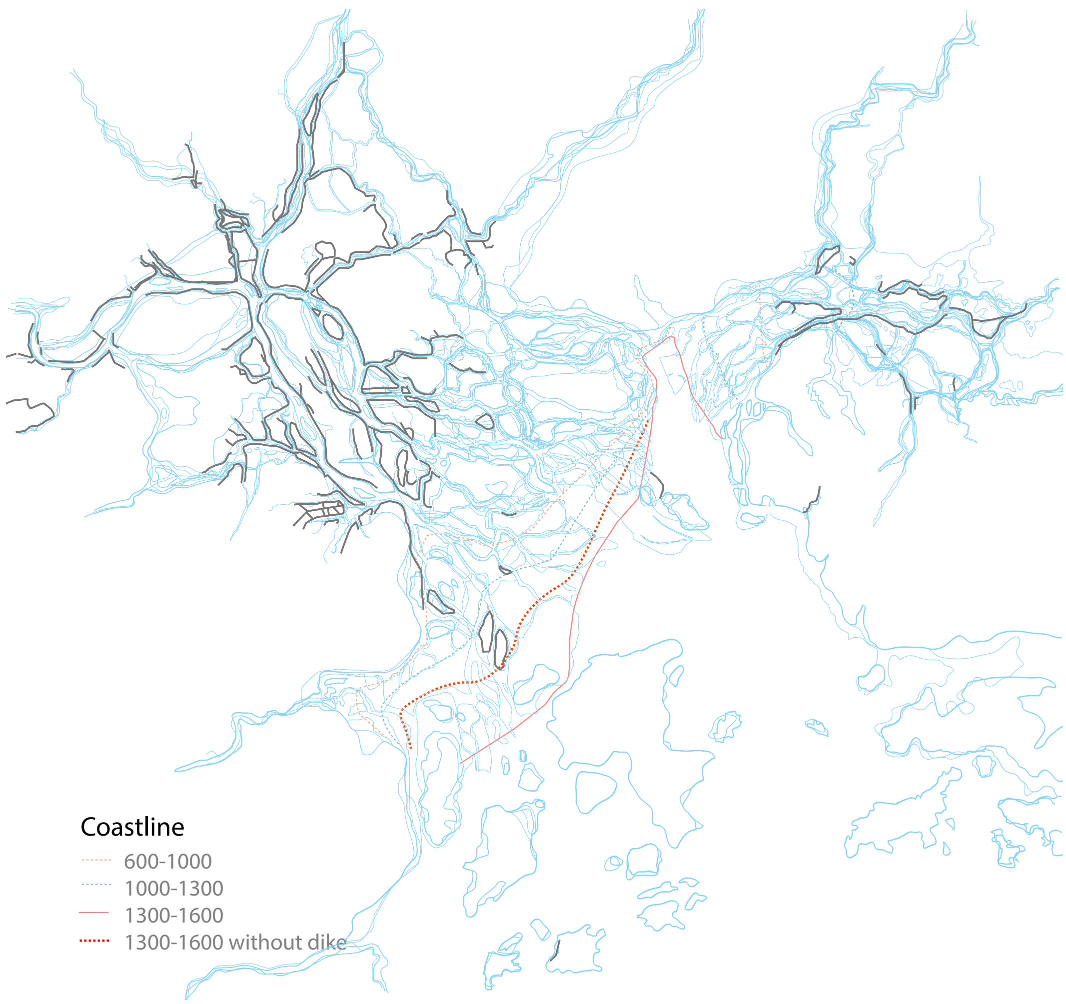

FIG. 4.2 **Dike and coastline development in 1300-1600.**
A clear change of speed in the development of the delta can be identified by comparing the hypothetical and empirical coastlines in 1300-1600. The hypothetical coastline development (1300-1600 without dikes) was based on the hypothesis of a linear development in which both natural and human processes maintained the same dynamic as in the 1000-1300 period. The empirical coastline development (1300-1600) was derived from historical maps. The considerable difference between the two coastline developments suggests that the speed accelerated as much as two times. Such speed acceleration could be connected to the increasing dike construction (indicated by bold black lines) within the same time. Dikes prevented the flooding of the protected areas, leading to increases in both discharge and sediment load toward the estuaries. The increased discharge and sediment promoted the coastline to develop twice as fast as it had before dike construction. The impactor of the coastline development change (the dike construction) and its impaction (a twofold acceleration in speed) on the coastline development are both illustrated in the same map. Their spatial relationship is revealed by placing a speed reference line, namely the hypothetical development speed of the coastline in 1300-1600 in the absence of diking.

Interactions between subsystems

The second case reveals the spatial relationship between the infrastructure and landscape, as presented in Figure 4.3. Among the three illustrated layers of subsystems, there are six types of spatial interactions between the subsystems that could be investigated in this mapping setting, namely landscape influencing infrastructure, infrastructure influencing landscape, landscape influencing urbanization, urbanization influencing landscape, infrastructure influencing urbanization, and urbanization influencing infrastructure. In this case, the analysis reveals how the river channels changed during the development of the delta before the construction of dikes. Moreover, the maps imply that the dikes restricted the dynamic of the delta in the protected area, as well as a sharp contrast in the delta dynamic between the protected region behind the dike and the unprotected region in the lower stream of the delta. In this style of mapping, a clear view of the spatial relationship between the infrastructure and landscape is delivered. In 1600, the dynamic of the water system had a considerable influence on the development of the water infrastructure system. Because this map reveals the situation in 1600, the map readers were encouraged to inquire about what could be the state of the art of this type of spatial relationship. By providing a convincing perception of the past, the two-dimensional map analysis indicates to the map readers the possibility of a similar analysis of current circumstances.

Once a current map of the same style was created, it was possible to analyze the changes in the interactions between subsystems. Figure 4.4 highlights the changes between the water subsystem and water infrastructure subsystem. In this map, a much larger area of the dynamic delta landscape is indicated to have been contained by the dike system in 2015, revealing the change of the spatial relationship between the water and water infrastructure. A reader of the map can quickly identify the principle of water infrastructure development. The awareness achieved by seeing the changing spatial origination triggers the possibility of reflection and inquiry. Once the stakeholders realized they could benefit from the insight of this type of mapping approach, it became more likely that they would be willing to contribute to the study by providing data, skills, and awareness. In this way, the mapping allowed the readers to envision their roles in the planning and design process. Mapping encourages the cognition of current and future strategies, thereby providing possibilities for the formulation of alternatives.

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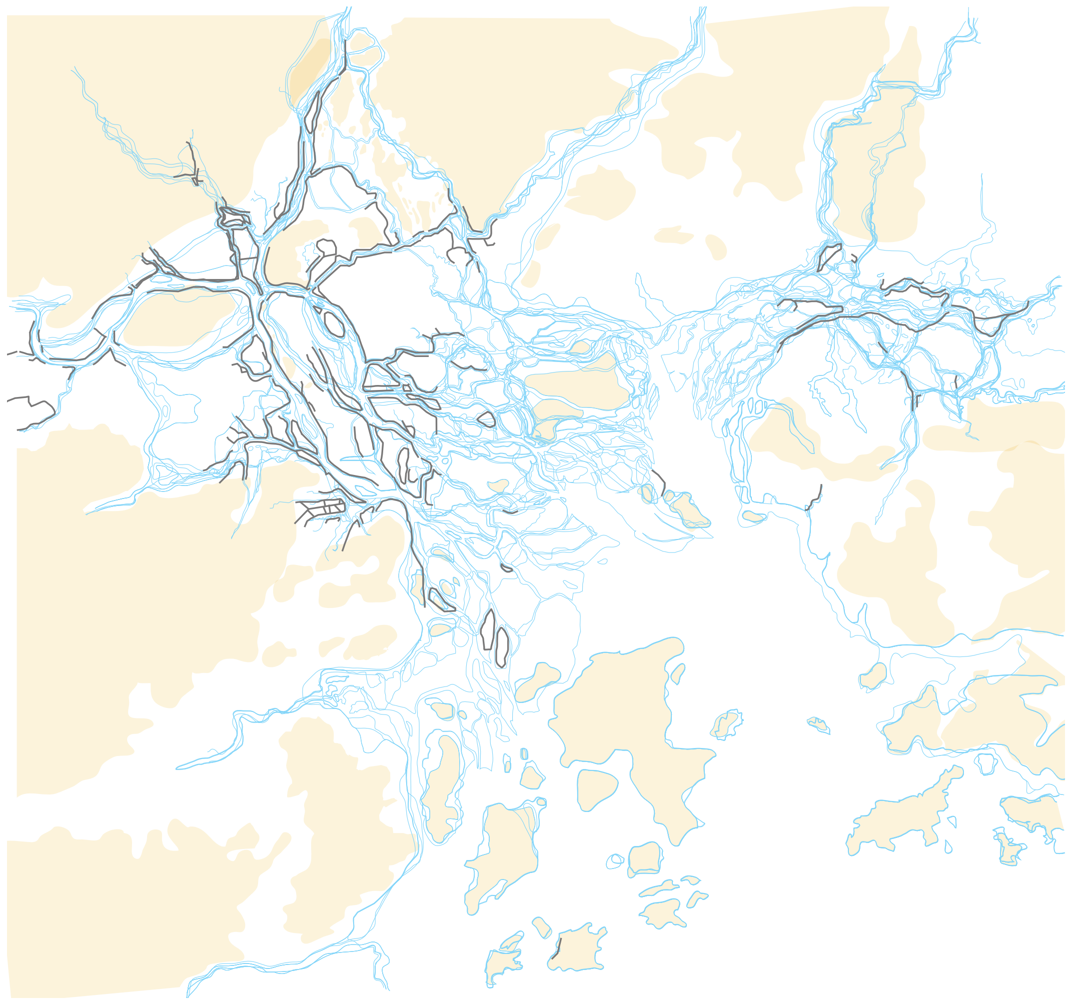

FIG. 4.3 **Dynamic comparison between protected and unprotected areas in 1600.**
This map illustrates a sharp contrast between the deltaic dynamics of the protected regions behind dikes (with fewer blue lines) and unprotected regions in the lower stream of the delta (with more blue lines). The map indicates the dike construction principle at this time (1600) when the dikes were built in the less dynamic part of the delta.

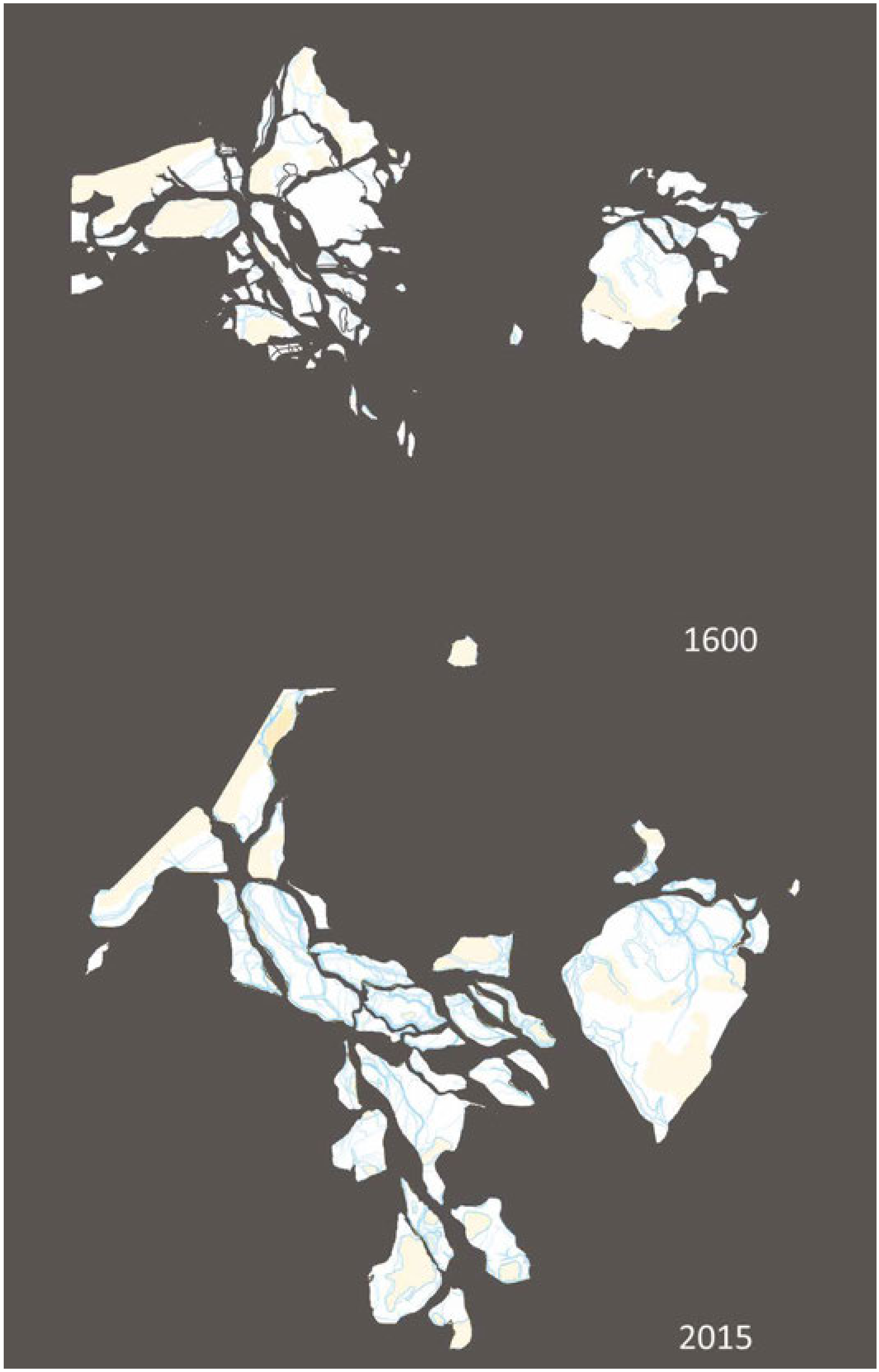

FIG. 4.4 **Landscape dynamic in the protected area.**
A much larger area of the dynamic delta landscape was contained by the dike system in 2015, revealing the change of the spatial relationship between the water and water infrastructure. A map reader can quickly identify the principle of water infrastructure development.

Three-dimensional spatial relationships

The three-dimensional analysis, constructed based on the two-dimensional analysis, reveals even more in-depth spatial connections within the delta. In a complex system that includes many subsystems with their own dynamics, two-dimensional spatial relationships are not isolated; instead, they co-exist and interweave to form more complex three-dimensional spatial relationships. Knowledge of the three-dimensional spatial relationships can be assembled from the analysis of the two-dimensional spatial relationships, which was mentioned in section 4.3.1. By combining the knowledge of the two-dimensional analysis, the three-dimensional analysis can generate new knowledge, and can also distinguish specific spatial or temporal changes to ultimately identify the early-warning signals of critical transition. By linking spatial patterns across times, scales, and subsystems, it is possible to achieve a deeper understanding of the spatial relationships within the delta. Within this understanding, natural and human processes of various scales and speeds of change are connected.

For instance, the interactions of different subsystems during two-stage changes can be identified by comparing the spatial patterns of 1600, 1900, and 2015 (Figure 4.5). In 1600, dikes were confined primarily to the top of the delta, where the river networks were less dynamic. The restriction of the river networks upstream had two direct impacts on the landscape development downstream. First, the narrowed river channel resulted in an increased high-water level; the width of the river channel near Guangzhou decreased from 700 meters to 100 meters from 1000 to 2004 (Z. Huang & Zhang, 2004). A narrowing of the river channel of 250 meters led to a 1.02-meter increase in the high-water level near Guangzhou from the 1950s to 2000s (Z. Huang & Zhang, 2004). It was riskier to reclaim the fertile part of the delta due to the higher water level in the flood season. Therefore, a spatial strategy of the use of smaller dike rings was adopted for most of the land reclamation from 1600 to 1900 (Figure 4.5b), instead of the use of linear dikes widely seen in 1600 (Figure 4.5a). Second, the protected flood plain in the upper stream led to an increased deposition downstream. As a result, it has been much easier to accumulate silt via technology in the downstream delta. Dike construction covered almost all the downstream areas of the delta in 1900, in contrast to the restricted coverage in the upper delta in 1600. The 1900s witnessed a rapid change in the morphology, scale, and allocation of the dike system. Decentralized small dike rings quickly emerged in the delta frontier. More than 887 km^2 of the tidal flat was reclaimed within the 122 years from 1753 to 1875 (Board of Pearl River Delta Agriculture Gazetteer in Foshan Revolutionary Committee, 1976, pp. 41–42). The reclamation speed in 1600-1900 was triple that within the previous time period. Nevertheless, the spatial pattern of the dike system has experienced a rapid overhaul since 1900. The smaller dike rings proved to be incapable of protecting the lower delta region. The much more frequent flooding forced the development of a new strategy of flood protection, whereby smaller dike rings were integrated into stronger and higher delta-scale dike rings (Figure 4.5c). In the first half of the 1900s, there was no significant development in the water infrastructure. After the fall of the Qing Dynasty in 1911, the PRD experienced a fundamental change in land ownership after the People's Republic of China was established in 1949, and large-scale dike integration began. The number of dike rings plummeted from over 10,000 to 53 between 1949 and 1982, and the length of the dikes was reduced by 663 km (Z. Huang & Zhang, 2004). The boxed delta ensured much better flood protection in the short term. Urbanization has taken place at an unparalleled speed in the PRD since the completion of the delta-scale dike system. However, one might question the consequences of the reaction of the slower layers. Those slower processes might occur later, but they would never vanish. By analyzing the three-dimensional spatial relationships, the impacts of certain interventions in both the short term and long term, on both small and large scales, and through different subsystems can be identified. These impacts serve as an analytical tool for the identification of past critical transitions and their causes, and provide a possibility to explore future critical transition thresholds.

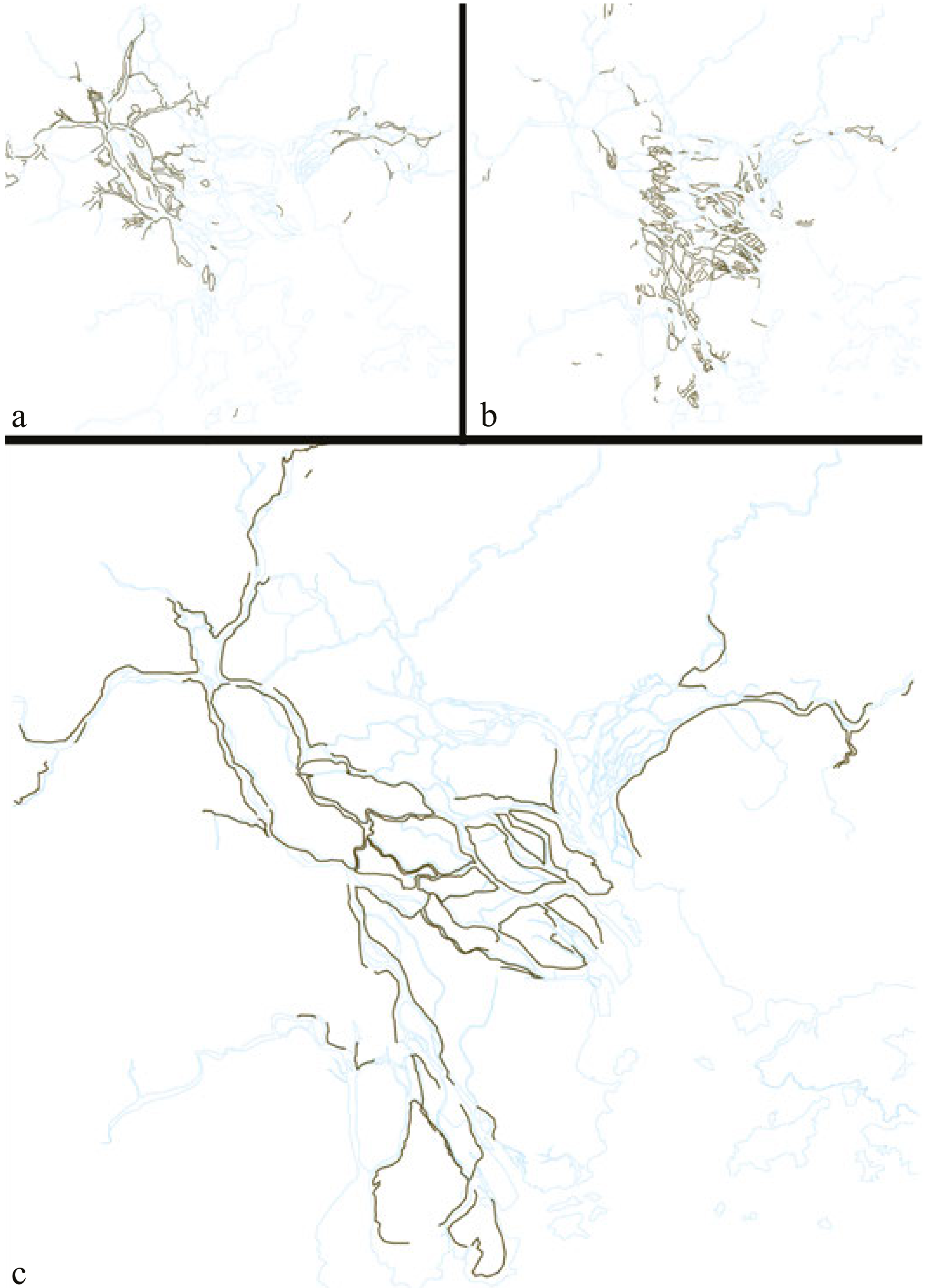

FIG. 4.5 **Significant changes in the delta system can be identified by comparing the spatial structures.**
By compaing spatial structures in (a) 1600, (b) 1900, and (c) 2015, the spatial changes indicate critical transitions in 1600-1900 and 1900-2015.

4.3 Identifying critical thresholds

Similar to other complex systems, sudden changes in the spatial pattern, and the critical slowing down or flickering in the time series, during the development of the PRD can also be found via the multi-dimensional mapping analysis. The period of 1600-1900 could be considered a critical transition phase, during which the major flood frequency increased by 2.3 times (Board of Pearl River Delta Agriculture Gazetteer in Foshan Revolutionary Committee, 1976, p. 111). As mentioned in section 3.3.2, the changes in the dike system led to an increase in flood events. Therefore, the change of the spatial pattern of the dike system could be regarded as an early-warning signal of the critical thresholds of the flood events between 1600 and 1900. The use of smaller dike rings was implemented to more effectively reclaim the land and better protect the region. However, this strategy failed to address the dynamics of the other subsystems. When the landscape development reacted to the intervention imposed by the dike system, the delta system transformed into a new state in which the expansive, weak dike rings were unsustainable due to the increased discharge. The dike system itself had become part of the challenge that it aimed to solve. The opportunity to act adequately in the critical transition phase between 1600 and 1900 was missed. Consequently, urgent interventions were required to secure the dike system from a complete failure in 1900. Without a multi-scale understanding of the delta system, the identification of the signal of the critical thresholds is not likely, nor is the ability to take proper action.

