# Urban Sprawl Risk Assessment Based on Ecological Infrastructure: An Approach to Smart Conservation

## 1 Introduction

### *1.1 Characteristics of urban sprawl in China*

Urban sprawl is a global problem, but more serious in China for its fast growth of urbanization rate. Compared with the reverse urbanization in western countries with the main characteristics of the suburbanization of commercial and residential areas and the inner-city decay, the urban sprawl in China has some characteristics.

Urban space grows without inner-city decay in Chinese central cites. Urban space is expanding in urban fringe and new industrial development districts which leapfrog from the main city. Although the population density in the main city is reduced, the inner-city is still prosperous and compact. Urban sprawl with low density and simplex functions appears usually in suburb and new industrial park in exurb.

The future of urban growth is indeterminate due to land market condition and government policy changing. It is difficult to control urban sprawl only by urban development planning which is directed by economic principles and political demand.

The urban sprawl of major cities in central and eastern China is more serious. There are good natural resources and economic conditions for urban development in these regions. Emigration from other districts in China settles here continually, for example, emigration from the Three Gorges Reservoir area and emigration from the earthquake-stricken area in Sichuan Province. As a result, the urban space in these cities expands rapidly.

### *1.2 urban sprawl risks*

The swift consumption of land has induced the problems, such as waste of natural resource, geological disaster and damage to heritage, because of the social, economic and environmental impact of sprawl.

(1) Sprawl risk for urban safety. Urban development occupied the former natural areas where some hazardous landscape processes covered possibly, such as flood, tsunami and earthquake. It will increase the risk of natural disasters, and some parts of cities were eliminated by the earthquake in Sichuang Province. Aside from this, urban sprawl changed the landform and surface characters and then induced waterlog, landslide and debris flow.

These disasters occurred more often in the new development cites than in the old towns, it was a serious warning to rethink about the ecological safety of the modern cities in today's trend of urban growth.

(2) Sprawl risk for biodiversity. As natural areas give way to haphazard development, habitat diversity diminishes. Urban expansion not only shrinks the natural area but also fragments habitat into smaller and more isolated patches. The development and fragmentation obstruct the migration and diffuse processes of wildlife. As the habitats of some

endangered species are often intertwined with human settlements in suburb, the urban sprawl has a profound impact on the biodiversity.

(3) Sprawl risk for cultural heritage and human experience. Fragmentation not only significantly induces environment degradation but also impacts on the recreational and aesthetic quality. More and more historic lands or heritage are lost to sprawl. Only some isolated historical buildings survive in the sea of urban buildings. It is hard for people to have a sense of history, continuity and stability in the disruptive landscape.

### *1.3 spatial planning strategies*

Since the urban expansion is inevitable and the sprawl risk is serious in China, now, the main question is: how to conserve the land resource and make urban growth smart? There are two kinds of spatial planning thoughts about controlling the urban sprawl, one is limit of urban expansion compared to “Lake & Dam” model, and the other is strategic conservation for prevention sprawl compared to “Steam & Levee” model. (Duany, 1998)

Limit of urban expansion is a boundary or belt between the urban development area and the rural area. The greenbelt around city is the limit of urban which was put forward by Howard in his famous garden city model in 1898. Urban development is prohibited in or out of the greenbelt. Urban growth boundary (UGB) as a useful growth management tool prevails in North America which stops the growth out of boundary by control of infrastructure investment. UGB is used to achieve smart growth goal and it effects in a certain extent. However, it is difficult to limit “leapfrog” development and land consumption in rural–urban interface, (Robinson, 2005; Cho，2007) and hard to decide the appropriate location of boundary due to complication and change of market and policy. (Benfield, 2001)

Land conservation helps to shape the urban form. Greenway, green infrastructure and ecological network represents the strategies of smart conservation which promotes resource planning and protection in a way that is proactive not reactive; systematic not haphazard; holistic not piecemeal; multifunctional not single purpose; multi-jurisdictional not single jurisdictional; and multiple scale not single scale. (Benedict, 2002) The concept of ecological infrastructure (EI) has been accepted in China like green infrastructure in America. EI is composed of critical landscape structures that are strategically identified and planned to safeguard the various natural, biological, cultural and recreational processes across the landscape, securing natural assets and ecosystems services, essential for sustaining human society (Yu, 2006). It functions as a framework for urban growth and indicates where should not be developed.

