# Landform transformation on the urban fringe of Bangkok: the need to review land-use planning processes with consideration of the flow of fill materials to developing areas

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## Abstract

For large Asian cities situated on deltaic lowlands, landform transformation is essential for both agrarian and urban development. Understanding landform transformation processes and patterns is important for landscape planning in areas of mixed urban–rural land use on the periphery of these cities. We examined landform transformation processes and patterns in Bangkok at three scales: (1) meso-scale quantitative landform analysis on the urban fringe of Bangkok using aerial photograph interpretation and topographic measurements; (2) micro-scale field measurements in sample districts to investigate relationships between building styles and the types of fill material used; (3) macro-scale analysis of the flow of fill material from source areas outside Bangkok to end use on the urban–rural fringe of the city. Our 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. We 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 $1.5 \times 10^5$ $m^3$ $day^{-1}$, 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 suggest that deltaic landscape planning should incorporate the means of managing the flow of fill material from source pits to end use in urban fringe development areas.

## Keywords

Delta; Landform transformation; Land use; Landfill; Material flow; Landscape planning; Bangkok

## 1. Introduction

Large Asian cities in monsoonal areas are situated mainly on deltaic lowlands (Yeung, 2001), and landform transformation is essential for both agrarian and urban development (Hara et al., 2005). Recent economic growth has led to the expansion of urban areas into peripheral agricultural areas, and broad areas of mixed urban–rural land use are emerging (McGee, 1991, 1995). Mixed urban–rural land use materialized by landform transformation practice is creating many environmental problems such as water pollution in irrigation canals (Bolay et al., 1997) and frequent submergence during rainy season (Hara et al., 2002), 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), and furthermore, investigation of landform transformation in deltaic settings as a result of urban–rural land–use changes is a key issue for landscape planning (Hara, 2005; Hara et al., 2005).

Landform transformation for agrarian development in Asian monsoonal lowlands 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 deltaic 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 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 practice as a key element to understand the entire process by which agricultural landscapes change into urban landscapes. A study from this perspective can provide crucial information for landscape planning in peripheral areas of mixed urban–rural land use. We focus on Bangkok and its vicinity, and examine entire process and patterns of changes from agricultural to urban land uses, inherent landform transformation, and their interrelationships. We quantify entire land-use changes and landform transformation practice, thereby contributing to the establishment of usable indicators for land-use planning for Bangkok in consideration of inherent landform transformation.

# 2. Methods

## 2.1. Research design for multi-scale analysis of landform transformation

In this study, we used the combination of two approaches: “multi-scaling” and “anthropogenic geomorphology” based on their capability in addressing urban–rural land–use processes and patterns as well as landform transformation practice. “Multi-scaling” 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). “Anthropogenic geomorphology” 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).

In this study, we integrated the two approaches discussed above, and developed our research design as shown in Fig. 1. We used three spatial scales: the whole delta region (macro-scale), urban fringe areas (meso-scale), and development sites (micro-scale). We started our analyses of land use and landform transformation in the urban fringe at meso-scale. We next focused on development sites at micro-scale, and made qualitative observations of housing patterns and landform transformation. Finally, we traced the flow of soil materials used for fill in the entire delta region, taking into consideration geologic structure and transport routes.

### 2.2. Setting of two meso-scale study areas of contrasting agricultural land-use patterns in the urban fringe of Bangkok

Bangkok is a typical example of a large Asian city built on a continental delta. This study focuses on Bangkok and its hinterland. We selected two meso-scale study areas, BangkokNoi and Rangsit, on the basis of past agricultural land-use patterns (Fig. 2). 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* (*khlong* means canal in Thai) and broad rectangular rice fields (Takaya, 1987). We started our spatiotemporal investigation into these two contrasting meso-scale urban fringe areas.

## 2.3. Data sources and analytical methods in each scale

We 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 we verified land-use interpretations of aerial photographs, interviewed local people, recorded fill materials, and took landform measurements. We 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.