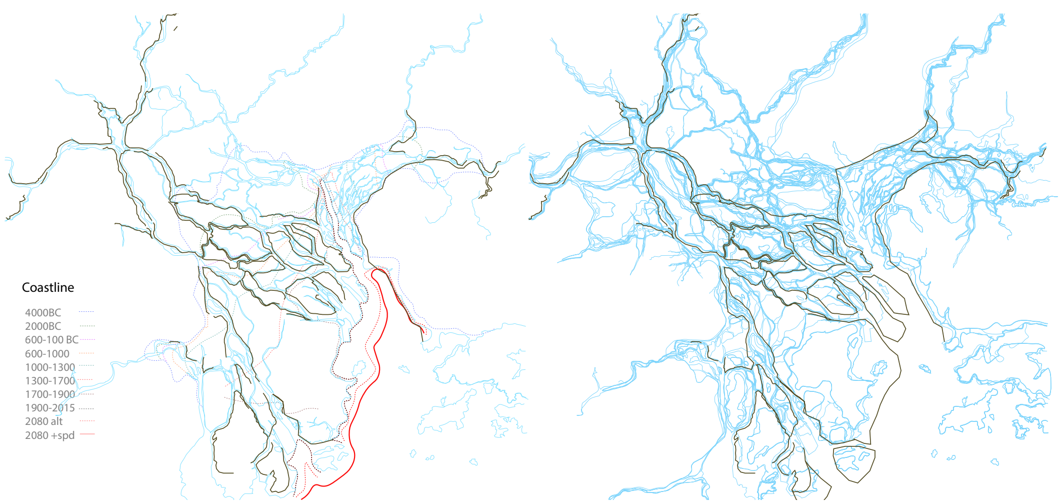

FIG. 4.6 **Probable future maps of 2080 that show the development of the coastline (left) and the dike system (right).**

A hypothetical map aids in the understanding of the trends of this critical transition and decision-making. Probable future maps of 2080 (Figure 4.6) were developed from the landscape (left), dike system (right), and urban system via a constant spatial pattern. By comparing the development of the coastline, a hypothetic coastline in 2080 was drawn based on its trend in 1950-2015 (left). The dike system was then extended following its trend in 1950-2015 (right), which exemplifies integration and extension on a large scale. Finally, the urban system was developed based on the trend in 1950-2015, namely unlimited sprawl within the dike ring (Figure 4.7). This map illustrates the probable future urban landscape of the PRD in 2080 if human activity sustains its current pace. In 2080, the urban area is projected to have increased by about 2100 km^2 and the reclaimed land is projected to have increased by about 3000 km^2, all of which is protected by the dike system.

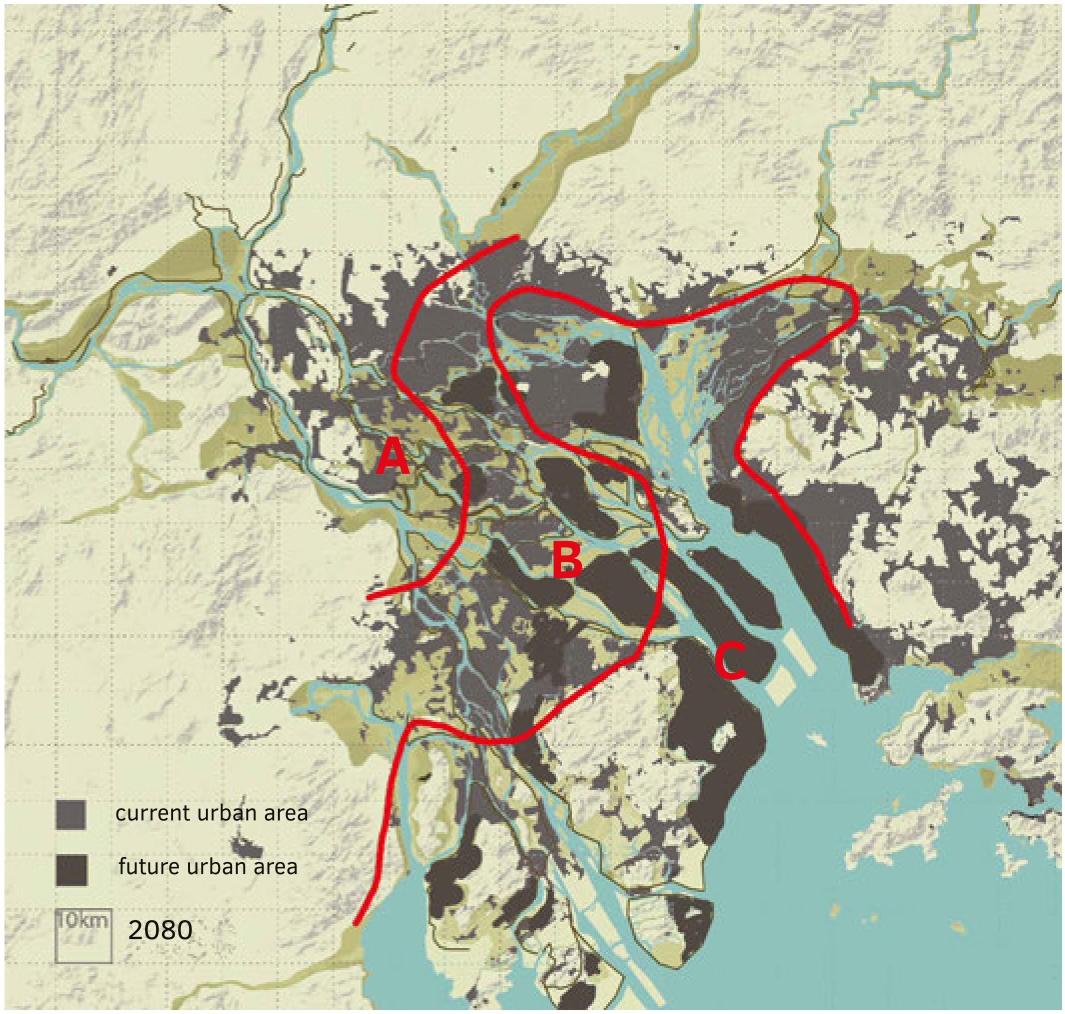

FIG. 4.7 **Probable urban landscape in 2080 with relative sea-level rise.**
(A) Low sea-level-rise area (30 cm); (B) medium sea-level-rise area (50 cm); (C) High sea-level-rise area (60 cm). Map by the author. Area division from (Z. Huang et al., 2001)

The future map provides a spatial reference for flood risk estimation. It is highly likely that the PRD will experience a rise in the relative sea level of up to 60 cm, as a study found a probable rise of 22-33 cm in the relative sea level in 1990-2030 (Z. Huang et al., 2001). The areas affected by sea-level rise can be divided into three areas, namely low, medium, and heavily influenced areas (Figures 4.5a-c, respectively), in which the increased amplitude of the floodtide water level is predicted to average 30, 50, and 60 cm, respectively. The future urban area is expected to be more adaptive to the rising water level because there will be more space for solutions, such as higher dikes or more space for water, whereas it would be more difficult for the current urban area to adapt due to the lack of space. Therefore, the flood risk in the current urban area is likely to be higher than that in the future urban area. As a result, the probable flood risk from high to low is as follows: current urban area in high sea-level-rise area, current urban area in medium sea-level-rise area, future urban area in high sea-level-rise area, future urban area in medium sea-level-rise area, current urban area in low sea-level-rise area, and future urban area in low sea-level-rise area. By integrating this information, a hypothetical flood risk map of the urban area in 2080 is illustrated in Figure 4.8.

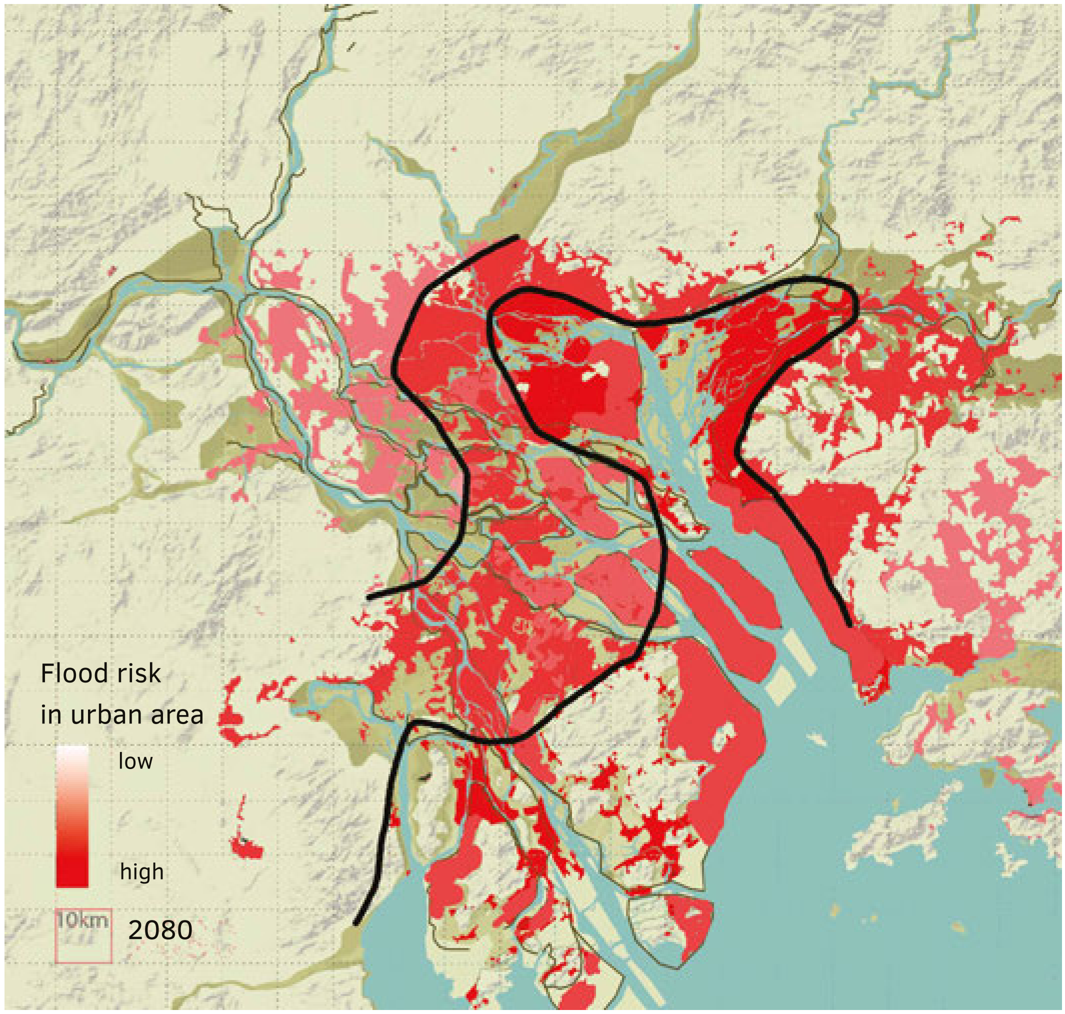

FIG. 4.8 **Probable flood risk map of the urban area in 2080.**

TABLE 4.1 **PRD delta system development in 1600-2080.**

Year	1600	1900	1950	2000	2030	2080
Major dike (km)	622 [b, c]	1357 [b, c]	2099[b]	3619[b]	2608[a]	3368[a, d]
Protected area (km2)	1333.4[c]	2220 [c]	NA	13284[a]	21861[a]	24861 [a, d]
Protected lowland (less than +0.5 m sea level) (km2)	50% [c]	40% [c]	NA	27% [a]	42% [a]	45% [a, d]
New protected lowland/new land	NA	25.0%	NA	24.3%	65.2%	70.0%

Source: a: Huang et al.(2001); b: Huang & Zhang (2004); c: Board of Pearl River Delta Agriculture Gazetteer in Foshan Revolutionary Committee (1976); d: Future map of 2080 by author.

With the help of the probable future maps of 2080 (Figures 4.6, 4.7, and 4.8), it is possible to derive the spatial information of the region. Therefore, the characteristics of the delta in 2080 can be compared with the past and current situations (Table 7), and significant transition can be identified both morphologically and quantitatively. A signal emerged from the comparison of the dike system between 1600 to 2080. The ratio of new protected lowland in the new protected area is projected to increase to 65% in 2030, and to continue to increase to 70%. The ratio increases almost 3 times from 2000 to 2080; in contrast, it stays steady from 1900 to 2000. This signal suggests a sudden change in the spatial pattern of the dike system. Therefore, the current circumstance of the delta should be considered as a transition threshold. Like in 1600-1900, a similar change in the spatial pattern can be observed in the dike system between 1900 and 2015, during which the morphology and spatial scale of the dike system experienced another sudden change. Larger, shorter, and stronger dike rings had replaced the previous dike rings, and this change should be considered as an early-warning signal of another critical threshold of the delta. Within the past century, the change in land ownership has enabled the implementation of the upscaling of the water infrastructure, which has in turn provided a condition for the change of the speed of the urbanization process. The substantial acceleration of the speed of the change of the urban system and infrastructure network has almost wiped out the condition of the landscape system and its cultural memory in the urbanized region. Challenges in all the subsystems emerged within their own scales and dynamics; while some emerged quickly and at sensible scales, others, especially those on larger scales and with slower dynamics, will strike at a later stage. Ignoring the scales and speeds of change of these processes has led to unexpected outcomes in the delta region during its fast urbanization and industrialization that began in the 1980s. Due to the "Open Door" policy, the villages of the PRD have experienced a change in their identity as one of the most productive agricultural regions, and the delta has been referred to as "the world's factory." The occupation layer gradually lost its connection with the landscape, and turned into a pattern that was heavily oriented by the infrastructure network. One might argue that the new dike system has successfully reduced the frequency of floods in the past decade. However, at the beginning of the 1600-1900 period, the smaller dike rings were also considered a good strategy for the reclamation of land from the water. There is always a lag between quick interventions and some essential dynamics. In the case of 1600-1900, it was not until the dike system caused increased discharge in the whole delta region in the later period of this stage that the once-successful dike rings began to fail systematically. It is highly possible that the delta landscape will again develop into a state with increased discharge and sedimentation toward the lower stream, as it was in 1600-1900; in this case, the current dike system would face even higher flood pressure than it did in 1600-1900. Moreover, large swaths of agricultural land have been turned into urban areas, leaving less space for water. With over 45% of the protected area projected to be below sea level in 2080, the two largest metropolitan regions of the world will drown once the dike system fails. The prosperity of the delta is at stake if this critical transition is not properly addressed.

The identification of the coming critical transition implies two options, namely repair or the control of the transition, and mapping provides visualizations of both options (Figure 4.9). If the plan was to repair and maintain the current system, the spreading urban pattern and extended river channel would require a stronger dike system. The dike system would need to heighten by an average of 1.4-1.8 meters and extend by 760 km to further protect the urban area with a security level to handle 100-year flood events. Additionally, 61.5% of changes to the dike system would be located in the current built-up area, which indicates a complicated refinement of the existing urban area. Considering that the main focus of Chinese planning and design has been on creating instead of refining, the lack of experience and practice would be a major obstacle to this choice of strategy, and the cost would be another challenge. There is also less profit to be made from redesigning and redeveloping the existing urban area; it is therefore possible that such a plan would not be economically feasible.

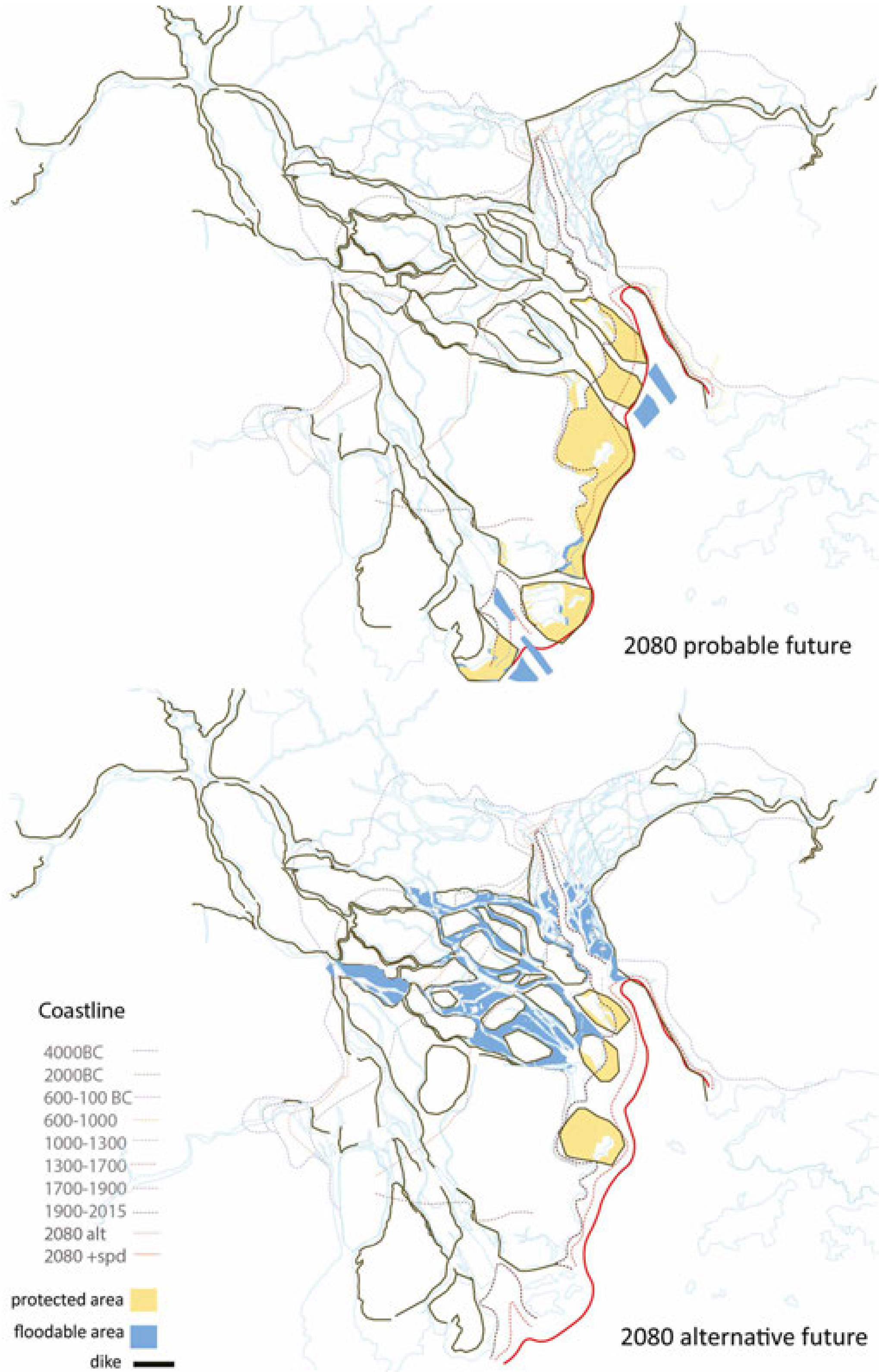

FIG. 4.9 **Probable future and one alternative future of the PRD in 2080.**
Based on the selected strategy, the PRD could have more room for the water in the delta, resulting in varied speeds of delta development and dike morphologies.

With the understanding of the PRD, it is possible to visualize other alternative future urban landscapes via mapping. In one of the alternative futures provided in Figure 4.9, it seems possible to influence the delta to have a more sustainable future. In this future, the redesign of the current urban area would be less essential; instead, the planning and design of the delta frontier would play a much more active role. A portion of the existing agricultural land would be transferred into space for the river, but more fertile land could be compensated at the estuaries. In this vision, the major challenges would be collaboration among governments and the integration of the related domains. Nevertheless, design aided by mapping could play an important role in initiation, communication, and allowing the stakeholders to envision the achievement of the transition of the delta into a new situation that is easier to manage.

Due to the nature of this study, none of the questions were able to be elaborated to a satisfactory level by the author himself. However, the power of mapping is not limited to answering questions; instead, mapping can transform the task of problem-solving by allowing the visualization of the unsolved challenges and the facilitation of the problem-solving process. The benefit of this transformation is that more stakeholders are able to contribute to the process, thereby enabling greater and enduring efforts to implement a sustainable strategy.

5 Generating interventions

The process of designing rapidly urbanizing deltas requires the willingness, wisdom, skill, and knowledge of the involved stakeholders. Multi-scale systematic mapping provides tools to encourage the involvement of the stakeholders in the planning and design processes. Moreover, it facilitates the possible planning and design process, making interventions visible for all the stakeholders. These two steps are essential to the mapping process. The individual mapping approach can be transferred to a collective mapping approach, and the individual understanding of the PRD can be transformed into a collective understanding of the delta. With this common understanding, collaboration can become possible. Both the probable and alternative future maps created in Chapter Four were introduced to the collective mapping process. The probable maps encouraged the involvement of the stakeholders, while the alternative future maps inspired the possible planning and design process. They served as a basis for new maps and ideas during the collective mapping process.