In planning practices, the comprehensive strategies apply, which combine smart growth and smart conservation. Chinese government has taken many measures to control urban sprawl including definition of urban growth boundary in urban master planning and definition of prohibited-construction areas in green space or greenbelt planning, but the urban development actually broke through these limits and then sprawled in its own way. We need a smarter way to control urban sprawl effectively.

## 2 urban sprawl risk assessment：Methodology

The negative effects of sprawl are associated with the spatial conflicts between urban expansion processes and other landscape processes, and concentrate in the urban sprawl risk areas. Urban sprawl risk area has two characteristics: one is that it has the possibility of urban invasion in the future and the other is that it belongs to ecological infrastructure now. Urban sprawl risk assessment is to identify the sprawl risk areas and deal with the conflicts between urban processes and other landscape processes in these areas.

Urban sprawl risk assessment based on ecological infrastructure provides benefits for both urban growth and land conservation. (1) It is an initiative and systematic conservation approach that goes ahead of irreversible urban development and provides a framework to guide future growth. (2) It is a flexible and exercisable planning tool for consideration of spatial demands of various landscape processes and alternative future growth with different scenarios. Thus it can be used to define the priority of land conservation and development. (3) It provides a more efficient and targeted way to protect land through analysis of urbanization pressure and important processes for ecosystems services. If the problems in sprawl risk areas are solved, urban space would grow healthily.

The urban sprawl risk assessment is divided into three main parts: (1) defining ecological infrastructure, (2) scenarios of urban expansion, and (3) identification and management of urban sprawl risk areas. (Fig. 1)

