Landform transformation on the urban fringe of Asian large cities:

Comparative case studies in Bangkok and in Metro Manila

（アジア大都市縁辺部の人工地形改変：バンコクとマニラにおける比較事例研究）

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I herewith express my deep appreciation to these evaluators.

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Abstract

For large Asian cities situated on low-lying plain, landform transformation is essential for both agrarian and urban development; and besides it is subject to macro-scale geomorphologic settings that range from continental deltas to foothill-rimmed insular lowlands. Understanding landform transformation processes and patterns in different geomorphologic settings is crucial for land-use planning in areas of mixed urban–rural land use on the periphery of these cities. I examined landform transformation processes and patterns in Bangkok as a representative of the cities on continental deltas and Metro Manila as a representative of the cities on foothill-rimmed insular lowlands at three scales: (1) meso-scale quantitative landform and land-use analyses on the urban fringe by interpretation of satellite imagery, aerial photographs, and topographic maps; (2) micro-scale field measurements in a low-lying district to investigate relationships between landform, land use, and the types of fill material used; and (3) macro-scale analysis of the flow of fill material from source areas outside the city area to end use on the urban–rural fringe of the city.

Bangkok case study showed that the type and the cumulative volume of fill material used are related to past agricultural land-use patterns, which in turn are related to the pre-existing natural local environment. The volume of landform transformation, or materials carried into the urban fringe area was rated at 5.7×10^3 m^3 km^{-2} $year^{-1}$. I found associations between building styles and types of fill material used: townhouses are built on clay fill foundations, whereas condominiums and roads with heavy traffic loads are built on sand fill. Each type of fill has a different flow from source to end use that is influenced by geologic and economic conditions. The flow of clay fill is limited to the meso-scale urban fringe area, whereas sand fill travels from sand pits on a natural sand levee 100 km upstream from its end use on the urban fringe. The sand output at its source was estimated to be 5.5×10^7 m^3 $year^{-1}$, which, depending on cost, is either trucked or transported by river to the urban fringe development areas. Thus, landform transformation was found to occur at multiple scales in the Bangkok region, and the delta is no longer flat. These findings suggested that land-use planning for Bangkok should incorporate the means of managing the flow of fill material from source pits to end use in urban fringe

development areas.

Metro Manila case study revealed that both the degree to which fill practices have been used and the cumulative volume of fill material used are spatially related to natural landform type. I calculated the rate of application of landfill to be 5.0×10^3 m^3 km^{-2} $year^{-1}$, most of which consisted of offsite disposal of construction waste or crushed rock produced through urban development and regeneration on the uplands. The bulk of these materials were used for landfill in low-lying land development areas. White sand is excavated at the foot of Mt. Pinatubo, and is trucked 60 km distance into land development sites on the urban fringe where used for surface filling and leveling. Estimated sand production during the peak period, shortly after the 1991 eruption of the Mt. Pinatubo volcano, was around 6.6×10^6 m^3 $year^{-1}$. In the Metro Manila region, the flows of fill material from offsite sources to onsite land transformation areas were on the basis of individual one-to-one trade-off relationships between suppliers and developers. I concluded that regulatory control of offsite and onsite landform transformation practices is essential for future land-use planning in Metro Manila and proposed that GIS technology systems would assist effective management of the region's characteristic one-to-one material flows.

Through the comparison between Bangkok and Metro Manila case studies, I disclosed that quantified and qualified landform, land use, and landform transformation are usable indicators for urban-rural land-use planning for these cities. These indicators are connected each other by fill material flows, and their emergent spatial scales differ depending on the macro-scale geomorphologic settings. In Bangkok that is located on a continental delta, quantified land use and landform transformation are interrelated visible indicators for meso-scale space, whereas in Metro Manila that is situated on foothill-rimmed insular lowlands, quantified natural landform and landform transformation are interrelated emergent indicators for meso-scale space. Both in Bangkok and in Metro Manila, quality of fill materials and housing styles, qualitative aspect of land uses, are interrelated emergent indicators for micro-scale space. Structures of fill material flows in each city are dependent upon quality of materials, and quantity and spatial extent of these fill material flows are subject to availability and accessibility to material sources, that in turn are determined by the macro-scale geomorphologic conditions. Sand flow in the Bangkok region diffuses over 100 km distance, while that in the Metro Manila region travels across 60 km distance. The clay flow that is characteristic of Bangkok behaves not beyond micro-scale space, while the construction waste flow that is characteristic of Metro Manila can be scaled within meso-scale space. I concluded that further case studies under the same methodology are immediately needed to scale these indicators correctly in the macro-scale geomorphologic contexts, and finally to establish urban-rural planning strategies for Asian large cities.

論文要旨

アジア大都市の多くは低地帯に立地しており，農地および都市的土地利用双方の造成時に，人工地形改変行為が必須となる。人工地形改変の様式は，大陸デルタから島弧の沖積平野まで，アジア各都市が立地する大地形環境に規定される。多様なアジア各都市の縁辺部において，都市農村土地利用の混在化を地形改変と結びつけて事例検証していくことは，各都市の土地利用計画を改善する上で，さらにはアジア都市農村計画論の展開にとって前提要件である。こうした観点から，本研究では，大陸デルタ立地型のバンコクと，島弧低地立地型のマニラを事例研究都市としてとりあげ，地形－土地利用－地形改変の相互関係を精査した。研究は，以下３つの空間スケールにわたって進められた。(1) 両都市縁辺部にメソスケールの調査対象地域を設定し，空中写真，衛星画像，地形図の判読およびデジタル化・空間解析を通じて，都市化による土地利用変化と地形改変量の関係を定量的に算出した。(2) 両都市の上記メソスケール対象地域内部の新規宅地造成地において，測線測量，埋立材質記録，開発者へのインタビュー調査を行い，ミクロスケールな開発形態－地形改変様式の相互関係を把握した。(3) 前出の新規宅地造成地を起点として，インタビュー調査により埋立使用材のフローを遡上，最終的にはマクロスケールに分布する掘削地の位置情報を取得し，埋立材フローの全容をモデル化した。

バンコクにおける事例研究より，当地では過去の農地開拓パターンが，土地利用変化および付随する地形改変様式に影響をおよぼしていることが示された。バンコク縁辺部に位置するメソスケールの研究対象地域における投入土量は，5.7×10^3 m^3 km^{-2} $year^{-1}$ と試算された。ミクロスケールな宅地造成地の現地調査を通じて，上物開発形態と埋立宅盤の関係性が明らかとなった。すなわち，軽量タウンハウスは主に粘土宅盤を用いて造成されるのに対し，荷重のかかる高層マンションや主要道路は砂材基盤によって造成されていた。フロー追跡調査により，各埋立材はそれぞれ固有のフロー構造を持ち，それらは地質条件とコストパフォーマンスにより決定されることが分かった。粘土のフローは郊外の土地利用混在域内に限定されているのに対し，砂材は都市縁辺部からさらに 100km 隔たった上流部にて掘削され，都市縁辺部の新規開発地まで陸送・水送されていた。砂材掘削量は 5.5×10^7 m^3 $year^{-1}$ と推定された。バンコク地域では全ての空間スケー

ルで地形改変行為が観察され，大陸デルタ表層は全体的に不均一化してきていることが明らかとなった。これらの結果より，バンコクにおいては，旧来の農地パターンを考慮したゾーニングと埋立土量の総量規制，そして埋立材フローの各結節点における課税・監督行為の強化が，土地利用計画の実行力を高める上で重要であると提案した。

一方，マニラにおける事例研究により，当地では，メソスケールでの自然地形条件と地形改変量が連関していることが示された。都市縁辺部の研究対象地域における投入土量は，5.0×10^3 m^3 km^{-2} $year^{-1}$ と算出された。低湿地の埋立材の多くには，近接する台地上の都市内再開発および新規開発のレベリングを通じて産出・運搬される，建築廃材・低品質砕石が使用されていた。埋立表層に使用される砂材は，都市縁辺部から 60km 離れたピナツボ火山麓の，ラハール堆積地域から陸送されていることが分かった。砂材掘削量は 6.6×10^6 m^3 $year^{-1}$ と推定された。これら埋立材のフローは，いずれも生産地から埋立地まで直送され，生産者と開発者の間には相互依存の関係がある。これらの結果より，マニラにおいては，自然地形を考慮したゾーニングおよび地形単位毎の埋立総量規制，そして地理情報システム整備による埋立材生産者と開発者間の直送フローの適正化が，土地利用計画の実行力を高める上で重要であると提案した。

バンコクとメトロマニラにおける事例研究の比較を通じ，地形，土地利用，地形改変の定量指標化が，都市縁辺部における都市農村土地利用計画に寄与することを明示した。これらの計画指標は埋立材のフローにより相互に関係づけられており，その都市が立地する大地形環境により，各空間スケール内における指標の現出優先順位は異なってくる。大陸デルタ上に立地するバンコクでは，土地利用面積・分布パターンと地形改変量が，メソスケールな拡がりを持つ郊外地域における優先計画指標となるが，島弧立地のマニラでは，地形分布と地形改変量が，同様な都市郊外地域において優位な計画指標となる。しかしながら，ミクロスケールな新規宅地開発空間では，両都市とも埋立材質と上物開発形態が有意な指標となる。各種埋立材フローの空間構造も，各都市の大地形環境，すなわち地質条件とソースへのアクセス性により規定される。例えば，バンコクの砂材フローは延長 100km におよぶが，マニラのそれは 60km 弱である。また，バンコクに特有の粘土フローは隣接地所間などミクロな空間に限定されるが，マニラの建築廃材フローは台地から低地へメソスケールな空間内にて観察される。今後，アジア各都市で本研究同様の事例調査を進めることで，計画指標の階層性および出現要因を抽出し，

体系化していく必要がある。本研究は，アジアの風土に根ざした都市農村計画論の構築に向けて，その端緒を拓いた。

1. Introduction

1.1. Background

Large Asian cities in monsoonal areas are situated mainly on low-lying areas (Fig. 1). Recent economic growth has led to the expansion of urban areas into peripheral agricultural areas, and broad areas of mixed urban–rural development are emerging (McGee, 1991, 1995). Mixed land use is creating many environmental problems, so that effective control of urban growth is urgently needed (Yokohari et al., 2000; Marcotullio, 2001). A thorough understanding of land-use change processes and patterns of mixed urban–rural land use is essential to allow effective land-use planning (Antrop, 2005; Ichikawa et al., 2006). Moreover, investigation of landform transformation as a result of urban–rural land-use changes, depending on macro-scale geomorphologic settings that range from continental deltas to foothill-rimmed insular lowlands, is a key issue for urban-rural land-use planning (Hara, 2005).

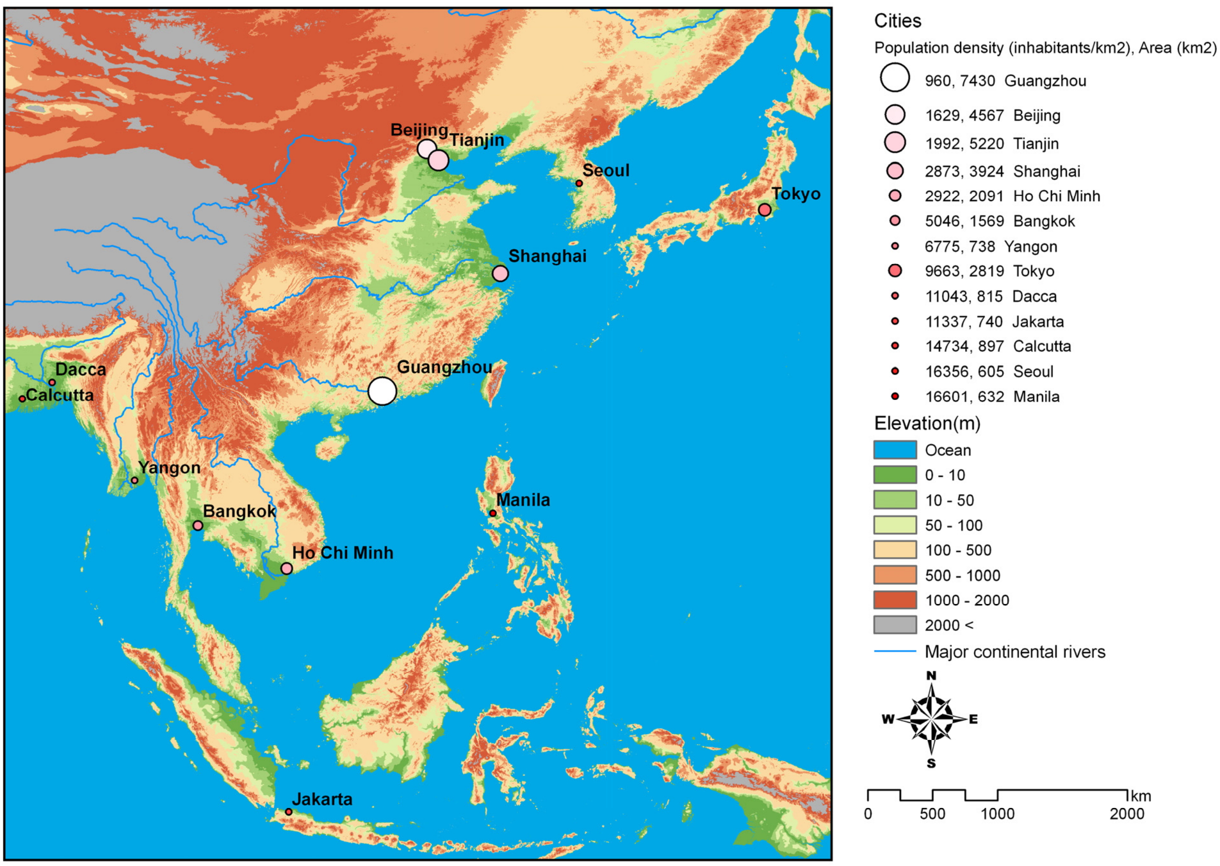


Fig. 1. Locations of low-lying Asian cities with populations of more than 5 million.

Landform transformation for agrarian development in Asian monsoonal plains has been studied mainly from the agricultural engineering viewpoint. Many previous studies have considered rice cultivation, the predominant agricultural land use in Asia, and have described the gradual transition of Asian agricultural landscapes from natural landform-based irrigation to large-scale artificial irrigation (Tanaka, 1991; Watabe and Fukui, 1997). These studies also suggest that the diversity of alluvial landforms in Asia, ranging from continental deltas to insular plains, generates hydrologic diversity and leads to a diversity of agricultural landscapes (Takaya, 1985; Kaida, 1991). Most of the previous studies focus on macro-scale classification of agricultural areas; however, few have performed a quantitative micro-scale evaluation of the effects of landform transformation practices on landscape structures and patterns.

Case studies of the urbanization process in foothill-rimmed lowlands of Japan deal with vertical landform transformation practice; for instance, studies of the Osaka (Tanaka et al., 1983; Hashimoto et al., 2003) and the Tokyo (Takeuchi and Yoshioka, 1982; Miwa et al., 1991; Sakuma, 2002; Taniguchi, 2004) metropolitan areas. Tamura et al. (1983) summarize trends in landform transformation practice in Japan. There are also case studies of other Asian cities: Kamal and Midorikawa (2004) describe the expansion of a built-up area using landfill in Dhaka; Hara et al. (2002) investigated the processes and distribution of landfill development in the suburban lowlands of Metro Manila; Kato and Narumi (2003) discuss land-use change and land reclamation in Hanoi from the urban planning viewpoint. However, these studies do not consider the volume, characteristics, and spatial flow of landfill materials.

Thus, few studies have used landform transformation as a key element to understand the entire process by which agricultural landscapes change into urban landscapes. A case study from this perspective can provide crucial information for land-use planning in peripheral urban-rural land-use mixed areas of each city. Land-use planning using the prevailing zoning systems is not functioning well in Asian cities (Yokohari et al., 2000), hence the use of both horizontal zoning and vertical landform transformation control can be expected to result in more effective land-use planning (Ministry of Land Infrastructure and Transport, 2003; Hara, 2005). It is expected, furthermore, that there are both similarities and differences in urban–rural land-use patterns and landform transformation practices, depending upon macro-scale geomorphologic settings that range from continental deltas to foothill-rimmed insular lowlands. Comparative case studies can contribute to establishing effective and practical urban-rural planning strategies in Asian urban fringes. From these viewpoints, I selected two case study cities: Bangkok as a representative of the cities on continental deltas; and Metro Manila as a representative of the cities on foothill-rimmed insular lowlands.

1.2. Methodology

The following two approaches are useful for addressing urban–rural land-use processes and patterns as well as landform transformation practice.

1.2.1. Multi-scaling

This is a commonly used approach in the field of landscape ecology. The study area is scaled hierarchically into several spatial layers. Spatiotemporal relationships among landscape components within each spatial layer, and relationships between layers are examined (Wu, 2004; Uuemaa et al., 2005). The multi-scale approach mirrors the hierarchical structure of the administrative bodies that handle spatial planning; therefore, the research results can be applied in practice (Bouman et al., 1999; Steinhardt and Volk, 2002).

1.2.2. Anthropogenic geomorphology

This approach considers human activities as a third force on surface landform change processes, and examines man-made landforms using both quantitative and qualitative topographic measurements (Kadomura, 1985; Hooke, 2000; Drew et al., 2002). Studies on cut-and-fill operations for land development in hilly areas (Tamura and Takeuchi, 1980) and on landforms in mined areas (Moriyama, 1983) are typical examples. As well as these descriptive studies, a considerable number of studies deal with rehabilitation plans and methods for man-made landforms degraded by activities such as coal or aggregate mining (Jaakson, 1981; Graupner et al., 2005).

1.2.3. Multi-scaling land use and landform transformation

In this study, I integrated the two approaches discussed above, and developed my research design as shown in Fig. 2. For both Bangkok and Metro Manila, I used three spatial scales equally: the whole hinterland region (macro scale), urban fringe areas (meso scale), and development sites (micro scale). I started my quantitative analyses (for Bangkok and Metro Manila separately) of landform, land use and landform transformation in the urban fringe at meso scale. I next focused on development sites at micro scale, and made qualitative observations of housing patterns and landform transformation. I then traced the flow of soil materials used for fill in the entire hinterland region, taking into consideration geologic structure and transport routes. Finally I made a comparison between Bangkok and Metro Manila in terms of land-use patterns, landform transformation methods, their interrelations, and spatial extent of fill material flows.

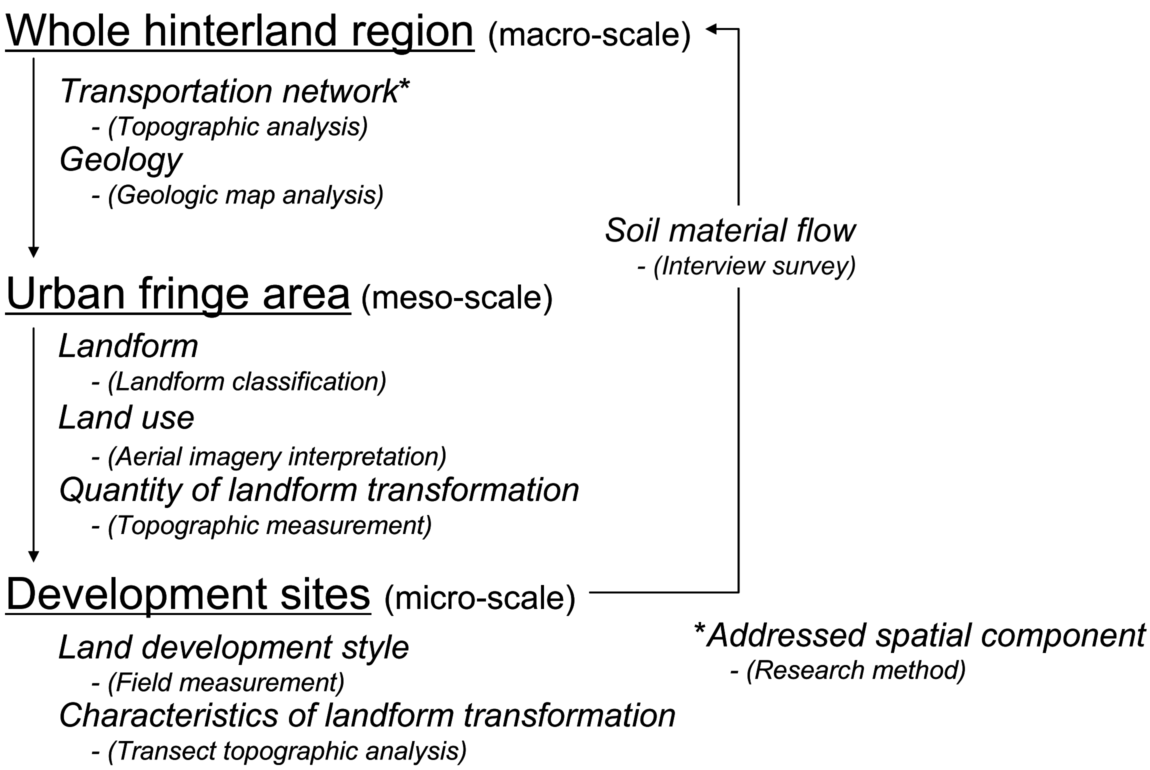


Fig. 2. Research design for multi-scale analysis of landform, land use, and landform transformation.

This study revealed multi-scale human practices of landform transformation that are interactive, and for which soil material flow is a common thread. This study showed that landform transformation is a key issue in urban–rural land-use planning both in Bangkok and in Metro Manila even if its pattern differs. Through the comparison between Bangkok and Metro Manila, this study also presented a clue to establish effective and practical urban-rural planning strategies in Asian urban fringes.

2. Bangkok case study

2.1. Study area

Bangkok is a typical example of a large Asian city built on a continental delta (Fig. 3). This chapter focuses on Bangkok and its hinterland.

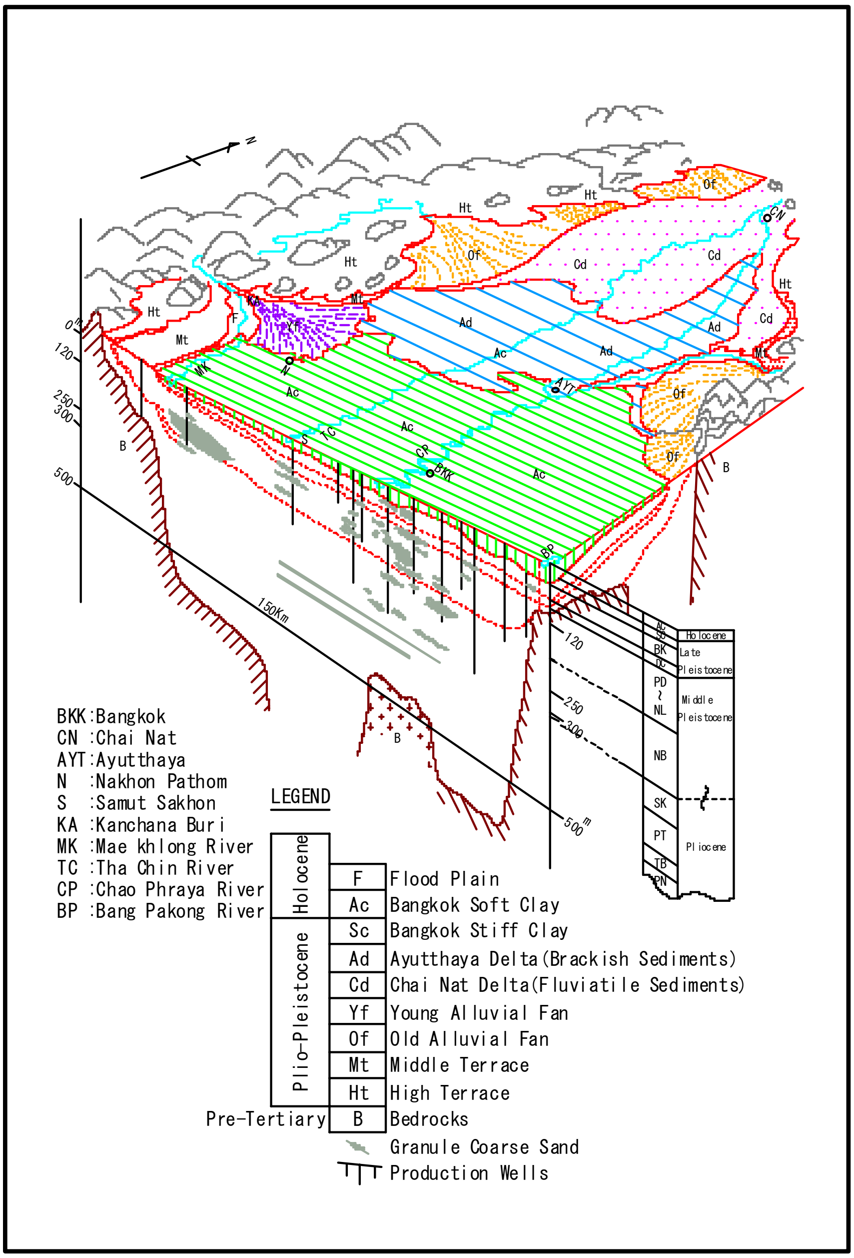


Fig. 3. Bangkok built on the continental Chao Phraya delta (modified after JICA, 1995).