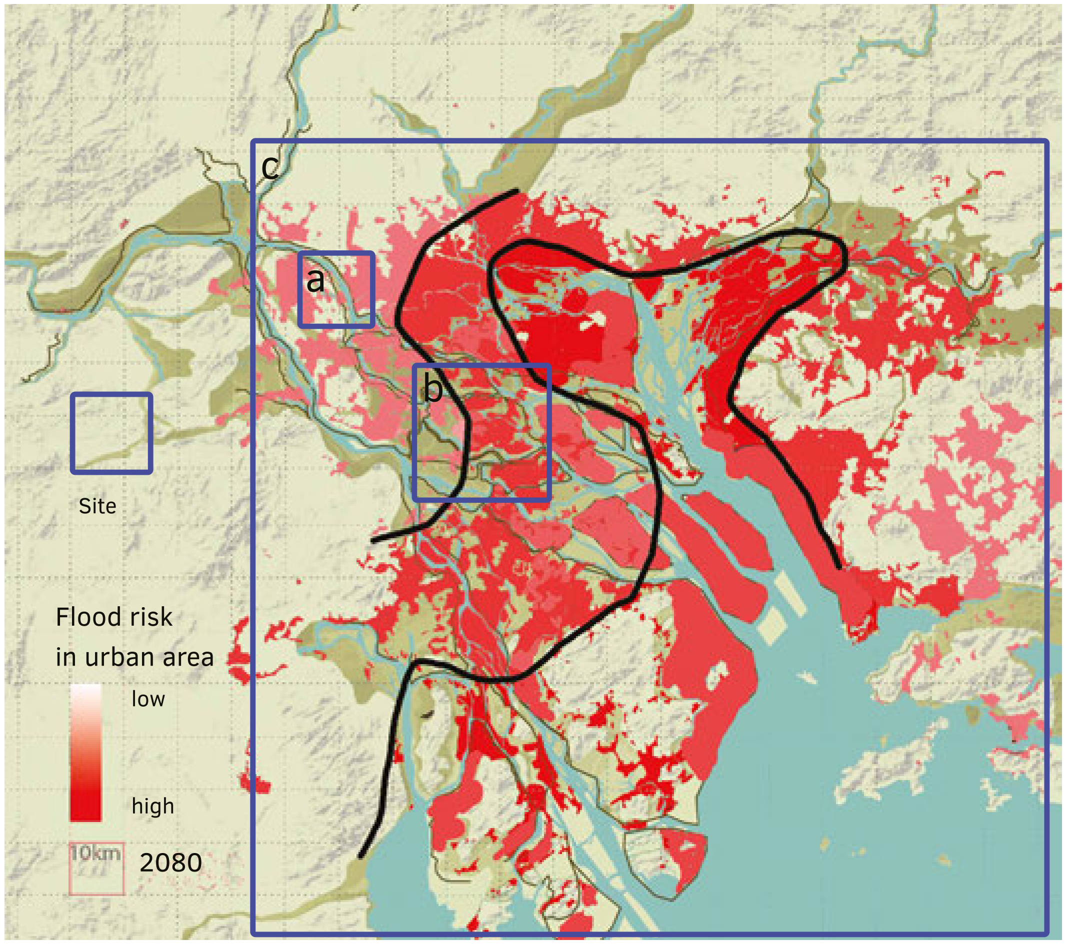

FIG. 5.1 **Mapping sites in the PRD with stakeholders: (a) with designers; (b) with policymakers; (c) with the interested public.**

The probable maps aimed to trigger discussions of the current critical transition of the PRD. By introducing the comprehensive understanding of the PRD to spatial-temporal models with maps on both the delta and local scales, the probable future maps that highlight the studied site could provide a similar spatial-temporal model for the participants of the collective mapping process. Stakeholders were able to understand their positions in the probable future (Figure 5.1). With the flood risk map of 2080, a designer (Figure 5.1a), policymakers (Figure 5.1b), and interested public (Figure 5.1c) were able to think visually about the current critical threshold. The future flood risk of each site was framed within the extent of the delta. In this way, the awareness of the scales of the sites and the whole delta was suggested to the participants. This inter-scale setting provided a real-time experience for the participants to understand the impacts of their interventions at both scales. The data source of the probable map was also made clear to the participants. For the designer, this helped him search for similar publicly accessible data. For the government, the publicly accessible data ensured a common ground for inter-sectional discussion. For the interested public, this type of data was also easy to track and verify. The presentation of the mapping approach was open, scientifically sound, and welcoming. Regarding the knowledge backgrounds and schedules of the stakeholders, the mapping process and its insights were presented in different ways. For the designer, multiple in-depth, face-to-face discussions and mappings were conducted on the individual level. For the policymakers, a one-day workshop was arranged with groups of 20 participants at the municipality and district levels. For the interested public, a seven-minute lecture in a popular massive open online course was given to over 10,000 participants. Despite the narrative, the message conveyed by the probable mapping process was clear: if nothing changes in the current urbanizing trend, over 45% of the protected area will be below sea level in 2080; thus, dikes need to be extended for 760 kilometers and heightened by 1.4-1.8 meters, and 61.5% of the dikes must be located in the complicated built-up area. If the dike system fails, two of the largest metropolitan regions of the world will be drowned. The probable mapping activity therefore transformed the systemic view of the PRD from the individual level to the collective level, in which the interventions and strategies of the delta, be it repair or transit, could be raised, imagined, visualized, calculated, evaluated, and ultimately achieved.

The alternative future map aimed to inspire planning and design activities for a transition with a focus on connecting interventions at different scales and speeds, and offered one possible vision for the delta. In this vision, the coastal reclamation is less aggressive and more space is available for flood discharge during the peak season. The spatial pattern of the protected area changes so that economic efficiency is not highly prioritized as compared to other planning and design targets. Slower processes, such as flooding and sedimentation, were considered in the development of the delta. The local scales of each studied site were once again linked to the larger scale. In this way, the participants were able to project their local initiatives onto the regional vision, and the local impacts would contribute to the region. The changes in upstream would be reflected downstream, and vice versa. Additionally, the fast and slow processes would all become parts of the factors that influence the planning and design process. For the designer (Figure 5.2a), a section of a river channel in the upper delta region was chosen. Although the flood risk at the local scale is low, the potential for contributing to the overall flood security is high. For the policymakers (Figure 5.2b), a dike ring in one of the oldest cities was chosen in the core of the north-west sub-delta. The area suffers from medium-high flood risk, yet its heritage of the historical dike system and strong economic power might provide opportunities for changes. For the interested public (Figure 5.2c), the entire delta region was brought into the vision. Participants were encouraged to contribute local visions and allocate those visions within the extent of the delta. In this way, interventions at different scales were synthesized, different dynamics cooperated, and different domains were coordinated.

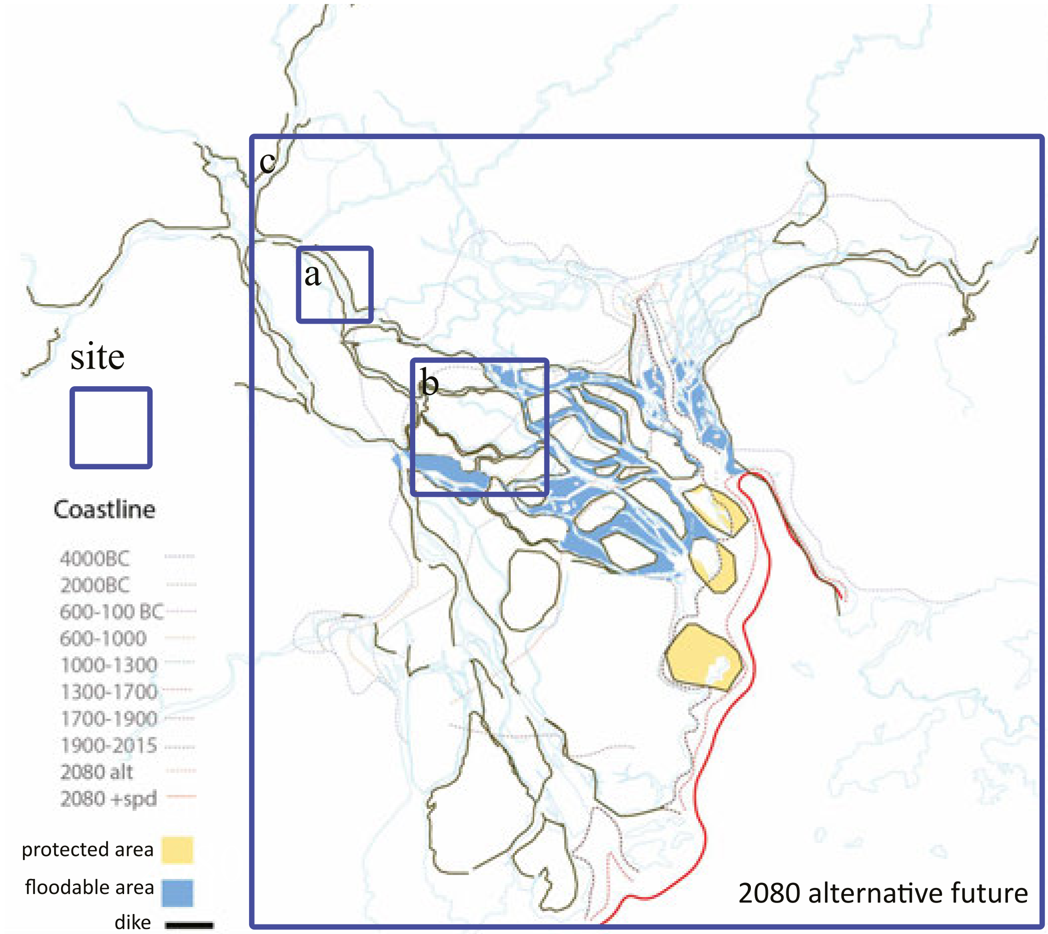

FIG. 5.2 **An alternative future of the delta highlighting the studied sites.**

5.1 Mapping with designers

Designers are expected to provide solutions to design and planning tasks. Their work depends on their creativity and the vision of development. It is essential to inspire designers to analyze and adjust the system while considering the elements to be spatially and temporally interrelated. It is also helpful to develop spatial principles that the designers can later apply. Therefore, the value of mapping is that it not only provides a proper understanding of the multiple spatial and temporal scales involved in the system before the actual design activity takes place, but also supports the design process with flexibility.

5.1.1 Setting of the mapping process

An experiment was set up to test how the mapping process could benefit the designers dealing with the PRD. The experiment was carried out in the form of multiple in-depth, face-to-face discussions and mapping processes between a junior urban and landscape designer and the author. During the experiment, the dialogue took place with both verbal and visual language. The form of multiple in-depth, face-to-face discussion and mapping allowed the mapping exploration to be explained and applied in the most direct way. It was possible to witness the idea development of the designer during the entire process. Therefore, the discussion, interaction, and drawing during the dialogue were used as materials for the assessment of the mapping. The designer was chosen for the following reasons. First, the designer is a native Chinese speaker and a local citizen of the PRD, and he is therefore able to make use of the local literature and knowledge. Second, the designer is a fifth-year student completing an independent design project. The designer has been equipped with adequate skill, yet the influence of the other approaches is reduced to an acceptable degree. This setting of the experiment had one obvious limitation; in practice, it is rare for an urban and landscape designer to work on his or her own. Due to the nature of design and planning, designers always work with other professionals and stakeholders in the real world, during which they utilize their skills of both creativity and communication. In this experiment, focus was placed on creativity, while the benefits of communication in the mapping approach are elaborated in the discussion.

The design task was to promote industrial area renewal and industrial upgrade at the local scale. After independently choosing the site, the designer was introduced to the maps and methodology of this study. The designer then developed the research and design on his own, in parallel with several sessions of discussion about updates on his work. Therefore, his research and design practice could be considered sufficiently reliable to evaluate whether and how the mapping exploration benefitted the design.

5.1.2 The outcome of mapping

The designer was supported by the mapping approach throughout the entire design process. To be specific, the designer was able to develop the following aspects using the mapping of spatial and temporal scales: the identification of a spatial hierarchy, comparison among spatial scales, distinction of rhythm-based subsystems, and generation of interventions according to the speed of change.

Identification of spatial hierarchy

The designer built the foundation of his analysis upon a scale hierarchy that was identical to the levels of the scale used in the mapping exploration presented in Chapter 3. In the design research phase, the transformations of the four subsystems, namely dikes, settlements, landscapes, and roads, were analyzed. Then, a multi-layer approach was applied with 3 subsystems of the delta, namely the substratum, network, and occupation (Figure 5.3)). Five layers were further distinguished according to their speed of change, namely the geomorphology, water management, vehicle infrastructure, agriculture network, and urban pattern. The design exhibited the same logic in the choice of scale hierarchy as the original mapping approach from two aspects: (1) both the land-based and the water-based scale hierarchies were deemed important for the understanding of the delta region, and (2) the understanding was based on the analysis at multiple levels of scale. The designer acknowledged both the land-based and water-based scale hierarchies in the understanding of the delta region, for which there were two pieces of evidence found in the design. First, the designer selected a scale hierarchy that combined both the land-based and water-based scales in the research framework. It included five spatial levels in the analysis, namely the multi-river basin, river basin, delta, regional, and local levels (Figures 5.5, 5.6, and 5.7). The multi-river basin, river basin, delta, and local levels are water-based scales, while the regional level is a land-based scale that included two neighboring prefectures. As compared to the scale selection of this study, two more levels of scale were added to the design, namely the scales of the multi-river basin and region. The second piece of evidence was that the choice of cases for comparison also reflected the consideration of both land-based and water-based scales. At the level of multi-river basin analysis (Figure 5.4), the designer compared the PRD with two other major river basins in China. He drew a map with three deltas and their river network, and a land-based extent, namely a national boundary, was applied to river basin analysis. This demonstrates that both the land-based and water-based scale hierarchies were considered to be relevant. The designer chose to compare deltas within a similar political boundary, instead of to reflect its geomorphological neighbors.
The designer developed the same principle for planning and design with a water-based scale perspective not only in the analysis phase, but also in the strategy-making phase. In the zoning plan (Figure 5.4), a water-based scale could be recognized by three pieces of evidence. First, the boundary of the site was based on its relationship with the water around it. Second, the legend of the map (dry zone, open polder, and restoration zone) reflected that the focus of this zoning was the water and the water management infrastructure. Third, the zoning map was illustrated in a way that covered the oriental urban pattern. Compared to the best part of the map, the urban pattern of the site was hidden beneath the zoning. The background of the site lightly illustrated the road and river network. Moreover, the major reference for zoning was also the rivers. These details indicate that a strong water-based scale was implemented in the development of the strategy.

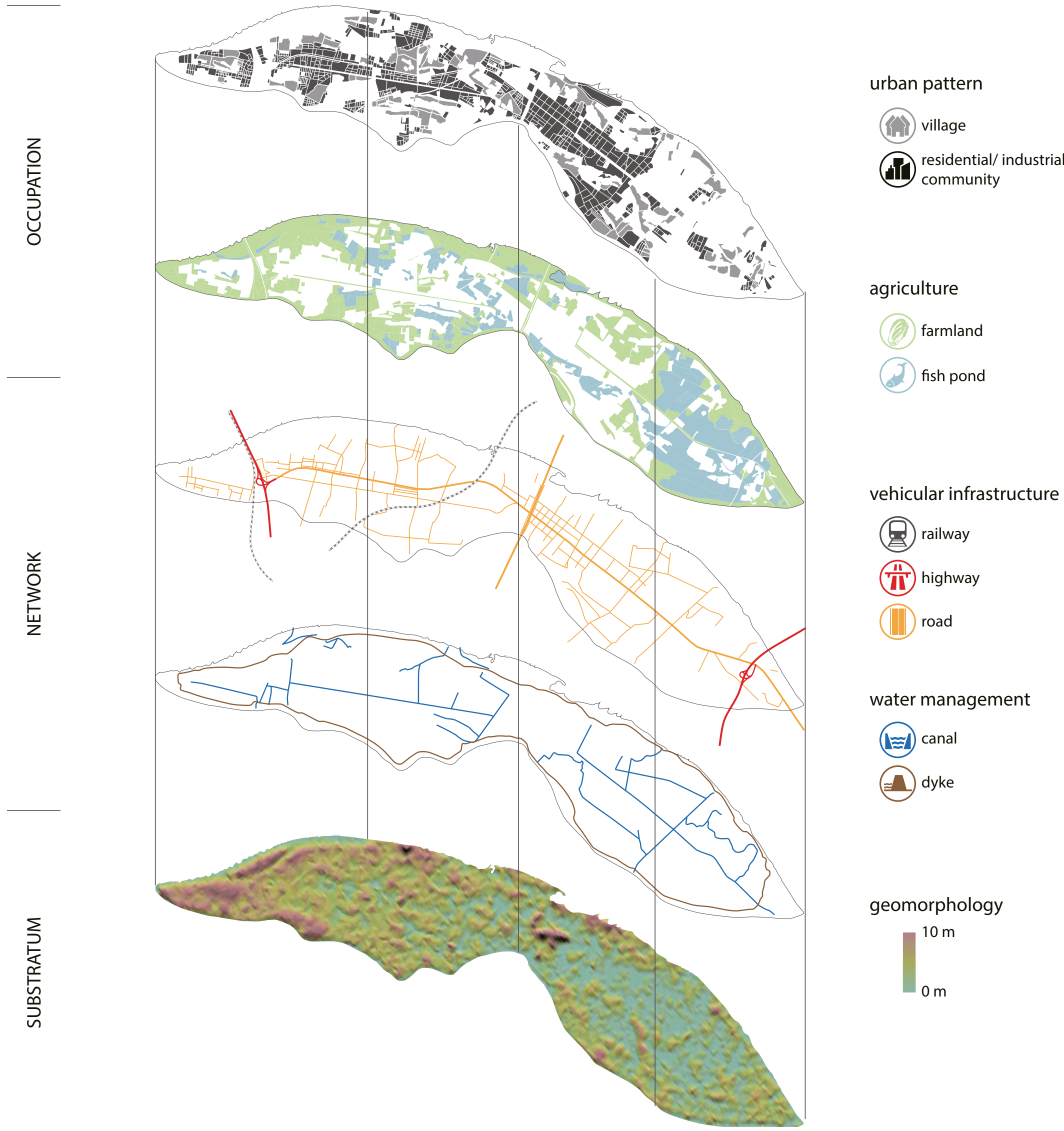

FIG. 5.3 **Multi-layer analysis.**
Based on the three subsystems of the substratum, network, and occupation, the designer illustrated 5 layers according to their speeds of change. This new way of classification and analysis led to solutions that address the temporal linkages within the system. Figure from Zhou (2017, p. 34).

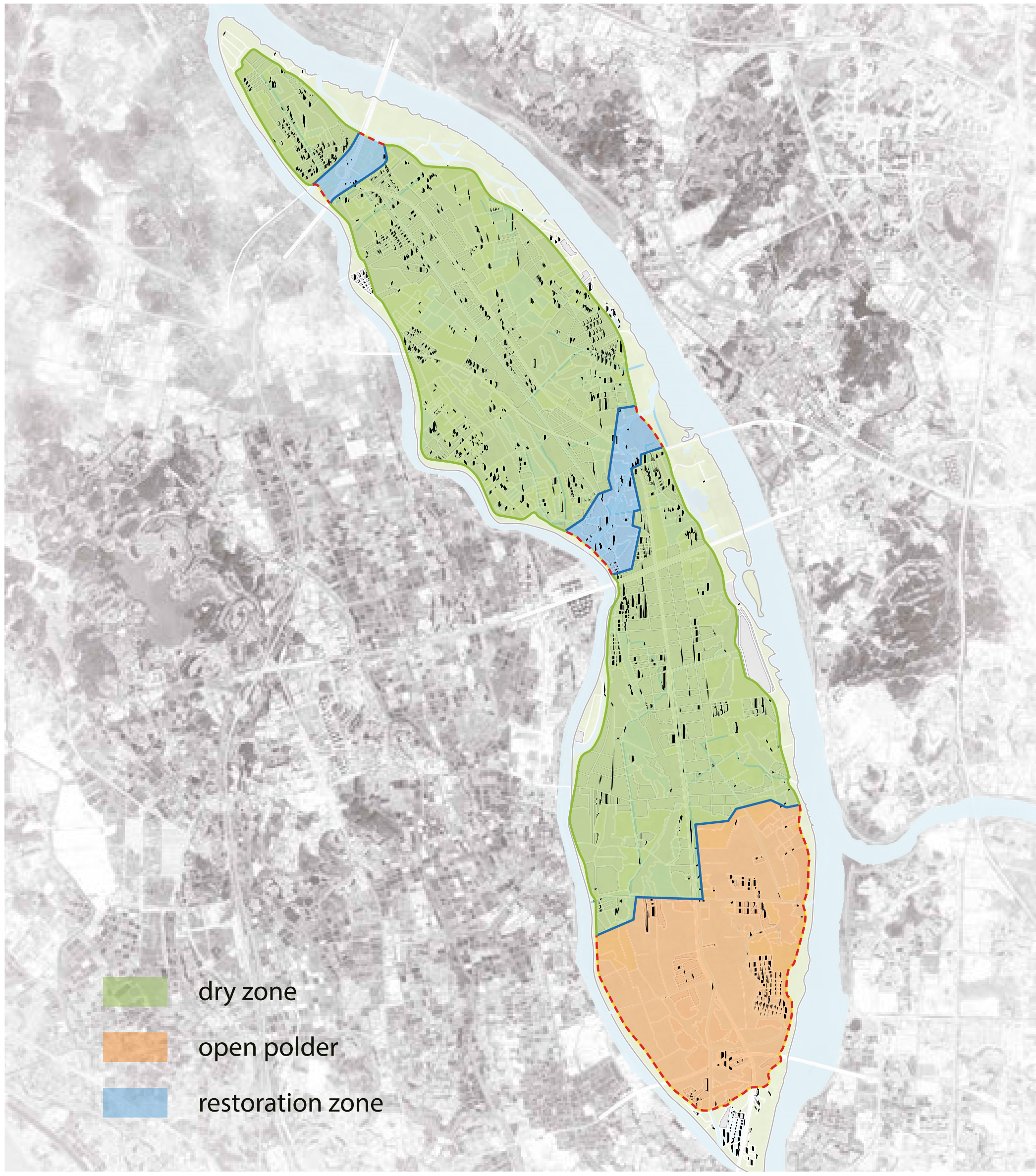

FIG. 5.4 **Zoning plan for the site.**
The application of a water-based scale can be found in two places on this map, namely the boundary and the legend. The boundary of this site is a piece of independent territory surrounded by water. Additionally, the names of the zones reflect their relationships with a water and water infrastructure. Both pieces of evidence demonstrate that the zoning plan is based on a water-based scale. Figure from Zhou (2017, p. 59).

Comparison among spatial scales

In addition to the scale hierarchy, the approach helped the designer to develop the understanding that a delta region requires analysis from a multi-level perspective, for which there were two pieces of evidence. The first piece of evidence is the analysis at the delta level (Figure 5.5). In addition to the main extent of the delta scale, the extents of both the regional and local scales were identified in this map. This reflects the designer's awareness of the function of multiple levels for the understanding of the territory. Furthermore, he zoomed in to the level of the regional scale (Figures 5.6 and 5.7). In this case, the lower extents and local scale were still focuses of the map. The designer continually highlighted the lower extents in the maps to help him with the site analysis. The two treatments during the mapping process demonstrate that, in this case, knowledge could be generated via the comparison between spatial scales.