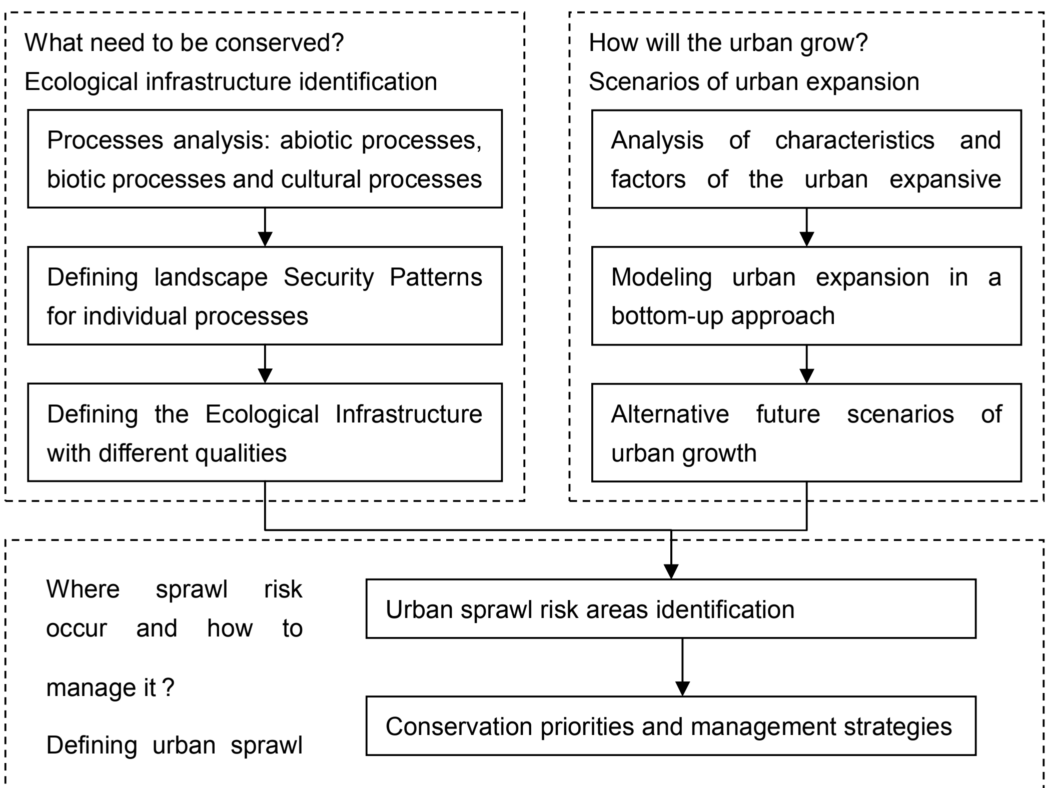


**Fig.1 Diagram of urban sprawl risk assessment (Li Bo, 2008)**

### *2.1 What need to be conserved? ecological infrastructure identification*

(1) Landscape processes analysis

Critical processes associated with ecosystems services need to be safeguarded before urban growth. Geographical Information Systems (GIS) is an efficient tool to simulate natural and cultural processes across the landscape.

Three categories of processes are targeted by the proposed ecological infrastructure. Abiotic processes associate with the regulation and life supporting services of ecosystems, and also relate to natural disaster which threats city. Biotic processes connect with native species and biodiversity conservation. Cultural processes associated with information functions include visual perception, heritage protection and recreational activities. (Yu, 2006)

(2) Landscape security patterns for individual processes

The security patterns are composed of elements and spatial positions that are strategically important in safeguarding the different processes across the landscape. Models including suitability analysis, minimum cost distance and surface analysis were used in the identification of Security Patterns for the individual processes (Yu, 1996).

(3) Defining ecological infrastructure

Using overlapping technique to Integrate landscape Security Patterns for individual processes, alternative ecological infrastructure at different security levels are developed at different quality levels: high, medium and low. Ecological infrastructure network which consisted of greenways and strategic hubs contains the land needing to be protected before urban development.

### *2.2 how will the urban grow? scenarios of urban expansion*

Ecological infrastructure can be used as a structural framework for urban growth from the point of view of best land conservation. Urban expansion is a transformation process of self-organization driven by socio-economic and natural complex facts. Even if the Ecological infrastructure planning and urban planning are implemented, there is the possibility that urban space expands out of plan’s limit for its self-organization. It is necessary to simulate the future urban growth with different planning strategies.

(1) Analysis of characteristics and factors of the urban expansion dynamics

From a practical point of view, several factors influence urban growth, such as environmental characteristics, existing land use characteristics, and spatial characteristics of the cities, urban and regional planning policies. Analyses of the work of these factors assist in modeling dynamic spatial process.

(2) Modeling urban expansion in a bottom-up approach

Using cellular automata or other spatial dispersion model, the urban expansion process is simulated based on self-organization. Through the model calibrating compared result with actual urban patterns, the transition rules of spatial growth emerge and then can be used in simulation for future expansion.

(3) Alternative future scenarios of urban growth

Urban growth as a self-organized process is affected by exotic-organized plan and policies. Various plans direct different scenarios as well as consideration of the transition rules. Three scenarios based on three plan strategies are simulated, which is expansion without any plan, growth with direction of urban master planning and growth with restriction of ecological infrastructure.

### *2.3 Where sprawl risk occur and how to manage it: defining urban sprawl risk areas*

(1) Urban sprawl risk areas identification

Not all expansion leads to sprawl, only some new development areas in the scenarios have risk of occupation ecological infrastructure. The overlaying technique is used to identify the urban sprawl risk areas, and different quality EI are developed at various risk levels.

(2) Conservation priorities and management strategies

Risk management strategy is developed corresponding to every landscape security pattern in these areas. Some parts of risk area are prohibited for any development, and others are restricted for land use and development intensity. Through analysis of comprehensive risk parameters based on EI and scenarios of growth, the priorities of conservation and development was established.

## 3 Hangzhou city as a case study

Hangzhou city, the capital of Zhejiang province, is one of the most important central city in eastern China. It consists of eight districts with a total area of 3,068 square kilometers, and more than 5.3 million populations in 2005. From estimate of urban planning, there are 5.7 million populations in 2010 and 6.5 million in 2020. Hangzhou city is famous as “paradise in the world” for its good natural environment and the socio-economic conditions since the ancient time. It is now one of the fastest growing areas in China. The urban population will rise from 3.1 million in 2005 to 3.6 million in 2010 and 4.5 million in 2020. Under the great pressure of urbanization, several problems followed the sprawl.