2.1.1. Agricultural and urban development in Bangkok and its hinterland

Bangkok was founded in the late 18th century as a fortified city surrounded by a moat and was built on a sandbar in the lower Chao Phraya delta. Takaya (1987) describes the area subsequently developed for agriculture around Bangkok and its hinterland as a broad deltaic wasteland.

Excavation and subsequent extension of *khlongs* (*khlong* means canal in Thai) are necessary landform transformation practices to deal with the extreme hydrologic conditions characteristic of monsoonal deltas. These range from complete submergence during the rainy season to desert conditions during the dry season. Construction of *khlongs* allowed the cultivation and irrigation of rice fields and provided a means of transport. Soil excavated from the *khlongs* was used to fill and raise low-lying areas on which houses and other structures could be built. The rudimentary *khlongs* were essential for transport (Tanabe, 1973a) and were particularly important after the Bowring Treaty of 1855, which marked the beginning of free trade and resulted in a rapid expansion of the *khlong* network to irrigate new rice fields to meet the high demand for rice for export (Tanabe, 1973b). Artificial levees along the *khlongs* were extended and interconnected to develop a landscape of canals and dykes. The introduction of power pumping devices later allowed reclamation of more land for new rice fields (Takaya, 1987).

After World War II, the Greater Chao Phraya Project, which aimed to irrigate and cultivate the whole Chao Phraya delta as a rice bowl for the world, was initiated under the supervision of the Food and Agricultural Organization (FAO). As part of this project, the Chai Nat Dam at the head of the delta was completed in 1957, and greatly improved irrigation and cultivation for the whole delta. The availability of irrigation provided a means of landform transformation that brought agricultural diversity at the individual land parcel level, and a variety of agricultural landscapes have since emerged (Fujioka and Kaida, 1967; Kaida, 1990; Kono and Saha, 1995; Molle et al., 1999).

Many previous studies of the urbanization of Bangkok approach it from an urban planning or architectural viewpoint (Archer, 1986; Iwata and Watanabe, 1988; Kidokoro, 1990; Watanabe, 1991; Japan International Cooperation Agency, 1997; Shigetomi, 1998; Tasaka and Nishizawa, 2003; Pornchokchai and Perera, 2005). However, most studies deal with the expansion of urban land use on a macro scale, regarding the delta as a flat empty area without agricultural development. A few urban–rural landscape studies, however, specifically examine the shift from agricultural to urban land uses, and include consideration of landform transformation practices. Tachakitkachorn and Shigemura (2005) show the important role of orchards in development of the housing base. Sundaravej (2004) emphasizes the parallel relationship between the digging of the irrigation *khlongs* and the construction of roads. Hara et al. (2005) quantifies the volume of fill required for different land uses, and associated agricultural land-use patterns with urban housing styles.

In this study, I further developed the approach of investigating landform transformation practices to understand changes in the urban–rural land uses. I examined both qualitative and quantitative aspects of fill materials and soil flow, and considered the development of mixed urban–rural land uses.

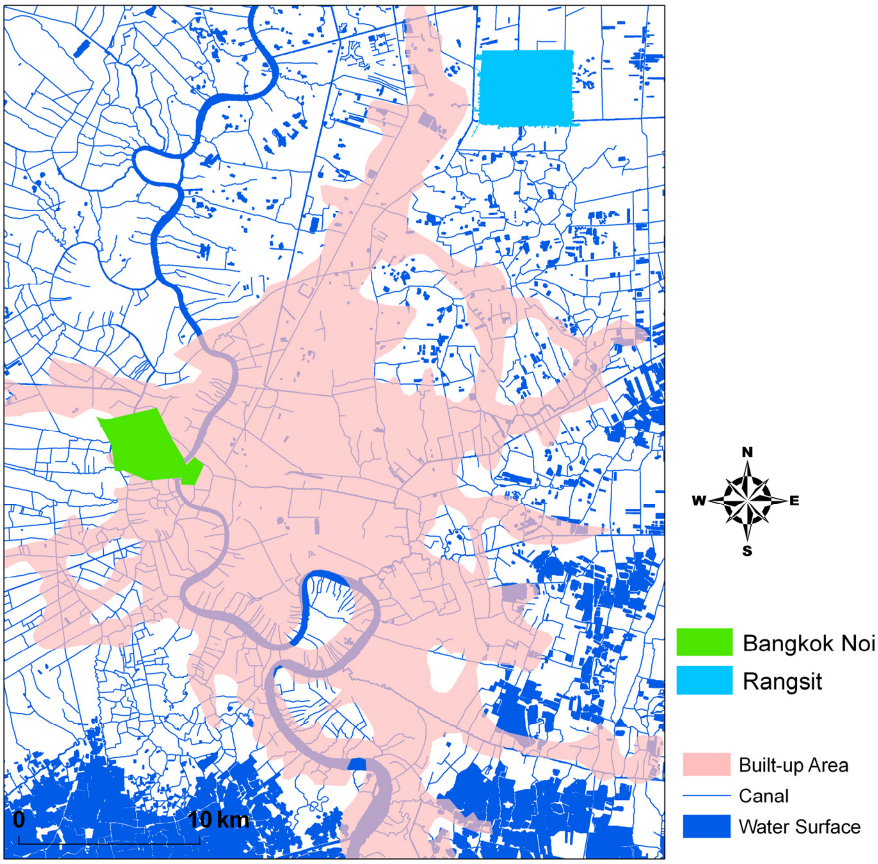


Fig. 4. Location of meso-scale study areas (BangkokNoi and Rangsit).

2.1.2. Two meso-scale study areas of contrasting agricultural land-use patterns in the urban fringe

I selected two meso-scale study areas, BangkokNoi and Rangsit, on the basis of past agricultural land-use patterns (Fig. 4). The BangkokNoi area is situated in a relatively elevated area alongside a former main tributary of the Chao Phraya River, and it has been an orchard growing area for many years (Tachakitkachorn and Shigemura, 2004). The Rangsit area was reclaimed during the late 19^{th} and early 20^{th} centuries under government direction, and is characterized by a gridded system of *khlongs* and broad rectangular rice fields (Takaya, 1987). I studied these two contrasting meso-scale urban fringe areas, and carried out spatial analyses of change processes and patterns in the shift from agricultural to urban land uses.

2.2. Data sources and analytical methods

I conducted field surveys for a total of approximately five months between 2001 and 2006, and collected data from various agencies and organizations (Table 1). In the field I verified land-use interpretations of aerial photographs, interviewed local people, recorded fill materials, and took landform measurements. I used Geographic Information System (GIS) technology (TNTmips version 7.0, MicroImages Inc, Lincoln, NE, USA; ArcGIS version 9.0, ESRI, Redlands, CA, USA; VectorWorks version 11.5, Nemetschek North America, Columbia, MD, USA) for data digitization, spatial analyses, and drawing of figures.

2.2.1. Digital land-use maps

I produced digital land-use maps for BangkokNoi and Rangsit for 1952, 1967, 1979, 1987, 1995, and 2002 using field-verified aerial photograph (Table 1) interpretations. I used land-use categories defined by Hara et al. (2005) in a detailed investigation of urban–rural land-use interactions. My land-use interpretation was supported by interviews with older local residents and officers from local land offices with good knowledge of local history, and topographic, housing, and cadastral maps. I scanned photos at a resolution of 600 dpi, added georeference data, and compiled a raster mosaic image for each of the six years. I then manually digitized the

Table 1. Data sources of Bangkok case study

	Year	Scale	Format	Publisher
Aerial photographs	1952	1:40 000	Print (black and white)	Royal Thai Survey Department
	1967	1:50 000	Print (black and white)	
	1979	1:15 000	Print (black and white)	
	1987	1:20 000	Print (black and white)	
	1995	1:20 000	Print (black and white)	
	2002	1:25 000	Print (color)	
Topographic map	1996	1:50 000	Digital and paper	Royal Thai Survey Department
Detailed city topographic maps	1987	1:4000 and 1:10 000	Paper	Bangkok Metropolitan Administration
	2000	1:4000	Paper	
Geologic map	1970s-present	1:250 000	Digital and paper	Royal Thai Department of Mineral Resources
Geologic column	1995	-600m<	Paper record	Japan International Cooperation Agency
Soil map	1972	1:100 000	Paper	Department of Land Development
Housing map	1998	1:8000 and 1:10 000	Atlas	Agency for Real Estate Affairs
Cadastral map	2000	1:1000	Paper	Department of Lands

interpreted land-use boundaries and overlaid them on the raster mosaic for each of the six years.

2.2.2. Measuring land elevation

I acquired detailed topographic maps of Bangkok (Table 1), which provided elevations accurate to within 10 cm. I scanned the maps covering my two study areas (five sheets each for BangkokNoi and Rangsit) at 300 dpi resolution, and added location information. I then extracted elevation points (472 points for BangkokNoi and 197 points for Rangsit) and digitized them as vector point data to provide elevation attributes for GIS analysis.

2.2.3. Associating land use with land elevation and quantifying the cumulative fill volume

I grouped the digitized elevation points for the BangkokNoi and Rangsit areas according to land-use type by overlaying them on the digital land-use map for 2002. For areas where it was clear that landform transformation had occurred between 2000 and 2002, I used the land use interpreted from the detailed city topographic map for 2000. I then tested the association between land elevation and land-use type by multiple comparison using the Mann-Whitney U test and applying the Bonferroni correction ($P < 0.05$).

I used the following method to calculate a theoretical volume of introduced fill. For each area of changed land use, the increase in elevation as a result of addition of fill to effect the land-use change was multiplied by the area that had undergone change. I used a pond depth of 1.5 m, and a *khlong* depth of 2.5 m, based on my field observations and the work of Hara et al. (2005).

2.2.4. Recording fill materials in development sites and measuring transect features

In order to corroborate the land use – land elevation associations derived from my GIS analyses, I field surveyed development sites within BangkokNoi and Rangsit, and recorded the characteristics (texture and color) of fill materials, the height of the fill profile, and any layering within the profile. Where possible, I also interviewed site managers, workers, developers, and landowners to find out what fill materials they use, why they use them, and their source and cost.

Transect analysis is considered a valid approach to investigate changes of landscape. I selected four typical transects (two each for BangkokNoi and Rangsit) based on comparison of the detailed topographic maps of the city for 1987 and 2000. Along each transect I recorded land uses and used a hand level and laser rangefinder 400LH (Opti-Logic Corporation, Tullahoma, TN, USA) to take field measurements of the height of fill. For sites that had already been developed, I recorded the exposed features of fill where it was visible, and obtained details of fill materials and volumes from the developer.

2.2.5. Tracing the flow of fill material into the development sites

Because of a lack of usable government records on land development and mining in Bangkok I mainly used field interview methods to obtain the data I needed to trace the flow of fill material. I undertook extensive interviews with local contractors at river piers and pits on matters such as the price of fill, the supply–demand balance, and government regulations related to fill material. I also conducted interviews and collected data about the flow of fill material in Bangkok at the Bangkok Metropolitan Administration office, the Ministry of Natural Resources and Environment, the Ministry of Industry, and at several major construction companies.

2.3. Results

2.3.1. Land-use changes in the two study areas

Land-use maps for each of the six years used in my study for BangkokNoi are shown in Fig. 5, and for Rangsit in Fig. 6. Both study areas show a transition from agricultural to urban land use; however, the transformation processes differ.

The BangkokNoi area was almost entirely covered by orchards in 1952. Traditional *khlong* house settlements lined the tributaries of the former main river course, and urban housing and factories occupied the southeastern area facing the old city center across the Chao Phraya River. Urban land use and some roads had expanded northwestward by 1967. This trend had strengthened by 1979, when there were many detached houses along secondary dead-end roads, separated by clusters of slum-type housing. By 1987, there was a new main road running from east to west across the northern part of the area, where there was a marked increase in urban

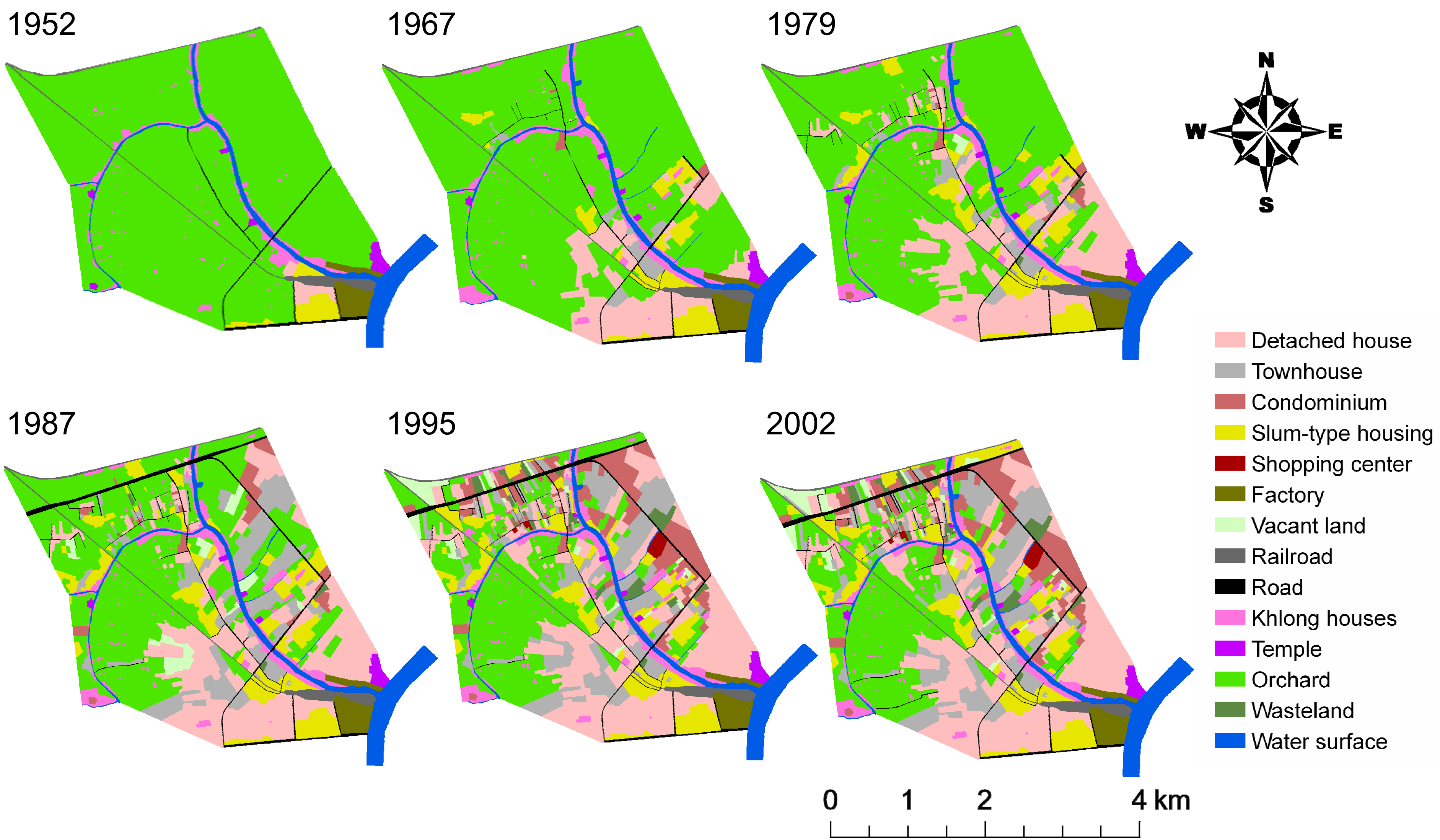


Fig. 5. Time series of land-use maps of BangkokNoi.

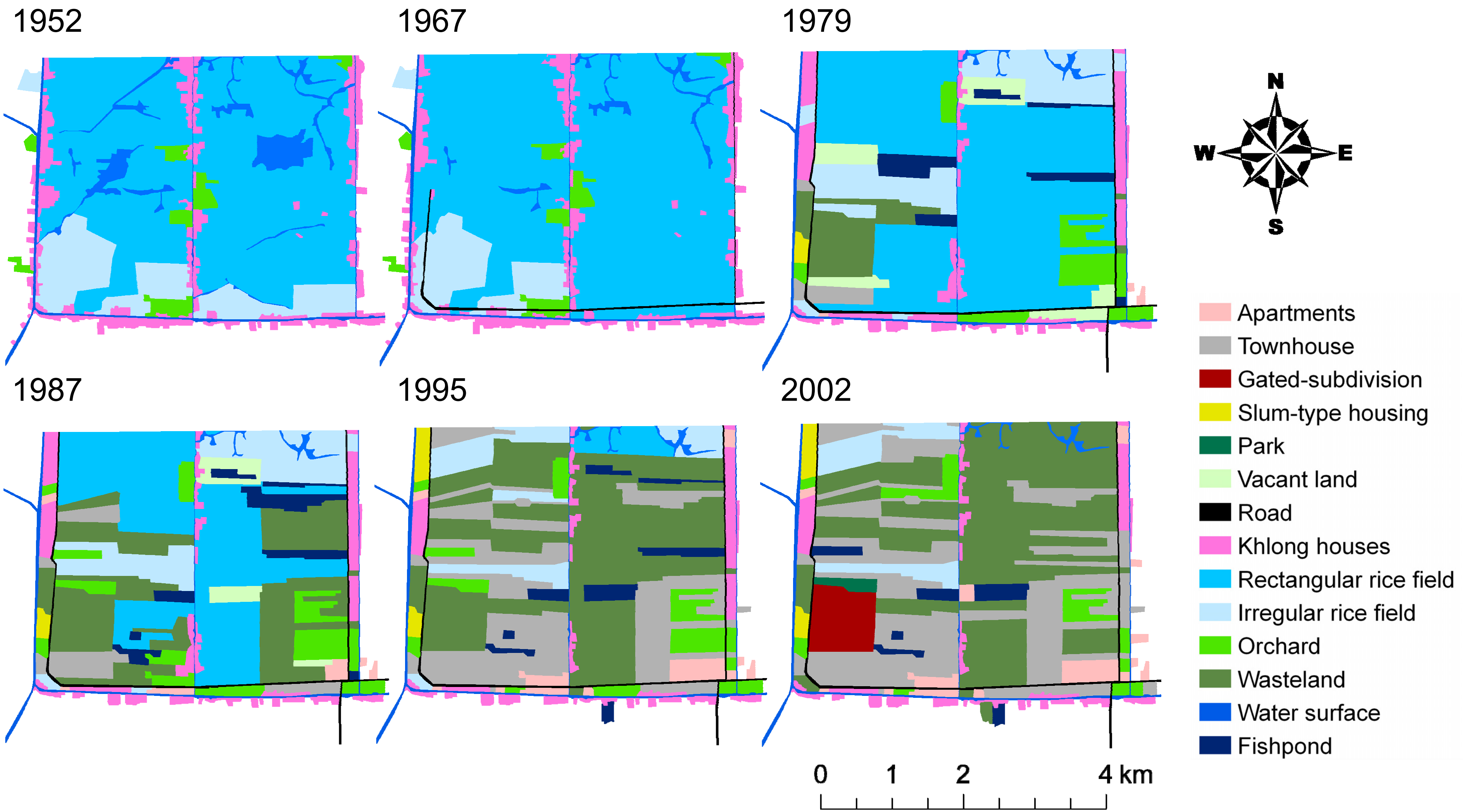


Fig. 6. Time series of land-use maps of Rangsit.

land use, with the development of condominiums in particular. In the western area, which the road network had not yet reached, the *khlong* houses remained along the main *khlong* that was formerly a river tributary, but were accompanied by new detached houses with elevated concrete floors that had been built for relatives of the *khlong* house dwellers (verified by inhabitants during field survey). By 1995, urban development had increased along the main roads, and many condominiums had been built in the north. There were few changes in land use between 1995 and 2002, probably owing to unfavorable economic conditions. Thus, urban development in the BangkokNoi area was relatively continuous from 1952 to the mid-1990s.

The Rangsit area was covered by large rectangular rice fields in 1952. At this time *khlong* houses lined the grid-shaped *khlong* system. In 1967, a main road running from east to west had been constructed in the south. By 1979, east–west oriented strips of fishponds and townhouse developments had emerged from new main roads along the eastern and western boundaries of the area into the hinterland. This trend had strengthened by 1987, and the land parcels between the fishponds and townhouses had been converted into small irregular rice fields, or had become abandoned wastelands. Land-use changes between 1987 and 1995 were remarkable; many townhouses were built on the 1987 wastelands. Although there were no dramatic changes of land use between 1995 and 2002, the urban development trend continued. Most of the rice fields were replaced by townhouses, or were abandoned and became wastelands. It was also apparent that some new fishponds and orchards had appeared, and subsequently disappeared, at various locations between 1952 and 2002.

Thus, both study areas have been transformed from *khlong*-oriented agricultural landscapes to road-oriented urban landscapes. However, the processes by which the shifts took place, and the spatial patterns and styles of the emerging urban housing are different, seemingly influenced by landform transformation patterns. This point is discussed further in the next section.

2.3.2. Land elevation – land use relationships and cumulative fill volumes

Land elevation – land use relationships in both study areas are shown in Fig. 7. For analysis of each study area, several land-use categories were combined, because the topographic maps provided only a limited number of elevation points within them, and my field survey showed that they occupied areas of similar elevation.