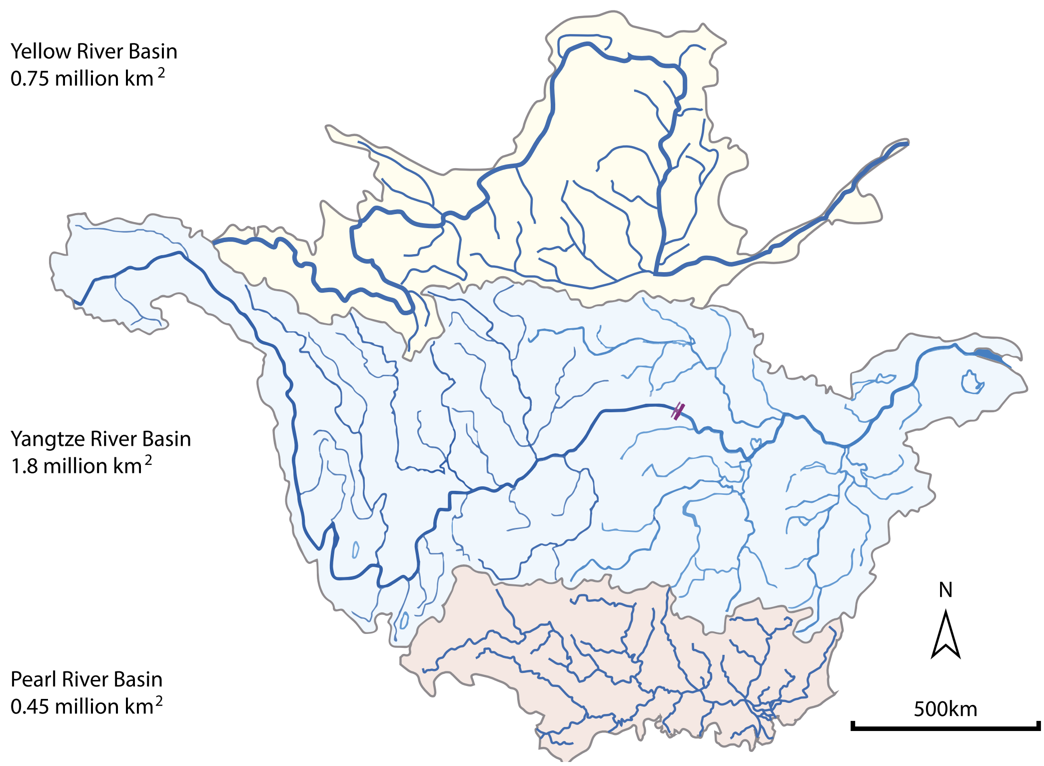

FIG. 5.5 **Multi-river basin analysis**
The designer chose to compare three main river basins in the Chinese territory. The comparison includes the area, mainstream morphology, and river network. Figure from Zhou (2017, p. 3).

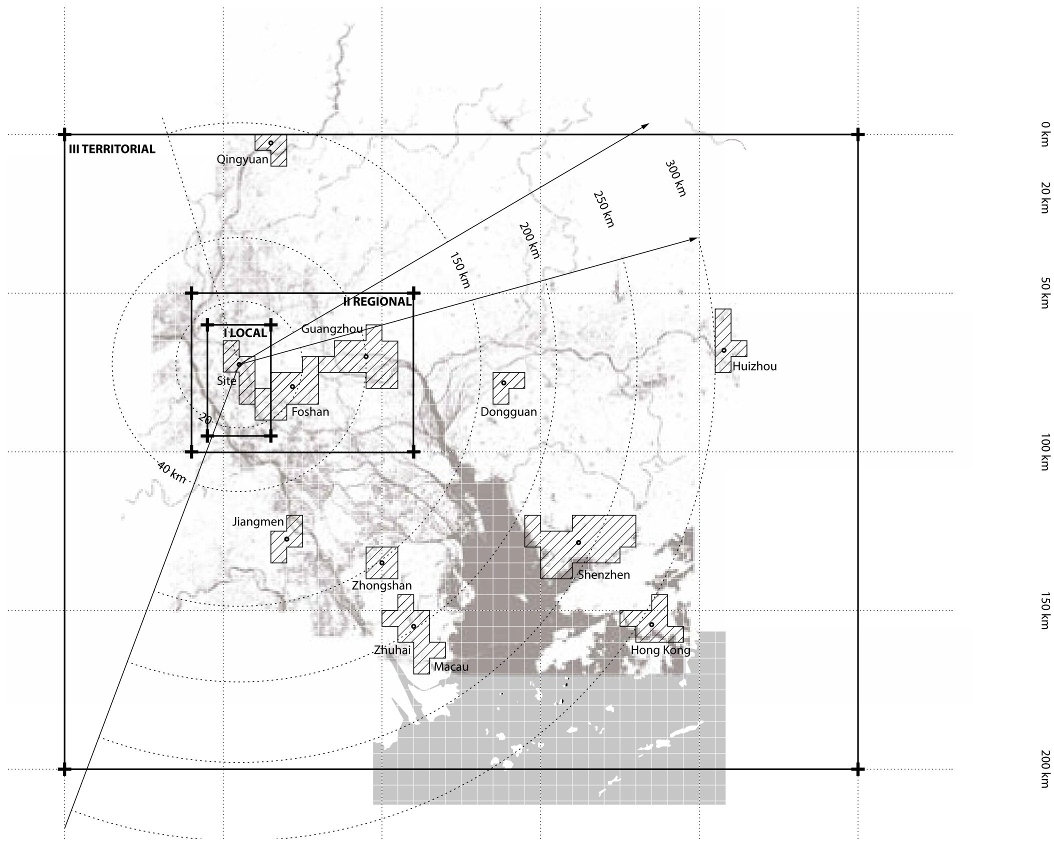

FIG. 5.6 **The delta-level analysis with the extents of the regional and local scales.**
In this design analysis, the designer identified the distances to the most urbanized and densified areas within the delta, though this is not the most important information presented. Instead, the three extents, namely the delta, the region, and the local extents, are emphasized with bold, rectangular frames. Figure from Zhou (2017, p. 29).

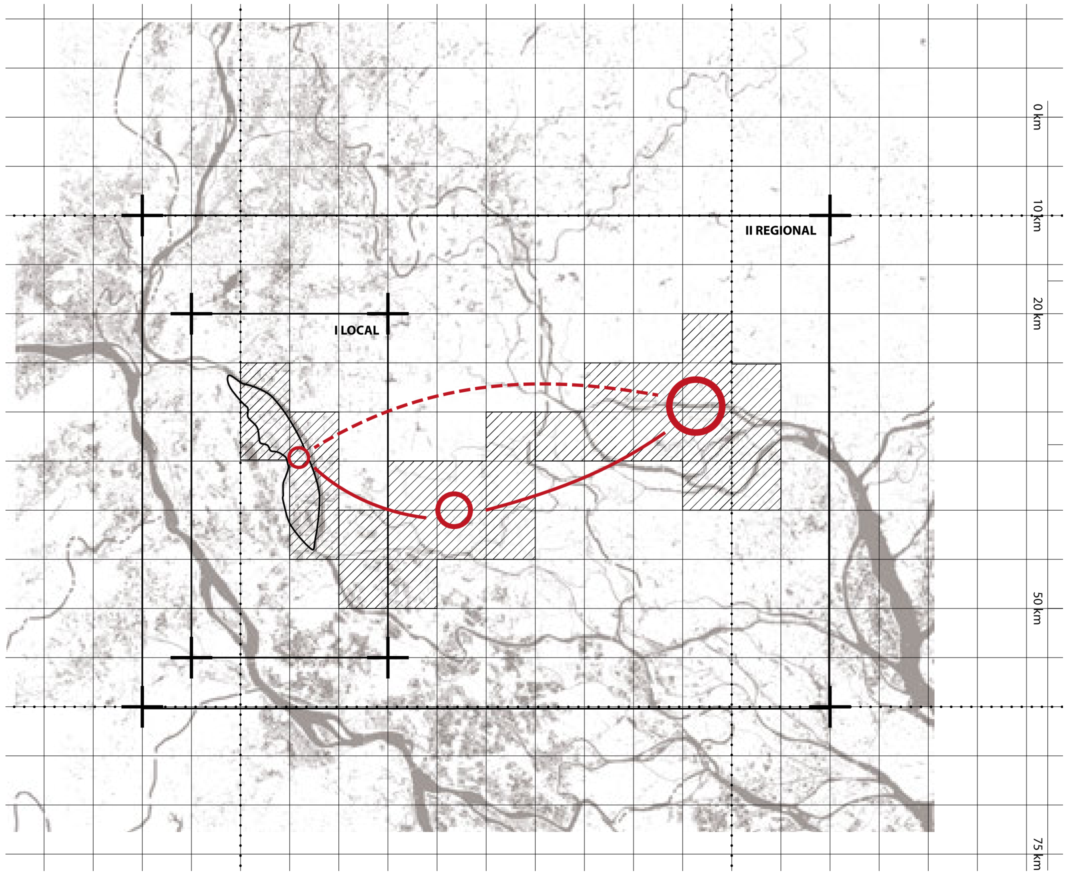

FIG. 5.7 **The regional-level analysis with the extent of the local scale.**
In this map, red indicates the relationships among the sites, the capital of the municipalities, and the capital of the province. However, the extents of both the local and regional scales are still emphasized with bold frames. Figure from Zhou (2017, p. 30).

Distinction of rhythm-based subsystems

The speed of change is another important component of spatial-temporal mapping exploration. The division of the speed of change in the designer's map of the dike system was the same as that used in this study (Figure 5.8), and belongs to the subsystem of the network. In the map series of the dike system, all the maps indicate morphological changes in the dike system, excluding the map of 1949. The designer could have chosen to not draw this map because there were no changes during the period; however, he chose to place a redundant map of 1949 to match the original mapping exploration, which included a map of approximately 1950 at the delta scale. This action indicates his attempt to maintain the continuity of the mapping technique. This unnecessary map of 1949 and the similarity in the mapping of the speed of change of the dike system are clear signs that the designer applied the division of the speed of change presented in this study.

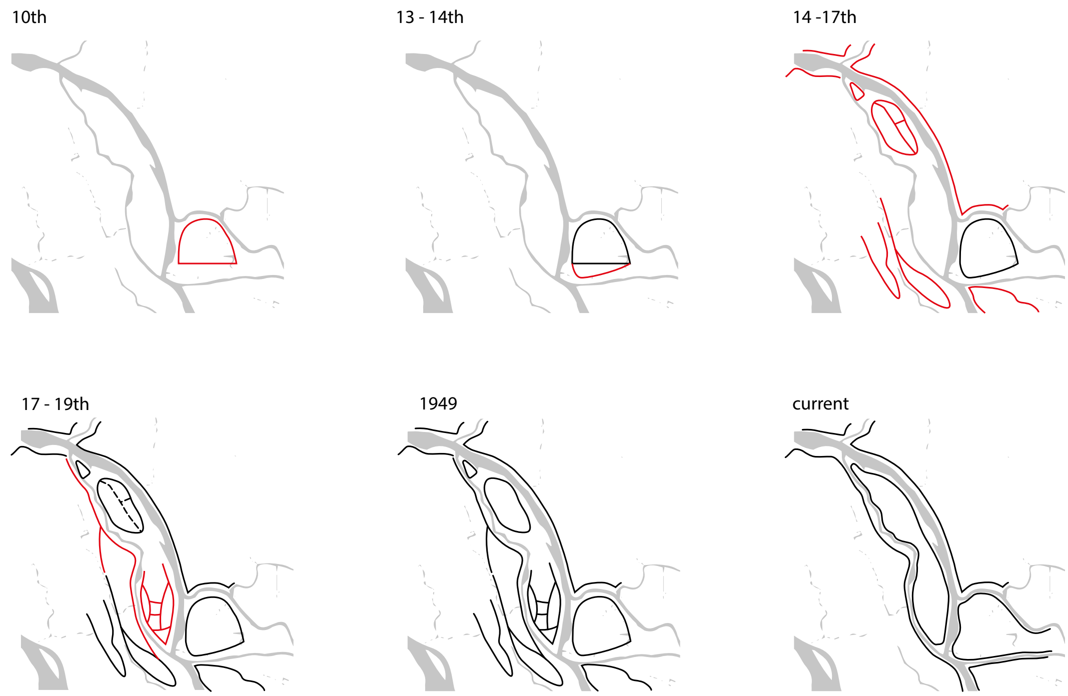

FIG. 5.8 **Development of the dike system.**
The speed of change of the dike system in the design is the same as that used in this study. All the maps reveal morphological changes in the dike system, excluding the map of 1949. Figure from Zhou (2017, p. 31)

Generation of interventions according to the speed of change

During the application, the designer adjusted the approach to better fit the context of his design and research. A finer resolution was introduced by the designer during the local-scale analysis. Additionally, the subsystem was identified in more than one level, in which several types were distinguished in each layer. In total, there were two types of urban patterns, two types of agricultural land use, three types of vehicle infrastructures, and two types of water management networks. This finer resolution acted as a strong foundation for the later experimental design at even smaller scales (Figures 5.3 and 5.9). This difference reveals that the system perspectives in both the design and this study were well developed. In this study, the delta was interpreted as a two-level system that consists of subsystems. In contrast, in the design, the delta was interpreted as a three-level system that consists of subsystems, each of which also has its own subsystems. In both the two-level and three-level system perspectives, a proper resolution was chosen for distinct purposes. In this way, the three subsystems of the substratum, network, and occupation were even more convincing in the research and design of the delta region. This adjustment reveals a good adaptivity in the application of the approach.

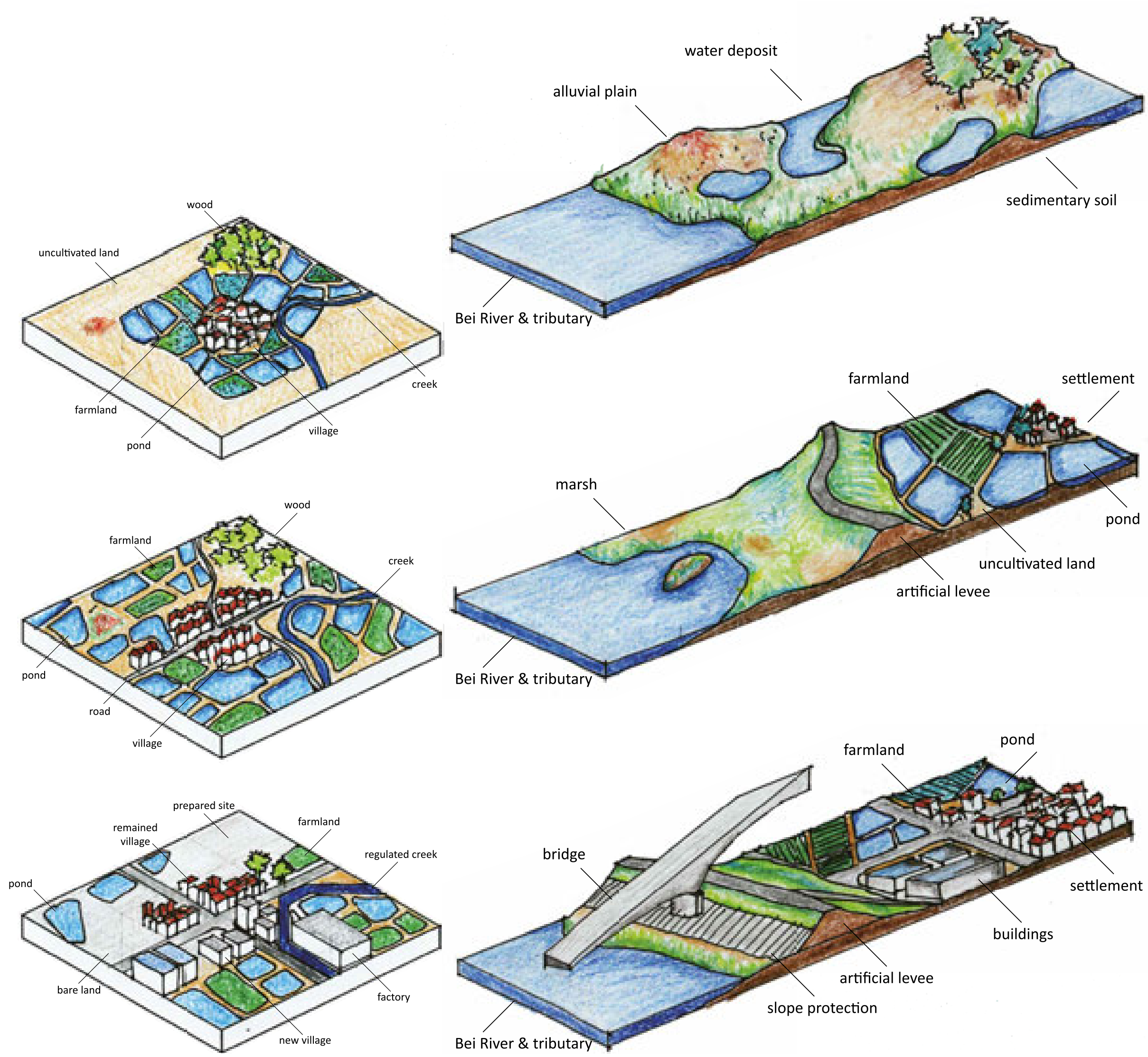

FIG. 5.9 **Occupation (left) and landscape (right) development. Several types of development are distinguished in each subsystem of the delta.**
Figure from Zhou (2017, p. 32).

In this setting, the spatial-temporal mapping approach functions as an analytical tool. This systematic method of analysis enabled four features for mapping exploration, namely a division of subsystems based on the speed of change, a spatial-scale hierarchy that includes both land and water scales, an analysis via comparison between spatial scales, and a division of the case by the localized speed of change. These features supported the designer in the decomposition, comparison, and linking of the spatial-temporal information. A high inter-subjectivity was witnessed based on the design perspectives of the scale, subsystems, and speed of change utilized by the designer. Because the design is a product of the way of thinking of the designer, these design perspectives reflect the interpretation of the designer. The more similar the design and the perspective provided in this study, the more confidently it can be said that the designer interpreted this approach in the same way as the researcher. The application exhibits a high similarity between the design and this study from the perspectives of scales and subsystems. Regarding the perspective of the speed of change, the designer highly acknowledged the speed of change in water management infrastructure, which is part of the network subsystem. However, there was a disagreement in the strategy of the mapping of the subsystems. The designer chose to apply an independent speed of change for each subsystem, whereas this study recommended continuity in the application of the speed of change for all three subsystems. A further discussion of the impact of this difference is presented in the following related section. Overall, there was a high similarity between the interpretation of the chosen design and this study.

There were several principles of spatial organization drawn by the designer during the application of the spatial-temporal mapping approach. The first principle of spatial organization was to reintroduce the visualization of the delta landscape to the public; the same principle was developed in the design. In the spatial organization principle of the site (Figure 5.10), the designer visualized the delta landscape by linking the water network inside the site. This principle would increase the accessibility of the original delta landscape for the site, thereby increasing the visibility.

FIG. 5.10 **The spatial organization principle of the site.**
The priciple aims to restore the current state to its natural state to a certain degree. Figure from Zhou (2017, p. 60).

The second principle was to create more room for water using old dike rings. Although it was not indicated in the text, this principle could be recognized in the experimental design of the local scale by comparing the design with the historical situation. Figures 5.11 and 5.12 present the spatial intervention for the creation of more room for water via the use of old dike rings. In Figure 5.11, interventions take place in three locations of the site. The modification and construction of the current dike rings (left) are actually the restoration of the morphology of the dike rings in the 17th through 19th centuries (right). The high similarities with the older locations and forms can be recognized in the dike systems of the north and center interventions. In the south intervention, although the form is different, the locations of the intervention are the same as those of the old dike rings. Figure 5.12 reveals high similarity between the designed water storage and the former form of the dike ring in the 17th through 19th centuries. This spatial organization principle exists without a formalized expression.

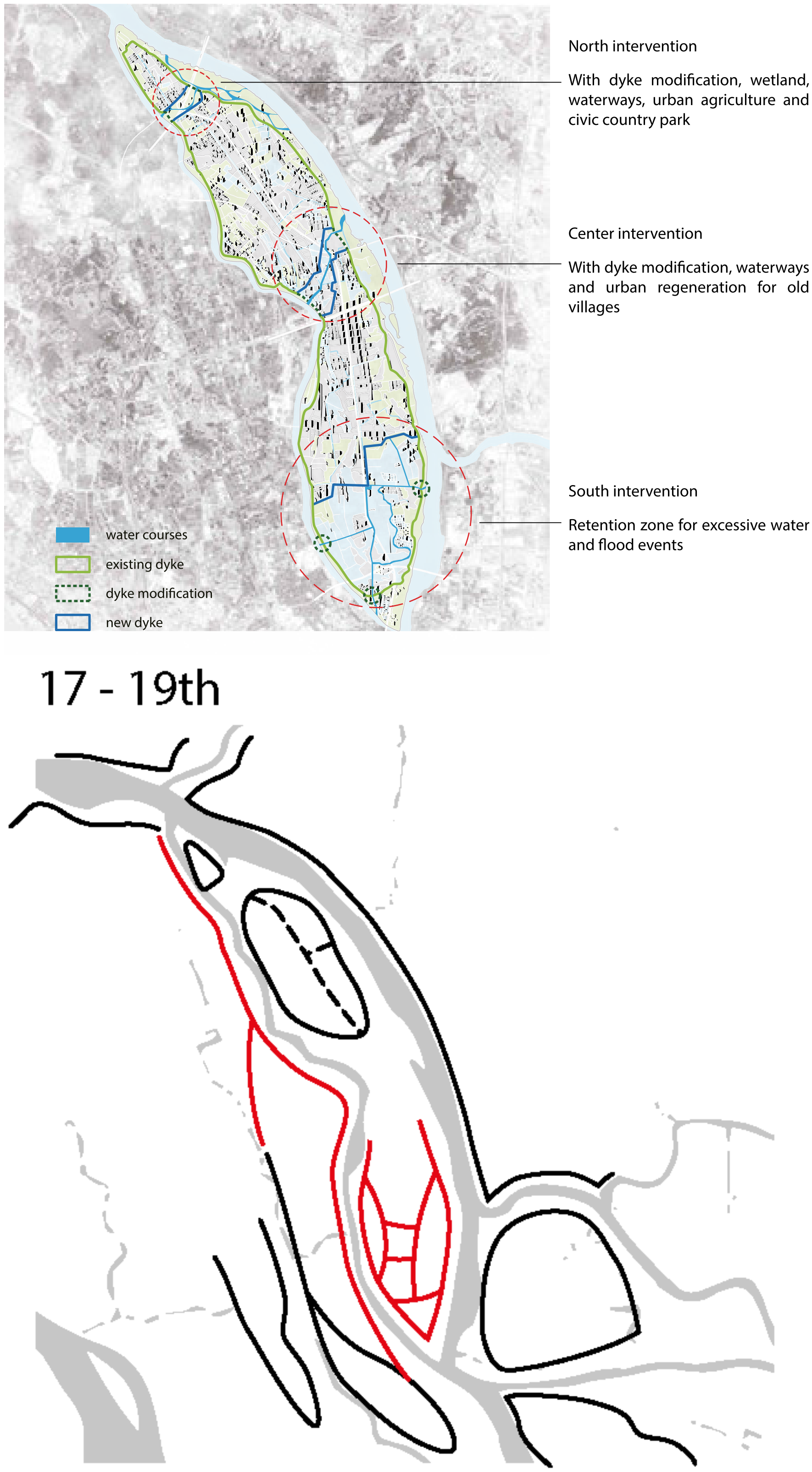

FIG. 5.11 **Strategy to link the water network around the site.**
Referring to the old dike system development in the 17th through 19th centuries (bottom), dike modification and construction are highlighted as the main actions by which to create more room for water. Figure from Zhou (2017, p. 60).