Many wetlands and rivers have been filled in order to transfer to land for development in last twenty years. As natural water system shrinking and fragmenting, flood and waterlog appeared frequently, and the water quality degrade because of losing the capability of self-purification. Many aqueous habitats vanished while the risk of biodiversity decay occurred.

Apart from natural ecological system degrading, cultural heritages have been destroyed as well as visual and recreational experiences have been totally ignored. Only several tourism scenic areas, such as Xihu resort, and isolated historical relics were protected well, the famous landscape character of “water place of Jiangnan region” in history can be seen no more.

### *3.1 Ecological infrastructure network*

(1) Critical landscape processes

The important abiotic processes focus on geologic factors, storm water and flood management. Geological structure and topography are taken into consideration for safety. Hydrological data and flood water levels in history and the changes in surface water are analyzed and stored in a geographical information system.

The living of native wildlife is the main biotic processes. Five indicative species including egret, squawk, ring-necked pheasant, yellow weasel, and frog are analyzed for they represent various habitat types and different activity patterns. Some of them live far from human settlement, and others can tolerate human interference.

The targeted cultural processes include historical processes of cultural heritage sites, visual experience, and the process of recreational use of the landscape. All kinds of cultural heritage and recreational resource in open space are identified for a more comprehensive conservation and usage.

(2) Defining Landscape Security Patterns

There are two steps to define landscape security pattern for individual process. First, the source of process should be found, through the suitability analysis base on vertical relationship between different landscape layers. Secondly, the horizontal process between landscape units or across landscapes is simulated and then security pattern is identified, using the surface model of minimal cumulative resistance or others.

Geological security patterns are based on suitability analysis for risk of geological disaster. Floodable areas are calculated for three highest flood levels in historical record, which are used as the criteria for the definition of security level of floods. Storm water management security patterns include the existing rivers, wetland, and filled wetlands and depression, which are waterlog vulnerable areas.

The habitat of each indicative animal is estimated according to suitability evaluation. Evaluation factors including land use, altitude, gradient, distance to water and distance to built-up areas, are calculated with weighted superposition in GIS. The areas with high value are the source of origins of species dispersal. Then the land uses are classified as a relative resistant surface according to their effect on the process of species movement, and the security patterns on a surface are identified.

The human experiences for cultural heritage and recreation are spatial dispersal processes too. Some linkages are important for the potential coverage of the landscapes. The cultural heritage and recreation security patterns that will define the connection between the sources are based on the least-distance model result. The visibility of landscape from main tour routes is analyzed to develop the visual security patterns.

(3) Identification ecological infrastructure network

Individual landscape security patterns are integrated into a comprehensive ecological infrastructure network with diverse quality levels: high, medium and low. Two kinds of overlay methods are used in this step, one is to mosaic them immediately, and the other is to calculate the sensitive parameters of security patterns using Analytical Hierarchy Process (AHP) for weighted superposition.

Ecological infrastructure network is the most important land for conservation. Urban planning about the prohibited or restricted development area should include this network, which ensured the integrity of the ecological service and the connectivity of landscape processes. (Fig. 2)