### *2.3.1. Digital land-use maps for two meso-scale study areas*

We 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. We used land-use categories defined by Hara et al. (2005) in a detailed investigation of urban–rural land-use interactions. Our 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, cadastral maps, and previous publications (Takaya, 1971, 1987; Hanks, 1972; Kono and Saha, 1995; Tasaka and Nishizawa, 2003; Bangkok Metropolitan Administration, 2004). We scanned photos at a resolution of 600 dpi, added georeference data, and compiled a raster mosaic image for each of the six years. We then manually digitized the interpreted land-use boundaries and overlaid them on the raster mosaic for each of the six years.

#### *2.3.2. Measuring land elevation within two meso-scale study areas*

We acquired detailed topographic maps of Bangkok (Table 1), which provided elevations accurate to within 10 cm. We scanned the maps covering our two study areas (five sheets each for BangkokNoi and Rangsit) at 300 dpi resolution, and added location information. We 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.

#### *2.3.3. Associating land use with land elevation and quantifying the cumulative fill volume in two meso-scale study areas*

We 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, we used the land use interpreted from the detailed city topographic map for 2000. We 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 ($P < 0.05$).

We 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. We used a pond depth of

1.5 m, and a *khlong* depth of 2.5 m, based on our field observations and the work of Hara et al. (2005).

### *2.3.4. Recording fill materials in micro-scale development sites and measuring transect features*

To corroborate the land use – land elevation associations derived from our meso-scale GIS analyses, we conducted a field survey of under construction development sites in 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. In the areas that we were able to communicate, we 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 (Hara et al., 2005; Xie et al., 2006). We 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 we 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, we recorded the exposed features of fill where it was visible, and obtained details of fill materials and volumes from the developer.

### *2.3.5. Tracing the flow of fill material from micro-scale development sites toward*

***source pits dispersed across macro-scale delta region***

Because of a lack of usable government records on land development and mining in Bangkok we mainly used field interview methods to obtain the data we needed to trace the flow of fill material. We 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. We 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.

# 3. Results

## 3.1. Land-use changes in the two meso-scale study areas

Land-use maps for each of the six years used in our study for BangkokNoi are shown in Fig. 3, and for Rangsit in Fig. 4. 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 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.

### 3.2. Land elevation – land use relationships and cumulative fill volumes in the two meso-scale study areas

Land elevation – land use relationships in both study areas for 2002 are shown in Fig. 5. 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 our field survey showed that they occupied areas of similar elevation. For instance, most of the vacant lands in the BangkokNoi area were regarded as the ground for future detached houses development, whereas those in the Rangsit area were supposed to be the base for future townhouses development. Slum-type housing in the BangkokNoi area was built on the orchards (considered as an initial land surface) without any firm foundation, while that in the Rangsit area was built on the rice fields (considered as an initial land surface) without any firm foundation.

Cumulative changes in fill volume, which represent the amount of fill introduced from outside the study areas, are shown in Fig. 6. 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 (Fig. 5). There are statistical differences ($P < 0.05$) 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 ($P < 0.05$) in land elevation among urban land uses. The fill volume increased linearly from 1952 to 1995 (Fig. 6).

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 (Fig. 5). 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 ($P < 0.05$) 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 (Fig. 6).

Thus, the distribution of land elevations in the Rangsit area is more variable than that in the BangkokNoi area (Fig. 5). The fill volume in BangkokNoi increased linearly between 1952 and 2002, while that in Rangsit increased exponentially (Fig. 6).

### 3.3. Characteristics of fill materials in the micro-scale development sites

The sites where characteristics of fill materials were investigated, and the results of the investigations, are shown in Fig. 7 and Table 2 for the BangkokNoi area, and in Fig. 8 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 ground bases 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 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.

### 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. 9, and for the Rangsit area in Fig. 10. The areas covered by the topographic maps are consistent with the dotted squares of the maps shown in Figs. 7 and 8.

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.

In summary, in BagkokNoi 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.