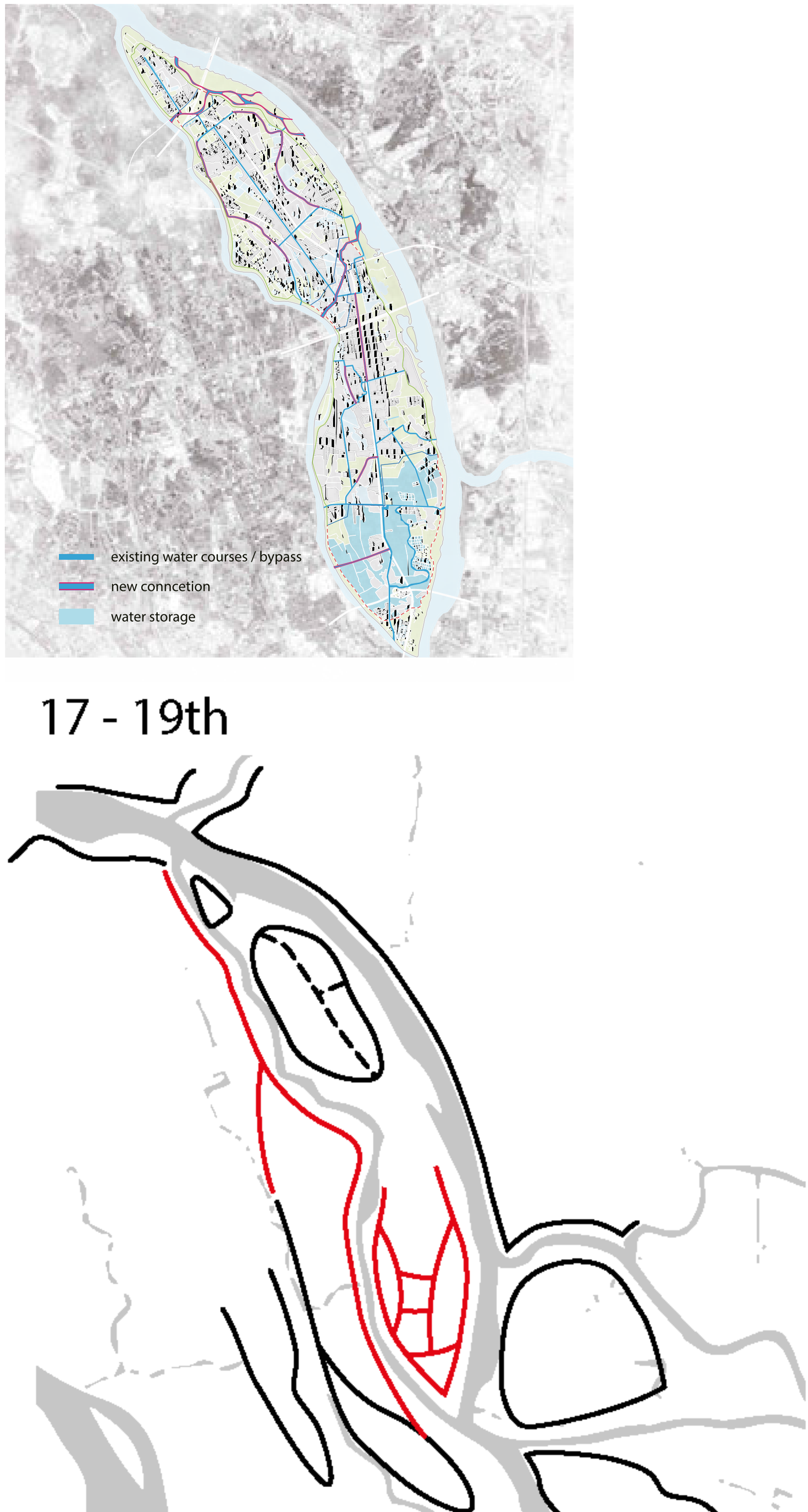

FIG. 5.12 **Linkage of the water network within the site.**
Compared to the dike system in the 17th through 19th centuries. The water storage in the design covers the area where new dike rings were built in the 17th through 19th centuries. Figure from Zhou (2017, p. 61).

5.1.3 Discussion

Mapping of the PRD with a designer

The experiment of mapping with a designer appeared to be fruitful. By exploring spatial relationships via the multiple levels of spatial and temporal scales, the designer gained new possibilities for tackling the challenges in the design assignment. There were three aspects from which mapping was demonstrated to be beneficial to the designer, namely comprehensiveness, integrability, and flexibility. These aspects ensured that the designer had a perspective and tools that were easy to understand and utilize.

The first advantage of using the multi-scale mapping approach during the design process is its comprehensiveness. In the experiment, the design appeared to be consistent from the analysis, to the spatial principle, to materialization. The systematic analysis of the delta ensured a scientific and comprehensive understanding of the region. This understanding directed the design toward interventions that addressed the challenges in a similarly systematic manner. Figure 5.1 shows that, by analyzing the connections according to the speed of change, a new design perspective was developed in which the design challenges were approached from the regional level to the building level, allowing for a comprehensive solution to the assignment. In addition to being beneficial to the assigned task, this new way of designing uncovered new challenges that were originally absent. The outcome of the design provided solid evidence of the power of this mapping approach in discovering new challenges and solutions.

The second advantage of this approach is its integrability. The experiment revealed that the approach performed well for the organization of information and knowledge according to spatial and temporal relationships. The new way of structuring knowledge provided insights for the designer. Moreover, there were no significant differences found between the expressions of the new way of structuring (Figure 5.2). With similar visual language, the designer was able to develop spatial strategies that optimized the spatial and temporal relationships. Visual language played a consistent role in the design process, suggesting that this mapping approach could be well integrated into current design practices. Designers do not need to learn new languages of exploration and designing, but a new perspective from which to utilize their skills is beneficial.

The third advantage of this approach is freedom during the design. The designer had great flexibility in identifying the relevant spatial and temporal levels during the design activity. In the experiment, the designer chose to develop three different speeds of change in his analysis of different subsystems, rather than using a consistent speed of change for all the layers as specified in the original mapping approach. The speeds of change varied in the analysis of the layer of road and settlement development (Figure 5.13) and the layer of urban pattern development (Figure 5.14). In these two layers, the speed of change was identified based on the morphological and typological changes. However, the designer chose to not synthesize the rhythm difference within the same scale. In contrast, in the original spatial-temporal mapping approach, the rhythms of the three subsystems were synchronized. Applying separate speeds of change helped to reduce redundant information in the layers with slower speeds of change, and also contributed to the easier understanding of the focused layer. However, the drawback lied in the difficulties of overlaying the layers and making a multiple-layer analysis. The choice to use separate speeds of change for each subsystem led to a lack of analyses of the interactions among the three major subsystems in the design, though such interactions are one of the key issues addressed in this study for the understanding and design of the delta region. A synchronized speed of change is also part of the system's ability to be used to study the interactions among the subsystems, as the speeds of change of subsystems are not isolated, but rather influence each other. Such rhythmic differences and connections have been some of the causes of ineffective planning and design in the delta region, which has been explained in previous chapters. Therefore, a coherent rhythm among all the subsystems was recommended. Such a variation in the perspective of the speed of change could possibly lead to a change in the current planning and design practice. Despite the recommendation of the author, in practice, designers could also judge the situation themselves to better suit the complex circumstances. The high level of freedom supported by this multi-scale mapping approach will ensure the creativity of designers.

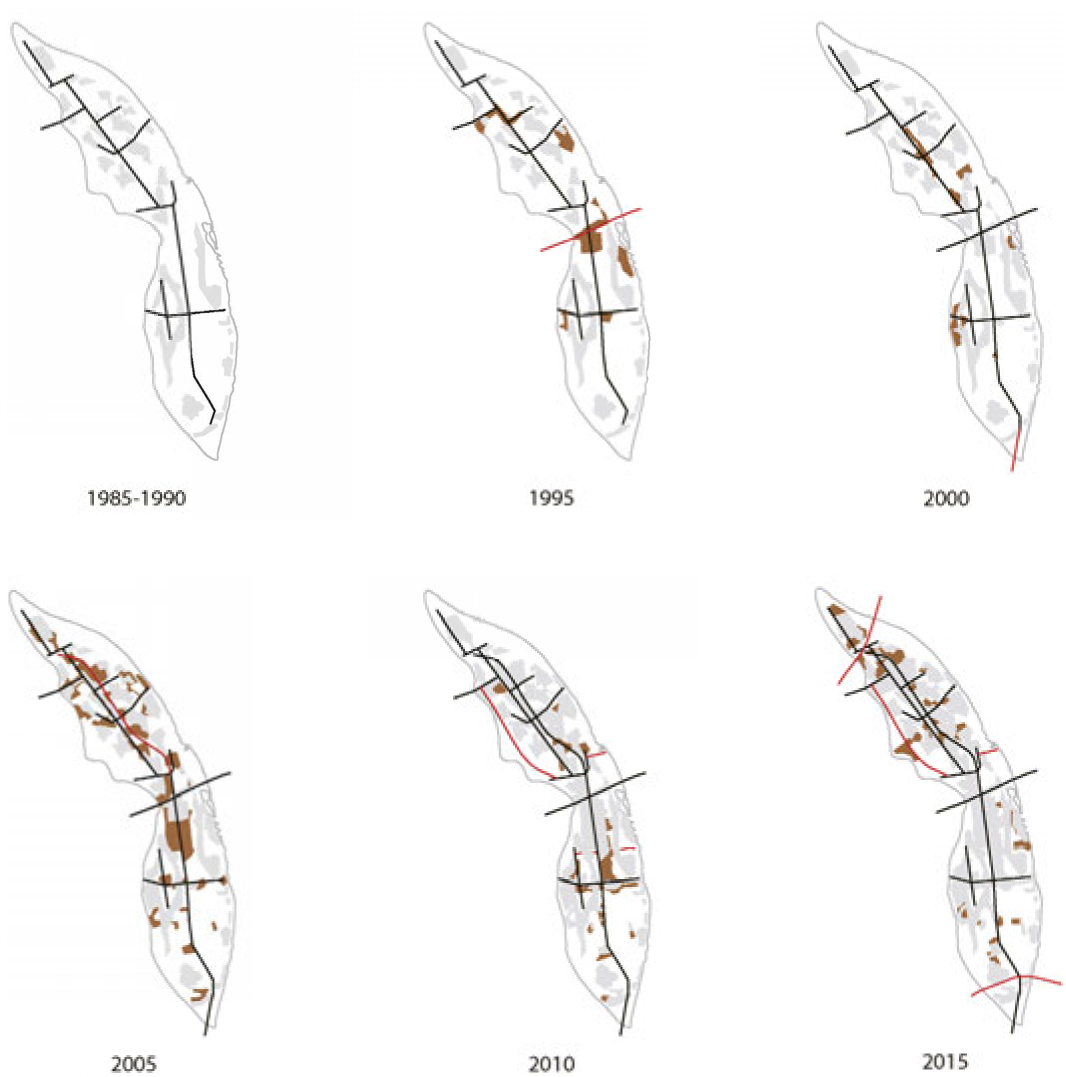

FIG. 5.13 **The speed of change in the design.**
The designer chose to use different speeds of change in his design, rather than the synchronized speed of change recommended in the original study. In the phase of the road and settlement development, the speed of change is different from that of the layer of the dike system. Figure from Zhou (2017, p. 33).

FIG. 5.14 **The resolution chose in the design.**
In the mapping of the urban pattern development, a finer resolution was developed by the designer to explain the morphological typology development. Figure from Zhou (2017, p. 38).

The experiment exhibited a very promising result for the application of the proposed multi-scale mapping approach in the design. In the form of multiple in-depth, face-to-face discussions and mapping processes, a junior urban and landscape designer learned the proposed approach and utilized it in the design process. As mentioned at the beginning of this section, the experiment limited its assessment to the support of the creativity of designers at the individual level. However, there exist many cases in which designs and plans are developed by a team. Regardless of how the design and plan were created, all the designers would go through a process with the involved clients. In the case of the PRD, the government is the main client of the design and plan, and masterplans are developed with policymakers in the form of presentations. Therefore, meetings with policymakers play an important role in collective design. A second experiment was therefore conducted to test how the mapping approach is beneficial in a group setting.

5.2 Mapping with policymakers

In addition to designers, policymakers are other dominant players in the development and implementation of spatial plans. The complexity theory in urban planning and design suggests that the structure of planning should be taken into consideration when making a plan (Portugali, 2011). The capability of the design has a strong connection with the complexity of its application context. The role of mapping, therefore, requires the ability to facilitate the different roles of the plan-making process. Since the re-organization of China's planning system, the central government has displayed ambition in abandoning the segregated planning culture. This has provided opportunities for the emergence of new methods of design and planning. In this section, the mapping approach is applied to the government, and the related experiment focused on the capability of developing a comprehensive plan via a collective design setting.

5.2.1 Setting of the mapping process

An experiment was conducted to test how the mapping process could benefit policymakers in the PRD. A workshop was arranged for policymakers in groups of less than 20 participants. The workshop was applied at both the municipality and district levels. During the workshop, the researcher first gave a lecture on the mapping method and the insights generated by the maps. Then, a free discussion was organized based on an analysis of the local site. Finally, the participants were invited to introduce current challenges to the local map.

In the Foshan workshop, two bureaus of the Foshan government, namely the Foshan Bureau of Land Resource and Urban-rural Planning (FLUP) and the Foshan Water Authority (FWA), as well as one institution, namely the Foshan Institute of Urban Planning, Survey, and Design (FSPS), which is under the umbrella of the FLUP, were involved. FLUP organized the workshop. In addition to a senior researcher from the China Development Institute (CDI) and the researcher himself, there were 12 participants from Foshan City. In the Shunde workshop, there were 31 participants from the involved bureaus at the district level and representatives from the local street level (the former village unit before urbanization). The Shunde Bureau of Land Resource, Urban Construction and Water (SLUW) organized the workshop. Three decision-makers from three levels, namely the district, sub-district, and township-street levels, were involved with the SLUW. At the township-street level, 2 towns and 3 streets were involved. Two institutes affiliated with SLUW also joined the workshop, namely the Shunde Institute for Water Resources and Hydropower Survey and Design (SIWSD) and the Guangdong Shunjian Planning and Design Institute Co., Ltd. (SDPDI).

5.2.2 The outcome of mapping

The spatial-temporal mapping approach helped the participants generate a common understanding of the relationship between flood defense and urban development. The approach was used to understand multi-scale knowledge, distinguish rhythm-based subsystems, generate common knowledge and insights, promote inter-discipline cooperation, and seek innovative solutions. A conversation about the exploration and understanding of the current issues in water management and urban planning was initiated based on the maps. The application of this approach resulted in a section map that combined the knowledge about local water and urban information. Further collaboration was also agreed upon by the participants.

Understanding multi-scale knowledge

The mapping approach helped to present a body of multi-scale knowledge of the PRD, which was well received by the participants. This was supported by three pieces of evidence. First, a layperson utilized the maps to gain more insight into his own memory of local flood events and regional causes. The layperson was able to explain floods on the local scale with several pieces of regional evidence presented to him, and was capable of understanding the causes of several flood events in the past. This finding was the same as the interpretation of this study. The second piece of evidence was that the local officials started to use this perspective to communicate and make decisions. By placing themselves in the political and territorial hierarchy with the help of the maps from the local and delta scales, the officials shared their knowledge under the multi-scale framework that was developed in the spatial-temporal mapping approach. The engineers suggested that the researcher present the findings to upper-level governments, and believed that the decisions made at this level would lead to a solution in their own region. This implies that they realized the existence of scale and scale-related solutions.

However, based on their experiences, the officers stated that there would exist the possibility of unexpected restrictions if the upper-level governments paid too much attention to this topic; therefore, they preferred to make some achievements on the local scale before reporting to the higher-level governments. The reaction from the local officers demonstrated how decisions could be made in local governments based on the understanding of the level of scale both politically and territorially. The third piece of evidence was a call from the experts for more in-depth research on the local and lower scales. The participants realized the power of this narrative in generating knowledge and developing a possible strategy for the region, and they therefore demanded a specific study of the local or lower-level situations to aid in their decision-making process. In one of the workshops, the participants reflected that there exists an urgent lack of study in underground, subsidence, and section. While they expressed that the mapping presented in this study is useful for decision-making, exploring challenges and possibilities, and shaping strategies, they believed the results of this study to be insufficient for their current objectives. Therefore, the decision-makers invited the researcher to conduct further research at lower scales to generate insights that could support their practice. This invitation demonstrated not only the acknowledgment of the power of multi-scale mapping, but also the interpretation that local knowledge can shed light on improvement. All these reactions showed that, regardless of educational levels and knowledge backgrounds, the advantage of the multi-scale perspective in understanding the delta as a multi-scale system was sufficiently interpreted by the participants within the local context. Fragmented and isolated knowledge was connected in a well-organized way, and this multi-scale knowledge was helpful for both experts and laypersons in understanding the delta region. The interpretation with a local context also helped to enhance this approach for the real planning and design of the region on the local scale. It can be confidently said that the multi-scale perspective was well received in a similar way as it was presented. This systematic way of thinking helped the local participants to understand the delta from the perspectives of various scales.

Distinguishing subsystems and their speeds of change

The spatial-temporal mapping approach enabled the understanding of the speed of change of the system by the participants. The speeds of change in different subsystems were understood and utilized in one of the workshops. Because of the involvement of the speed of change during the analysis, participants were able to address the difficulties encountered in planning and design with a perspective that had never been used before. One participant from the urban planning and design sector recalled a failed attempt to cooperate with the water sector when they ignored the request to collaboratively identify undesired spatial interventions at that moment. This new perspective of the problem provided possible solutions that could not have been imagined previously. This participant used the concept of the speed of change to argue that the collaboration between the two sectors would be of common benefit. In the argument, the difference in the speed of change and the importance of connecting the two subsystems were emphasized. The participants from the water sector stated that their difficulty in collaboration was partly related to the time required to make a plan. By visualizing the differences in the speeds of change of the evolution and planning in the two subsystems, the two parties realized that part of their miscommunication had been due to the difference in the speed of change. This finding helped them to build up trust and understanding for further collaboration. The participants from the planning and design sector initiated cooperation in data and knowledge-sharing in an invite-only lunch after the discussion, and the chief officer of the water sector orally agreed to this proposal. A list of pilot projects on the local scale was also agreed upon during the lunch. The application of the difference in the speed of change during the argument demonstrated that both the water sector and the planning and design sector interpreted the presentation in the same way, and an agreement was reached based on this common understanding. The capability of the mapping approach to work around several issues by providing a new perspective by which to interpret the local knowledge was revealed.

Generating common knowledge and insights

The mapping approach also demonstrated its usefulness in reaching an agreement by providing a common language for communication. Using the same approach, participants from the two workshops drew the same conclusions about future risk and its theoretical location in the delta region. There was a point after the presentation during which some participants disagreed with the researcher on a major conclusion. The participants from the water sector brought up the discussion of the flood risk during both workshops. They claimed that pluvial flooding is currently the main focus of the flood defense of the region, whereas the presentation expressed that fluvial flooding will be the main threat to the delta with dispatched urbanization. Participants with other backgrounds joined the discussion by contributing their understanding of the site. The power of a common language functioned during the exchange of ideas and specialized knowledge; by engaging in a discussion with the maps in view, the specialized knowledge of each of the two domains was able to be understood by the other party. A common acknowledgment and understanding of the site were ultimately reached with the knowledge input to the same space from the perspectives of both hydraulic engineering and urban planning. By viewing the situation from the perspective of a complex system, the participants developed the conclusion expressed in the presentation about future risk and its theoretical location. Therefore, the disagreement about the outcomes of the mapping approach could be debated. With the help of both the section map and the local scale analysis, some planners reminded the group of a recent fluvial flood 12 years ago by pointing to the location. Finally, the group concluded the discussion with a balanced concern for both fluvial and pluvial flooding. With the help of mapping, the participants from the government broadened their focus from a sectoral scope to the scope of the delta as a complex system. Their focus also switched to the prediction and planning of the future security of the region. The reliability of the study was supported by the change of opinion of the participants from the water sector on the focus of flood risk in the region. The mapping approach was therefore proven to be able to generate common knowledge during the decision-making process.

One notable outcome of the experiment was that common knowledge was generated through collective mapping. In both workshops, officers from different sectors were convinced and shared their knowledge to make a new section map of the studied area. For the first time, knowledge from different sectors was gathered in real-time and presented in a visual way according to the participants of both workshops. Because data segregation has been an obstacle to the communication between the water and land sectors in the region for more than 18 years, it is rather rare for both planning departments to directly interact with each other using visual language.
To achieve this, the collective mapping was carefully designed. Before the collective mapping, a comparative study of two other delta cities, namely New Orleans, USA and Dordrecht, Netherlands, was introduced to the participants. In the study of New Orleans (Figure 5.15), a photo of the flood wall was accompanied by a section map of the flood defense along the river. The human scale was established by both the photo and the data in the section map. The researcher then asked the participants to imagine a height of five meters from the top of the flood wall to the ground. The researcher used the high of a two-story building as a reference to strengthen the visual image of the participants. The flood defense return period of New Orleans, a 100-year flood, was also provided in this section map. Its return period was the same as that of the location of the workshop so that the participants could link this case to their own experience. After the visual imagination and comparison, the researcher reminded the participants of the failure of the flood defense system in this case during Hurricane Katrina in 2005. The case of Dordrecht was then introduced in the same style (Figure 5.16). A photo of the on-site flood wall was accompanied by a section map. The participants were also reminded of the height difference of 5.5 meters from the top of the flood wall to the ground, and the flood security level in Dordrecht was then explained. The researcher told the participants that, in the case of Dordrecht, the current standard of 10,000-year floods will

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decrease sharply to 100-year floods. This shrinkage will be caused by similar processes to those in the PRD, such as sea-level rise and land subsidence. However, the pace of the PRD will be far quicker than that of Dordrecht because of its fast urbanization process. After the two cases were presented, the researcher casually invited the participants to make a similar section map using their local knowledge.