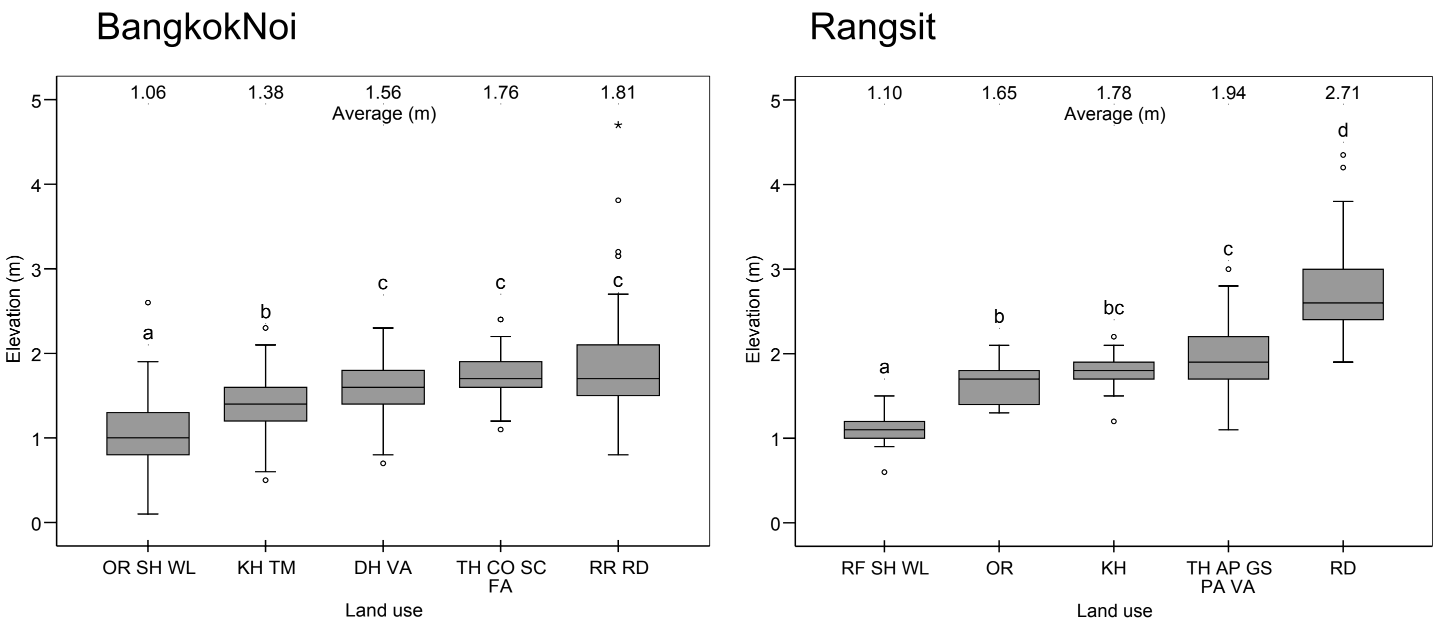


Fig. 7. Land use – land elevation relationships at BangkokNoi and Rangsit. Small letters (a, b, c, d) indicate the land-use types that display similar ranges of elevation by multiple comparison using the Mann-Whitney U test with Bonferroni correction ($P < 0.05$). OR = Orchard; SH = Slum-type housing; WL = Wasteland; KH = Khlong house; TM = Temple; DH = Detached house; VA = Vacant land; TH = Townhouse; CO = Condominium; SC = Shopping center; FA = Factory; RR = Railroad; RD = Road; RF = Rectangular and irregular rice fields; AP = Apartment; GS = Gated subdivision; PA = Park.

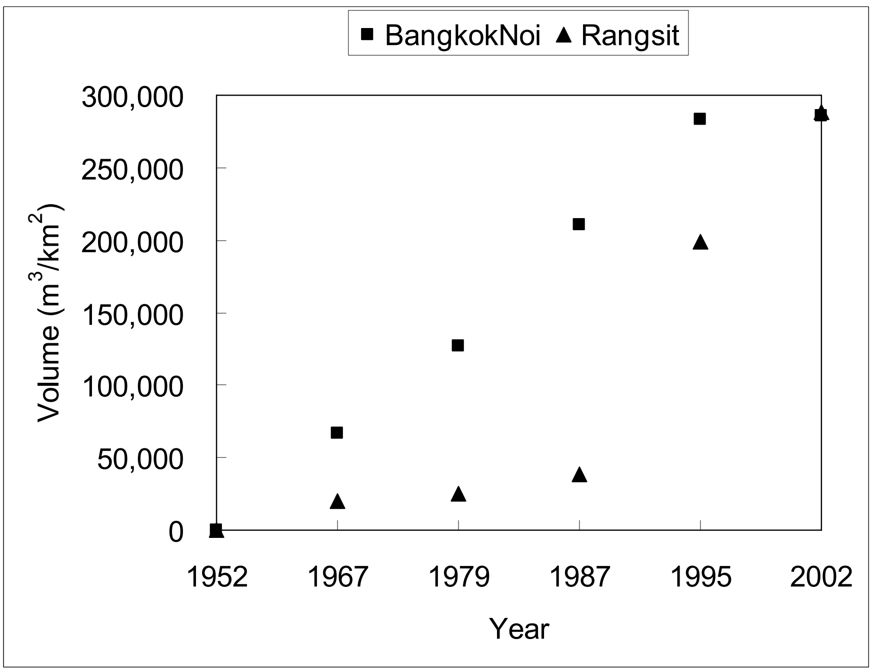


Fig. 8. Cumulative growth in fill volume for BangkokNoi and Rangsit from 1952 to 2002.

Cumulative changes in fill volume, which represent the amount of fill introduced from outside the study areas, are shown in Fig. 8. The volumes were standardized to $m^3\,km^{-2}$.

In the BangkokNoi area, land elevation rises gradually through areas of orchard, *khlong* houses, detached houses, townhouses, and condominiums, to roads. There are statistical differences in land elevation between areas of orchard and those of *khlong* houses, and between *khlong* houses and urban land uses (detached houses, townhouses and condominiums, roads). There is no statistical difference in land elevation among urban land uses. The fill volume increased linearly from 1952 to 1995.

In the Rangsit area, rice fields have the lowest land elevations, followed by orchards, where the land elevation is 55 cm higher than that of rice fields. Elevations are higher for *khlong* houses, and higher again for townhouses. Roads are at the highest land elevation, and are 77 cm higher than townhouses. The elevation of rice fields is significantly lower than those of all other land uses, and the elevation of roads is significantly higher than those of all other land uses. There is no statistical difference between the elevations of orchards and *khlong* houses, but orchards are significantly lower than townhouses. The fill volume increased slowly from 1952 to 1987, but increased rapidly thereafter.

Thus, the distribution of land elevations in the Rangsit area is more variable than that in the BangkokNoi area. The fill volume in BangkokNoi increased linearly between 1952 and 2002, while that in Rangsit increased exponentially.

2.3.3. Characteristics of fill materials in development sites

The sites where characteristics of fill materials were investigated, and the results of the investigations, are shown in Fig. 9 and Table 2 for the BangkokNoi area, and in Fig. 10 and Table 3 for the Rangsit area.

Most of the fill material in BangkokNoi is sand. Several contractors provide sand for fill in BangkokNoi, and the piers from which the sand is distributed are situated along the Chao Phraya River and a *khlong* that was formerly a main tributary.

Some sand is used in the Rangsit area, but local clay is the dominant fill material. In particular, the foundations for townhouses, which are relatively light, are mainly clay. Many contractors deal with fill materials in the Rangsit area, but there are no piers for their

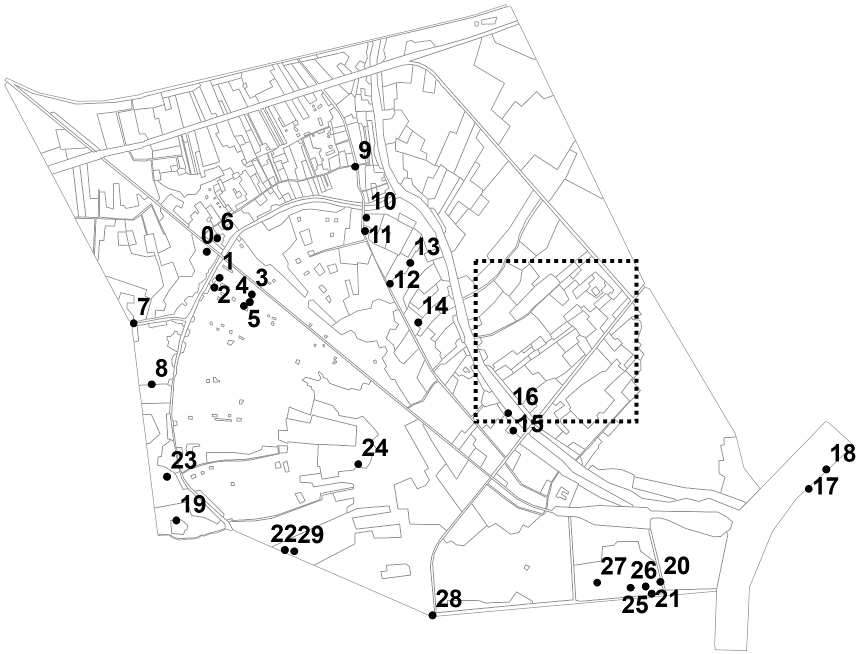


Fig. 9. Location of sites where fill was surveyed in BangkokNoi (survey results in Table 2). The dotted square is consistent with topographic maps in Fig. 11.

Table 2. Fill material survey for BangkokNoi

Site number	Land use	Main fill material			Price (bahts/m^3)		
		Type	Texture	Color	Crushed rock	Sand	Laterite
0	Road	Sand	S	10YR6/6	320	250	270
1	Detached house	Sand	S	10YR6/6	-	-	-
2	Detached house	Sand	S	2.5Y4/3	-	-	-
3	Detached house	Sand	S	2.5Y5/4	-	-	-
4	Detached house	Sand	S	10YR6/3	-	-	-
5	Detached house	Sand	S	10YR6/6	-	-	-
6	Fill contractor's shop	Sand	S	2.5Y4/2	-	-	-
7	Fill contractor's shop	Sand	S	2.5Y4/2	-	-	-
8	Condominium	Sand	S	10YR6/6	-	-	-
9	Townhouse	Sand	S	10YR6/6	-	-	-
10	Fill contractor's shop	Sand	S	10YR6/6	-	350	-
11	Detached house	Sand	S	10YR6/6	-	-	-
12	Detached house	Sand	S	10YR6/6	-	-	-
13	Condominium	Sand	S	10YR6/6	-	-	-
14	Townhouse	Sand	S	2.5Y4/2	-	-	-
15	Condominium	Sand	S	10YR6/6	-	-	-
16	Pier	Sand	S	10YR6/6	-	150	-
17	Pier	Sand	S	10YR6/6	-	-	-
18	Pier	Sand	S	10YR6/6	440	330	-
19	Condominium	Sand	S	10YR6/3	-	-	-
20	Condominium	Sand	S	10YR6/3	-	-	-
21	Detached house	Sand	S	10YR6/3	-	-	-
22	Temple	Sand	S	2.5Y4/2	-	-	-
23	Fill contractor's shop	Sand	S	2.5Y4/2	-	-	-
24	Townhouse	Sand	S	2.5Y4/2	-	-	-
25	Detached house	Sand	S	10YR6/3	-	-	-
26	Detached house	Sand	S	2.5Y4/2	-	-	-
27	Detached house	Sand	S	2.5Y4/2	-	-	-
28	Townhouse	Sand	S	2.5Y4/2	-	-	-
29	Townhouse	Sand	S	2.5Y4/2	-	-	-

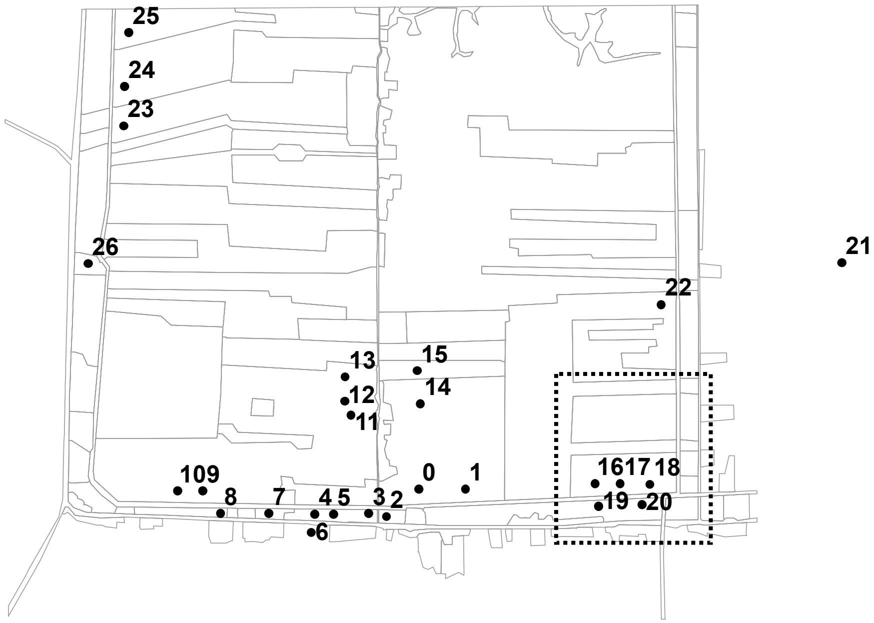


Fig. 10. Location of sites where fill was surveyed in Rangsit (survey results in Table 3). The dotted square is consistent with topographic maps in Fig. 12.

Table 3. Fill material survey for Rangsit

Site number	Land use	Main fill material			Price (bahts/m^3)		
		Type	Texture	Color	Crushed rock	Sand	Clay
0	Vacant land	Clay	CL	5Y5/1	-	-	-
1	Vacant land	Clay	CL	5Y5/1	-	-	-
2	Fill contractor's shop	Sand	S	10YR6/6	450	350	160
3	Fill contractor's shop	Sand	S	10YR6/6	-	-	-
4	Fill contractor's shop	Sand	S	10YR6/6	-	-	-
5	Fill contractor's shop	Sand	S	10YR6/6	-	-	-
6	Vacant land	Sand	S	10YR6/6	-	-	-
7	Fill contractor's shop	Sand	S	10YR6/6	-	-	-
8	Vacant land	Sand	S	10YR6/6	-	-	-
9	Townhouse	Clay	LiC	2.5Y4/2	-	-	-
10	Townhouse	Clay	HC	5Y4/1	-	-	-
11	Townhouse	Clay	HC	5Y4/1	-	-	-
12	Townhouse	Clay	CL	5Y5/1	-	350	175
13	Townhouse	Clay	HC	5Y4/1	-	-	-
14	Vacant land	Clay	CL	5Y5/1	-	-	-
15	Townhouse	Clay	SiC	7.5YR6/4	-	-	-
16	Townhouse	Clay	HC	5Y4/1	-	-	-
17	Detached house	Sand	S	2.5Y4/3	-	-	-
18	Detached house	Sand	S	2.5Y4/3	-	-	-
19	Vacant land	Crushed rock	-	-	-	-	-
20	Fill contractor's shop	Sand	S	10YR6/6	-	-	-
21	Sand pit	Sand	S	2.5Y4/3	-	160	-
22	Townhouse	Clay	HC	5Y4/1	-	-	-
23	Detached house	Clay	CL	5Y5/1	-	-	-
24	Vacant land	Sand	S	10YR6/6	-	-	-
25	Townhouse	Clay	HC	5Y4/1	-	-	-
26	Townhouse	Clay	LiC	7.5YR4/3	-	-	-

distribution on the rectangular man-made *khlongs* in the area. There is a sand pit near the eastern boundary of the study area that supplies sand for fill despite the fact that it is unsuitable for that use.

2.3.4. Past and present cross-sectional profiles

Detailed topographic maps of the BangkokNoi area in 1987 and 2000, and cross-sectional profiles for those years, are shown in Fig. 11, and for the Rangsit area in Fig. 12. The areas covered by the topographic maps are consistent with the area of the maps shown in Figs. 9 and 10.

The NW–SE profile of the BangkokNoi area shows sequential secondary and tertiary *khlongs*. In 1987, orchards lay between these *khlongs*, in an irrigated orchard landscape that Molle et al. (1999) described as a "poldered raised bed system". By 2000 most of the orchard land had been covered with sand and a surface layer of crushed rocks and concrete to provide foundations for detached houses and townhouses. Some *khlongs* were isolated from the rest of the *khlong* system, and others were reclaimed.

The SW–NE profile at BangkokNoi shows the above development trends more clearly. By 2000, secondary roads from the main road had been opened to service townhouses, indicating progression toward car-oriented housing development. According to interviews, the heavy high-rise buildings, such as condominiums, are supported by pillars that penetrate Pleistocene basement rocks at depths of greater than 20 m. Lighter buildings, such as two-story townhouses, use pillars approximately 6 m in length, which terminate in soft Holocene clay sediments.

In the Rangsit area in 1987, the W–E profile shows an uneven distribution of fishponds and orchards separated by rice fields, and *khlong* houses near the *khlong*. By 2000, the rice fields had been replaced by townhouses using local clay as fill and for foundations.

The S–N profile at Rangsit in 2000 shows a series of townhouses, and a temporary soil pit (at the northern end of the profile), which supplied fill material in 1987, had become wasteland.

The roads with heavy traffic loads in the Rangsit area were constructed using sand fill, while clay fill was used for most other land uses, with a surface cover of sand, crushed rock, and concrete planks. According to interviews, most of the pillars supporting townhouses are less than 6 m in length.

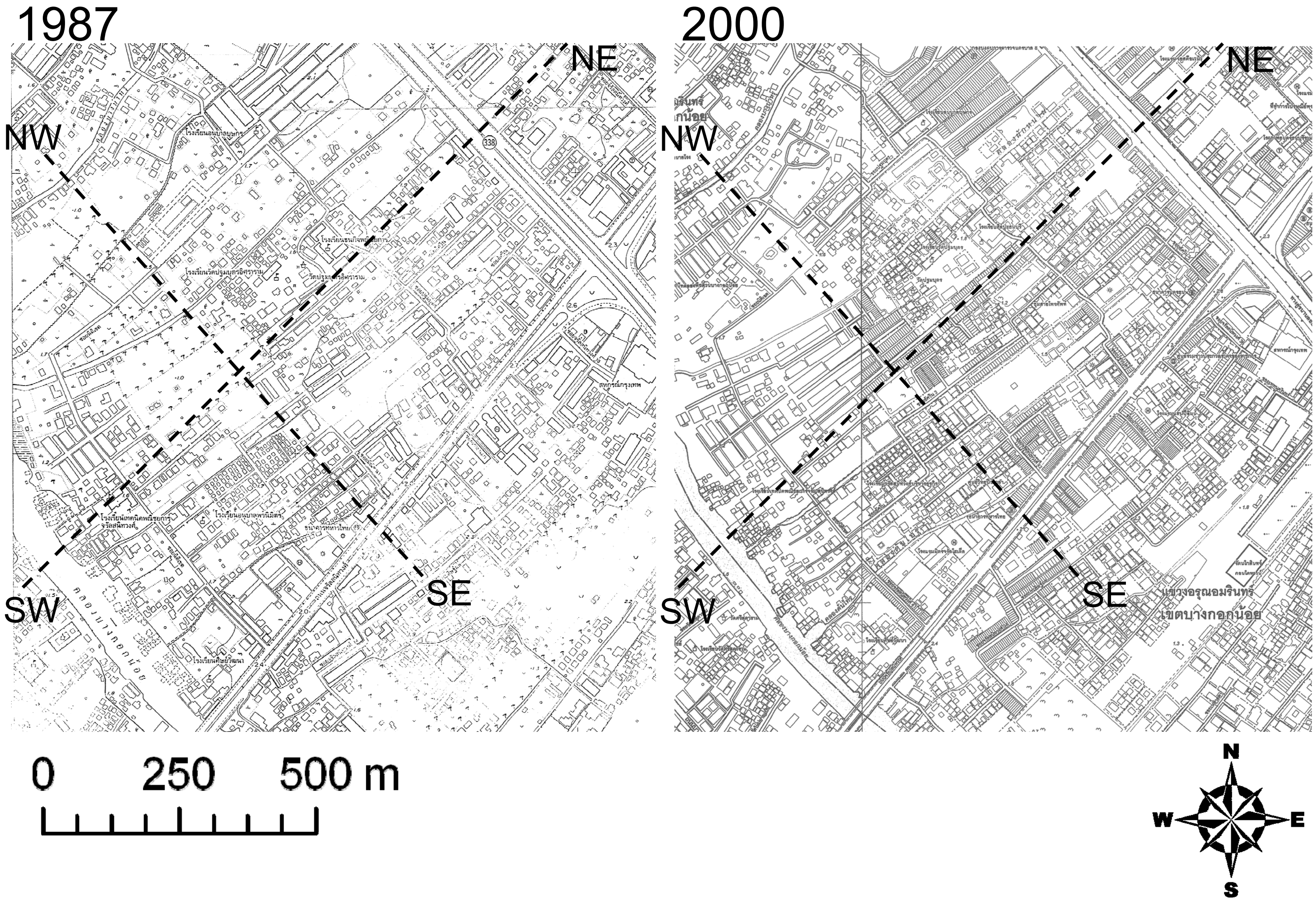


Fig. 11a. Detailed city topographic maps for BangkokNoi for 1987 and 2000.

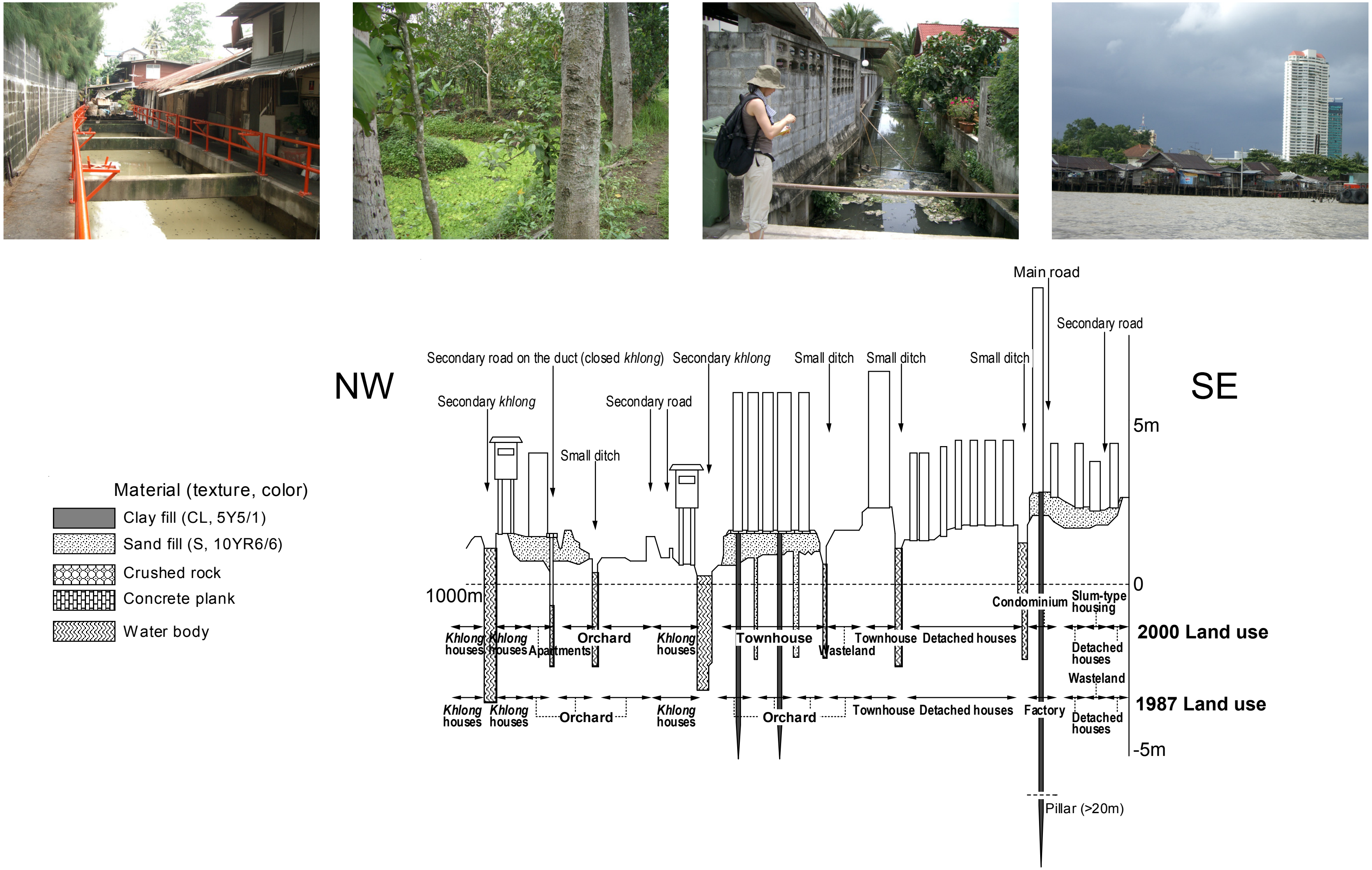


Fig. 11b. NW-SE cross-section for BangkokNoi.