### 3.5. Flow of fill material from source to end use

Fig. 11 shows the sources for fill materials in the Bangkok region, and Fig. 12 provides a model for the flow of fill material from source to end use.

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. 11. 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 we conducted our 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. 13). 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. 11, without the use of water transport.

As shown in Fig. 11, 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 wave 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, we estimated that about 7000 $m^3$ (250 $m^3$ × 4 × 7) of sand is carried daily from each pier. Aerial photographs of this area 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 public waters along the riverbank. However, because it caused bank erosion 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 $m^3 \times 25$) of sand is taken daily from every pit. Pit owners also said that there were more than 1000 pits in the AngThong area. We therefore concluded that about 150 000 $m^3$ (150 $m^3 \times 1000$) 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. 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.

# 4. Discussion

## 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, 1973). 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 19$^{th}$ and early 20$^{th}$ centuries (Takaya, 1987). After World War II, there were rapid increases in rice production from the Rangsit area following the commencement of the "Greater Chao Phraya Project" which aimed to irrigate and cultivate the Chao Phraya delta as a rice bowl for the world under the supervision of the Food and Agricultural Organization (FAO) 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 of 1952 (Fig. 4) 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. 6). 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).

### 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 our 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. Our 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. 8) 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.

### 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. 11). Transportation routes from those sources to development sites in Bangkok differ (Fig. 12), depending on transportation cost. The AngThong Province (Fig. 11) 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. Our 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 fill material 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. This model (Fig. 12) is similar to that of the Tokyo Metropolitan Area during the Japanese economic boom of the 1960s and 1970s (Sakuma, 1984), but it differs in that it is also influenced by the geomorphologic characteristics of a continental delta. 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 (Sakuma, 1984). On the inland plain, soil from the nearest uplands or surplus soil produced during underground construction was used for land fill (Takeuchi and Yoshioka, 1982; Ministry of Land Infrastructure and Transport, 2003). In hilly areas, cut-and-fill was the main method used to prepare housing foundations (Tamura and Takeuchi, 1980). In Hanshin Metropolitan Area, a massive amount of soil from the Rokko Mountains was transported to the Kobe seaside area (Tanaka et al., 1983). These materials came from within 20 to 30 km of their place of end use, and reflected the geomorphologic characteristics of insular lowlands surrounded by foothills. By contrast, in Bangkok a tremendous amount of sand excavated from a natural levee on the delta, 100 km upstream from the city, has been transported across the delta to the downstream Bangkok urban fringe areas, where it has been used to make concrete and to provide the fill that is vital for construction of new houses. In Bangkok, the flow diffuses and becomes capillary toward its end.

We made a quantitative comparison of the flow of fill materials in Bangkok and Japan. However, data on building materials in and near Bangkok are limited; in particular, statistics on output from sand and rock pits are inaccessible (Moriguchi, 2003). Even in Japan, output per prefecture is the most detailed statistic available (Sudo, 2001). Our comparison is therefore approximate and expressed in round numbers. Sand production from the main sand pits used for development in Bangkok is approximately $1.5 \times 10^5$ $m^3$ $day^{-1}$, which is equivalent to $5.5 \times 10^7$ $m^3$ $year^{-1}$. Asahi et al. (1993) estimated sand production for development in Tokyo from the major sand pits in the Kimitsu area during 1973 at about $3.8 \times 10^7$ $m^3$ $year^{-1}$; 1973 was the peak of the Japanese economic boom. The output for Bangkok is larger than that for Tokyo in the 1970s. The total volume of fill material flowing into BangkokNoi and Rangsit alone is $5.7 \times 10^3$ $m^3$ $km^{-2}$ $year^{-1}$. For the Tokyo lowland the figure is $3.3 \times 10^4$ $m^3$ $km^{-2}$ $year^{-1}$ (Takeuchi and Yoshioka, 1982), and for the Manila lowland it is $4.9 \times 10^3$ $m^3$ $km^{-2}$ $year^{-1}$ (Hara et al., 2002). These flows of sand and rock material 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 we need further data to allow us to relate spatial development patterns with the end point of the flow in each city.