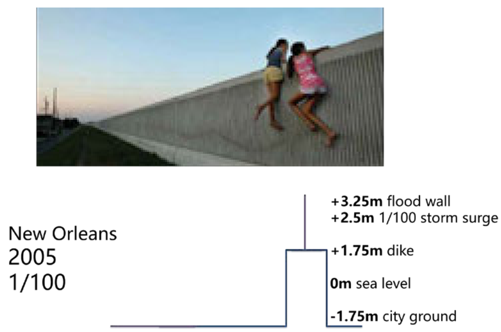

FIG. 5.15 **Case study of New Orleans for the visualization evaluation.**

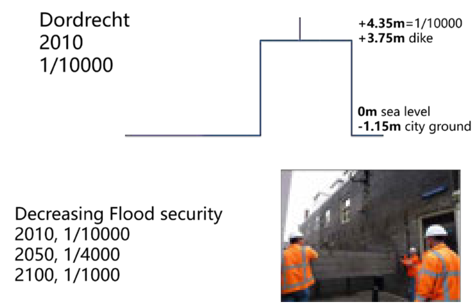

FIG. 5.16 **Case study of Dordrecht for the visualization evaluation.**

The visual communication succeeded in strengthening the sense of emergency in both workshops. The photos conveyed direct experience, while the section maps offered a solid elaboration of the challenges. The power of mapping was acknowledged by the participants. Therefore, when asked to contribute to a similar section map of the local situation, the participants from the two groups were active and willing to share their knowledge. With the help of the researcher, section maps of the Foshan Municipality and Shunde District were successfully made by the participants (Figure 5.17). The researcher presented a section map similar to those of the previous cases of New Orleans and Dordrecht on a screen, then removed all the figures and renamed them using the local names. He then asked the participants for information about the basic local elements, such as the height of the dike, the ground level, and the sea level. After each value was given by the participants, the researcher marked the number on the screen. The participants immediately acknowledged the usefulness of this visualization process of the localized section map, and the urban planners soon began to use the map to question their colleagues from the water sectors. As demanded by the urban planners and offered by the engineers, the flood security level was also identified in the section map in the forms of both the return period and height. In the Shunde workshop, the planners included the height of the farmland with the help of the engineers. The inquiry of the missing spatial information soon developed into the further interpretation of the spatial information. The visualization of the spatial information made the information understandable, and further communication based on the common information therefore became possible. During the collective mapping session, the engineers used the map to explain the mechanism of the flood defense system to the urban planners. They distinguished the differences in flood security levels with or without the presence of dam control in the upper stream. At the end of each workshop, a rather informative section map was generated. Each map served as a medium that assisted the knowledge exchange between the sectors, and also embodied the materialization of the visualized common knowledge and insights. The collective mapping proved to be effective in bridging the gap between domains and sparking new ideas by the policymakers.

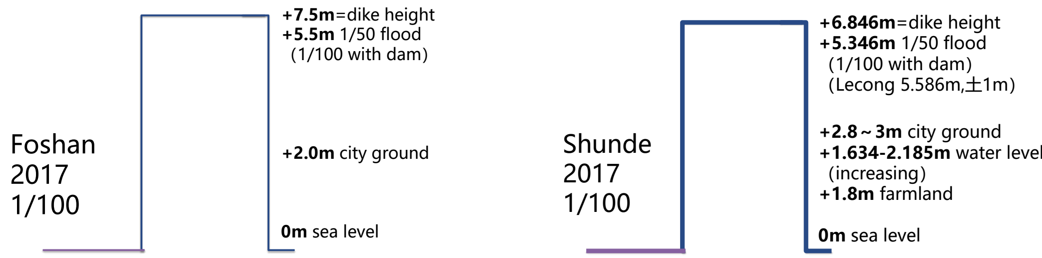

FIG. 5.17 **Section maps created during workshops with local governments.**
Left: section map from the Foshan workshop. Right: section map from the Shunde workshop

Promoting inter-discipline cooperation

The approach also displayed its great potential to promote inter-discipline cooperation. Despite the historical miscommunications and institutional obstacles, the two sectors reached a primary agreement on cooperation through the mapping process in the workshop. With a common understanding of the system dynamics and potential risk in the near future, the two sectors achieved two stages of cooperation, namely the making of principles and the commitment to pilot projects.

Spatial organization principles were proposed from the section scale to the delta scale. The five spatial organization principles with their connected scales are as follows:

- Planning and design with a water-based scale – all scales;
- Introducing the visual landscape of the delta to the public – section scale, local scale;
- Utilizing the old dike rings where the newly urbanized region has been developed – local scale;
- Creating more room for water using old dike rings – local scale;
- Enhancing roads, railroads, power, and other essential infrastructure - delta scale.

In the Shunde workshop, the discussion went so well that the researcher decided to invite the participants to bring up the principles. Instead of bringing up the principles himself, the researcher was able to discern principles that were identified by the participants. The participants concluded the presentation and discussion with the action of principle-making. The researcher posted each principle that each participant raised on the screen so the whole group could see and discuss it. The participants from 3 levels of government, 2 sectors, and their affiliate institutes joined the discussion and worked out a collective conclusion.

In addition to the collective effort on discussing principles, some pilot projects were also agreed upon during the invite-only lunch. The urban planning and design sector used the workshop as a chance to establish further communication with the water sector. In both workshops, chief officers of the water sector were invited for a lunch with the officers in the urban planning and design sector, as well as the researcher. During the lunch, the officers from the two sectors discussed the cooperation in a more relaxed and open way, explained the concerns of their own sectors to each other, and agreed on certain institutional obstacles. At one of the workshops, the urban planning and design sector proposed to further collaborate by combining the water infrastructure with the urban fabric in the phases of planning, design, and technology. The chief from the water sector agreed with the proposal. The attitude toward cooperation in the lunch was quite different from that in the previous discussion. This change could have resulted from the common knowledge and principles agreed upon by both sectors. It can be confidently said that the mapping approach successfully promoted cooperation between the sectors in local government.

Seeking innovative solutions

The knowledge generated from the mapping approach inspired the local government to seek innovative solutions in the future. After a discussion with more local knowledge input, none of the participants questioned the correctness of the knowledge in the end; instead, both engineers and planners demanded more investigations on lower levels of scale. The participants called for further study on innovative solutions such as integrating water management and urban design, and inter-scale planning. Because the data used in the mapping approach were all publicly available and had low resolution, a more detailed study on lower levels of scale demands more precise data.

With the help of the spatial-temporal mapping approach, the participants proposed to cooperate in water security spatial classification, the integration of recreational and hydraulic plans, the combination of urban design and water infrastructure, and the enhancement of water education. They also found it necessary to invite more governmental sectors to cooperate.

5.2.3 Discussion

In the setting of collective decision-making, the spatial-temporal mapping approach functioned as both an analytical tool and a communicative tool. The approach was well acknowledged by both the municipal government and the district government. The two workshops showed that this mapping approach was comprehensive for the decision-makers within the local context. During all the sessions of the two workshops, there were no doubts about the structure, data collection, material analysis, or interpretation of this study. Participants from all backgrounds, including architecture, landscape architecture, water resources, engineering, and laypersons, agreed that the study was easy to understand. The presentation of the mapping approach served as a platform for discussion, and an extensive discussion was successfully triggered after the presentation. This indicates that the participants understood and agreed with the knowledge provided in the presentation, and utilized this knowledge to reflect on their own experiences. The multi-scale visualization of spatial relationships contributed to the conditions for the adaptive and cooperative decision-making processes of fast-urbanizing regions. It helped the participants from different domains to understand multi-scale knowledge, distinguish subsystems and their speeds of change, generate common knowledge and insights, promote inter-discipline cooperation, and seek innovative solutions. This approach successfully (1) involved both governmental and public knowledge, (2) created common interest, and (3) promoted collaboration between sectors.

The analytic capacity of this approach in the collective decision-making setting is related to data accessibility, while its communication capacity is related to both the governmental structure and the planning culture. The usefulness of this approach will be limited when (1) the higher-level decision-maker prefers an oral brief instead of a visual brief or group discussion, or (2) a trusted long-term relationship has not been properly built up. Due to these two reasons, this approach was unable to promote experimental design in both workshops.

Security and trust

The experiment of mapping with a designer appeared to be more challenging, yet rewarding. Unlike the junior designer in Experiment 1, the policymakers were more conservative to the consideration of new approaches. For the multi-scale mapping approach, their main concern lied in data security. Despite the fruitful outcome developed in the two workshops, there were signs of the policymakers' hesitation to commit to further dedication in the approach.

The first sign emerged at the very early stage of this study, during which the author requested access to several sources of spatial data from the provincial government. Most sectors rejected the request and stated that such data were not available. One of the sectors received the author for a face-to-face interview; after the explanation of the methodology and background check, the officer told the author that the requested data were too large to provide. In the most extreme case, another officer rejected with the reply, “Who do you think you are, and why should we respond to your request?”; they evidently disregarded the open data policy clearly stated on their website. Even when one of the deputy ministers was convinced of the urgency and value of this research, the best he could do was to send the author to a retired engineer, who only had memory of data from over thirty years ago. It was then that the author realized that it would be impossible to acquire data from the government without a solid study. The government appeared to resist opening their databases for a new research perspective that had yet to prove its value.

The second sign of hesitation occurred during the workshops. Given the positive feedback of the collaborative mapping of the section, the author proposed to conduct a more elaborate session by pointing out the ongoing plans and designs regarding both water and land. This mapping exploration was expected to combine the plans from both the water and urban planning sectors in a single map, which would require more sensitive spatial data. However, both groups avoided discussion of this proposal. In the Foshan workshop, once the local scale map was presented, one of the engineers tried to hijack the topic by starting to argue the main conclusion that was agreed upon in the previous stage. The author's attempt to create a local plan that combined both water and land was frequently interrupted by the participants during the workshop. Due to the time limitation, the organizer had to end the discussion session without making such a map. Coincidently, when the proposal of making a local map was presented in the Shunde workshop, both the water sector and urban sector started to complain about the communication barrier between the sectors based on their previous cooperation experience. Therefore, the mapping on the local scale was also not finished in the Shunde workshop. After the workshop, some participants expressed their concern for providing sensitive spatial data for a research project that was being executed by a foreign organization.

The analysis component of this approach had not been fully developed during this experiment, for which there were three possible reasons according to the researcher's observations. These reasons include the high sensitivity of the data policy, the discouragement of cooperation among domains by the current political structure, and the ill-preparedness of the planning culture for new ways of planning and design, in this case, through mapping.

The high sensitivity of the data policy created difficulties for both the researcher and the participants during this application. Unlike the open data environment for spatial information that is present in the Netherlands, spatial data are regarded as classified information in the Chinese context. Therefore, some of these data were not available for public access. Even for data that are available to the public or researchers, the government tends to place extra barriers to its access, as their action would lead to unforeseeable faults if the policy were to change. For instance, in Guangdong Province, previous lawful data sharing with a foreign design firm led to the prosecution of the involved officers.[2] In general, the government is discouraged from sharing its data with the public. Although the participating officers understood the importance of data for a more detailed study at the lower level, they still hesitated to share the necessary information with the researcher. In one of the workshops, the sectors refused the request for data for further study due to a security policy. In the other workshop, one sector agreed to make the data accessible under the condition that all the data processing, analysis, and results were kept within the sector. Due to this limitation, further application at a lower scale could not be completed in this study.

In addition to data accessibility, the current political structure also limits the application of the mapping approach by discouraging cooperation among domains. The participating officers found that the main obstacle to cooperation is the current political structure. At the end of the workshop, the two groups agreed that the barrier of cross-section cooperation existed in three aspects: the different coordination systems in the GIS, the different elevation references, and the lack of interest in communication and collaboration. The barrier was caused by the current political structure, in which a sector must place a higher priority on supervisors than on other sectors at the same level of government. Although both the water sector and the land sector had previously been integrated into the same bureau for the two involved local governments, these sectors had to report to different ministries at the national level. Fortunately, one year after the workshop, the central government implemented a re-organization of territory management, and the structural limitation will soon disappear.

The third limitation of the application was that the planning culture is not ready to adopt a new way of planning and design via the use of mapping. In addition to the data limitation, a more basic limitation was that the current planning culture is not used to visualization, comparison, and debate. Much planning and design used to be conducted within the government; therefore, it was not easy to create enough design proposals to compare and debate. There also exist competitions hosted for planning and design; however, without an open data environment, such competition still could not provide enough possibilities. Therefore, the ability to distinguish excellent design and plans has also been reduced. Moreover, several international design competitions have been organized in the neighboring city of Shenzhen, during which much more detailed data were shared with the public. This demonstrates that the country used the design and planning of Shenzhen as an experiment to test if a more accessible data environment would lead to better solutions. However, it was still unclear whether other cities would adopt a similar method. Regarding the design and planning in the PRD, there has not been an experiment to investigate an issue of this scale and complexity.

Due to the current data policy, the entire planning and design system of the PRD has been in a rather embarrassing state. The government is not willing to share spatial data with the public, and various sectors are not willing to share with others. These barriers have also discouraged public organizations from sharing their data. The lack of valid spatial information for research and education has also become a reality in universities. Without accessible data, researchers cannot study and develop systematic education programs, while students cannot learn about different possibilities and how to implement these possibilities in the design process. Later, when these students become designers and planners, they will realize that their education was hardly sufficient. Regarding the design and planning quality, it is also impossible to evaluate them in a scientific manner. Overall, planning and design become vague without proper access to data, and this is the de facto situation of the current Chinese planning and design system. The data

2 This information was conveyed during one of the workshops. All the participants were aware of the incident; however, the author could not find public news supporting it.

security concern appears to be a major limit in the further application of the proposed mapping method. This difficulty indicates the potential to build up closer relationships between researchers and policymakers.

Despite the significant data disadvantage rooted in this context, this study demonstrated that mapping provided promising possibilities in an alternative way. It was able to provide support for the researchers and designers to form similar levels of understanding from the accessible data. Table 8 presents a comparison of the principles generated by the participants, and reveals a considerable overlap between the participants with or without specific data accessibility. The results showed that, even with limited data accessibility, a systematic examination of the spatial relationships in the PRD could help researchers and designers to gain similar insights about the region. Moreover, researchers and designers were able to utilize this approach to provide possible visions, which facilitated their involvement in the decision-making process. By presenting those visions, the policymakers were more likely to acknowledge the professional skills of designers and researchers by recognizing their capabilities of analysis and design with limited data. In this way, the mapping approach helped to build up trust between the government and the specialists without the security concern.

TABLE 5.1 **Principles raised by participants in the mapping approach.**

Principle	Researcher	Designer	Policymakers
Integration within masterplan	•		•
Improved water quality			•
Water education	•		•
Cooperation between two sectors	•		•
Combination of landscape and engineering	•	•	•
Pilot project on a small scale	•	•	•
Multi-sector involvement	•		•
Caution regarding the over-confidence of technology			•
Room for slower processes	•	•	•
Acknowledgment of local wisdom	•		
Strengthening research	•		
Upgrading essential networks	•	•	
Multi-scale cooperation	•		

Top-down and bottom-up

The acceptance of the mapping approach is largely dependent on the planning culture of the government. As it was developed in a typical bottom-up mode, the experiment received positive feedback and active involvement from both the Foshan Municipality and Shunde District. Remarkably, the researcher himself contributed to a consultancy report to the deputy mayor and shared the results of the workshop, after which an in-depth discussion was held with the Chief of the Bureau of Planning and Design. On the contrary, the attempt to share the mapping approach was unable to be done in top-down cities such as Guangzhou and Shenzhen. Compared to the rest of China, the PRD is considered a laboratory of urban development; it is therefore reasonable to expect that the mapping approach would experience much more resistance from the governments in other regions without strong support from the higher levels of government. The Chinese planning and design system is experiencing a critical transition, during which the barriers have been broken from within from the top down. It is high time to seize the opportunity of assisting with the re-organization of the planning system with the use of the collective mapping approach. The experiment showed that the approach could steer and facilitate collaboration among the policymakers; it enabled the formulation of new questions that had not been considered by the policymakers, thus leading to new directions of solutions.

The mapping approach would be more beneficial with the support and trust of the government. The experiment showed that such support could be achieved by demonstrating the capability of mapping to generate insights with basic data. Moreover, the mapping approach offers a solution for the government to hear from specialists without the need to share sensitive data. In the current planning and design system, the government depends on two major sources for their plans, namely its affiliated planning and design institute, and design competitions. Both sources require dedicated data to provide plans. These plans limit the possibility of the government itself to think visually and spatially. On the contrary, by exploring the spatial relationships together with the government, the collective mapping approach would allow the government to understand the region and the outcomes of its strategies in spatial terms. The maps developed are the result of an interactive and collective mapping process, instead of a product that meets the requirements of a design assignment. Sensitive data could also be kept under the control of the government during consultation, as the roles of the designers and researchers will have changed from data manufacturers, who require data to generate a product, to coaches of visual and spatial thinking, who guide the data owner to make better use of their data. The mapping approach converts the design and planning activities of specialists from working *for* the government to working *with* the government.

5.3 Mapping with the interested public

The public, being a long-ignored stakeholder in the Chinese planning context, have great potential for participation in the planning and design process. They have been prevented from acquiring a good understanding of their living environment due to a lack of data and skills. The lack of public involvement in planning and design has allowed for a quick decision-making process in recent decades; however, an increasing number of projects have been criticized by the public due to their different understanding from that of the government. Several essential projects, including the construction of an incineration plant and a p-Xylene plant, were actively protested by citizens all over the country due to environmental concerns. The drawbacks of the absence of the public have begun to emerge. On the one hand, the lack of communication has prevented the government from sharing its vision with the public and increased the difficulty of the implementation of the plans. On the other hand, the public have become more vulnerable to rumors and distrustful of the government. A harmonious society cannot be achieved without a trusting relationship between a government and its citizens. In this experiment, the mapping approach was applied to the interested public to help them to join the planning and design process.

5.3.1 Setting of the mapping process

The mapping approach was introduced to the interested public in the massive open online course (MOOC) “Rethink the City: New Approaches to Global and Local Urban Challenges” made by the Faculty of Architecture and the Built Environment, Delft University of Technology (Figure 5.18). This MOOC was promoted mainly through Archdaily.com and several personal education networks. In China, it was promoted on the most popular Chinese video-sharing website for youth, namely Bilibili, under the category of education. Closed captions were available in English, Spanish, and Chinese. The English and Chinese captions were written by the researcher himself, while the Spanish captions were translated based on the English version. The video is available at

- The edX.org platform (registration required, with quiz): https://courses.edx.org/courses/course-v1:DelftX+RCUC101x+1T2017/course/#block-v1:DelftX+RCUC101x+1T2017+type@sequential+block@ec7c5cada14f45169f83050731697e01;
- YouTube (registration not required, without quiz): https://www.youtube.com/watch?time_continue&v=6YvNlzohfPM.

The mapping approach was introduced in a 7-minute video lecture focusing on the delta scale. In the video, the teacher applied the spatial-temporal mapping approach to present the transformation of the delta region, resulting in a set of maps illustrating essential subsystems and their dynamics on the delta scale. It aimed at establishing a multi-scale, rhythm-based system for students without the local context within a limited time and interaction. The teacher first introduced the multi-scale perspective of the system, and the method of mapping with different speeds of change was then explained, followed by an extensive explanation of the reading of three series of maps. The temporal feature of the spatial-temporal mapping approach was well utilized in the educational presentation. The teacher generated an animation to display the dynamics of the three subsystems with their coordinated speeds of change. The map series in Chapter 4 was used to create the animation, in which every 250 years of spatial change was illustrated in 1 second. The three subsystems of the landscape, water infrastructure, and urbanization were able to be presented side-by-side, and the dynamics of the three subsystems could be compared in a more direct manner. After the map set was introduced, the participants were asked to take a quiz to evaluate whether their knowledge of the PRD had increased. The evaluation of the mapping approach was based on the responses to the online course.