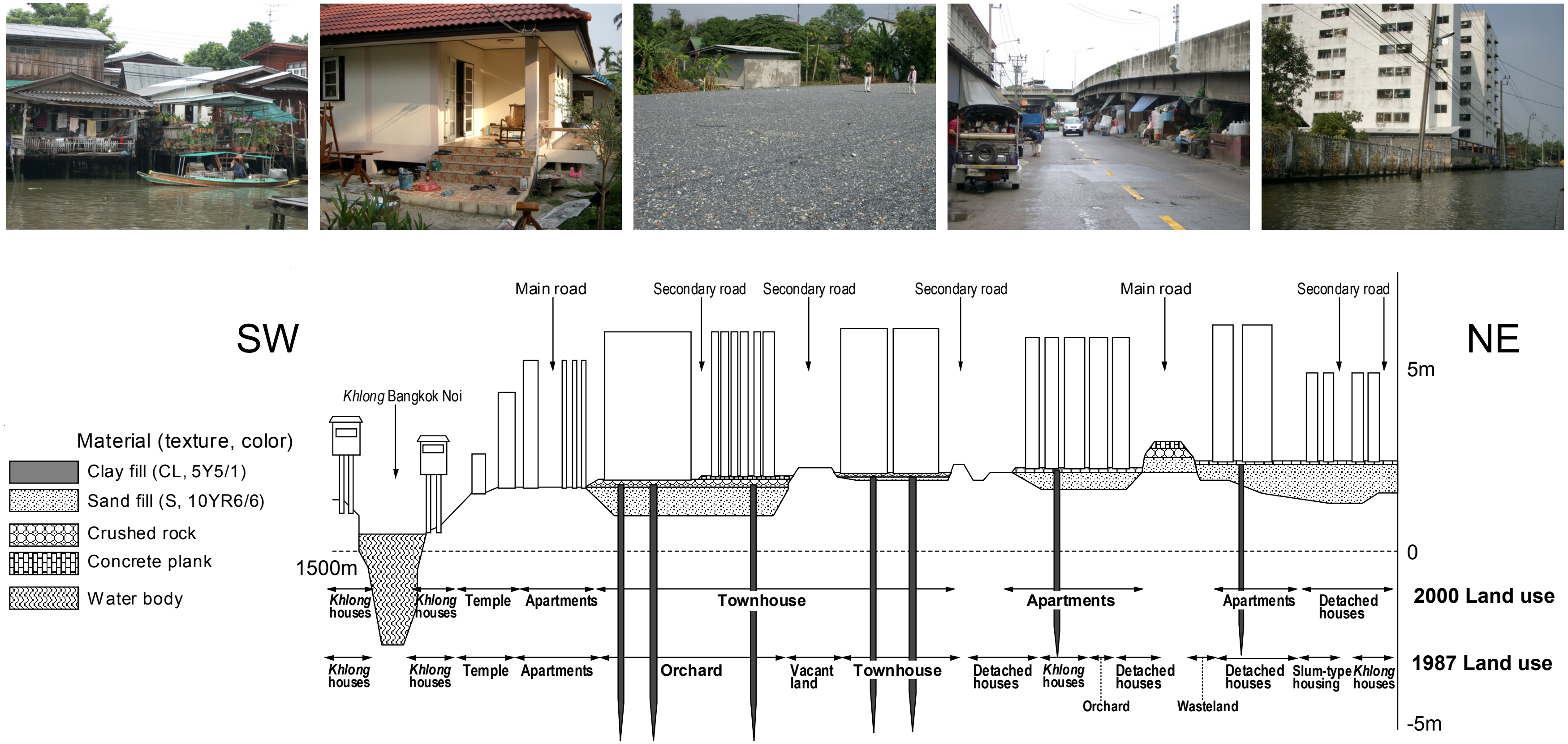


Fig. 11c. SW-NE cross-section for BangkokNoi.

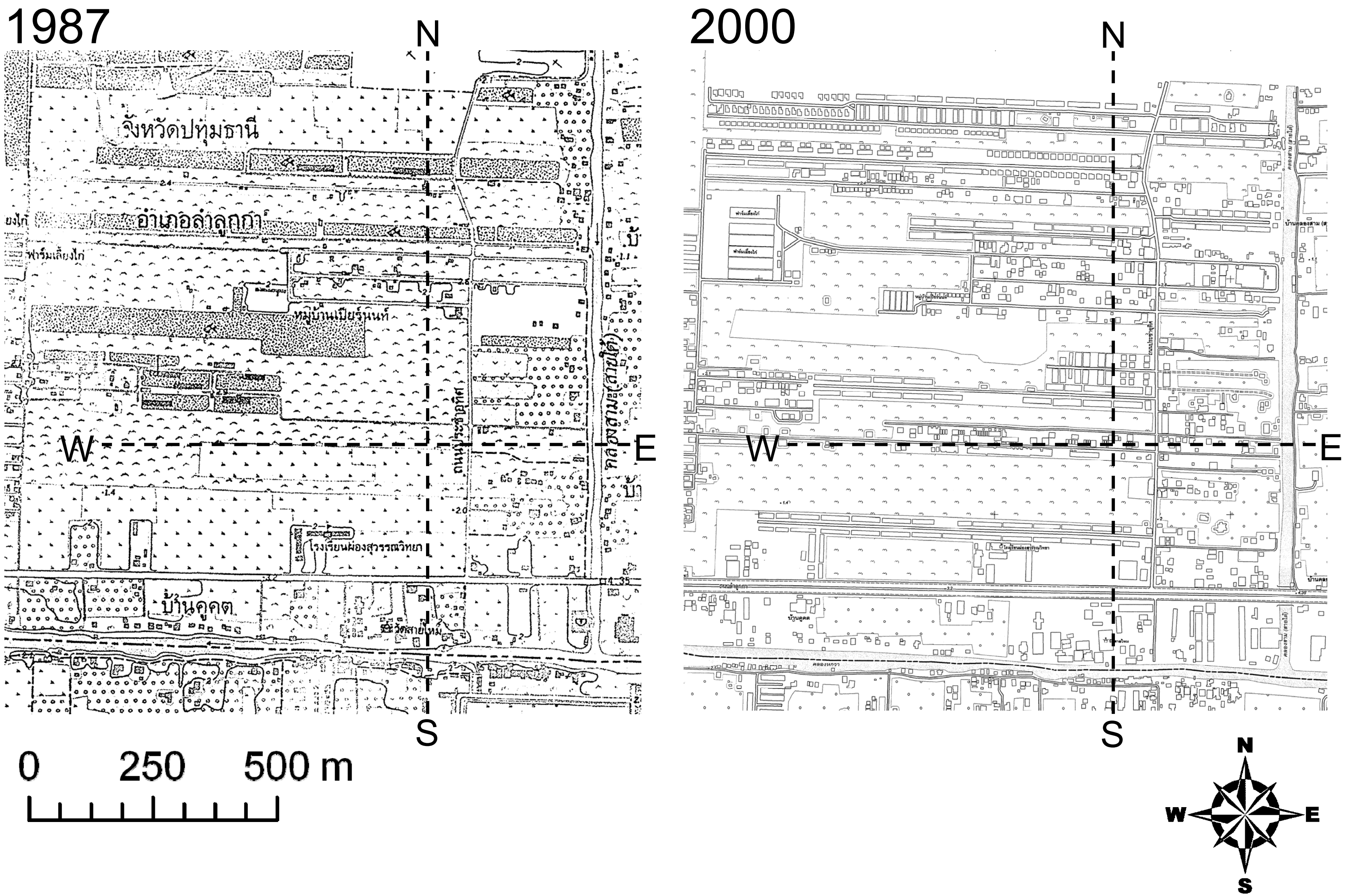


Fig. 12a. Detailed city topographic maps for Rangsit for 1987 and 2000.

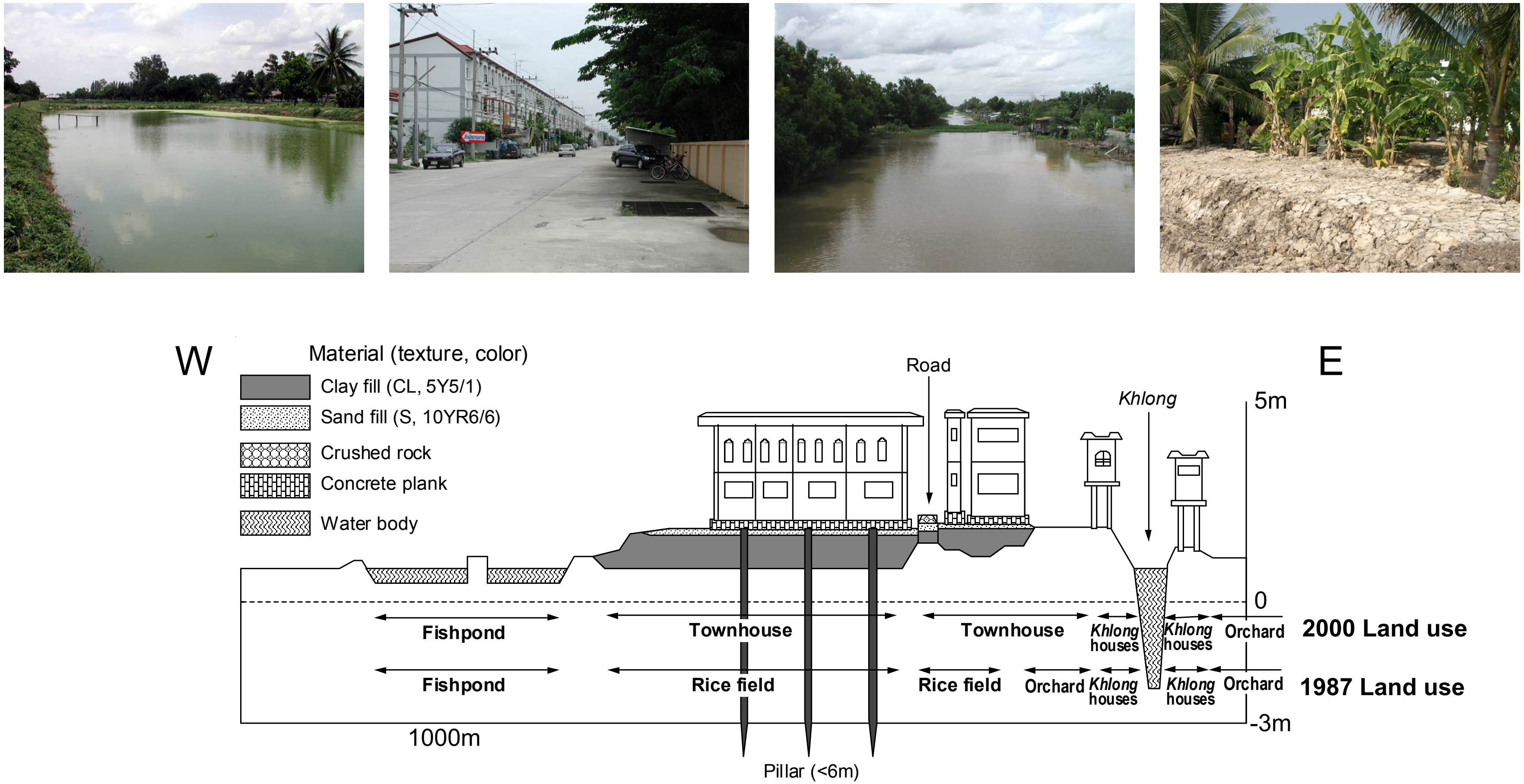


Fig. 12b. W-E cross-section for Rangsit.

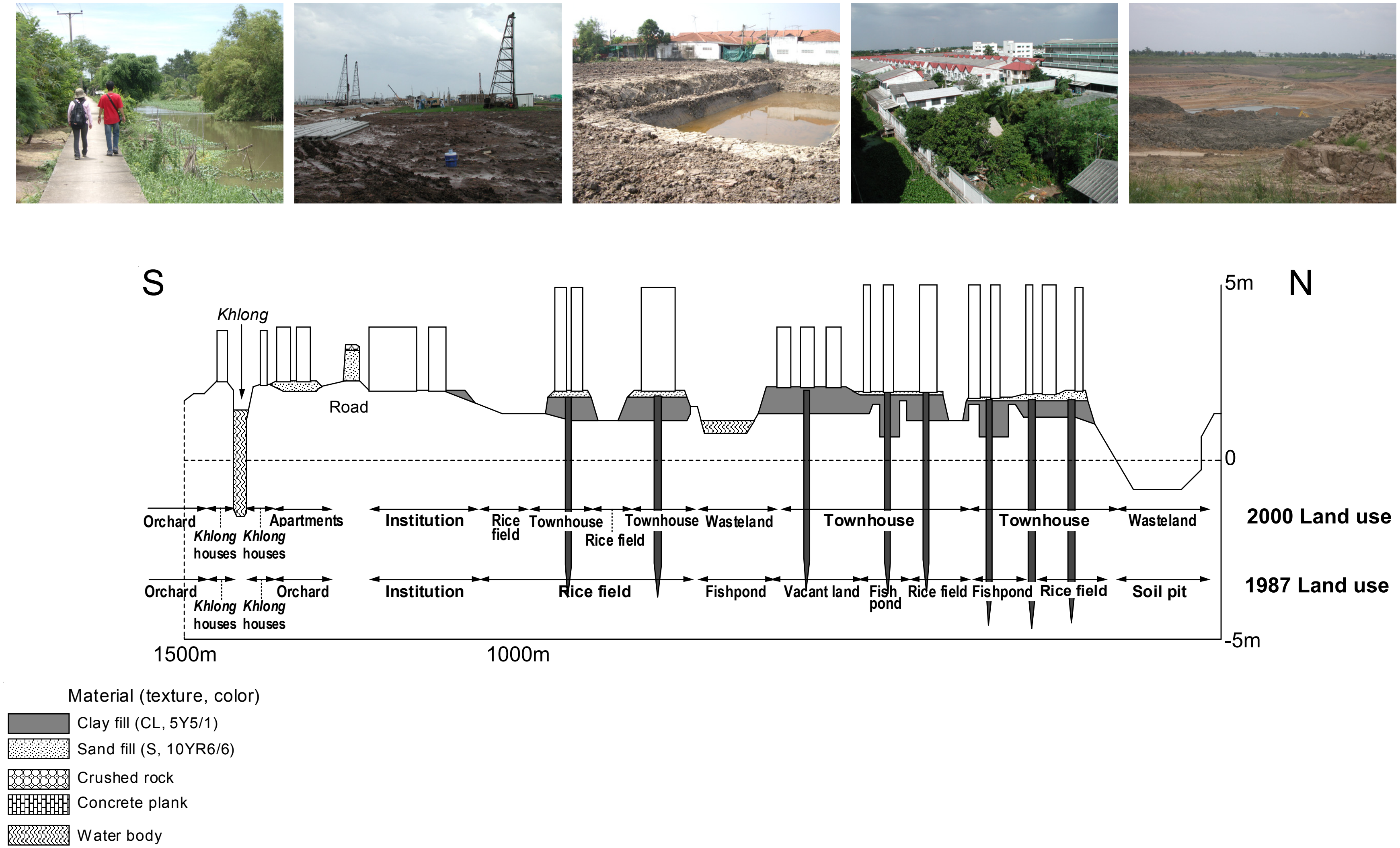


Fig. 12c. S-N cross-section for Rangsit.

In summary, in BangkokNoi urban development in the form of detached houses and townhouses on sand fill has replaced orchard lots within a dense network of small *khlongs*. In Rangsit, land-use changes have resulted in the transformation of mainly rice fields, but also some fishponds and orchards, into townhouse developments, creating an uneven distribution of townhouses, fishponds, orchards, and clay pits.

The relationship between fill used and the type of buildings constructed is demonstrated by the development of heavy buildings in BangkokNoi, where sand fill is mainly used, in contrast to Rangsit, where lighter buildings (e.g., two-story townhouses) have been developed on predominantly clay fill.

2.3.5. Flow of fill material

Fig. 13 shows the sources for fill materials in the Bangkok region, and Fig. 14 provides a model for the flow of fill material from source to end use. Figs. 15, 16 and 17 show typical features of sand pit, laterite pit and rock pit respectively.

In the BangkokNoi area, virtually all sand for fill is delivered to sand piers on the Chao Phraya River and the main *khlong*. From the piers it is trucked to inland development sites. For construction sites close to the piers, and for large-scale housing projects, fill sand is transported from the pier to the site without the use of third-party transport contractors. However, for inland sites where detached houses are built, sand is transported by one or two local contractors, whose fees raise the overall cost of the sand. For the detached houses built behind traditional *khlong* houses in the western part of BangkokNoi, sand is carried from the piers in small motor boats, because of easy access via the *khlong*. For some private housing developments, and for government-funded road construction, sand and laterite fill are trucked directly to the work site from commercial or public pits at locations shown in Fig. 13. Crushed rock is also trucked directly to development sites.

In the Rangsit area, clay fill for new housing was often dug from neighboring land parcels. However, when I conducted my field survey in Rangsit in 2001, housing development had been proceeding for some time, and speculative retention of land prevailed, making it difficult for developers to buy neighboring plots from which to get their fill clay. As the demands for fill material increased, the mining of fill material becoming a highly profitable business. Several rice lots were bought by a developer, and were dug to a depth more than 20 m below the original surface, which caused small landslides. According to geologic data provided by the Japan International Cooperation Agency (1995), fine to medium Pleistocene sand lies at and below a depth of approximately 20 m. This appears to have been the target. In some cases fill material mine increased in size immensely so it is hard to control or mitigate environmental impact or simply being neglected (Fig. 18). Consequently, the inappropriate sand mine created conflicts with local residents. Local people said in interviews that there were some conflicts between the developer and neighboring landowners. They also said that several similar pits within the province had been filled with water or waste after the excavation. The sand produced from this pit was locally known as “special clay”, and was used at new housing sites or stored at local contractors’ shops. The price of this sand was lower than that of sand carried from more distant sources, but higher than that of local clay. Crushed rocks, and high-quality sand for the construction of concrete planks, were trucked directly from privately owned pits at locations shown on Fig. 13, without the use of water transport.

As shown in Fig. 13, sources of fill material are limited, and are constrained by geologic factors as well as accessibility. The AngThong Province, a major source area for sand, is situated on a natural levee in the old Chao Phraya delta (Takaya, 1971; Ohkura et al., 1989) and is the lowest point on the delta from which sand can be excavated. It is also at the upper navigational limit for access by boats towing sand barges. There are a considerable number of sand piers in the AngThong area. According to interviews, there was a rapid increase in the number of piers 10 years ago. Sand from AngThong goes mainly to the Nonthaburi Province (near BangkokNoi) and the SamutPrakan Province (downstream from Bangkok). Transport by barge takes two-and-a-half days, on average, but the time fluctuates depending on tide conditions. Each barge carries about 250 m^3 of sand, and each boat usually tows four barges. Seven boats per day sail from each pier. Therefore, I estimated that about 7000 m^3 (250 $m^3 \times 4 \times 7$) of sand is carried daily from each pier. Aerial photographs of this area (Fig. 19) show at least 15 piers, so around 100 000 m^3 of sand might leave this area by water transport each day.

Land transport by truck is also feasible, as a main highway (number 32) and other major national roads run through the AngThong area.

At AngThong, sand excavation has been from rice lots bought for that purpose. Initially sand was dredged from the river bottom of public waters along the riverbank. However, because it caused bank erosion and collapse, and was opposed by local residents, it was prohibited by the Harbor Department around 10 years ago. Since then, inland sand pits have been developed in the former rice fields, and their numbers have increased rapidly. According to interviews with several sand-pit owners, every day around 6 a.m., 20 to 30 ten-tonne trucks (including both company-owned and privately owned trucks) collect sand to take to development sites in Bangkok, or to the nearest sand pier. On the premise that one truck carries 6 m^3 of sand, approximately 150 m^3 (6 m^3 × 25) of sand is taken daily from every pit. Pit owners also said that there were more than 1000 pits in the AngThong area. I therefore concluded that about 150 000 m^3 (150 m^3 × 1000) of sand is taken daily, 100 000 m^3 by water and 50 000 m^3 by land.

Sand excavation from private lots was formerly permitted with a license, but permission from the Ministry of Industry is now required. Before starting excavation, an engineering assessment is required, and a buffer zone must be defined around neighboring plots. Sand-pit owners must renew their permission every 4 years. Pit owners also explained during interviews that after several years of excavation, groundwater wells up from the bottom of pits, so that they must dredge sand from the bottom of the pit, and then sift and dry it on the riverbank before transporting it (Fig. 15). Good quality homogeneous sands with regular grain size are used for concrete materials; others are used as fill. The size of the excavation for almost all pits is limited to 20 m depth and an area of 30 ha. Most pits become abandoned water bodies after excavation has been completed; however, several owners plan to rehabilitate their pits, probably for development of water-activity-based resort housing. Some conflicts with neighbors over mining activities and impacts on surrounding lands and the environment were also reported during interviews.

Production sites for crushed rock are situated in the Mesozoic hills rimming the central plain, especially where there is easy access to a highway. SaraBuri and LopBuri are well-known limestone production areas that provide crushed limestone for urban development in Bangkok. The combined daily production from these two sites is estimated to be 100 000 m^3 (S.P.S. Consulting Service Co. Ltd., 1995). Most of the production is used to make cement, and the low-quality residuals are used for landfill. Soapstone is also produced around this area (Sudo, 1997), and residuals are transported to Bangkok.

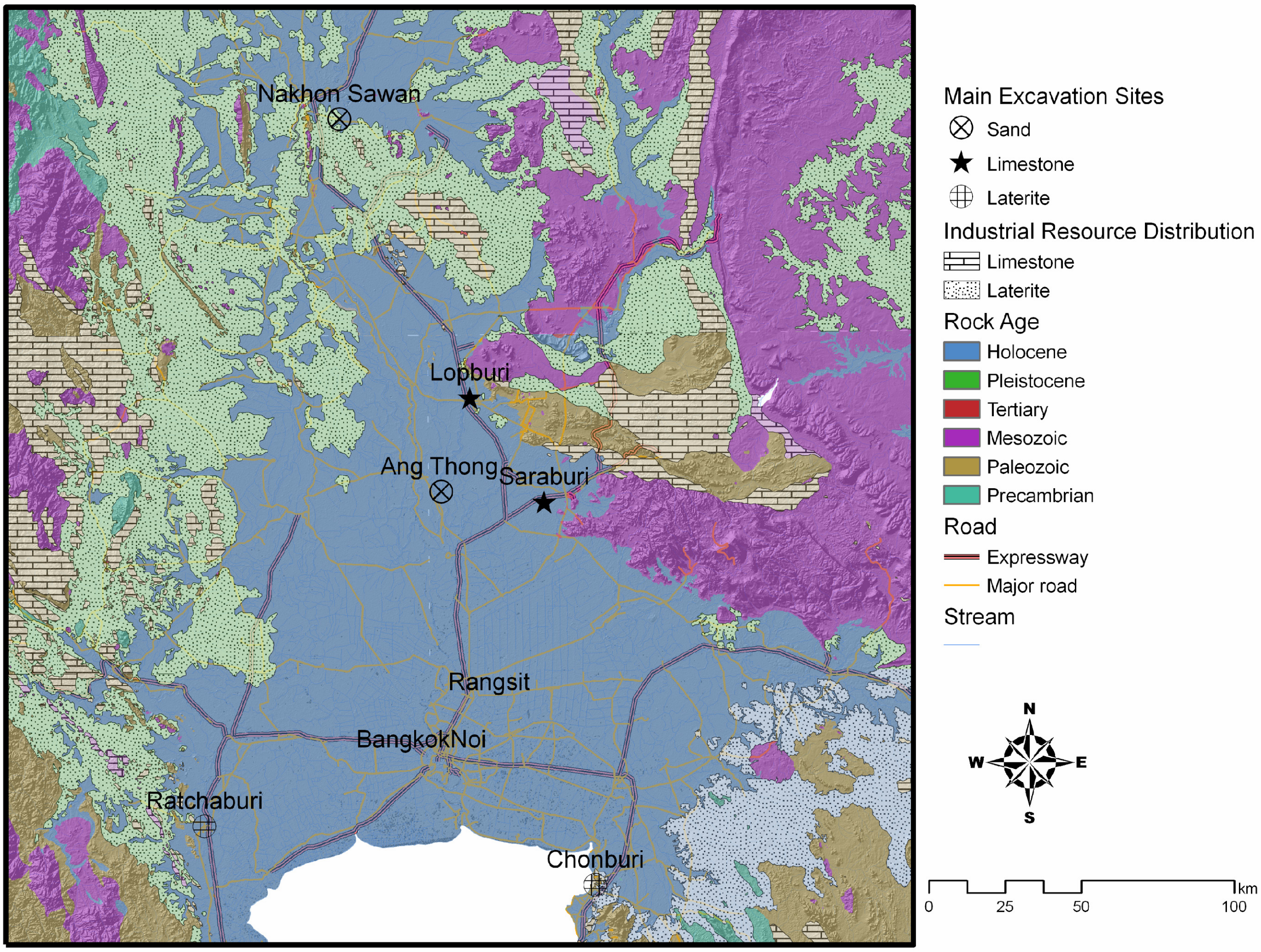


Fig. 13. Map showing locations of sources of fill material in relation to local geology and geography.