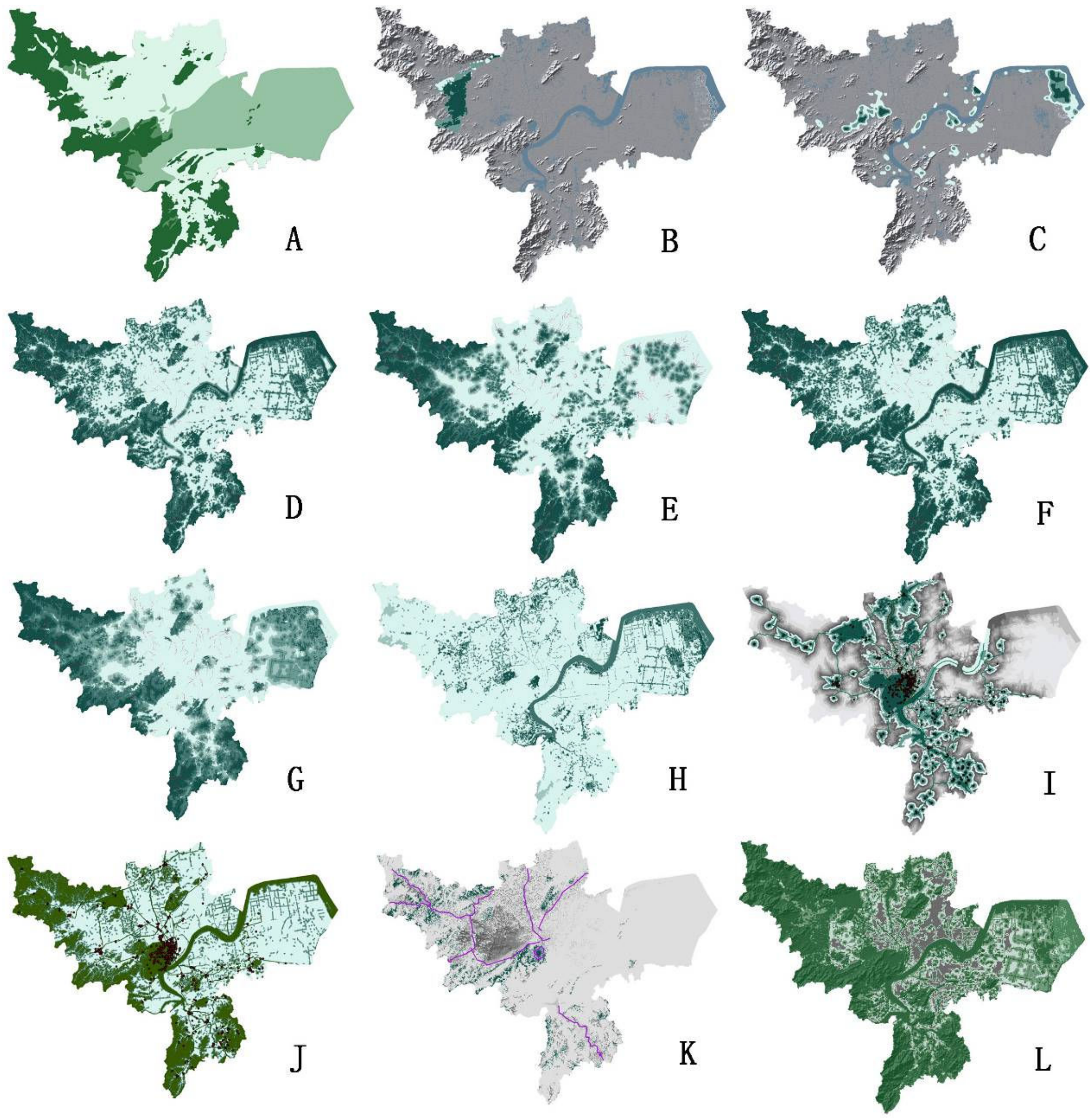


**Fig.2 individual landscape security patterns and ecological infrastructure (Li Bo, 2008)**
**A) geological SP; B) flood SP; C) waterlog SP; D) egret SP; E) ring-necked pheasant SP; F) squawk SP; G) yellow weasel SP; H) frog SP; I) cultural heritage SP; J) recreation SP; K) visual sensitivity SP; L) ecological infrastructure network**

### *3.2 urban growth scenarios*

(1) Stimulative and restrictive factors for urban growth

Since urban is a complex huge system, the dynamic growth has its own logic responding to stimulative and restrictive factors. The accessibility to existing transportation network (i.e. railway, highway, artery, and road) and to urban center (i.e. city center, county center, and town center), as well as the present and past land use patterns, are taken into account as stimulative factors. Some parts of land coverage (i.e. rivers and other natural barriers) and slopes are represented as constraints for urban growth.

Urban planning and policies in China are also important exotic-organized factors for urban growth. Transportation network and development patterns in the planning are the stimulative factors, but the prohibited and restricted construction patterns in the planning are the restrictive factors. There are some uncertain factors related to decision-making processes in the future. These stochastic factors can not be predicted, but can be supposed as scenarios in case of various preferences.