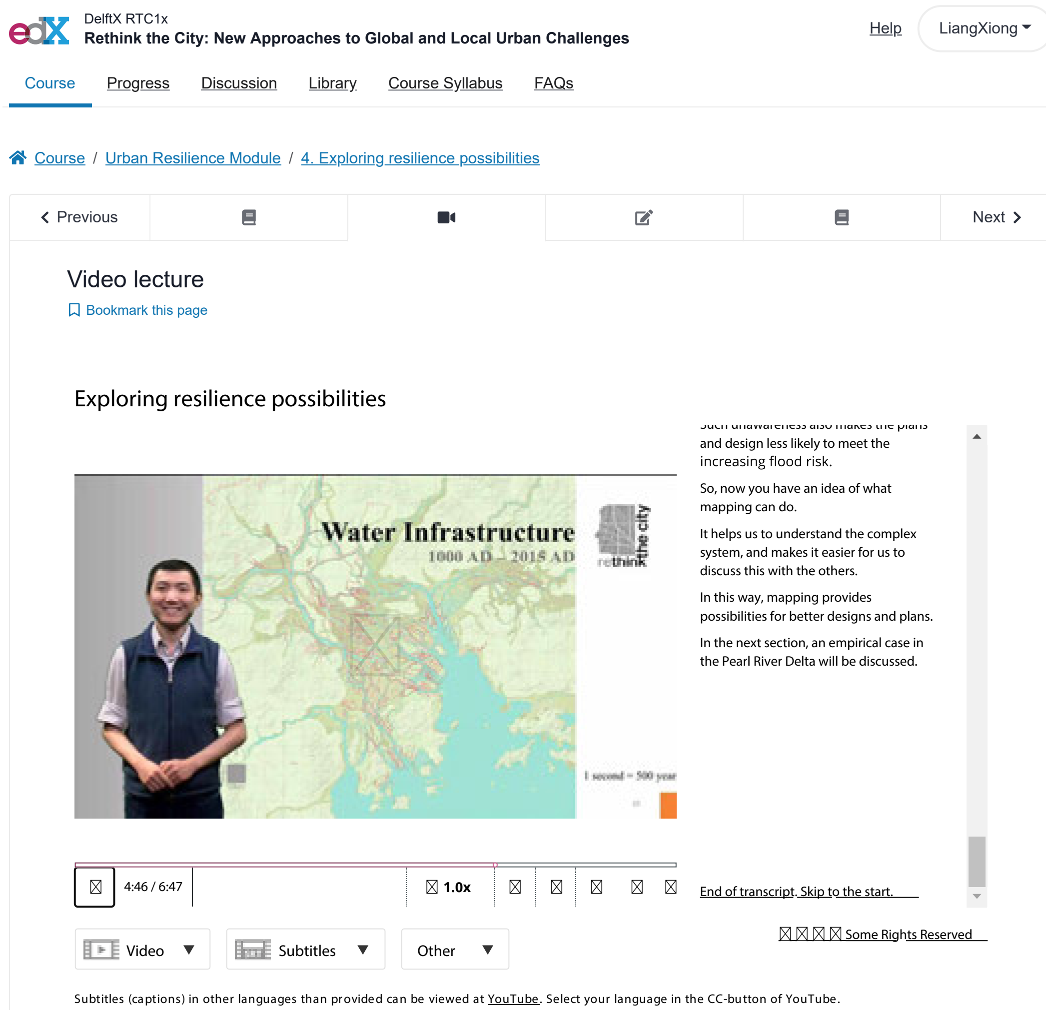

FIG. 5.18 **Video lecture of this study in the MOOC "Rethink the City: New Approaches to Global and Local Urban Challenges."**

5.3.2 The outcome of mapping

The mapping approach was widely received by the public. A total of over 10,000 participants enrolled in the course and watched the video during its first active course period between March and June 2017 on the edX.org platform. The participants were from 160 countries and regions all over the world, of which China was one. Because of the considerable quality of the course, it was shared by professional networks and the general public. The Association of European Schools of Planning (AESOP) acknowledged the course as "vital for planners to explore critically, objectively and confidently in a post-truth political climate." The course was awarded the 2017 AESOP Excellence in Teaching Award. In 2018, the second year after its launch, the number of course participants exceeded 20,000. In 2019, the course was promoted by the United Nations for the understanding of the UN Sustainable Development Goals (Pickard, 2019). The course has now become available annually, and the mapping approach is expected to reach a larger audience every year.

The quality of the mapping approach was also well received. In 2017, there were 557 attempts made to take the quiz out of over 10,000 participants. The overall correctness rate was 65.1%. This result indicates a high comprehension of the knowledge passed to the participants, and implies that the knowledge referred to in the lecture was recognized by the majority of the participants. The vulnerability of cities in the PRD region to potential economic losses was acknowledged. Moreover, the results showed that most of the participants were capable of applying the classification of cities, a simplified mapping method conveyed in the video, to other cities that were not mentioned in the study. This indicates that the mapping skill was successfully transferred to the participants. Such a way of understanding living environments could allow each participant to study his or her own region. The distinction of the different dynamics among the subsystems was considered as the most difficult part of the experiment; over 73.8% of the participants could not identify the correct answer to a question that required an awareness of the subsystem dynamics. With the limitation of the use of a 7-minute video as a communication tool, the quantitative test proved that the approach presented in this study is comprehensive.

5.3.3 Discussion

The spatial-temporal mapping approach functioned as a communication tool in this collective education setting, and was proven to effectively pass knowledge to students without local knowledge or mapping skills. The temporally-related characteristic of this approach could be easily utilized with new teaching technologies, such as animation, and the visualization of spatial information provided attractive material for online broadcasting. The majority of the students gained insight into how the different subsystems work, and could identify the differences in the speeds of change of the subsystems. Some of the students were also able to understand the relationship between adaptivity and the speed of change of the delta urbanization process. The one-way communication of the mapping approach was useful for the students to apply it to their own regions. With the additional interaction after the presentation, more students were able to understand and make use of this approach. The feedback from the students and the scores of the quiz both demonstrate that the mapping approach functioned as an effective communication tool in the collective education setting.

The experiment showed that the mapping approach could be widely and properly received by the public. In this experiment, the topic of flood risk was analyzed via the use of maps that were generated by public information. A considerable number of participants learned how to understand the region by making and comparing maps. The mapping approach provided a critical tool for the public to understand the challenges of their living environment on multiple scales. It is possible to solve many of the conflicts in planning and design once citizens gain access to insights into the other scales. They could also use this tool to think for themselves, instead of believing rumors from unreliable sources. In this sense, the mapping approach equipped the citizens with both an analytical tool to address the challenges, and a communicative tool to join the planning and design process. With such a visual analysis skill, the public could play a more visible role in the development of the region.

The power of the citizen needs to be strengthened and guided in a proper, and preferably neutral, way. The aforementioned postponed projects in China were the result of a lack of common understanding and agreement. The previous experience of the protested projects shows that neither the citizens nor the government have benefited from this method of communication. Mapping could serve as an alternative method of communication between the government and the citizens throughout the different stages of planning and design. However, based on the

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experiment, the skill of mapping was not easily transferable to the public in a short amount of time. During the making of the video, the researcher found that the degree of interaction would affect the effectiveness of the mapping approach. An amination used in a one-way lecture proved to be insufficient to deliver the mapping skill to many of the students. While some interactions helped to clarify the limited presentation, several questions were raised by students for the clarification and elaboration of the mapping technique. Therefore, the forum attached to the lecture functioned well for additional interaction between the teachers and students. This experience indicates that the teaching of the mapping approach would work better in an interactive environment as compared to a one-way communicative environment; therefore, the approach requires professional guidance.

5.4 Synthesis, cooperation, and collaboration

New ideas, insights, designs, and plans emerged during the collective mapping process. New participants made their own contributions to improve the likelihood of the achievement of the alternative future. In Experiment 1, the designer created a possible intervention that did not exist in the original alternative future. This design makes use of the quick intervention of manufacturing in the built-up area to re-establish the slower process; the partially-opened dike ring will allow for the redeposition of the sediment. The designer also took the initiative to impact the region on the local scale. By offering more space for flooding in the upper stream, it contributes to the overall reduction of the peak water level during a flood event. The collective mapping with the designer exhibited a strong synthesis of scales and cooperation of temporality. In Experiment 2, possible interventions emerged during the collective mapping between two domains, and the exchanges of knowledge and data between the domains were triggered. Realizing the current critical threshold, participants from the water sector and urban planning sector proposed pilot projects on which to collaborate. Moreover, short-term targets became connected to a long-term vision. The collective mapping with the governments indicated promising collaborations between domains and cooperation with time. In Experiment 3, positive feedback from the interested public showed that the mapping method was well-received. The collective mapping process provided the public with both the knowledge and skill to be involved in the discussion of planning and design. The public acquired a tool to evaluate the quality of the plans and design by aligning them with the collective agreed-upon future vision, with which their individual choices would be well synthesized. Given the various professions and backgrounds of the public, a wider collaboration among the domains can become possible. The collective mapping with the public generated both synthesis in scales and collaboration among domains. With the stakeholders' inputs during the collective mapping process, the vision delivered by this study is evolving; it is no longer the vision of the author, but is turning into a vision of the involved stakeholders. The map presented in Figure 5.2 has become a living mapping activity, in which interventions at different scales have been synthesized, different dynamics have cooperated, and different domains have coordinated, making it more realistic and applicable.

6 Conclusion and discussion

6.1 Mapping the long-term perspective in a highly dynamic urban delta

The systematic mapping approach was used to organize and analyze both short-term and long-term spatial data during the rapid delta urbanization processes by transforming spatial data via scales, times, and domains. The mapping approach works with insufficient data, which is often the case in a rapidly changing environment, to identify spatial challenges from a long-term perspective. It was the first time that the knowledge of the development of the urban landscape had been inventoried, synthesized, and presented in its own spatial-temporal model using maps. The present flooding issue was revealed by identifying the critical threshold signals, namely sudden changes in the spatial pattern of the dike system. The mapping approach provided a probable vision of 2080, and a possible alternative vision. The two visions offered both the options of repair and transformation for the discussion of future planning and design.

6.1.1 Inventory: From data to information

In this research, the multi-scale mapping approach was employed in the inventory of the PRD for (1) the collection, evaluation, and interpretation of ancient, modern, and contemporary data, (2) the digitization, geo-rectification, and vectorization of data, and (3) the scaling and integration of the data into a digital landscape model of the PRD. These steps allowed the data to be developed into information.

To understand the subsystem dynamics of an urbanizing delta system over time in the context of spatial planning and design research, it is important to view the data of these dynamics at different significant time-slice snapshots. Such snapshots are possible when a large amount of spatial data can be related to accurate temporal information, and the inventory of these spatial-temporal data enabled the scaling of the data into proper time-slice snapshots.

Regarding the PRD, mapping offers the possibility to evaluate spatial data, thus enabling the review of the accuracy and reliability of historical maps. Many historical maps were produced in a relational way that focused on the spatial relationships among the elements. Unlike the common Western maps that focus on spatial allocation, such spatial relational maps require more skill and technique to be spatialized and interpreted. Cross-references from other data aided in the evaluation and interpretation of the maps. Many well-documented local archives provided literature evidence to support the mapping approach. The understanding of the mechanisms among subsystems also helped to distinguish the accurate positions of the elements in the relational maps. By comparing data from the same time, the accuracy and reliability of the maps were improved. This technique was utilized more in the more recent map data, for which more sources were available. Another frequently-adopted technique was the examination of the same element throughout time. Based on the more accurate and reliable maps from later times, the elements in the older maps could be traced, confirmed, and spatialized. The well geo-referenced contemporary data served as a framework for organizing and validating the older data. The mapping approach functioned as a design tool for comparing, evaluating, and selecting cartographic data as information.

While contemporary geo-referenced vector and raster maps, together with soil and geology, provided a base to construct a multi-scale map series, they had to be augmented with information from other sources. A territorial map of the delta was able to be constructed based on the data of landscape elements, such as the road networks, river networks, and built-up regions, much of which could be derived from the geo-referenced vector and raster maps. These data were enhanced with underlying data, such as data on soil and geology. With such enhancements, the historical data could be evaluated and criticized based on the understanding of the landscape processes. In particular, the historical data of dike locations, river network locations, coastline locations, and occupation locations were rectified based on the enhanced data. The spatial coherence of both the digital data and paper data was successfully achieved in this study. The data accuracy could have been improved by augmentation with other data, such as the heights of the dikes and the water levels. However, the augmentation was not successful due to the availability of contemporary data; applications for data-sharing were rejected by several governments because this research was carried out in a foreign university.

The scaling of the spatial and temporal data was a key innovation during the integration of the data into information. This mapping exploration established a database that included data from over 6000 years. All the major historical data before 1900 were well-integrated; however, the modern and contemporary data were not. Because of the high sensitivity of the data for the period after 1900, applications for access to several data sources were rejected. Therefore, in this study, it was impossible to establish more large-scale time-snapshots after 1900. The data difficulty was countered by applying the exploration to a smaller spatial extent. The location of the study resulted in the inability to examine the most dynamic period of delta urbanization. After discovering that the cause of data accessibility was the location of the research institute, cooperation with local universities was promoted. Based on this solution, two joint studies have been initiated. The first is a joint Ph.D. research program between the South China University of Technology and Delft University of Technology. This Ph.D. research covers the mapping exploration in the temporal extent of 1980-2017, during which the fastest urbanization of the PRD took place. The second joint research project was established among the South China University of Technology, the University of Sheffield, and Delft University of Technology. This four-year research project covers the mapping of the modern and contemporary eras and the application of the spatial extent of the delta to the decision-making process. These ongoing studies can possibly complete the data integration that was unable to be achieved in the present study.

6.1.2 Synthesis: From information to knowledge

In this research, the multi-scale mapping approach was employed to explore the PRD to (1) employ analytical principles based on scaling rules, and (2) reveal changes and developments from the multi-scale perspective. With the help of the scaling rules, the information inventoried from various data sources was converted among both spatial and temporal scales. Analytical principles were applied with the same scaling rules as those for the inventory process, which enabled the synthesis of data with different spatial and temporal scales. Over 6000 years of data with various spatial extents and grains were analyzed, compared, and synthesized into a map series on both the delta and local scales. Time-snapshots were identified with a changing grain decreased from 2000 years to 50 years. By distinguishing the time-snapshots, the changes and developments of the delta could be understood from a multi-scale perspective. The mapping approach was able to integrate and transform the information into spatial knowledge by creating a map series, and these maps were the products of analysis and visualization. By examine the maps (and the animation that was created based on the maps), spatial mechanisms among delta development, infrastructure construction, and urban expansion could be easily understood by their relationships in both space and time.

The multi-scale mapping approach turned out to be an apt tool for the systematic analysis of the interactions of the subsystems via the spatial and temporal scales. The various spatial information was able to be organized and synthesized into general knowledge. Featuring a strong spatial-temporal co-relation, the mapping method enabled the analysis of the spatial inter-relationships among the three subsystems without a loss of information. The decomposition, comparison, and overlaying of the subsystems were reliable and replicable, and this approach therefore enables the possibilities of falsifiability and evaluation. It also provides the possibility to add more data in the future. This multi-scale mapping approach offers a scientific and open method of systematic analysis via the spatial and temporal scales.

The construction of a multi-scale map series extended the field of focus, generated new knowledge, and provided possibilities for design and planning. It established the spatial links among the three subsystems on several spatial scales, and also revealed the dynamics of the interactions among the subsystems. This perspective enabled a new understanding of the processes during the urbanization of the delta. It also introduced a broader vision to the territory, resulting in members of both the water management and urban planning sectors being able to expand from their respective fields of focus and begin to work on a solution that would benefit both sides. The new knowledge generated by the establishment of the map series also provided spatial principles for future design and planning. Both designers and planners were able to utilize the maps in their own way. The multi-scale map construction also provided the possibility of further development in similar circumstances.

6.1.3 Presentation: Revealing and communicating knowledge

In the presentation of this research, the multi-scale mapping approach focused on revealing and communicating knowledge among various domains via visual language. Text, numbers, and maps were combined in the map series in a consistent visual language. The knowledge from geography, water management, urban design, and planning was merged and presented in a visual way. This method of visualization helped the knowledge to be revealed and communicated among different domains. It also allowed the potential for public participation in knowledge-sharing and decision-making. The narrative played a decisive role in communication during the making of the maps and the workshops. In addition to the scientific aspects in revealing text, numbers, and graphics, the methods of video, music, emotion, body language, etc., were also adopted for communication. This research utilized several approaches to improve the narrative, including publishing, conferences, face-to-face lecturing, and online lecturing. Among all the approaches, the online teaching experience proved to be a good way to improve the comprehensiveness of the research. The new media also increased the power of the mapping approach in the presentation.

In the case study of the PRD, this mapping approach was applied to the process of using graphic analytical techniques, such as dissection, overlaying, comparison over time, narratives, interactive mapping, and animation. Mapping was applied to visual thinking and communication to explore and visualize the system dynamics through spatial and temporal scales via the map series and animation. During education and decision-making, the visual language played an essential role in knowledge generation and collaboration initiation. In the design, the designer adopted a similar way of presentation, indicating his acknowledgment of the power of the approach.

Despite its significant contribution, the visual thinking and communication approach was still considered to be insufficient from several perspectives. First, some decision-makers were not used to visual thinking and communication, and it was hard and sometimes impossible to encourage these participants to get out of their comfort zone. Therefore, the power of visual thinking and communication became limited when it had to be transferred to language or text for presentation. Another issue is that the interaction of visual thinking and communication could not be established when there was not enough willingness to act; this occurred during the decision-making setting. The third issue is that interaction would be limited during education if there was a high student-to-teacher ratio. During the education setting, the researcher found it to be nearly impossible to interact with over 20,000 students. Although there were many techniques available, visual thinking and communication proved to not guarantee a result.

6.1.4 Initiating: From knowledge to planning and design

The systematic mapping method provided both a platform and generator to transfer the understanding of the delta into the planning and design of the delta. Its solid argumentation for the critical transition allowed a wide range of stakeholders to realize the urgency of the flood challenge, and its flexible communication ability allowed the stakeholders to think, discuss, and explore the challenge with a common language. Scholars, designers, policymakers, and the interested public were able to approach different phases of the planning and design process. The individual knowledge generated by this study has therefore become part of the common knowledge for planning and design. The challenges it revealed have triggered the planning and design agenda of an increasing number of participants, and the systematic mapping methods have laid the ground for an adaptive planning and design process for the flood issue in the PRD.

6.2 Revealing complex challenges and a spatial strategy

The systematic spatialization approach provided a comprehensive understanding of the flood issue of the PRD by allowing for the analysis and interpretation of spatial relationships and interactions among different subsystems, each with their own dynamic. Such an overview enabled the understanding of the consequences of the interventions of the past, present, and future. By revealing the consequences of the interventions in the past, it identified current critical spatial transitions in flood defense, namely the decreasing room for water. Therefore, it is also possible to provide a probable future (less room for water) and possible alternative (more room for water) by design.

The mapping approach revealed the complex flood challenges and a possible spatial strategy in the PRD by linking the spatial relationships of the subsystems in different scales and spaces. It managed to distinguish the critical transitions in the flood defense system and their signals during the development of the delta. This study succeeded in identifying a past critical transition and its signal, and also established the link between spatial patterns and the critical transition of the flood defense system. This interrelation between spatial structure and management laid the ground for the comprehensive analysis, understanding, and evaluation of regional sustainability. The intervention of this mapping framework was applied and evaluated in terms of design, decision-making, and education, and the insights gained were used to discover new possibilities and strategies for the delta. Based on the discoveries, spatial and management principles were generated for the mapping of other urban deltas. Both empirical and hypothetical mapping were deployed to provide a comprehensive understanding of the delta. Mapping served as a tool with which to not only represent existing knowledge, but also to seek missing knowledge.

Three types of processes (landscape formation, infrastructure extension, and urbanization) were identified according to their speeds. Spatial interactions were illustratively explained on both the delta scale and the local scale from 4000 BC to the present with a time extent ranging from 2000 years to 50 years. The visualization revealed a transition of the regional pattern from a water-based mode to a land-based mode, during which an unawareness of the landscape and a detached urban pattern were developed. Such trends increased the flood risk in the new urban areas on both the delta and regional scales. During the fast urbanization process, another signal of critical transition was distinguished with the upscaling of the water infrastructure. This large-scale water infrastructure shaped the knowledge and understanding of the delta into an ignorance on local scales of its increasing flood risk on a large scale. This change resulted in a future with increasing dependence on the flood defense system. This link in the spatial relationships among the subsystems then was used as the signal to explore the present situation. With a hypothetical mapping exploration of the future, the trend of delta development was able to be visualized and calculated, resulting in the discovery of a new signal for the current critical transition.

6.2.1 Employing the inter-discipline capacities of mapping

In the case of the PRD, visualization was used to construct the spatial-temporal map series to integrate the knowledge of different domains. During Experiment 2, the participating engineers did not recognize the potential power of visualization to solve the current flood issue. They stated that the principle of the Room for the River program was not new to them, yet it was impossible to apply it to the local case because they had already tried diligently to secure space for water from the planners. The low willingness of cooperation from the engineers was their reflection of their prior difficult collaboration with the planners; this is exactly the point that the mapping approach aims to tackle. With the help of mapping, the planners began to realize the urgency of the flood issue; the visualization of information helped them understand the knowledge that was previously only accessible to the engineers. An inter-domain platform was able to be established with a common visual language, based on which a common understanding of the current challenges of the region was reached. Therefore, a further inter-discipline solution could be demanded in both domains. After the planners recognized the problems that the engineers had been suffering from, they proposed further studies to secure the urbanized area with the collaboration of the engineers. Through more rounds of the data-knowledge-design process, the engineers could possibly get more familiar with such an approach with the help of a designer, and the planners could learn more about the knowledge from other domains. With the generation of more in-depth data and knowledge, a more satisfying design could be agreed upon by planners and engineers. Mapping therefore not only serves as a vehicle through which to spatialize and visualize knowledge that is presented in text, numbers, and graphics, but also facilitates a platform for knowledge exchange and generation between domains.

6.2.2 Employing the inter-scale capacity of mapping

The visualization of multiple spatial scales provided the possible communication of scale-sensitive knowledge, thus leading to spatial consistency. The inter-scale capacity could reveal challenges that the participants were not aware of; thus, solutions were able to be developed. A multi-scale paradox was witnessed in the application of mapping; the local decision-makers were revealed to be facing the problem of receiving attention from both upper and lower levels of government. On the one hand, the local decision-makers expressed mixed concerns regarding the attention of upper-level governments. They believed that their work would be much easier if the upper-level government also received such multi-scale knowledge, as multi-scale planning and design could not be achieved without corporation among the local governments and coordination from the upper-level government. However, they also showed concern about the increasing attention from the upper-level government; in other words, more support would lead to less flexibility. Their political risk also increases once there is more attention on their work, leading to a decreased likelihood of being bold to find possible solutions. This concern also influences the openness of the government decision-making process; many experiments or cooperation may be hidden from the public.

Within the government, the approach would be more effective if higher-level political actors were convinced to use it. The decision-making process during the workshop revealed a strong political hierarchy. Although it is tougher to convince a higher officer to adopt a new approach, their decision to do so would seldom be questioned. The focus and agreement settled upon during the discussion were easily changed by a higher officer who did not join. In both workshops, the participants realized the urgent situation and the need for cooperation, and also concluded with several aspects from which to further the study and application. In contrast, their leaders would depend largely on personal briefings to make decisions because none of them joined the workshop. This suggests that a successful 5-minute briefing of a higher officer is more effective than a 3.5-hour collaborative discussion.

The inter-scale visualization implied an inter-scale governmental hierarchy, and such a visualization generated a new perspective for knowledge-sharing and collaboration. The broadened vision helped the participants to distinguish obstacles in the current governmental hierarchy. With the knowledge and obstacles mapped in space, a new governmental structure was implied with its own boundaries and hierarchy. In this way, the visualization stirred the possibility of government restructuring.

6.2.3 Employing the integrative and analytical capacities of mapping

The map series identified in this approach provides a vehicle through which to integrate and analyze multiple dynamics across multiple scales. A framework of space and time was presented throughout the mapping processes, from data collection, to information synthesis, and ultimately to knowledge generation and communication. This sense of time and space provided the conditions for both the input and output of knowledge. Even with simple settings, the capacity for integration and analysis was well observed in the design, decision-making, and education processes. The senses of time and dynamics contributed to the synthesis of interdisciplinary and inter-scale planning and design.