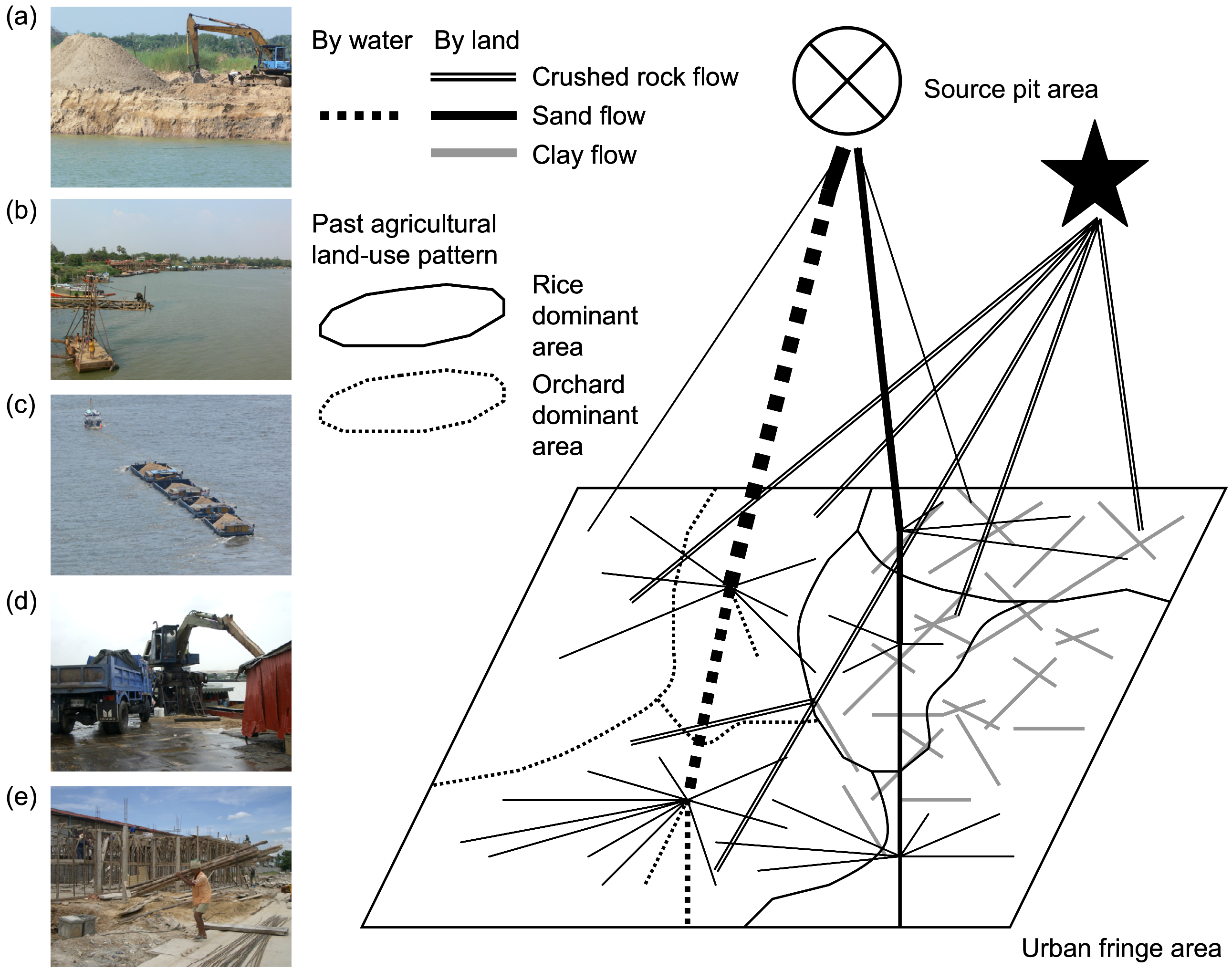


Fig. 14. Model showing flow of fill material. Photographs show elements of the flow of sand fill from source to end use: (a) typical sand pit with 2.5Y5/4 color fine sand; (b) upstream sand pier close to sand source; (c) sand transport by boat along the Chao Phraya River; (d) downstream pier where sand is loaded onto trucks; (e) typical construction site on urban fringe.

Fig. 15. Sand pit features.

Fig. 16. Laterite pit features.

Fig. 17. Rock pit features.

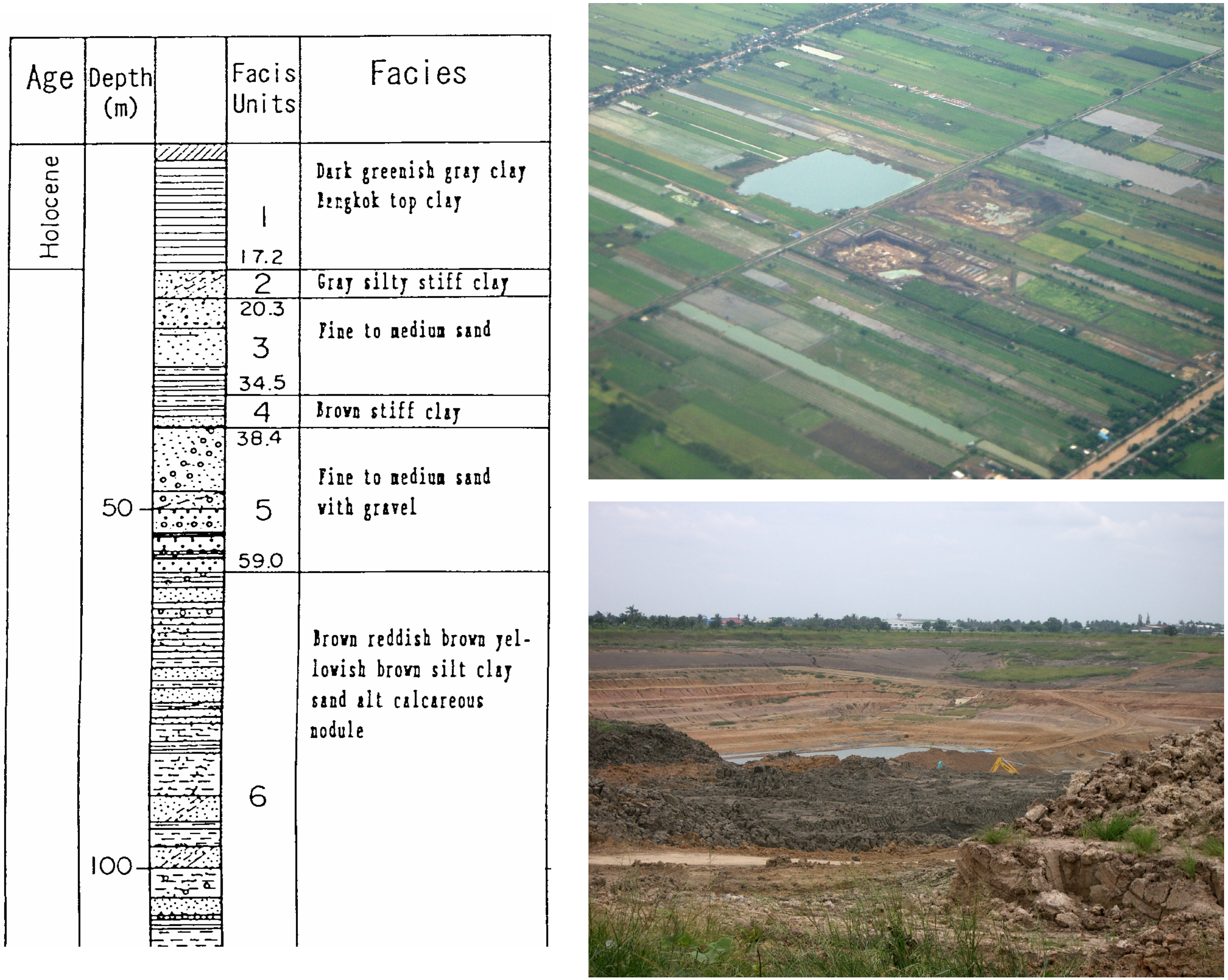


Fig. 18. Geologic column for Rangsit area (JICA, 1995), and an example of inappropriate sand mining.

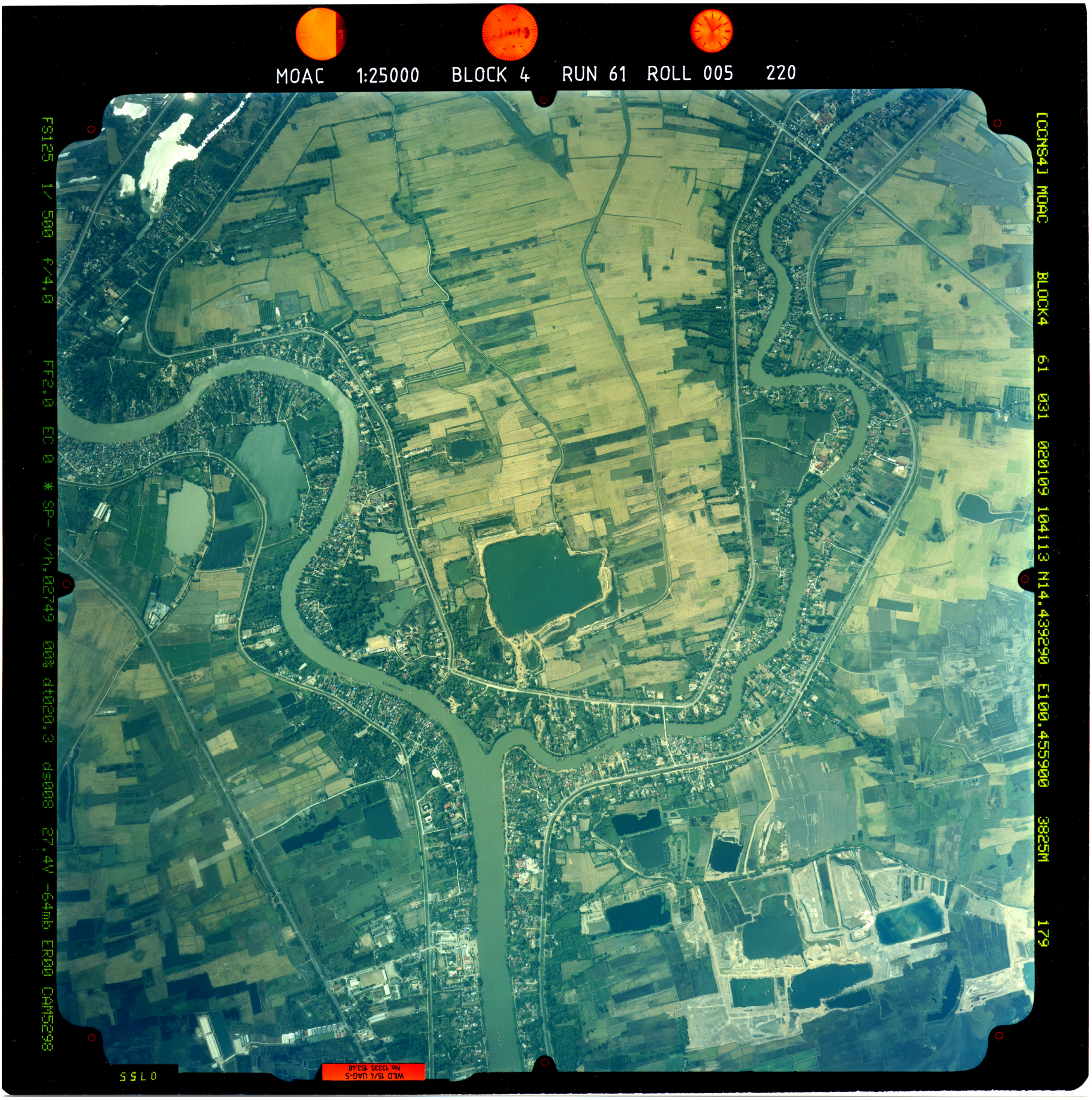


Fig. 19. Aerial photograph of AngThong area showing sand excavation sites and piers.

2.4. Discussion

2.4.1. Links between urbanization, past agricultural land-use patterns, and the landform transformation process

In both BangkokNoi and Rangsit, landform transformation has been an unavoidable prerequisite for land-use change. In 1952 the spatial pattern of agricultural development in both areas reflected the process of conquering the extreme hydrologic conditions of a deltaic environment.

The BangkokNoi area had access to a main channel of the delta before completion of river channel modifications during the Ayutthaya period (Tanabe, 1973a). Annual irrigation in the area was possible before the channel modification. Hence, an orchard landscape of "poldered raised bed systems" (Molle et al., 1999) was developed with a dense network of secondary and tertiary *khlongs* (Fujioka and Kaida, 1967; Tachakitkachorn and Shigemura, 2004).

In the very flat Rangsit area, where acid marine soils predominate, annual irrigation was impossible until a gridded *khlong* system was developed in the late 19th and early 20th centuries (Takaya, 1987). After World War II, there were rapid increases in rice production from the Rangsit area following commencement of the "Greater Chao Phraya Project" and, in particular, after completion in 1957 of the Chai Nat Dam at the head of the delta (Fujioka and Kaida, 1967; Takaya, 1987). The land-use map for 1952 (Fig. 6) shows land use during this period.

These initial differences in agricultural land-use patterns for BangkokNoi and Rangsit were influential in determining the different processes of urban expansion and the resultant patterns of urban land use in the two areas.

In the BangkokNoi area, it was difficult to get local clay for fill because of the dense system of *khlongs* and orchards. Access to the main river channel provided water transport and hence cheap access to sand fill. Housing foundations of sand acquired from outside the area characterized development in BangkokNoi from the beginning of urbanization. Small areas of orchard were replaced by detached houses and condominiums, which require a relatively small area of ground, or into townhouses if enough adjacent lots could be acquired.

In Rangsit there were large rectangular rice fields, and orchards, and a grid of man-made *khlongs* that were inaccessible to sand boats. Consequently, housing foundations used local clay excavated from fishponds, and agricultural diversification (Kaida, 1990) and urban housing development (Hara et al., 2005) proceeded initially in parallel. The dominant land use later changed from large rectangular rice fields to large blocks of townhouses. In addition, rising land prices introduced a trend toward speculative landholding, which made it difficult for developers to buy neighboring plots to supply clay for fill. The import of fill from other areas therefore increased rapidly (Fig. 8). Furthermore, orchards were regarded speculatively as future housing sites because their elevation was already suitable for building urban dwellings without the cost of extra fill material (Hara et al., 2005).

2.4.2. Building styles and characteristics of fill materials

In deltaic lowlands, traditional raised-floor dwellings that cope well with deltaic hydrologic conditions have been used for a long time. There has been a transition from water transport to land transport, and housing structures have changed from the traditional raised-floor style, to a construction with the floor at ground level. The protection of these houses against flooding and moisture has become an important issue (Takamura et al., 2002; Iwaki, 2005).

In BangkokNoi, new detached houses behind traditional *khlong* houses were built on a base of sand fill, but with raised concrete floors. According to interviews with local inhabitants of this area, fill sand was carried by relatives and neighbors from sand piers to the building site in small motor boats and wheelbarrows. It is possible that local knowledge of the difficulties of acquiring sand, and the choice of a light building structure, led them to use a raised-floor structure. However, condominiums and townhouses along the main roads were all built directly on sand foundations. Based on my interviews with civil engineering institutions, structures in Bangkok that are heavy, or are required to take heavy loads, (e.g., condominiums, roads, and airport runways) are mostly constructed on sand foundations, whereas lighter structures are built on a base of the local clay. In the BangkokNoi area the use of sand fill, influenced by past agricultural land-use patterns, has been an important influence on the style of housing development and has contributed to the development of condominiums.

In Rangsit both clay and sand are available for fill, but two-story townhouses on a local clay base are the predominant style of development. My field surveys and interviews with developers and local contractors indicated that clay costs 160 baht m^{-3}, the “special clay” (produced at site 21 of Fig. 10) costs 175 baht m^{-3}, and sand carried from the AngThong Province by land costs 350 baht m^{-3} (100 baht ≈ US$2.40). There is no incentive to use the more expensive sand as a base for light-load townhouses. Therefore, although local clay was initially used for fill, the “special clay” gained increasing favor owing to a lack of local land available for clay excavation. The expansion of urban land use in the form of two-story townhouse developments on a clay base, and taking full advantage of the space provided by the large rectangular rice lots, has been more acceptable than high-rise building development supported by a sand base.

2.4.3. Flow of fill material as determined by geology, accessibility, and profitability

The locations of usable sources of fill material are determined by geologic conditions and accessibility (Fig. 13). Transportation routes from those sources to development sites in Bangkok differ (Fig. 14), depending on transportation cost.

The AngThong Province (Figs. 13 and 15) is a major sand production area and has good accessibility by both land and water. It is therefore an attractive source of sand. Prices at AngThong are 120 baht m^{-3} for good-quality sand suitable for making concrete, and 90 baht m^{-3} for fill sand. Sand from AngThong is transported downstream by barge to the nearest pier to the area being developed. Barge transport costs raise the price of the sand at the pier nearest to BangkokNoi to 150–250 baht m^{-3}. Transport from the pier to the development site raises the price still further, by an amount dependent on the distance. My field survey showed that the final cost of sand at an inland development site in BangkokNoi was approximately 380 baht m^{-3}, which included a 50-baht surcharge at the local contractor’s shop.

The Rangsit area is close to a main highway, but far from the main stream of the Chao Phraya River, so sand is trucked in from the AngThong Province. In Rangsit, high-quality sand from the AngThong Province is used mainly to make concrete, and costs 350 baht m^{-3}. According to interviews, several concrete factories in Rangsit have private sand pits in the AngThong Province, and transport sand directly by land to their factories. For landfill in Rangsit, the previously mentioned “special clay” (175 baht m^{-3}) is mainly used.

Thus the flow of sand in Bangkok is dependent on spatial nodes and linkages that are determined by geology, accessibility, and profitability; and it becomes a capillary flow structure toward the end.

In Bangkok, crushed rocks are carried on land from the source area directly to development sites, or to nearby local contractors. The SaraBuri and the LopBuri Provinces are major rock production areas and are situated on main highways. They are approximately 50 km from the southern part of the AngThong Province, which is the upper navigational limit for sand boats. Hence, to transport rock by boat is not a viable option. According to interviews with local contractors, the price of crushed rock is 440 baht m^{-3} in BangkokNoi, and 450 baht m^{-3} in Rangsit, reflecting the high cost of transport by land.

2.4.4. Taking past agricultural land use and flow of fill materials into consideration in urban–rural planning

From the results of Bangkok case study, I propose three inter-related strategies to be applied in urban–rural planning for Bangkok, which I discuss in the following.

2.4.4.1. Zoning in consideration of past agricultural land use

This study illustrated that patterns of past agricultural land use on the Chao Phraya delta were influenced by the agrarian development process, and influenced the process of shifting from rural to urban land uses, and that landform transformation relates to both. Therefore, consideration of past agricultural land-use patterns may improve the planning function.

In the current planning system in the Bangkok area, the Bangkok Metropolitan Administration takes responsibility within the boundaries of metropolitan Bangkok, and the Department of Public Works and Town & Country Planning (Ministry of Interior) takes responsibility outside those boundaries. Although the importance of cross-boundary regional planning has been recognized, more attention has been given to development of linear infrastructure, such as the highway network, and sub-center plans (Tapananont et al., 1989); coordinated land-use planning has not been emphasized (Hino, 1991). Furthermore, irrigation districts administered by the Royal Irrigation Department correspond to agricultural land-use patterns, and are not consistent with other regional administrative boundaries.

According to the Bangkok Master Plan (Bangkok Metropolitan Administration, 2006), the development densities allowed by zoning decrease with increasing distance from the center of the city, and a greenbelt has been defined in peripheral areas to prevent inundation. However, the zoning system appears to be based on current land use and, rather than zoning boundaries controlling development, they have been changed in response to the uncontrolled expansion of built-up areas. Agricultural lands within the greenbelt have recently been transformed into sprawling housing developments, which demonstrates the difficulty of regulating lots with strong private landholding of historical origin (Pimcharoen, 2004).

The trend of decartelization, which aims to bridge the gap between agricultural boundaries and administrative boundaries and to transfer spatial planning authorities to local government bodies (Kinoshita, 2000), might be expected to help develop a functional zoning system that takes past agricultural land-use patterns into consideration.

2.4.4.2. Quantitative zoning code goals for fill volumes and land transformation

This study demonstrated an association between the type and distribution of landfill and building styles within agricultural districts. Therefore, an effective way of mitigating urban pressure would be to impose maximum volumes of landfill used for landform transformation.

At present, layout plans of a flood-control pond named "Monkey Cheek" might be considered one of the quantitative strategies being applied in Bangkok (Bangkok Metropolitan Administration, 1999). This project was initiated as a Royal Project, and several flood-control ponds have been completed. However, the relationship between projects such as this and land-use planning is unclear, making it difficult to provide a floodwater retention capability for the whole of Bangkok. In fact, the flood mitigation function of agricultural lands (such as broad rice fields) within the greenbelt is mentioned without a quantitative description from the urban planning perspective (Bangkok Metropolitan Administration, 2006). Flood-control matters are mostly dealt with by the infrastructure-oriented civil engineering branch of administrative bodies.

Regulation of landform transformation practices could support both traditional and adaptive land-use patterns. For instance, a requirement to offset excavation volume for a pond with fill volume to create orchards or housing may be effective. This approach may also provide an incentive to developers to prepare flood-control measures in new housing developments. This strategy may be particularly applicable in areas where regulating has been difficult, such as those areas where private landholding is long-standing and secure.

2.4.4.3. Adjustment of the nodes and linkages of fill material flow

This study showed that the flow of fill material was in the form of a node–linkage structure, terminating with a capillary flow. Observation and control of the price of fill at nodes might help to mitigate pressures at the end of the flow, the urban fringe of Bangkok.

Prices of building and fill materials are dependent on transport costs. I showed that the price of sand increased over its 100-km downstream journey to Bangkok. Ito (2004) reported that the cost of earthworks in Bangkok was sometimes more than 70% of the total construction cost. During my field survey in the BangkokNoi area, many developers complained of recent increases in the cost of material owing to the effect of rising price of gasoline on land transportation costs. Price control, within an overall flow-control mechanism, might be an improvement on the current system.

Current policies concerned with the flow of fill material are in need of review. Control on excavation at source pits used to be by a license system, but was changed to a permission system under the Ministry of Industry. However, environmental assessment before excavation and guidelines for and restoration after excavation appear to be ineffective, especially lacking of proper environmental impact mitigation during excavation, which occasionally cause conflict between local residents.

Control at sand piers on the river is lacking. Many of the piers that I visited during my field survey are privately owned, and there is little regulation of their activities, other than payment of minor taxes to the Harbor Department.

Bangkok Metropolitan Administration exercises some control on linkages by prohibiting daytime sand-truck transport. To avoid traffic congestion and to prevent splashing other road users, they are allowed to run only from 9 p.m. to 6 a.m..