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.

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

From the results of our study, we propose three inter-related strategies to be applied in urban–rural planning, which correspond to our multi-scale approach (Fig. 1). We discuss them in the following.

#### *4.4.1. Zoning in consideration of past agricultural land use*

Our meso-scale land-use analysis 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; Japan International Cooperation Agency, 1997; Shigetomi, 1998). Furthermore, irrigation districts administered by the Royal Irrigation Department correspond to agricultural land-use patterns, and are not consistent with other regional administrative boundaries (Royal Irrigation Department, 2005).

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.

### *4.4.2. Quantitative zoning code goals for fill volumes and land transformation*

Our meso-scale quantitative analysis and micro-scale qualitative investigation for landform transformation 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 by each abovementioned agricultural zone.

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 (Japan International Cooperation Agency, 1997).

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.

### *4.4.3. Adjustment of the nodes and linkages of fill material flow*

Our study showed that the flow of fill material was in the form of a node–linkage structure, terminating with a capillary flow (Fig. 12). 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. We 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 our 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 we visited during our 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.

## 5. Conclusions

This study demonstrates that the present mixed urban–rural landscapes on the urban fringe of Bangkok are linked with past agricultural land-use patterns and landform transformation processes. In the BangkokNoi area where connected small orchard patches were initially predominant, land-use changes from orchards into detached houses and condominiums using sand fill are inherent patterns supported with accessibility to sand by water transportation. In the Rangsit area where broad rectangular rice fields were originally developed, land-use changes from large rice fields into townhouses using clay fill are inherent patterns supported by availability of clay produced from adjoining parcels. Moreover, this study shows that the flow of fill material, which plays a major role in landform transformation practices, spreads over the whole delta. The flow has a node–linkage structure, and terminates in a capillary structure at the urban fringe of Bangkok. At source, the sand output was estimated to be $1.5 \times 10^5$ $m^3$ $day^{-1}$, which, depending on cost, is either trucked or transported by river to the urban fringe development areas where the volume of landform transformation, or materials carried into was rated at $5.7 \times 10^3$ $m^3$ $km^{-2}$ $year^{-1}$. Landform transformation was found to occur at multiple scales in the Bangkok region, and the delta is no longer flat. We conclude that deltaic landscape planning should incorporate the means of managing the flow of fill material from source pits to end use in urban fringe development areas.

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Table 1. Data sources

| | 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 |

Table 2. Fill material survey of BangkokNoi study sites

| 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 | - | - | - |

Table 3. Fill material survey of Rangsit study sites

| 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 | - | - | - |

## Figure captions

Fig. 1. Research design for multi-scale analysis of landform transformation.

Fig. 2. Location of meso-scale study areas (BangkokNoi and Rangsit).

Fig. 3. Time series of land-use maps of BangkokNoi.

Fig. 4. Time series of land-use maps of Rangsit.

Fig. 5. Land use – land elevation relationships in 2002 at BangkokNoi and Rangsit. A boxplot consists of the smallest observation, lower quartile, median, upper quartile, and largest observation. The circle mark shows an outlier, and the star mark shows an extreme outlier. 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. 6. Cumulative growth in fill volume for BangkokNoi and Rangsit from 1952 to 2002.

Fig. 7. Surveyed filled site locations in BangkokNoi. Numbers correspond to site

numbers of Table 2. The dotted square is consistent with topographic maps in Fig. 9.

Fig. 8. Surveyed filled site locations in Rangsit. Numbers correspond to site numbers of Table 3. The dotted square is consistent with topographic maps in Fig. 10.

Fig. 9. Detailed city topographic maps and cross-sections for BangkokNoi for 1987 and 2000.

Fig. 10. Detailed city topographic maps and cross-sections for Rangsit for 1987 and 2000.

Fig. 11. Map showing locations of sources of fill material in relation to local geology and geography.

Fig. 12. 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. 13. An example of poorly environmentally managed sand mining.