6.3 Initiating adaptive planning and design

The systematic spatialization approach provided a spatial analysis-based design and planning alternative. In this approach, evidence-based arguments facilitated the cooperation and collaboration of professionals, stakeholders, and the interested public during the planning and design of the delta. During knowledge gathering and the re-mapping process, current stakeholders from different domains were able to collaborate, new stakeholders (the citizens) became involved, and enough awareness of natural processes was created to spur cooperation during the decision-making process. To summarize, the systematic mapping across scales, time, and domains provided the stakeholders with a new mindset during design and planning, in which they were able to collaborate with each other and develop interventions that could cooperate with the natural process in the rapidly urbanizing delta. The mapping approach also directed possibilities of sustainable planning and design process by generating a circulation among the individual design, collective design, and mass awareness of the PRD. The mapping approach thus served as a vehicle that brought awareness to the spatial relationships, exchange of knowledge, and means of collaboration in both the short term and long term, on both small and large scales, and among different domains and stakeholders.

6.3.1 Overcoming the data shortage, inaccuracy, and censorship

The quality of the mapping exercise was largely dependent on the input data. Obtaining the correct data in the correct form has always been a challenge in this type of study. The issues of data shortages and inaccuracy are much more noticeable in fast-developing deltas. Research on a particular region or a certain spatial scale would face the issue of data censorship. Censorship against researchers abroad has been especially strong, which was the case in this study. Several requests to gain access to necessary data, such as data on infrastructure locations and capacity, land use, elevation, and underwater depths, were rejected by regional river commissions, provinces, municipalities, and districts. The inaccessibility of the spatial data on the PRD after 1900 was a serious limitation to the mapping exploration in this study. The lack of data made it is almost

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impossible to map the entire complex system on all possible scales. The accuracy of this approach was limited by the finest grain and the largest extent of the available data. Therefore, an adaptive research approach was applied in this study; the most consistent recorded processes available in each layer were selected and used, and the necessary but unavailable data were indicated. This study also provided some insights into how the missing data would have contributed to the mapping. Fortunately, not every study will find itself in the same data-lacking situation; this study has proven that, even with limited data, mapping exhibits capabilities of generating knowledge, identifying new focuses, and promoting collaboration in planning and design. This study also proved that the mapping capability would help to approach data that is censored. Nevertheless, with the development of technology and governmental awareness, it is possible to obtain more reliable and open data. For instance, drones have become more affordable and reliable for surveying with light detection and ranging (LiDAR), and underwater depth maps of the PRD region were released in a recent international design competition for a coastal reclamation and new town development project, namely the Shenzhen New Marine City, by the Urban Design Promotion Centre (Shenzhen Center for Public Art, 2018). Therefore, as an approach to explore unforeseen possibilities, this study embraced the possibilities of improving the results with better input.

6.3.2 Enhancing governmental participation

Governmental participation has a major influence on the application of the mapping approach. Not only is it possible to access valuable data by involving governmental bodies, but the impact of the mapping approach would also be enhanced by utilizing the approach in the decision-making process. To achieve a more involved design workshop with various governments, several recommendations are provided based on the findings of this study.

First, it might be beneficial to establish trust among the governmental bodies before a joint workshop. In a single-sector workshop, communication would be more open and friendly, whereas, in the joint-sector workshop conducted in this study, there was more complaining toward different sectors at the beginning of the discussion. This phenomenon suggests that it would be more effective to begin the workshop within a single sector. During the formal joint mapping workshop, there was a significant attempt to avoiding the mapping invitation; the participants from the two governmental sectors appeared to avoid putting their hands on the maps. In contrast, during the invite-only lunch after the formal meeting, the planners and engineers talked more openly about the collaboration. At this lunch, where only the heads of the two sectors and staff members from one sector were present, collaboration was much easier to achieve by expressing dissatisfaction with the political structure. A pilot project was agreed upon during the lunch because the chief of one sector proposed a unique way to bypass a regulation from the province. It was very interesting to witness how the two sections complained about each other publicly, yet privately cooperated on their common interests. This suggests that it is possible to achieve cooperation by establishing a common interest among local governmental officials. A previous unpleasant experience between the sectors did affect the willingness to collaborate; therefore, it would be more effective to emphasize the importance of collaboration at the beginning of the mapping session.

Second, there should exist an awareness of the participatory degree. If there exists a managerial hierarchy, it would be better to not hold an interactive mapping session; instead, knowledge gathering and discussion are suitable for this situation. The chief officials expressed a lower willingness to share a vision when there were more officials involved. In the three circumstances, namely the joint-sector workshop, the joint-sector lunch, and the individual report, the chief officials provided quite different information. More plans and personal understandings of the territory were provided in a more private setting. In contrast, during the joint-sector workshop, the gathering of information that was not commonly acknowledged between the sectors was effective.

Third, engaging in visual communication and interactive mapping with chief officials should be attempted individually. During the individual report to the chief officials, visual communication was limited, and the communication was primarily in the form of an oral report. Therefore, in such circumstances, it would be more fruitful to prepare a short visual communication with printed documents. Nevertheless, there was no attempt to engage in interactive mapping communication with the chief officials individually. Considering that they tend to be more open in this circumstance, it would be worthwhile to attempt a compact mapping interaction to demonstrate the power of the mapping approach.

Governmental participation is a study in and of itself. It would be worthwhile to further investigate this aspect, as there will be an increasing demand for such participatory decision-making for more delta regions in the near future. In the PRD context, the merging of all spatially-related ministries has proven that it is inevitable to foresee a collaborative decision-making process. The knowledge and skills of designers will also need to be updated with governmental structural changes.

6.3.3 Utilizing new technologies

This study calls for the utilization of new technologies and cooperation during data acquisition and presentation. The restrictive data policy led to considerable uncertainty and difficulty in this study; because of the highly sensitive data security for the period after 1900, applications for access to several data sources were rejected by various governments, and the modern and contemporary data were therefore not well covered. Thus, it was nearly impossible to establish more large-scale time-snapshots after 1900 in this study. The data difficulty was countered by applying the exploration to a smaller spatial extent. The location of the study resulted in the inability to examine the most dynamic period of delta urbanization. After discovering that the cause of data inaccessibility was the location of the research institute, suggestions were provided for future studies by promoting cooperation with local universities. Based on this solution, two joint studies have been initiated. While these collaborations proved to be able to acquire more data for mapping, it is still worthwhile to be independent of local institutions. These kinds of collaboration are not always available, and usually take a long time to be established. The application of more advanced data acquisition technologies is imperative for the improvement of the capability of this approach. New technologies, such as LiDAR, and drones, could provide alternative solutions to overcome data segregation and censorship.

There are also more possibilities for enhancing visual thinking and communication, such as virtual reality, augmented reality, and interactive animation. The MOOC platform turned out to be an effective way to apply visual thinking to communication. The first attempt at the use of the MOOC to teach the mapping approach received positive feedback. The Association of European Schools of Planning (AESOP) acknowledged the course to be “vital for planners to explore critically, objectively and confidently in a post-truth political climate,” and it was awarded the 2017 AESOP Excellence in Teaching Award. Between 2017 and 2018, over 20,000 students learned about this mapping approach via the MOOC. New techniques could contribute to a more precise and influential mapping approach.

6.3.4 Establishing trust between researchers and decision-makers

The study revealed that trust is another important aspect required to fully empower the mapping approach. Regarding the trust between the government and the researcher, the greatest obstacle was the data security policy. Although the local government showed great interest in, and demand for, a detailed study on a lower scale, it could not easily offer its data to the researcher. One participant mentioned that even data-sharing among sectors is not easy; applications must be put in for each attempt to share geographical data with a coverage of over 6 square kilometers between different sectors within a local government. Additionally, an earlier incident of a data leakage crime in the neighboring province, in which an officer was jailed for sharing geological information with a foreign design company during consultancy, has made the local government more cautious. This caution, however, has also impacted the government's engagement in introducing the mapping approach to the decision-making process. Because of this, the researcher was also excluded from further collaboration on the pilot projects between the two sectors, and there is little guarantee that the approach is being consistently applied in these projects. This policy not only reduces the scientific quality of the planning and design practice, but also prevents advancements in design-related research. Based on the experience of arranging the two workshops, an effective way to establish communication in this relationship could be to provide a brief research introduction through governmental consultants. The academic background of governmental consultants makes it easier to establish both trust and common research interests, and a solid, yet simple, research introduction would help the consultants recommend collaboration between the government and the researcher. A more general prospect would be to understand how to build up trust with the government as a researcher of design and planning; in addition to the trust earned by long-term relationships and reputations, there are likely other types of trust to explore. A further investigation of this topic should be based on a more trustful relationship between governments and researchers; therefore, long-term collaboration with the government would contribute to more in-depth findings.

6.3.5 Calling for public awareness

The participation level of the public is relatively low in the Chinese context of planning and design, which has enabled relatively fast decision-making processes. However, it has also resulted in low satisfaction in the quality of spatial intervention, and the government has suffered from the burden of misinformation. In this study, there was an attempt to publish the results of the workshops in the local newspaper to heighten public awareness of the delta situation. However, such communication between the researcher and the public was limited by the local government, which concealed the design and planning process from the public. One possible reason for this is that the government is still searching for a method of proper communication with the public. As compared to the city-level government, the lower district government involved more participants from the public, and invited local representatives to join the meetings to discuss planning and design. Additionally, all the invited streets sent representatives. This indicates a better participatory mode in the lower government. Despite the hesitation from the local government, the public had their own way of joining the decision-making process. Although none of the representatives of the local streets (Shunde workshop) or laypersons (Foshan workshop) joined the conversation during the two workshops, they took pictures of the concluding page that was contributed by the local government. Their preparation for this workshop indicates that they planned to either share the knowledge within their communities or preserve the knowledge and agreement for future reference. Interestingly, the researcher's driver began to talk about his opinion with the researcher in a one-on-one conversation after a workshop. He described the fluvial flooding that had occurred in the city 12 years ago, and told the researcher that the dike has nearly overflowed several times within the past decade. This information was missing from the feedback of the governmental participants. This case indicates that the public, when given enough privacy, can and are eager to contribute their local knowledge to the decision-making process. Public input can be a good source for knowledge acquisition, and their awareness also assists in the implementation of the plans. The local governments are aware of this paradox; however, they cannot solve it alone. This paradox provides further direction for the study of Chinese planning and design. There have been many studies on public participation in the Western context, and it would benefit both the Chinese government and researchers to implement similar pilot studies.

6.4 Discussion

6.4.1 The changing function and role of mapping

In this study, mapping was found to help readers understand the PRD region in a comprehensive way from the perspectives of processes, interventions, and stakeholders. Researchers, designers, governments, and the public were all found to benefit from this new perspective. By providing visualizations of the connections between spatial relationships in subsystems, scales, and speeds of change, mapping aided in the identification of the critical transition phases and possible ways to tackle the challenges.

Mapping was also found to work with known and unknown data. Unlike most maps that are based on available data, the proposed approach was used to map the PRD with both available and unavailable data. It selectively and reductively makes use of the available data (empirical mapping), and typological and morphological knowledge of delta urbanism could be used when the related data are unavailable (hypothetical mapping). The two types of mapping were deployed with a design approach to seek solutions. The function of mapping was therefore extended from representation and communication to design.

In this study, mapping became a vehicle between research and design. The role of mapping was not limited to the search for an answer, but was also extended to the search for the right questions. Mapping provided a comprehensive perspective so that new questions could be identified; the search for new questions thus provides possibilities for new solutions.

In this study, mapping also became a mediator for the involvement of stakeholders. Unlike the traditional mapping approach in which maps are provided to stakeholders, this approach not only enabled the stakeholders to generate and communicate with maps, but also provided a vision for the stakeholders regarding their spatial relationships with others. Via the circulation of individual mapping, collective mapping, and mass mapping, this mapping approach established a sharing and collaborating environment for the common good, in which stakeholders could contribute in an open and trustful way.

The swift of both the functions and role of mapping provides possibilities for a new paradigm for planning and design in the PRD. On the one hand, the use of mapping as a design tool does not necessarily provide solutions to existing challenges; instead, it provides possibilities to discover new perspectives, reveal new demands, and explore new solutions. On the other hand, mapping as a mediator encouraged stakeholders to spontaneously overcome existing segregation and fragmentation, and to join in the development of a sustainable planning and design approach for the delta.

6.4.2 Public maps and public mapping

This study revealed how a set of structuralized and consistent maps of the PRD was created with public data via a combination of exploration in science and art. The creation and meanings of the maps were publicly explained to stakeholders that were not able to join in the discussion.

Regarding policymakers, the use of public maps and public mapping is able to circumvent data censorship and solve the issue of domain segregation. Public maps can help policymakers to begin a discussion with a set of maps that both parties can access without worrying about using their own data. Public mapping then serves as a secure process in which the participants can contribute their own data at will. Public maps provide a direct impression of the power of the understanding of the spatial relationships within a site, while public mapping provides instant positive feedback to enhance the public maps when participants contribute their spatial data. The use of public maps and public mapping therefore serves as a bottom-up approach for the integration of domains.

Regarding the interested public, public maps and public mapping can help ease the tension of official decisions from the government. Instead of passively accepting decided plans and designs from the government, the explanation of public maps allows the public to understand the spatial challenges in other spatial and temporal scales. If the public are offered the same public mapping process undertaken to create plans and designs, they will be more likely to reach the same conclusions as the government and specialists. Moreover, public maps and public mapping open the door for potential public participation to drive planning and design to new levels. With more experience, knowledge, and wisdom focused on the spatial challenges in the rapidly changing environment of the Pearl River Delta, it is highly possible for the whole society to benefit from better ideas.

APPENDIX

Map source

Map source

Zhao, H. (1982) ‘**珠江三角洲的形成和发展**’ Forming and Development of Pearl River Delta, *Acta Oceanologica Sinica*, 4(5), pp. 595–607

Shoreline change of 4000 B.C., 600, 1300, 1700, and 1900.

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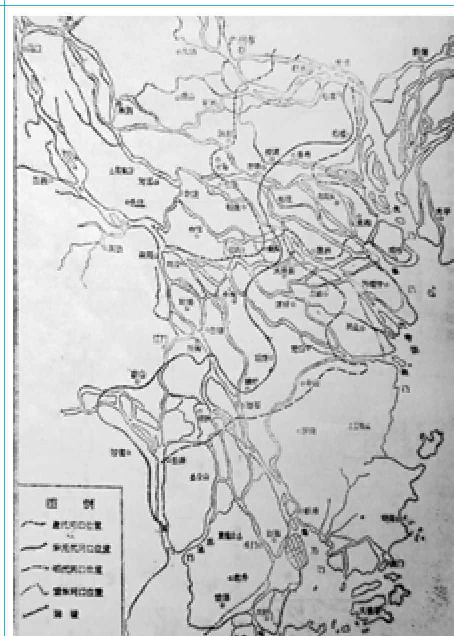
Estuary change in 600, 1000,1300, and 1900.



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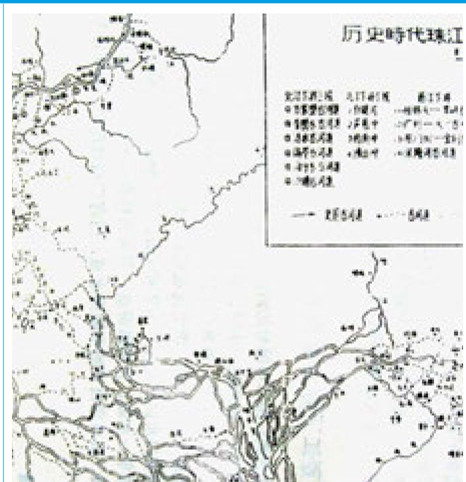
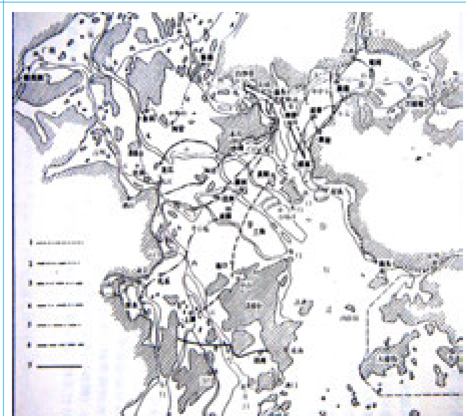
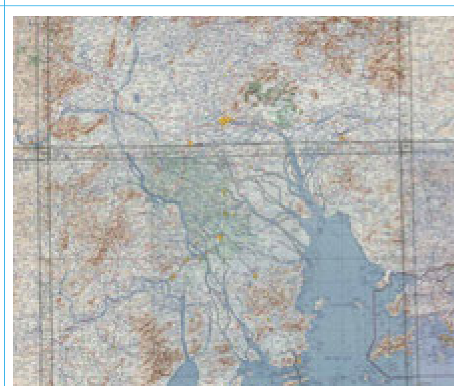
Map source	
Zeng, Z. and Huang, S. (1987) *A Research on Historical Geomorphology of Zhujiang Delta*. Guangzhou: Guangdong Higher Education Press (in Chinese). Available at Sun Yat-sen Library of Guangdong Province, Guangzhou. River channel change and dike construction from 3000 B.C. to 1987.	
Li, R., Qiao, P., Zheng, H., Fang, G. and Huang, G. (1991) *Environment Evolution of Zhujiang Delta in the Past 10000 Years*. Beijing: China Ocean Press. Available at Sun Yat-sen Library of Guangdong Province, Guangzhou. Shoreline change of 4000 B.C., 2000 B.C., 200 A.D., 600., 1000, 1300, and 1900.	
U.S. Army Map Service (1954) 'China AMS Topographic Maps, 1:250000, Series L500'. Washington, D.C. Available at University of Texas Libraries: http://www.lib.utexas.edu/maps/ams/china/	

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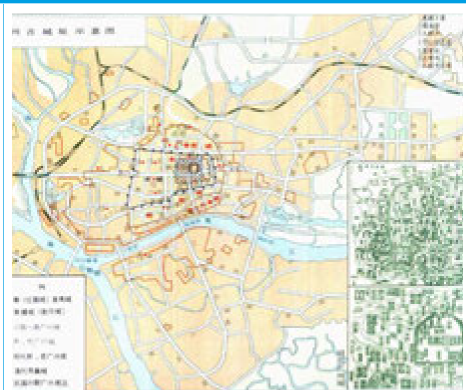
Map source	
Guangdong Historical Atlas Board (1995) 'Guangdong Historical Atlas'. Guangzhou: Guangdong Map Press(in Chinese). Maps of Guangdong Province in various years. Maps of Guangzhou and surrounding in various years.	
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Map source	
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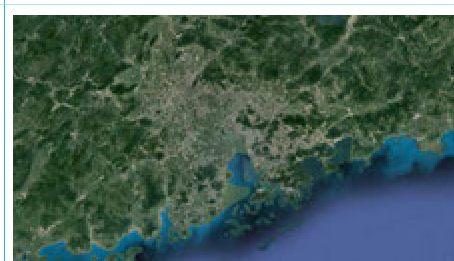
Google Maps/Earth, with various sources. Available at: https://www.google.com/maps/	

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Curriculum Vitae

Liang Xiong was born on 1 June 1985 in Hutubi, China. Studied in Electronics Engineering and Automation, he was fascinated by what Landscape Architecture can offer to the living environment. He switched major and completed his study in Landscape Architecture at China Agriculture University as a Bachelor of Agriculture, and in 2009, obtained his Master of Science in Landscape Architecture at Peking University. He studied the nature-based solutions in various scales. He was forced to live around China: from Hutubi, a remote county with a population of 0.2 million, to Hengyang (municipality, 7 million), Beijing (capital, 21 million), and Shenzhen (Special Economic Zone, 25 million). Despite the increase in knowledge and skills, his life quality decreased in larger and quicker developing cities. The mixed experience in large city spurred him to develop an interdisciplinary study among the Chair of Urban Design, the Chair of Landscape Architecture, and the Chair of Spatial Planning and Strategy in the Department of Urbanism at the Faculty of Architecture and the Built Environment, Delft University of Technology. There he works to develop a comprehensive design tool between the scales of large and small, the dynamics of rapid and slow, and the domains of design, planning and engineering.

As a reviewer of Landscape Architecture Frontiers (journal, English-Chinese), and Urban Planning International (journal, Chinese), he introduces the two journals into the TU Delft Library for the Dutch readers. At the meantime, he covers the trends of the Dutch urban and regional design and planning in Urban Planning International for the Chinese audience monthly. He was reviewer of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), regarding the assessment of impacts, adaptation, and vulnerability due to climate change. He also contributed to the massive open online course "Rethink the City: New Approaches to Global and Local Urban Challenges" addressing urban theories and methods in emerging countries, which was awarded Excellence in Teaching 2017 by the Association of European Schools of Planning, and later recommended by the United Nations for learning sustainable development and the Sustainable Development Goals. His book chapter, Exploring Spatial Relationships in the Pearl River Delta (with Steffen Nijhuis as co-author), was announced by Springer Nature Press as one of the best and most read papers in the field of Urban Studies in 2019.

Publications

Xiong L., Nijhuis S. (2019) Exploring spatial relationships in the Pearl River Delta. In Ye, X., Liu, X. (eds.) Cities as social and spatial networks. Human Dynamics in Smart Cities. Springer, Cham, 147-163.

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20#21

Pearl River Delta: Scales, Times, Domains

A Mapping Method for the Exploration of Rapidly Urbanizing Deltas

Liang Xiong

The research aims to provide an understanding of an urbanizing delta in which different scales, times, and domains are related to each other; and to examine how this understanding can be used in a planning and design process in a rapidly urbanizing delta. A mapping method is developed according to the key notions in the understanding of urban deltas, namely its systems, scales, and temporality. The systematic mapping approach was used to organize and analyze both short-term and long-term spatial data during the rapid delta urbanization processes by transforming spatial data via scales, times, and domains. The mapping approach works with insufficient data, which is often the case in a rapidly changing environment, to identify spatial challenges from a long-term perspective.

Applied in the Pearl River Delta, the knowledge of the development of the urban landscape had been inventoried, synthesized, and presented in its own spatial-temporal model using maps. Three types of processes (landscape formation, infrastructure extension, and urbanization) were identified according to their speeds. Spatial interactions were illustratively explained on both the delta scale and local scale from 4000 BC to the present with a time extent ranging from 2000 years to 50 years. The intervention of this mapping framework was applied and evaluated in terms of design, decision-making, and education, and the insights gained were used to discover new possibilities and strategies for the delta.

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