Appropriate regulation and taxation at nodes and linkages might help to control extreme landform transformation actions within private lots. It could help to effectively control elusive minidevelopments at the end of the fill material flow, and excavation at the source locations of fill material. There is a need to develop consistent planning processes along the fill material flow path, from restoration design at source pits to appropriate mixed landscape design at the end of the flow.

3. Metro Manila case study

3.1. Study area

Metro Manila is on the west coast of central Luzon Island; its tropical monsoon climate has distinct dry and rainy seasons. Metro Manila can be divided into three geomorphologic regions: the West Coastal Plain, the Central Upland, and the Laguna Plain (Fig. 20). Urbanization of Metro Manila began in the 1950s, and its population has increased rapidly since the 1960s (Murakami et al., 2005). The core of the city on the west coast is now extremely populous, and urbanization is increasing on the eastern side of the Central Upland, on the Laguna Plain in particular, where agricultural land use is becoming mixed with urban land use (Sierra et al., 1990).

My meso-scale study area (Fig. 20) covers the eastern part of the Central Upland and the western part of the low-lying Laguna Plain. It is at the forefront of the eastward advancing urbanization of Metro Manila. In this area in about the 14th century, before the arrival of the Spanish, people migrated from the Asian mainland and settled along the river. During the period of Spanish occupation (1521–1898), the local population lived mainly in isolated villages connected by water transport (Taguig City Development Planning Office, 2003). Under American rule (1898–1946), infrastructure and municipal systems gradually developed. After the Philippines became independent, there was large-scale business, commercial, and housing development in the upland area now known as the Makati district (Serote, 1991). These large-scale developments have also led to smaller scale developments to house workers in the low-lying Laguna Plain area (Murakami et al., 2003). Thus, my study area is appropriate for the examination of dynamic, meso-scale urban–rural land-use changes, landform transformation, and offsite–onsite material flows.

3.2. Data sources and analytical methods

I conducted field surveys for a total of approximately two months between 2001 and 2005 and collected data as shown in Table 4. In the field I verified land-use interpretations of aerial imagery, interviewed local people, recorded fill materials, and took landform measurements. I

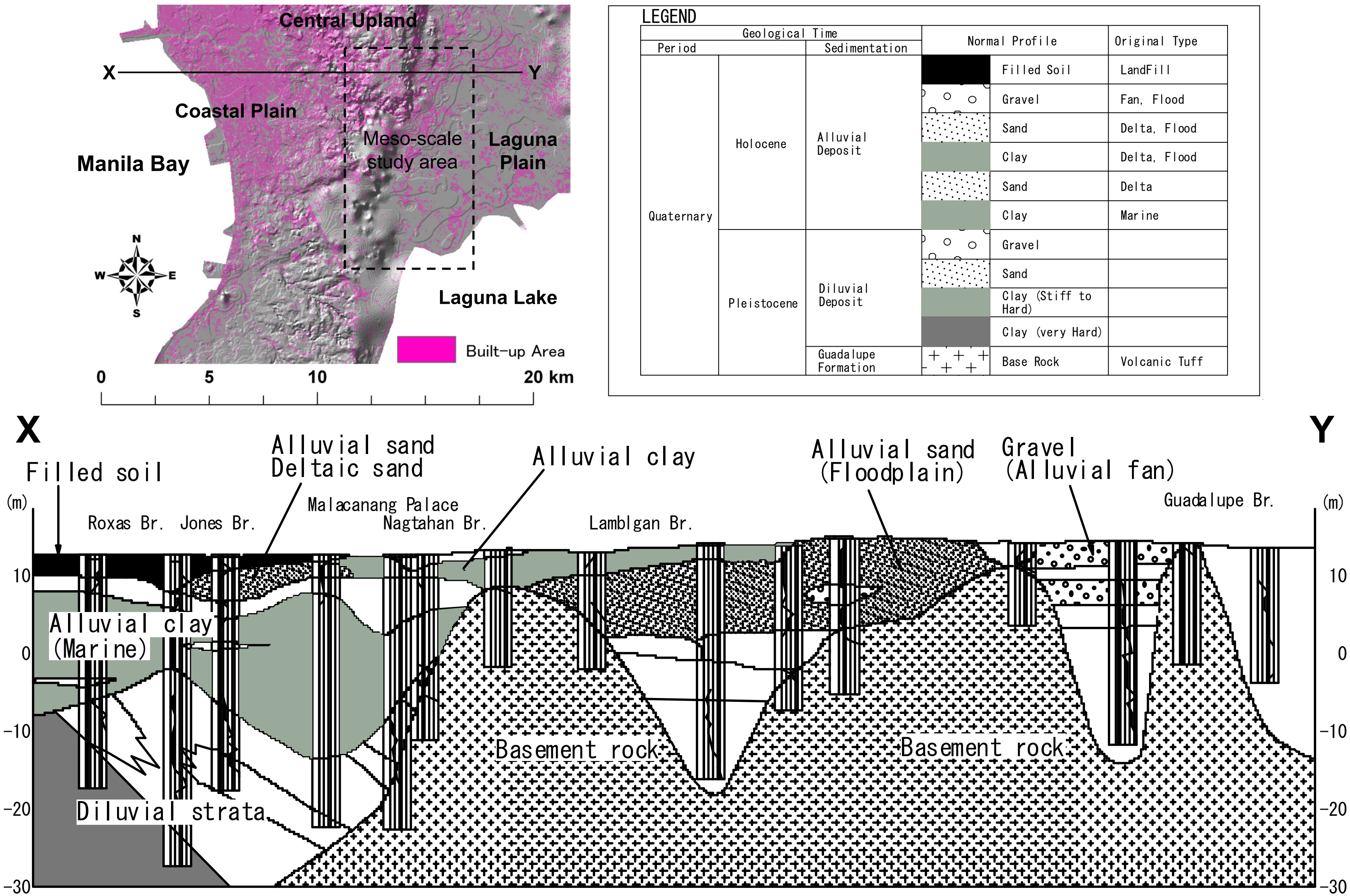


Fig. 20. Location map of the study area with geologic cross-section (modified after CTI Engineering International Co., Ltd., 2001).

Table 4. Data sources of Metro Manila case study

	Year	Scale	Format	Publisher
Aerial photographs	1966	1:10 000	Paper print (black and white)	National Mapping and Resource Information Authority (Philippines)
	2001	1:10 000	Digital image (black and white)	Geo-Surveys & Mapping Inc. (Philippines)
Satellite imagery (QuickBird)	2004	2.44 m resolution	Multi-spectral sensor image	DigitalGlobe Inc.
Topographic maps	1961	1:50 000	Paper	National Mapping and Resource Information Authority
	1966	1:10 000	Paper	National Mapping and Resource Information Authority
	1986	1:10 000	Paper	Japan International Cooperation Agency
Land-use maps	1966	1:25 000	Paper	National Mapping and Resource Information Authority
	1986	1:10 000	Digital vector format	Japan International Cooperation Agency
Landform classification map	2002	1:10 000	Digital vector format	Hara et al. (2002)
Geologic maps	1980s-Present	1:50 000	Paper	Mines and Geosciences Bureau (Philippines)
	2004	1:2 000 000	Digital vector format	Geological Survey of Japan

used Geographic Information System (GIS) technology (TNTmips version 7.0, MicroImages Inc, Lincoln, NE, USA; ArcGIS version 9.0, ESRI, Redlands, CA, USA; VectorWorks version 11.5, Nemetschek North America, Columbia, MD, USA) for data digitization, spatial analyses, and drawing of figures.

3.2.1. Preparation of digital land-use maps

I used an existing 1986 1:10 000-scale land-use map in digital vector format as a base map for my meso-scale land-use investigation and integrated land-use categories thereon to create 15 classes of land use (Fig. 21). Using this as a base map, I produced digital land-use maps in vector format for 1966 and 2004 by visual interpretation of aerial photographs and satellite imagery. I scanned the 1966 aerial photographs at 600 dpi resolution, added georeference data, and compiled a raster mosaic image to produce the 1966 land-use map. I used QuickBird satellite imagery to produce the 2004 land-use map. I then manually digitized the interpreted boundaries of my 15 land-use classes for 1966 and 2004. I used a 1961 topographic map, a 1966 land-use map, and a 2001 digital orthophoto mosaic to support my interpretation and also verified my interpreted land uses by interviewing local people.

3.2.2. Measuring changes in land elevation

I used 1966 and 1986 1:10 000-scale topographic maps, which provided elevations accurate to within 10 cm, to measure changes in land elevation. I first scanned these maps at 300 dpi resolution over my entire meso-scale study area and added location information. I next digitized and extracted the elevation points from the 1986 map. By comparing the two sets of elevation data I obtained the changes in elevation from 1966 to 1986 at 50-cm increments. These were expressed as 610 digital vector points within the meso-scale study area.

3.2.3. Associating elevation changes with landform and land use and quantifying the volume of landform transformation

By overlaying the previously determined elevation change data points on the 1966 and 1986 digital land-use maps, I extracted those points that had changed from rural to urban land use (residential use, business use, factory, vacant land, and road) between 1966 and 1986. I then grouped these points according to landform type by overlaying them on the digital landform classification map of Hara et al. (2002). I next classified these points within each landform type into land-use classes by overlaying them on the 1986 land-use map. I then graphed the relationship between elevation change and land use by landform type.

To evaluate the volume of landform transformation, I first compared the land-use maps for 1966, 1986, and 2004 to determine which areas had changed from rural to urban land use between 1966 and 1986, and between 1986 and 2004. I next compared these areas with the landform classification map and calculated the area of rural-to-urban land-use change for each landform type. By multiplying these areas of land-use change by the average elevation changes within those areas, I calculated the volume of landform transformation for each landform type.

3.2.4. Recording fill materials in the field and measuring transect features

To support the landform transformation–landform type–land use interrelationships derived from my GIS analyses, I undertook field surveys of development sites in the southern part of the study area where intensive land development is taking place. I recorded the characteristics (texture and color) of fill materials, the height of the fill profile, and the layering within the fill profile. Where possible, I also interviewed site managers, workers, developers, and landowners to find out what fill materials they use, why they use them, and their source and cost.

I initially compared the 1966 and 1986 1:10 000-scale topographic maps to select a representative transect over which to measure a fill profile. To supplement my interpretation of the 1966 topographic map along the selected transect, I then interviewed local government officers and long-term residents and took into account the information gleaned from them to determine an original 1966 base line of the land surface along the transect. I recorded land use along the transect and used a hand level and laser rangefinder 400LH (Opti-Logic Corporation, Tullahoma, TN, USA) to take field measurements of the current land-surface profile. I interviewed residents along the transect to find out when and how they made their housing foundations, what fill materials they used, and where they came from. In some cases I was allowed into properties and was able to check the fill materials at the plot boundary. To determine the timing and method of construction of public roads on my transect, I visited the civil engineering division at the Pateros Municipal Office and was shown records of road construction work.

3.2.5. Tracing the flow of construction material

Because of a lack of government records on land development in Metro Manila, I used mainly field interview methods to obtain the data I needed to trace the flow of fill materials for land preparation. I started my interviews at the development sites where I recorded the fill materials in use. I undertook extensive interviews with local contractors and pit owners on matters such as the price of materials, the supply–demand balance, and government regulations related to fill material. I also conducted interviews and collected data about the flow of fill material at the Mines and Geosciences Bureau of the Department of Environment and Natural Resources in Manila, at the Metro Manila Development Authority, and with the civil engineering divisions of Taguig and Pateros Municipalities.

3.3. Results

3.3.1. Land-use changes and landform types

Land-use maps for 1966, 1986, and 2004, as well as a landform classification map are shown in Fig. 21. In 1966, most of the developed areas, including the business district, were situated on the northwestern uplands of the study area, and factories were located on back marsh landforms along the river. Within the low-lying areas, most of the residential development was along the natural levees, showing that land-use patterns had adapted to the natural local environment. By 1986, clearing of forests and speculative development of vacant land had led to extensive residential and business development on the northwestern uplands. In low-lying areas, land development was mainly in the back marshes behind natural levees. By 2004, the southwestern upland was largely converted to residential land use, mainly through the development of large residential subdivisions. In the low-lying areas, residential land use and factories were beginning to fill the areas between natural levees (Fig. 22). Thus, in my study area between 1966 and 2004, land use had been transformed from patterns that were adapted to the natural environment to a diverse pattern that had overcome the restrictions imposed by natural landforms.

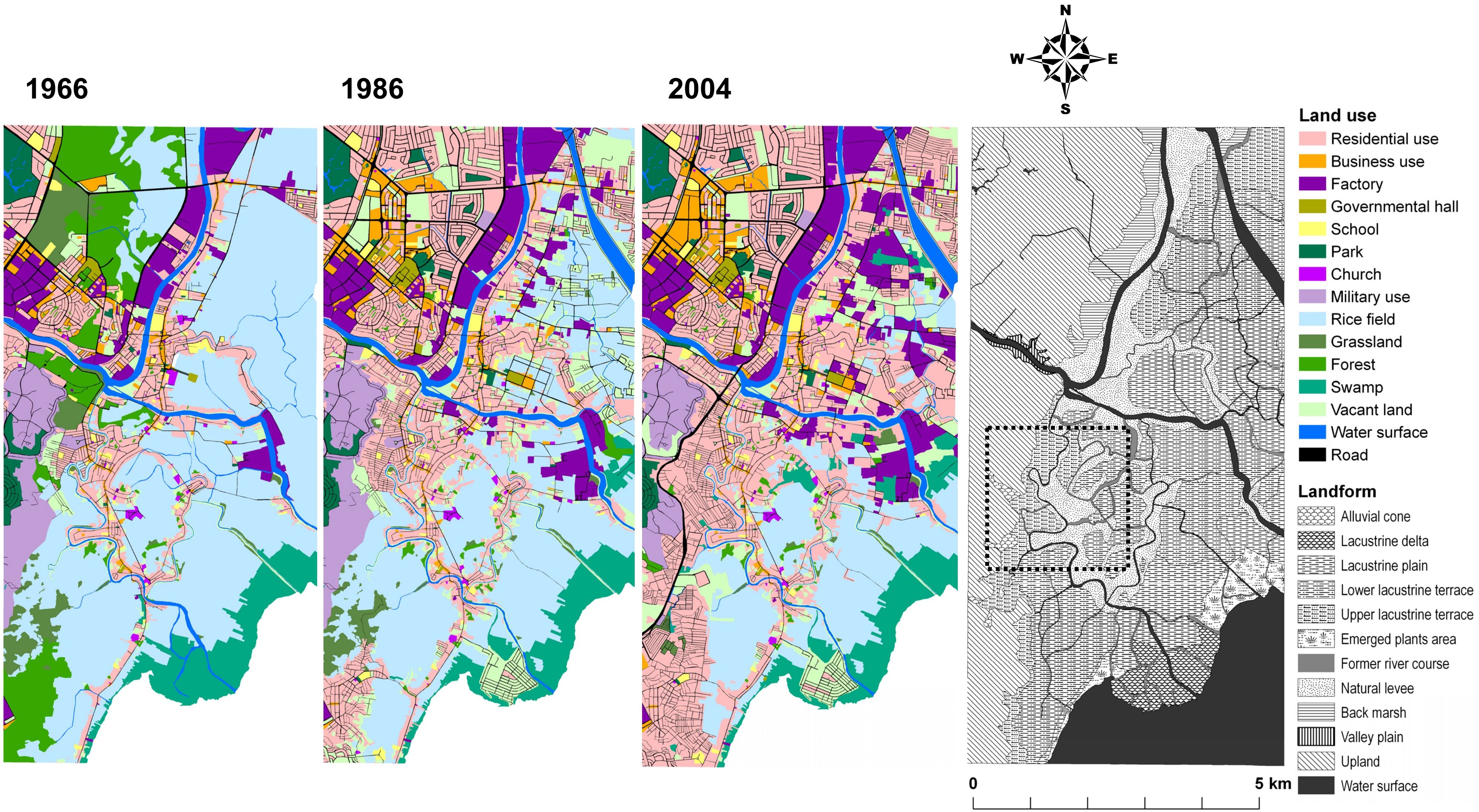


Fig. 21. Land-use maps for 1966, 1986, and 2004 and a landform classification map (Hara et al., 2002). The square on the landform classification map indicates the micro-scale study area, which is shown in detail on Fig. 25.

Fig. 22. Upper photo (taken in 1977 by Sampei, Y.) shows traditional settlement pattern on natural levee landform. Bottom photo (taken in 2003 by Minezaki, Y.) shows expansion of residential land use into the areas between natural levees.

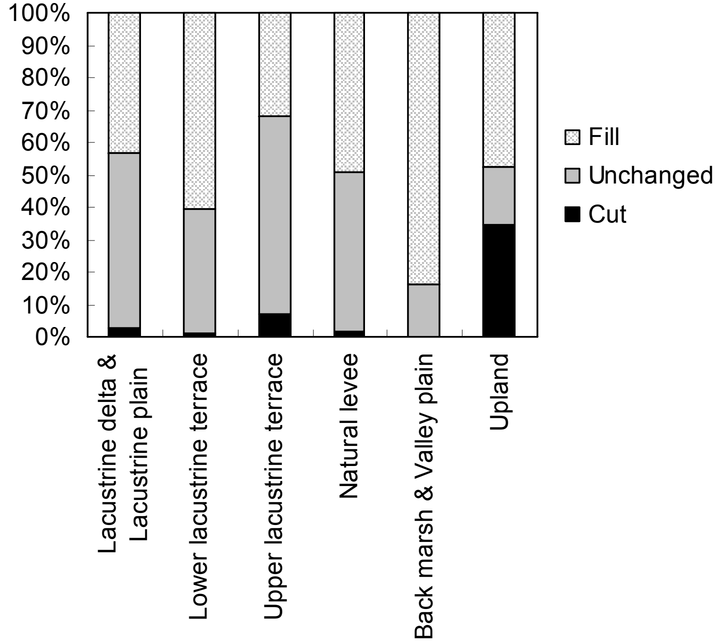
3.3.2. Interrelations among landform transformation, landform, and land use

Fig. 23 shows the interrelations among landform transformation, landform, and land use. Other than in the uplands of the study area, landform transformation has been achieved mainly by the use of fill practices. About half of the total urbanized land has been developed by using fill in low-lying areas, where the average thickness of fill is around 1 m. The maximum fill thickness for residential developments on the natural levee landform is about 1 m, whereas that on areas of lacustrine plain is less than 50 cm.

Fig. 24 shows my estimates of the cumulative growth of fill volume in the study area. The greatest increase in the use of fill occurred on the lower lacustrine terrace landform. Over the 40 years from 1966 to 2004, the volume of fill applied to landform transformation almost doubled in the study area.

3.3.3. Characteristics of materials used for landform transformation and development and a representative sectional profile

Fig. 25 and Table 5 show the characteristics of the materials used for landform transformation as observed during my micro-scale field survey. Many development sites use construction waste such as a broken concrete for landfill, although local contractors sell crushed rock (including a local product known as adobe) and white sand (locally known as lahar because of its association with the eruption of nearby Mt. Pinatubo). At several sites I found that landowners welcomed the dumping of construction waste on plots that they intend to develop in the near future. Surprisingly, at some sites landowners accepted dumping of construction waste for landfill for a payment by truck drivers of around 50 pesos per truckload, and also asked the truck drivers to level the land in preparation for construction. Therefore, at a considerable number of development sites, fill consists of mixed materials, including mainly broken concrete, but also adobe and other solid waste. I found that white sand is used mainly to make concrete blocks for wall construction and crushed rock is used mainly in asphalt for pavements and driveways.



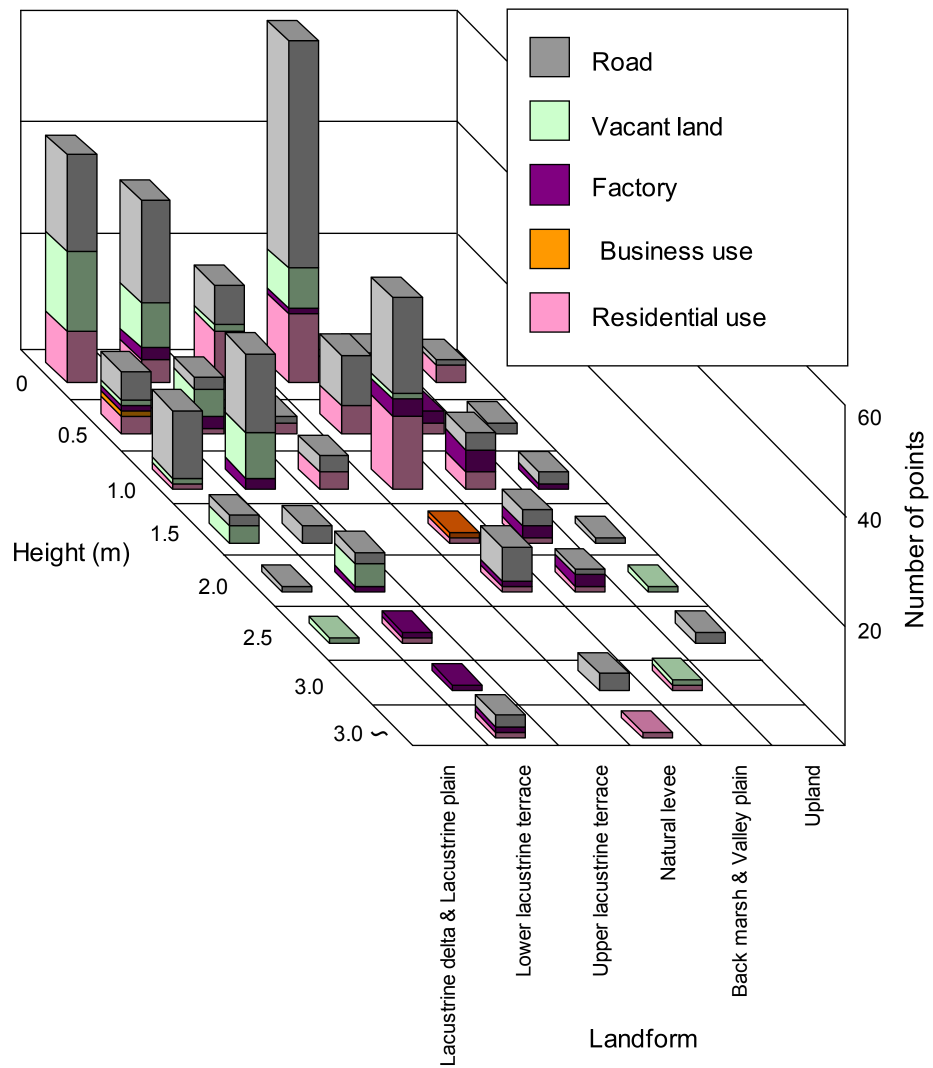


Fig. 23. Landform transformation, landform, and land use interrelationships within the meso-scale study area.

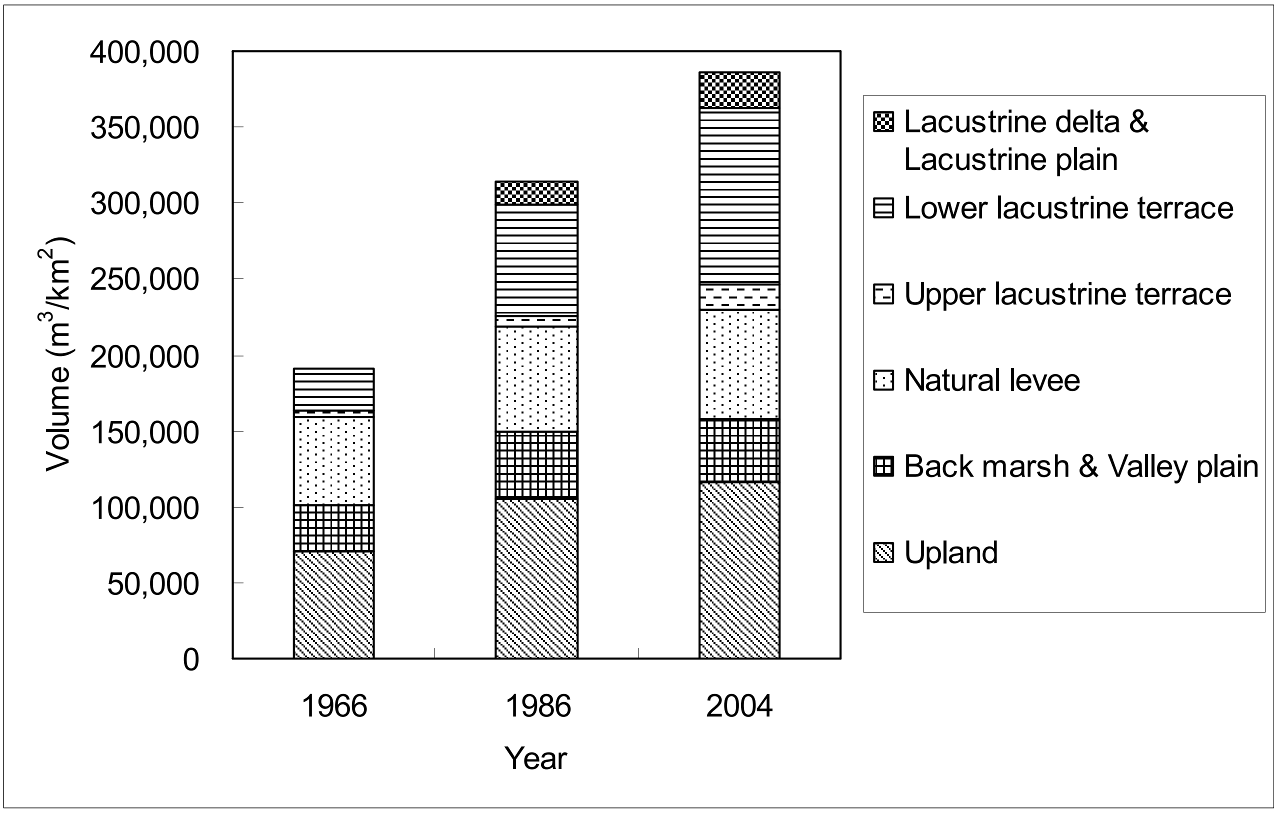


Fig. 24. Cumulative growth in the volume of landform transformation by landform type from 1966 to 2004 within the meso-scale study area.

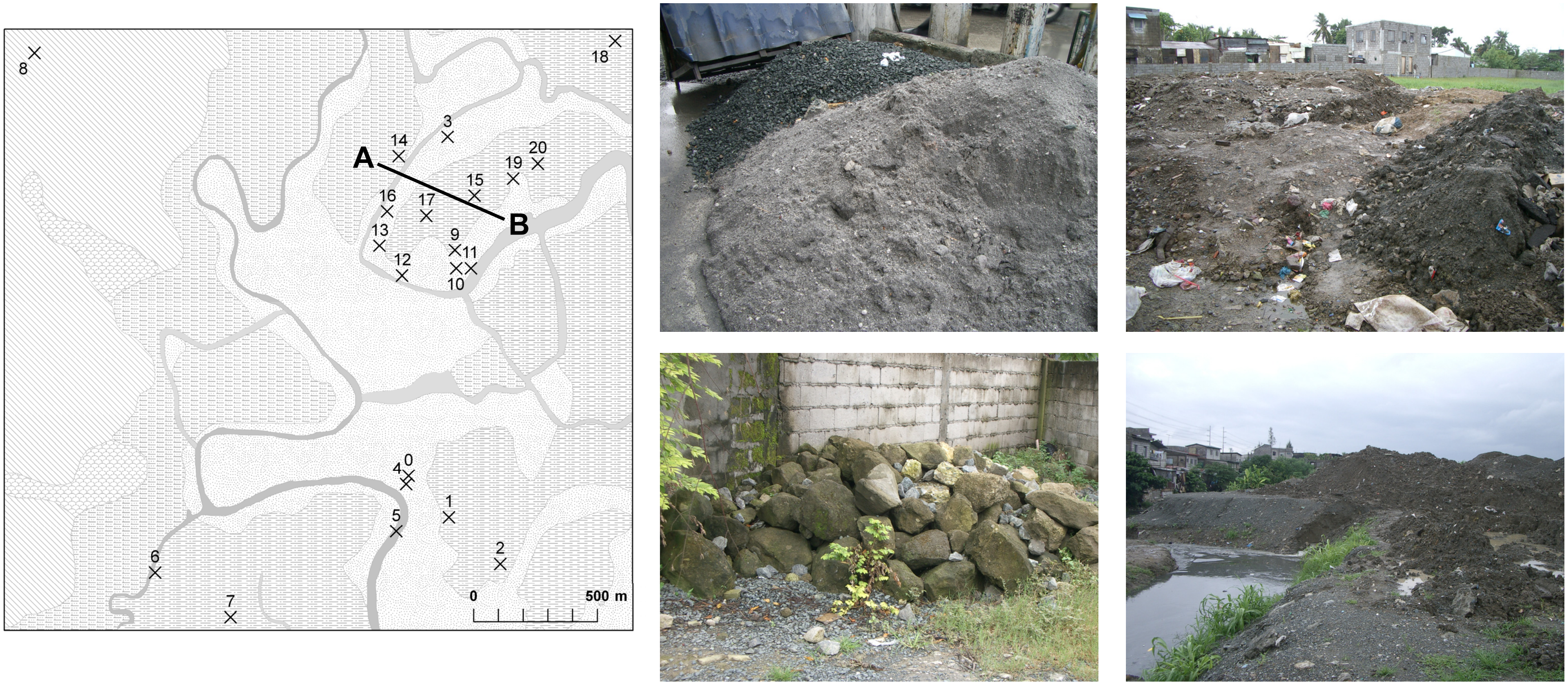


Fig. 25. Map and photographs of observation sites of micro-scale study. Table 5 provides details of material observed at numbered sites. Photographs show typical fill materials: white sand and crushed rock at a contractor's shop (top left), broken concrete fill (top right), adobe fill (bottom left), and local clay being used in road construction (bottom right). Sectional profile A–B is shown in Fig. 26.

Table 5. Material survey list

Site number	Development site for	Transformation	Main material			Price (pesos/m^3)			
		Type	Type	Texture	Color	Crushed rock	Sand	Laterite	Broken concrete
0	Residential use	Fill	Broken concrete	G	-	-	-	-	-
1	Governmental hall	Fill	Broken concrete	G	-	-	-	-	-
2	Residential use	Fill	Broken concrete	G	-	-	-	-	-
3	Fill contractor's shop	-	White sand (Lahar)	S	5Y5/1	500	500	500	-
4	Fill contractor's shop	-	Crushed rock	G	5B3/1	675	430	-	90
5	Fill contractor's shop	-	White sand (Lahar)	S	5Y5/1	550	550	-	-
6	Road	Fill	Local Clay	HC	2.5Y3/3	-	-	-	-
7	Road	Fill	White sand (Lahar)	S	5Y5/1	-	-	-	-
8	Residential use	Cut	Crushed rock (Adobe)	G	7.5YR3/1	-	-	-	-
9	Fill contractor's shop	-	White sand (Lahar)	S	5Y5/1	500	450	-	100
10	Residential use	Fill	Local Clay	HC	2.5Y3/3	-	-	-	-
11	Residential use	Fill	Crushed rock (Adobe)	G	7.5YR5/4	-	-	-	-
12	Residential use	Fill	Broken concrete	G	-	-	-	-	-
13	Fill contractor's shop	-	White sand (Lahar)	S	5Y5/1	500	500	-	-
14	Residential use	Fill	Laterite	LiC	7.5YR4/3	-	-	-	-
15	Residential use	Fill	Broken concrete	G	-	-	-	-	-
16	Residential use	Fill	Laterite	LiC	7.5YR4/3	-	-	-	-
17	Residential use	Fill	Crushed rock (Adobe)	G	7.5YR5/4	-	-	-	-
18	Residential use	Fill	Broken concrete	G	-	-	-	-	-
19	Residential use	Fill	Crushed rock (Adobe)	G	7.5YR5/4	-	-	-	-
20	Residential use	Fill	Broken concrete	G	-	-	-	-	-

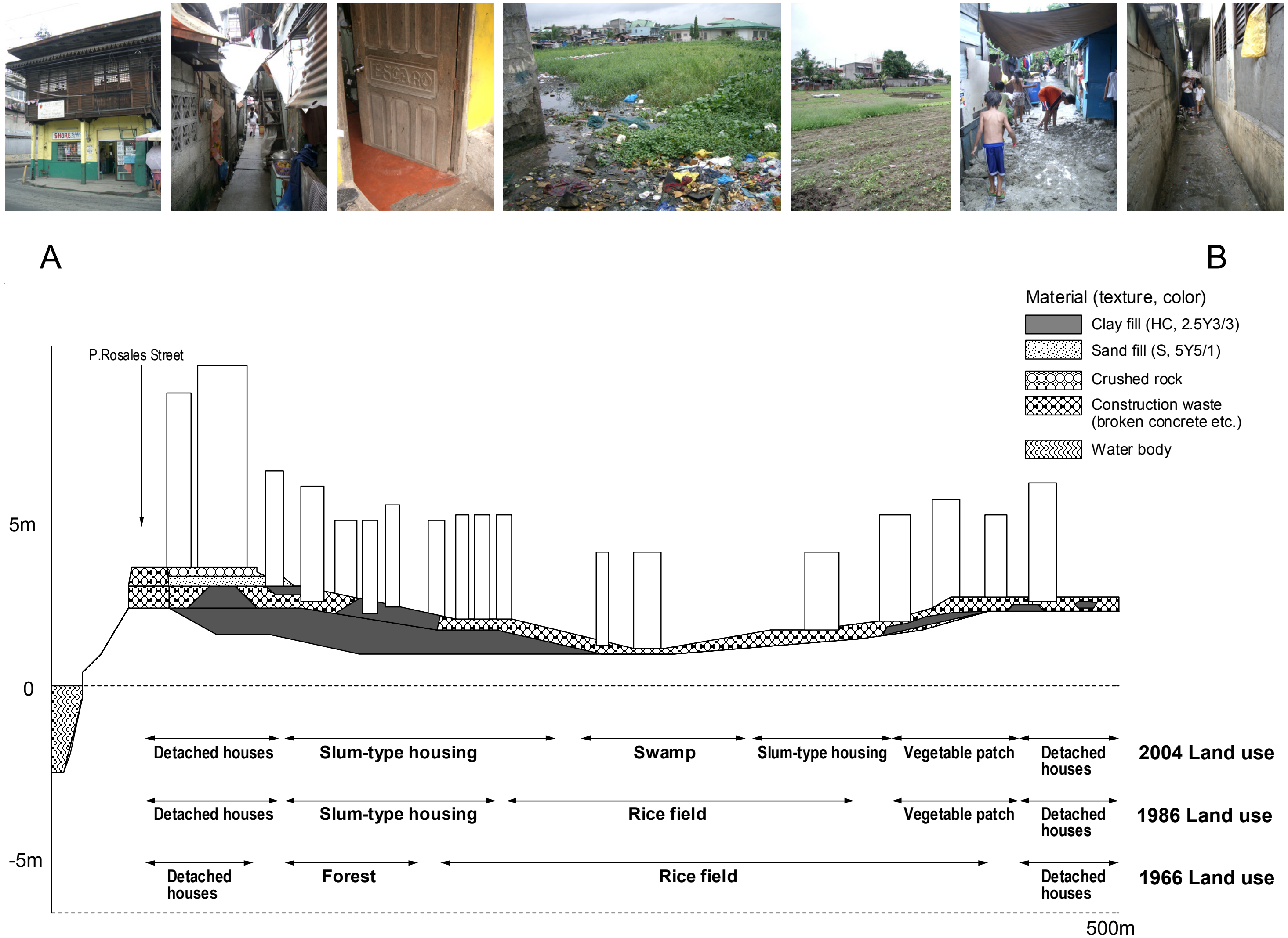


Fig. 26. Sectional profile from the micro-scale study area showing land use in 1966, 1986, and 2004. Photographs show examples of typical current land use and fill along the transect. From left to right: modified traditional raised-floor house on a natural levee, slum housing constructed of concrete brocks and zinc roofing, dwelling where regular addition of fill has necessitated cutting off the bottom of a door, swampy abandoned paddy field, vegetable patch, temporary housing on clay fill, and a path sloping up to the main road.

The sectional profile I compiled (Fig. 26) shows, from west to east, a characteristic pattern of fill along a typical sequence of low-lying landform units: natural stream, natural levee (originally inhabited place), lower lacustrine terrace, natural levee (originally inhabited place), and former river course. Fill has sometimes been used under traditional raised-floor houses on natural levees. In some old houses, landowners have placed fill material (mainly local clay and laterite) into the traditionally open-air ground floor of their houses, which is sometimes later enclosed to add to their living space. Some landowners have added fill several times over the past three decades, often during renovation of their houses. New houses are commonly built on higher foundations than traditional houses. P. Rosales Street, at the western end of my profile, follows the natural levee and was not paved until 1998 when fill of 50 cm was applied at a cost of approximately 800 pesos per cubic meter (according to the civil engineering division of Pateros Municipal Office). Moving east on my profile from the natural levee to the lower lacustrine terrace, the land surface becomes gradually lower, and temporary and slum housing constructed of concrete blocks with zinc roofing on fill of clay and construction waste begin to predominate. For houses built here in the 1980s, owners put additional fill onto the ground floors after initial construction, in some cases resulting in the need to cut the bottom off ground floor doors. Although owners have modified their houses using additional fill, the level of the pathways in front of their houses has remained, on average, around 40 cm higher than the ground floor of their houses because of regular addition of fill to the pathways by the local community. In the middle of the profile, between the natural levees, abandoned rice fields have become swampy vacant land. The swampy land has become unsanitary because of poor drainage and dumping of solid waste. East of the swampy area, the land gradually rises and temporary housing on clay fill continues until the next natural levee is reached.

3.3.4. Flow of fill material

Fig. 27 shows the geology and source areas for fill materials for the Metro Manila region, and Fig. 28 provides a model for the flow of fill material from source to end use. Figs. 29 and 30 show typical features of white sand (lahar) digging and rock pit respectively.

In the low-lying development sites within the study area, white sand (lahar) is almost exclusively used in concrete, and to make multipurpose concrete blocks in particular. It is sometimes also used for surface filling and leveling, especially for the construction of major roads that need to carry heavy loads. The white sand is trucked from an area at the foot of Mt. Pinatubo in Pampanga Province (Fig. 27 and 29). The cost to the end user in my study area is about 6000 pesos per truckload, which is equivalent to about 500 pesos per cubic meter. At the source, it costs 600 pesos per truckload, equivalent to 50 pesos per cubic meter. According to my interviews at the source pits, factories, and control points in the source area, production was more than 1300 truckloads per day, equivalent to 1.8×10^4 m^3 per day, during the peak period of reconstruction after the extensive damage caused by the 1991 eruption of Mt. Pinatubo. The white sand from Pampanga Province is used for construction as far away as Batangas Province, approximate 100 km south from Metro Manila.

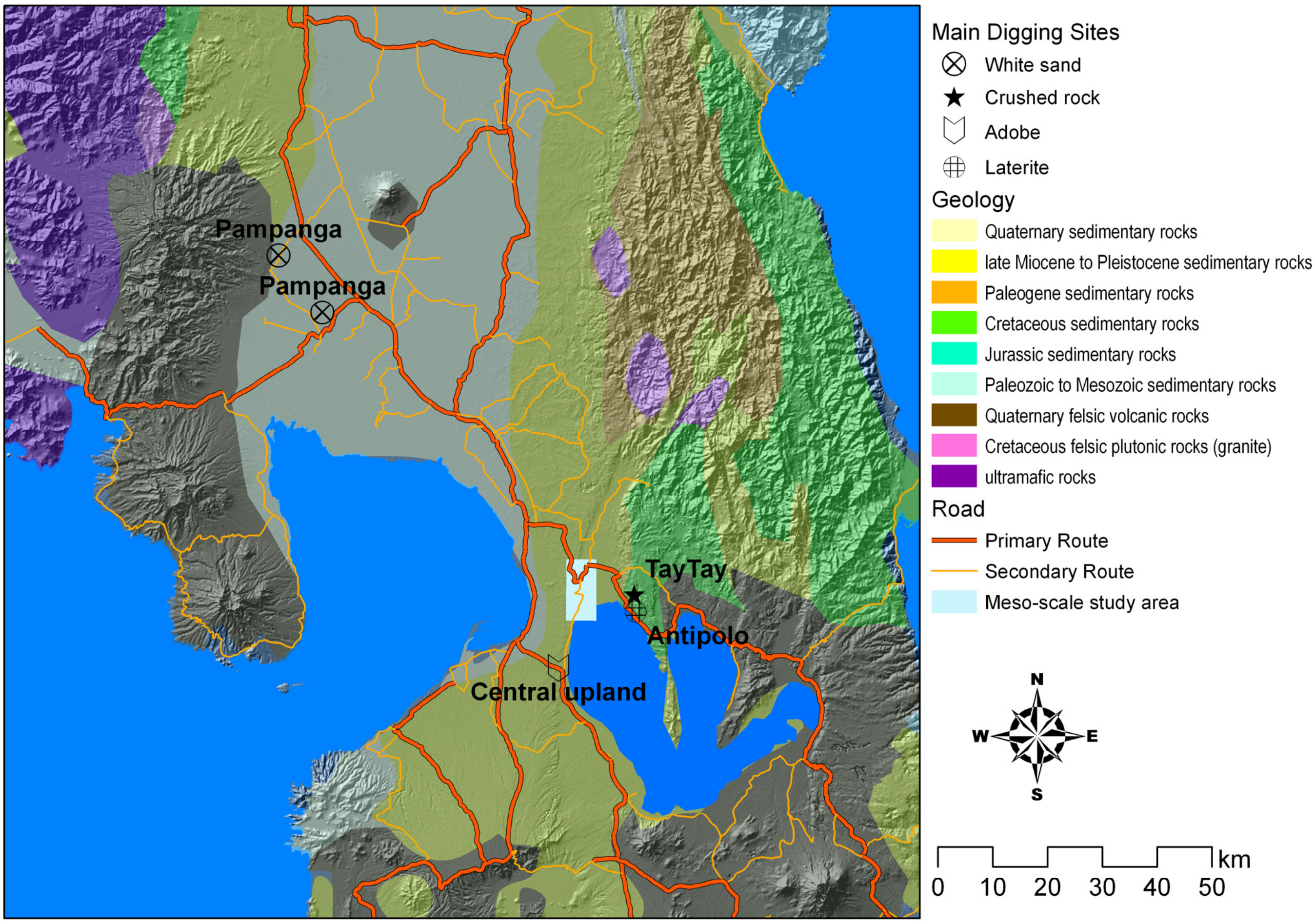


Fig. 27. Regional map showing sources of fill material in relation to geology and geography.

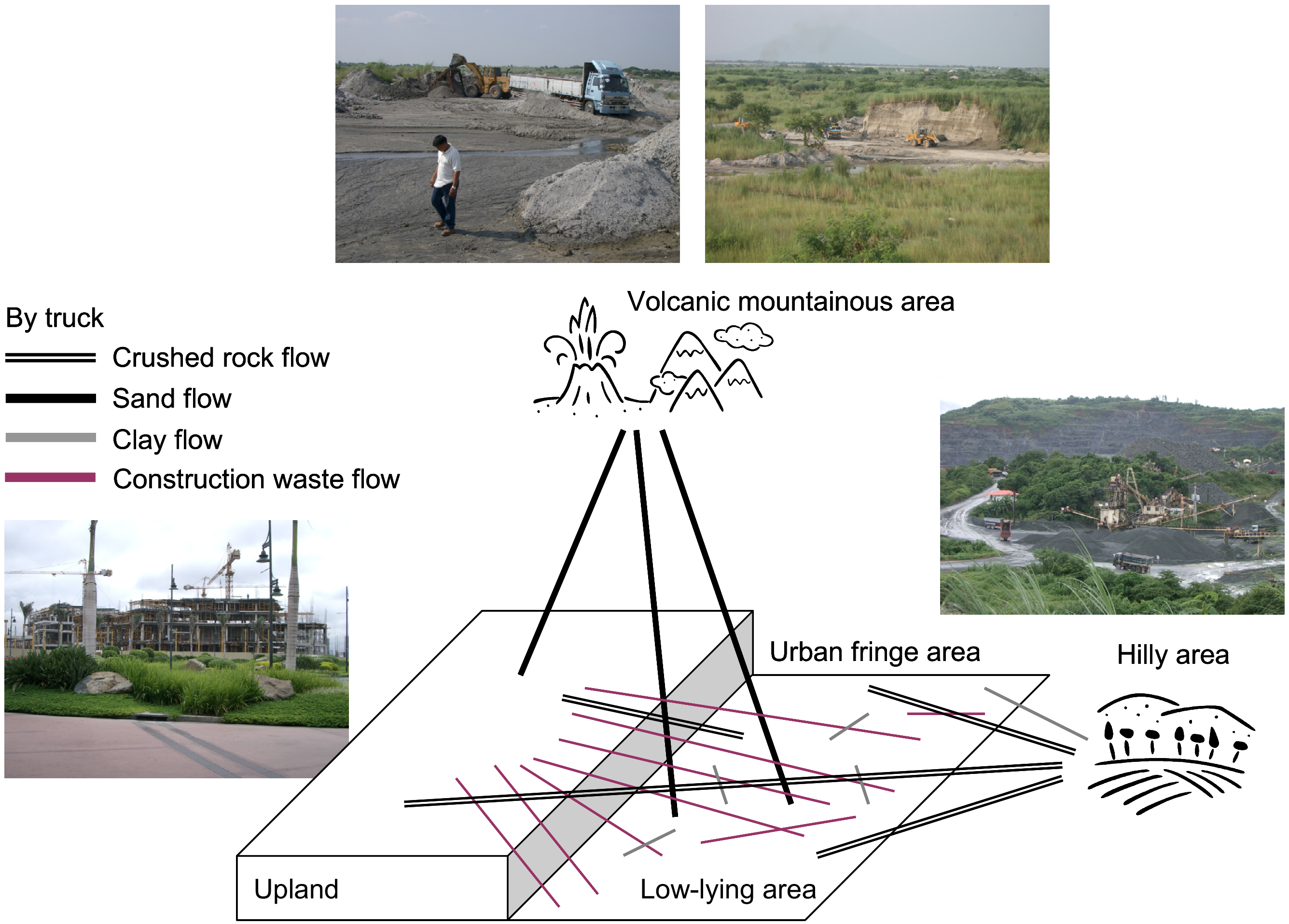


Fig. 28. Schematic model illustrating the flow of fill material at macro, meso, and micro scale. Photographs show typical features of each source area: lahar covered riverbank at the foot of Mt. Pinatubo in Pampanga Province (top), rock pit in the eastern hilly area (right), and large-scale construction work providing waste fill material in the upland area (left).

Fig. 29. White sand (lahar) excavation features.

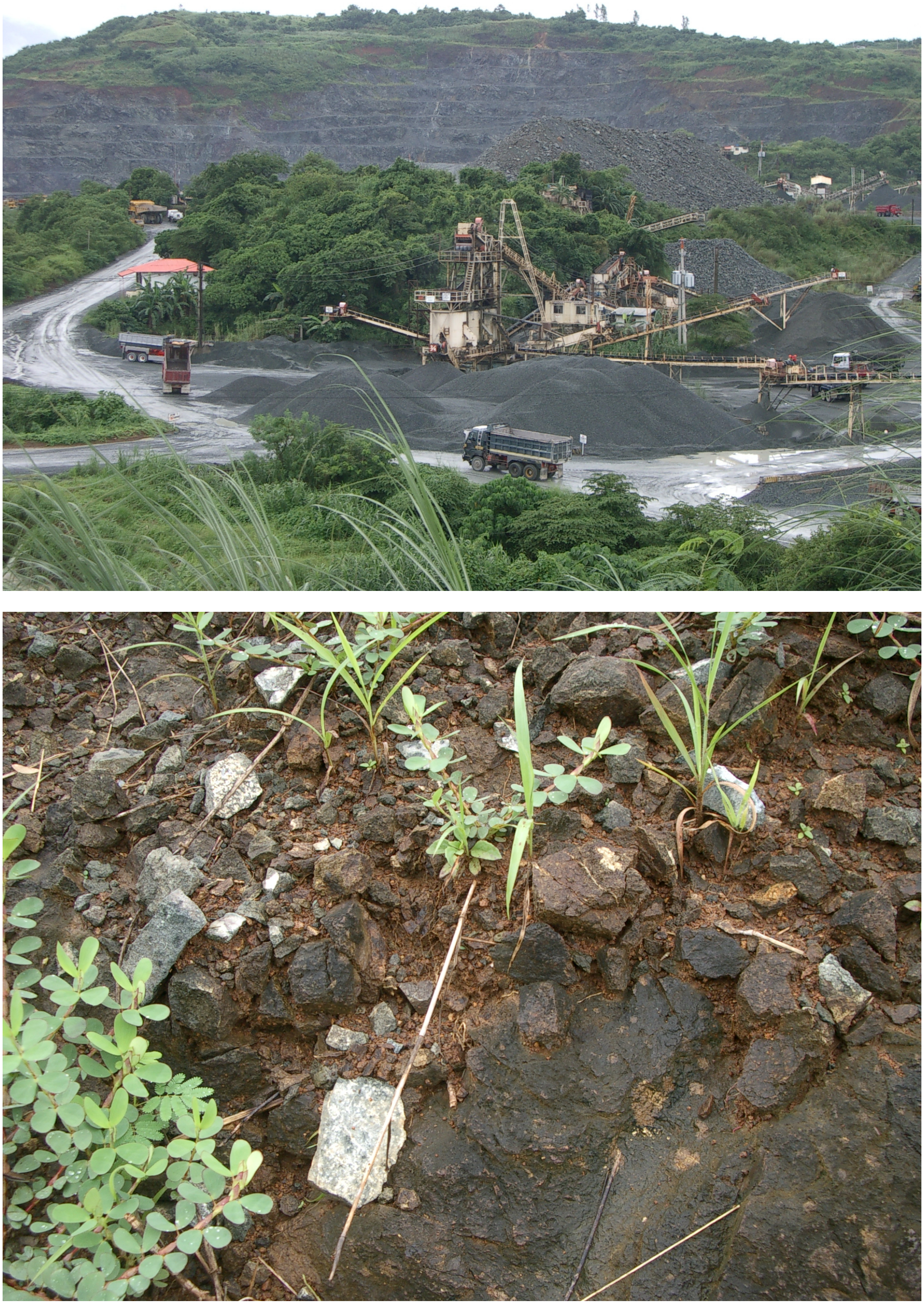


Fig. 30. Rock pit features.

Before the 1991 eruption of Mt. Pinatubo, river sand was commercially exploited for use as a construction material. The eruption deposited large volumes of lahar near the volcano, and local landowners soon began to use private contractors to remove the lahar from their land. The contractors pay an excavation fee to landowners. An organization comprising the private contractors and construction companies set up control points at the entrance to the source area to manage excavation practices. The organization pays a fee to the local government on the basis of the number of trucks passing through.

Crushed rock is used for surface filling and leveling. It is trucked mainly from San Mateo and TayTay in Rizal Province (Fig. 27 and 30), a hilly and mountainous area east of my study area. The cost to the end user of this crushed rock is about 7000 pesos per truck, equivalent to 580 pesos per cubic meter. A different type of crushed rock, locally called adobe, is used mainly for landfill. This is produced from the uplands of my study area through surface leveling work for large-scale shopping center or subdivision developments. In the uplands of my study area, the Pleistocene Guadalupe Formation (largely volcanic tuff; the basement rock in the geologic profile of Fig. 20) outcrops at the surface. Leveling, and in some areas cutting, of the uneven and rocky land surface for new land development provides large volumes of crushed rock (adobe) that are trucked directly to low-lying construction sites, or to contractor shops in the low-lying areas, where it is mixed with construction waste and sold for about 1200 pesos per truckload, equivalent to about 100 pesos per cubic meter. Interestingly, after leveling or cutting at upland construction sites, high quality white sand and crushed rock are used for surface filling to provide foundations to support large and heavy buildings.

Construction waste in the form of broken concrete is the main fill material used for low-lying development sites. It is produced mainly from the upland area as a result of building regeneration work and is mixed with adobe and trucked to development sites in low-lying areas. Demolition of old concrete government buildings in low-lying areas provides additional concrete waste for fill at nearby development sites. This waste is often dumped, with permission of landowners, into vacant plots for use as fill for future land developments. Otherwise it is provided to local contractor shops for on-selling.

Local people that I interviewed said that they previously used fill composed of clay and laterite from Antipolo, the nearest hilly region to the east of my study area (Fig. 27). The older people said that they used to regularly collect these materials and carry them by two-wheeled cart to fill onto their ground floors to protect their homes from flooding. They also said that, since the 1980s, construction wastes have been commonly used for landfill. Nowadays the local clay is more commonly used for other purposes, such as to temporarily repair paths that have been submerged and damaged during heavy rains (see photo in Fig. 26).

3.4. Discussion

3.4.1. Spatiotemporal relationships between landform and land use

In my meso-scale study area, land-use patterns have been transformed over time by a change from an approach that adapted to the natural landforms to one that modified those landforms, which is a common phenomenon in Asian insular foothill-rimmed lowland areas (Oya, 1993). Although the upland area had begun to develop a strong housing base in large-scale subdivisions in 1966 (mostly interpreted from 1966 aerial photographs) and there were also some business areas being developed, there was still a substantial coverage of forest to protect the area from natural disasters such as floods and landslides. In the low-lying areas at this time, residential land use was largely confined to the natural levees and was, therefore, relatively safe from the effects of flooding. A photograph taken in 1960 in a low-lying area (Fig. 31) shows an original waterscape that is typical of that time. There were traditional raised-floor settlements on the banks of the stream, and villagers used wooden boats as their main form of transport. Some of these elements can still be found in the field today. For example, the photograph on the left side of Fig. 26 shows a traditional wooden raised-floor dwelling where the original open-air ground floor has been enclosed by a concrete block wall. During my field survey, I also observed several abandoned wooden boats in settlements along the roads that have historically followed the natural levee landforms.

As the regional population has continued to become concentrated in Metro Manila, urban land use, and residential land use in particular, has been expanding into vulnerable areas such as the back marshes and lacustrine plains between the natural levees. Because these landforms are vulnerable to flooding, the extensive use of landfill is essential for development of the land

(Hara et al., 2002). Between 1986 and 2004, residential areas expanded into the areas well beyond the natural levees (Fig. 21). These residential areas were generally a mixture of slum housing and large subdivision developments on fill (Murakami et al., 2003). During this same period, business offices and large shopping centers were developed on vacant land on the upland (Serote, 1991). Thus, by 2004 in my study area, urban land use had conquered the restrictions imposed by natural landforms, but development patterns were still controlled to a degree by the relationship between landform and the economic value of real estate, or by preferred land development styles.

Fig. 31. Traditional village landscape along a stream and natural levee landform in the study area in 1960 (with kind permission to use by Nocheseda, E.I.).

3.4.2. Quantitative and qualitative characteristics of landfill

The use of landfill is by far the most common landform transformation practice for residential development on low-lying landforms in my study area (Figs. 23 and 24). The material mainly used for landfill for development of low-lying land is construction waste (Table 5, Figs. 25 and 26). However, according my field observations (Fig. 26) and interviews with local inhabitants, landfill practices seem to have been variable and to have adapted to make use of the most readily available fill material. Initially, local clay fill was used to raise the level of the ground floors of houses. The common need to cut off the bottom of ground floor doors in these areas (photo, Fig. 26) is evidence of the gradual and regular addition of fill. More recently, landowners have used construction waste for fill when they replaced traditional houses with detached houses. In new large-scale subdivision developments in low- lying areas, construction waste used for landfill has raised the land surface to a level higher than the average land elevation of nearby detached houses (Murakami et al., 2003).

These landfill practices are presumably for protection against flooding. Hara et al. (2002) reported that local people used whatever landfill was available to protect their homes against flooding, and in doing so, they created land-locked plots as poorly drained swampy land. For the maintenance of public roads, intermittent fill renovations have been carried out without consideration of appropriate building standards (verified by staff of the engineering division of municipal offices), inviting additional fill practices in the neighboring houses. Thus in this area, landfill has been a regular practice for many years, initially using local clay and, more recently, using the large volumes of construction waste that have resulted from building regeneration. As a result, the baseline of fill height has been gradually raised. I calculated the total volume of fill used in my meso-scale study area from 1986 to 2004 (Fig. 24) by using the average fill height in 1986 (calculated by comparison of the 1966 and 1986 topographic maps) as a baseline. However, on the premise that the baseline of fill height has been gradually raised, the cumulative volume of landform transformation over the entire period from 1966 to 2004 might be greater than I calculated.

3.4.3. One-to-one fill flow and trade-off

Construction waste, which is the most widely used fill material in the low-lying areas, tends to flow “one-to-one” from the source to the site where it is used, that is, directly from supplier to end user. Wreckers want to dump their waste economically, and landowners in low-lying areas want to acquire landfill to develop their land as cheaply as possible. Therefore, a one-to-one flow occurs in the form of a trade-off relationship. This relationship develops on a case-by-case basis, sometimes through acquaintances. For example, some landowners open their vacant lots for dumping, and wreckers can dump wastes for free or for a small fee. For large-scale building regeneration projects, however, demolition workers may look for nearby dumping sites by talking to neighbors or relatives. The recent trend of urban regeneration on the uplands (Fig. 21) appears to have resulted in a considerable one-to-one flow of construction waste and adobe into low-lying development plots.

The flows of white sand and crushed rock (excluding adobe) into Metro Manila are largely one-to-one, even though the sources areas, being dependent on geologic conditions, are distant from development sites. White sand is excavated at Pampanga, at the foot of Mt. Pinatubo. There is convenient highway access to the Pampanga from where the sand is trucked approximately 60 km to the low-lying development sites in my meso-scale study area; hence, it is transported directly from source to end use. Although there are some intermediate contractors in both the source and end use areas, the general flow is one-to-one.

Crushed rock is produced mainly from TayTay, which is the nearest hilly and mountainous area to the east of Metro Manila, and is trucked directly to low-lying development plots or to local contractors. Laterite and clay for landfill have also been trucked from these areas directly to the low-lying development areas, although the volume appears to have decreased as laterite and clay has been replaced by construction waste.

3.4.4. Taking onsite and offsite landform transformation practices into consideration in land-use planning

From the results of Metro Manila case study, I propose the following strategies to be applied in urban–rural land-use planning for Metro Manila.

3.4.4.1. Regulating onsite fill practice in consideration of natural landforms

This study has shown that adaptive, unplanned onsite fill practices are employed in low-lying areas. Hara et al. (2002) suggested that these practices cause changes in the distribution of flood-prone areas and long-standing swampy plots and can lead to unsanitary living environments. Hara et al. (2002) pointed out that controlling fill height, taking into account the natural landform patterns, is an effective way to avoid these situations. Therefore, zoning based on natural landforms, so that landfill practices are not in conflict with the natural environment, is important.

According to the current land-use planning system in this area (Pateros Urban Planning Office, 2000; Taguig City Development Planning Office, 2003), zoning is determined by and essentially parallel with the construction of main roads, without any consideration of fill volumes that may be required. Staff at both civil engineering and urban planning divisions of municipal offices confirmed that there are effectively no rules governing the use of landfill. The staff recognized that landowners determine the fill height for their plots, and generally match it to the elevation of the access road to their plot. The Department of Public Works and Highways (DPWH) provides a national building code (DPWH, 2005), which requires boring to test the geology and soundness of foundations for buildings of more than three stories. The Mines and Geosciences Bureau of the Department of Environment and Natural Resources also promotes geological and environmental assessment for new land development.

Nevertheless, individual fill practices are currently uncontrolled; in particular, there is no quality control for fill materials. The lack of an assessment system for landfill proposals and the lack of control of landfill material might result in serious or even disastrous environmental pollution. Therefore, there is an immediate need to develop and implement a zoning scheme based on natural landforms, incorporating both quantity and quality constraints on landfill practices. To achieve this strategy, the responsibilities for land-use planning (currently urban planning division) and building control (currently engineering division) must be amalgamated.

3.4.4.2. Constructing a system for efficient offsite–onsite flows with effective regulation

My study has revealed that the flow of fill material from offsite source areas to onsite landform transformation areas within my study area is predominantly on a one-to-one basis using trade-off relationships. Currently these flows take place independently without regulation or any form of management system. This situation promotes uncontrolled urban sprawl and unsanitary urban living environments. Development of a system for an effective and regulated flow of fill material in Metro Manila is a task of immediate importance.

Mapping and information systems based on GIS technology with a web-based user interface that are being tested in Japan (Ministry of Land Infrastructure and Transport, 2003) and other regions may provide an effective solution to the Metro Manila problem. Systems of this kind may have benefits for wreckers, developers, and landowners. With these systems, wreckers could more easily find sites for disposal of their construction wastes, and landowners and developers would be able to review and perhaps appeal zoning decisions related to their land.

GIS management systems could equally be applied to improve the efficiency of the flow of sand and crushed rock. The geologic controls of the source areas for these materials make them well suited to management in GIS systems. Such systems could be used to improve the balance of supply and demand and, if used for day-to-day flow control, could also be used for government needs, such as for determination of taxes on fill material.

However, the most important aspect of the government regulatory role would be overseeing and monitoring land transformation practices and ensuring that there are standard penalties for illegal dumping of polluted waste and for other inappropriate landfill practices.

4. Comparative discussion and concluding remarks

In this chapter, I make comparisons between Bangkok and Metro Manila on the basis of the results of my case studies. Table 6 summarizes comparative viewpoints.

Table 6. Emergent indicators in and across spatial scales in this study and for land-use planning

	Bangkok	Metro Manila
Meso-scale space	Land uses	Natural landform
	Landform transformation 5.7×10^3 m^3 km^{-2} $year^{-1}$	Landform transformation 5.0×10^3 m^3 km^{-2} $year^{-1}$
Micro-scale space	Building style (quality of land use)	Building style (quality of land use)
	Fill material (quality of landform transformation)	Fill material (quality of landform transformation)
Macro- to micro-scale fill material flows	100 km distance sand flow from source to end use 5.5×10^7 m^3 $year^{-1}$ (production)	60 km distance sand flow from source to end use 6.6×10^6 m^3 $year^{-1}$ (production)
	100 km distance crushed rock flow with a form of door to door	10 km distance crushed rock flow with a form of door to door
	Clay flow between adjoining plots in the urban fringe development area	10 km construction waste flow from building demolition sites on the upland to the low-lying development sites
Urban-rural land-use planning	Zoning based upon the past agricultural land-use patterns	Zoning based upon the natural landform pattern
	Controlling on maximum volume of landform transformation	Controlling on maximum volume of landform transformation
	Regulatory control at the nodes of fill material flows	Introduction of the GIS-based management system for effective one-to-one fill material flows

4.1. Quantitative comparison between continental Bangkok and insular Metro Manila in meso-scale landform, land-use patterns, and the volume of onsite landform transformation

In meso-scale spatial studies, Bangkok case study demonstrated the statistical association between land uses and the volume of landform transformation (Fig. 7), whereas Metro Manila case study provided the relationship between natural landform types and the volume of landform transformation (Fig. 23). This difference results from the difference in macro-scale geomorphologic settings.

Bangkok is located on a huge continental delta (Fig. 3), where landform can be considered as a homogeneous morphologically in my meso-scale spatial analyses. Therefore, rural land-use pattern had been subject to the rudimentary agrarian development process, or spatial progress of the manmade canals that provided annual irrigation, water transportation and living space for humans in the deltaic extreme hydrologic environment. Such rural land-use patterns have been influential in urban development. Different patterns of land-use changes between BangkokNoi (Fig. 5) and Rangsit (Fig. 6) strongly support this view. Thus, landform transformation has been inherent in Bangkok in which is located on a continental delta both for rural and urban land developments. Landform transformation practice has been related to rural and urban land uses entirely, and has been providing connections between them.

Metro Manila is situated on foothill-rimmed insular lowlands (Fig. 20), where natural landform pattern can be recognizable in my meso-scale study. Thereof rural land-use pattern had been superimposed on natural landform pattern, in consideration of convenience of gravity irrigation as well as protection against flash flooding. Along with population concentration into the city, however, urban land use has been expanding from patterns based on natural landforms to unrestrained urban sprawl (Figs. 21 and 22) that is achieved by landform transformation practices (Fig. 23). The use of landfill techniques has allowed urban land use to encroach into watery back marshes behind the natural levee banks that border many river systems (Fig. 26).

The volume of onsite landform transformation that can be useful for a planning indicator shows similar range between two cities: the figure for Bangkok is calculated at 5.7×10^3 m^3 km^{-2} $year^{-1}$; and that for Metro Manila is calculated at 5.0×10^3 m^3 km^{-2} $year^{-1}$. Takeuchi and

Yoshioka (1982) estimated the figure for the Tokyo lowland at 3.3×10^4 m^3 km^{-2} $year^{-1}$. These soil flows into development sites on the urban fringes are far greater than those of natural sedimentary processes (Kadomura, 1985). To make a more meaningful comparison between the flow of materials in these cities I need further data to allow us to relate spatial development patterns and stages with the end point of the flow in each city.

4.2. Qualitative comparison between continental Bangkok and insular Metro Manila in micro-scale fill development styles

In my micro-scale field observation on land development style, Bangkok case study clearly showed undividable relationships between building type and fill material used (e.g., townhouse – clay fill foundation or condominium – sand fill foundation) (Figs. 11 and 12), whereas Metro Manila case study showed variant housing type on the dominant waste fill foundation on a case-by-case basis (Fig. 26). This difference results from availability of fill materials and local knowledge of land development practice in consideration of water level control and flood protection.

In Bangkok, a built-up area as a form of low density urban sprawl has been expanding toward peripheral areas widely due to its homogeneous flat land condition (Fig. 4); hence, for fill, construction wastes produced through building demolition in the urban core are not more profitable than natural soil, sand, and aggregate. Additionally local inhabitants have gained land preparation techniques by means of landform transformation through their agrarian development processes as management history of water level for irrigation. This can be applied to preparation of the housing base using natural soil fill.

In Metro Manila, rural land-use patterns in the pre-urbanization stage had been adaptive to natural landforms. Expansion of rice fields into back marsh area had been materialized without large-scale land surface transformation. Then urban land uses have been seeping from stable landforms (e.g., natural levee) into flood vulnerable landforms (e.g., back marsh and lacustrine plain) (Fig. 22). In addition to this, a close distance from a business district where building demolition takes place to low-lying land development sites have been promoting utilization of construction wastes for land filling.

4.3. Scale comparison between continental Bangkok and insular Metro Manila through fill material flow path: from macro-scale distribution of offsite land excavation; via meso-scale distribution of nodes as piers or contractors; into micro-scale onsite land development sites in the urban fringe

In my fill tracking survey from micro-scale land development sites toward macro-scale fill material source pits, Bangkok case study disclosed the material flow model (Fig. 14) whose source areas for sand fill are more than 100 km from development sites (Fig. 13), and transport is via a node–linkage structure with capillary flow in its final stage. This flow model results from the macro-scale geomorphologic setting; huge homogeneous continental delta covered mostly with marine sediments, and a dense network of waterways.

By contrast, the structure of sand flow in Metro Manila (Fig. 28) is around 60 km in its one-to-one transport distance from source to end use (Fig. 27), which is adapted to the macro-scale geomorphologic setting of an insular, geologically controlled lowland rimmed by volcanoes and mountainous areas. This model (Fig. 28) is similar to that of the Tokyo Metropolitan Area (Sakuma, 1984) and the Hanshin Metropolitan Area (Tanaka et al., 1983) during the Japanese economic boom of the 1960s and 1970s. In the Tokyo Metropolitan Area, a massive amount of sand produced from the Kazusa Group in Kimitsu City, Chiba Prefecture, was used for concrete manufacture and for landfill in the coastal area of Tokyo Bay. In the Hanshin Metropolitan Area, a massive amount of soil from the Rokko Mountains was transported to the Kobe seaside area.

Prices of sand at nodes in Bangkok and in Metro Manila support this view. I reported that, in Bangkok, the sand price at source pits was 90 baht m^{-3} and that at end use was 380 baht m^{-3}, while in Metro manila, the white sand price in source area was 50 peso m^{-3} and that at end use was 500 peso m^{-3}. Using the exchange rates of 100 baht ≈ US\$2.40 and 100 peso ≈ US\$2.08, these currency numbers can be converted into US\$2.16, 9.12, 1.04, and 10.4 respectively. Even though GDP per capita differs between Thailand (US\$7400) and the Philippines (US\$4770), a price increase from source to end use in Manila is greater than that in Bangkok. This probably reflects the difference in transportation mode: by water (Bangkok); and by land (Metro Manila).

I made a quantitative comparison in round numbers of the sand production in Bangkok and

Metro Manila (from this study), and in the Tokyo Metropolitan Area (Asahi et al., 1993). Sand production from the main sand pits used for development in Bangkok is approximately 1.5×10^5 m^3 day^{-1}, which is equivalent to 5.5×10^7 m^3 $year^{-1}$. Estimated sand production from the main sand mining area used for development in Metro Manila during the peak period, shortly after the 1991 eruption of the Mt. Pinatubo volcano, was around 1.8×10^4 m^3 per day, equivalent to 6.6×10^6 m^3 $year^{-1}$. That in the Tokyo Metropolitan Area during 1973 was 3.0×10^7 m^3 $year^{-1}$. Although these numbers might be fluctuating due to demand, they are far greater than those of natural erosion processes (Kadomura, 1985).

Thus, sand flow in the Bangkok region can be spatially scaled from macro, via meso, and into micro scale, along with the form of a node–linkage structure, whereas that in the Metro Manila region can be scaled from macro to micro scale in the form of one-to-one. The amounts of sand production are tremendous both in Bangkok and in Metro Manila.

In Bangkok, clay flow used for fill can be observed and scaled spatially within micro scale (Fig. 14), while in Metro Manila such a flow is not apparent. Visible material flow used for fill in Metro Manila is offsite–onsite construction waste flow that can be scaled spatially within meso scale (Fig. 28), whereas this type of flow is invisible in Bangkok. In addition, both in Bangkok and Metro Manila, crushed rock flow can be scaled spatially from macro directly to micro scale (Figs. 14 and 28). These facts reflect also availability and accessibility by land or water transportation to fill materials, which in turn are related to macro-scale geomorphologic settings.

4.4. Outlook toward the establishment of new urban-rural planning strategy for Asian urban fringes

Through the comparison between Bangkok and Metro Manila case studies, I disclosed that quantified and qualified landform, land use, and landform transformation are usable indicators for urban-rural land-use planning for these cities. These indicators are connected each other by fill material flows, and their emergent spatial scales differ depending on the macro-scale geomorphologic settings.

In Bangkok in which is located on a continental delta, quantified land use and landform transformation are interrelated visible indicators for meso-scale space, whereas in Metro Manila that is situated on foothill-rimmed insular lowlands, quantified natural landform and landform transformation are interrelated emergent indicators for meso-scale space. Both in Bangkok and in Metro Manila, quality of fill materials and housing styles, qualitative aspect of land uses, are interrelated emergent indicators for micro-scale space. Structures of fill material flows in each city are dependent upon quality of materials, and quantity and spatial extent of these fill material flows are subject to availability and accessibility to material sources, that in turn are determined by the macro-scale geomorphologic conditions. Sand flow in the Bangkok region diffuses over 100 km distance, while that in the Metro Manila region travels across 60 km distance. The clay flow that is characteristic of Bangkok behaves not beyond micro-scale space, whereas the construction waste flow that is characteristic of Metro Manila can be scaled within meso-scale space.

I concluded that further case studies under the same methodology are immediately needed to scale these indicators correctly in the macro-scale geomorphologic contexts, and finally to establish urban-rural planning strategies for Asian large cities.

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