(2) Simulation of urban patterns by cellular automata

Constrained cellular automata model is a useful tool to simulate complex spatial processes characterized as non-linear ordinary differential equations with discrete space and time (Barredo, 2003). This model has the specificities including: the cell space and states, the cell neighborhood and its effect, the transition rule, and overall control layers.

The digital space in the CA is composed of grids with 30m x 30m each pixels. They are normalized to values in the range of 0–1, and represent the inherent capacity of a cell to support transformation from other land use to urban use. Each cell belongs to one of five states including building area, field, water body, forest, and beach. Since the research purpose is to simulate urban expansion, five states are integrated into two states: built- up area and non-built-up areas.

In this urban cellular automaton, the neighborhood space is defined as a circular region around the central cell with a radius of eight cells. The neighborhood space effect is calculated for each cell to decide which cell could be converted or the permanence in their original state, corresponding to the transition rule. Using logistic regression, correlation between urban expansion and special accessibility is analyzed to define the transition rule. Other factors such as urban planning are used as overall control layers to affect the transition rule.

A simulation for Hangzhou city has been produced for the period 1998–2006, in order to calibrate the CA model. The comparison for patterns between simulation and reality in 2006 show that the difference mainly emerges in non-continuous growth such as new industry park because of exotic-organization for government policies. (Fig. 3)

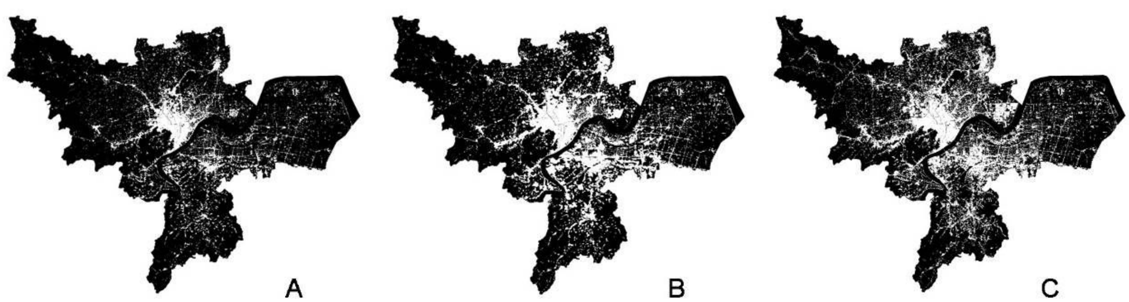


**Fig.3 urban growth maps from 1998 to 2006 (Li Bo, 2008)**
**A) urbanized area in 1998; B) simulated urbanized area in 2006; C) urbanized area in 2006**

(3) Three scenarios of urban growth

Alternative future growth pattern in 2020 based on various plan strategies are simulated in terms of constrained cellular automata model which has been calibrated. The cell states in 2006 are input into the CA model, and the overall control layers change according to three policy preferences. Thus various urban future scenarios emerge.

The first scenario is urban growth without any planning influence. The second is urban expansion in the direction of urban planning which has been approved for legislation. The last is urban growth with the limit of ecological infrastructure.

***3.3 urban sprawl risk areas***

(1) Three scenarios of urban sprawl risk areas

Using overlay technique, the urban sprawl risk areas are identified, which are both ecological infrastructure and urban space in the scenarios. The risk areas of first scenario are the largest because of lacking initiative control. The risk areas of second scenario are located in urban fringe and development districts in planning. A new industry park in the urban planning far from the main city is a special risk area, which is farmland and natural landscape now. The risk areas of last scenario are the smallest and emerge at urban fringe because they are the places where the intrinsic demands of self-organized growth conflict with land conservation.

(2) Conservation priorities and management strategies

There are 11 kinds of risk corresponding to individual security patterns in these sprawl risk areas. They can be ranked into three categories: risk of natural disaster, risk of habitat fragmentation, and risk of cultural landscape destruction. The sprawl risk areas have higher conservational priorities than other parts of ecological infrastructure network, and then three priority levels in these areas are ranked associated to the quality levels.

The highest risk levels of several security patterns, including flood, geological disaster, and habitat of egret and ring-necked pheasant, are considered as prohibited construction areas, and others are restricted construction areas. Demands of control are developed according to kinds and levels of risk. (Fig. 4)

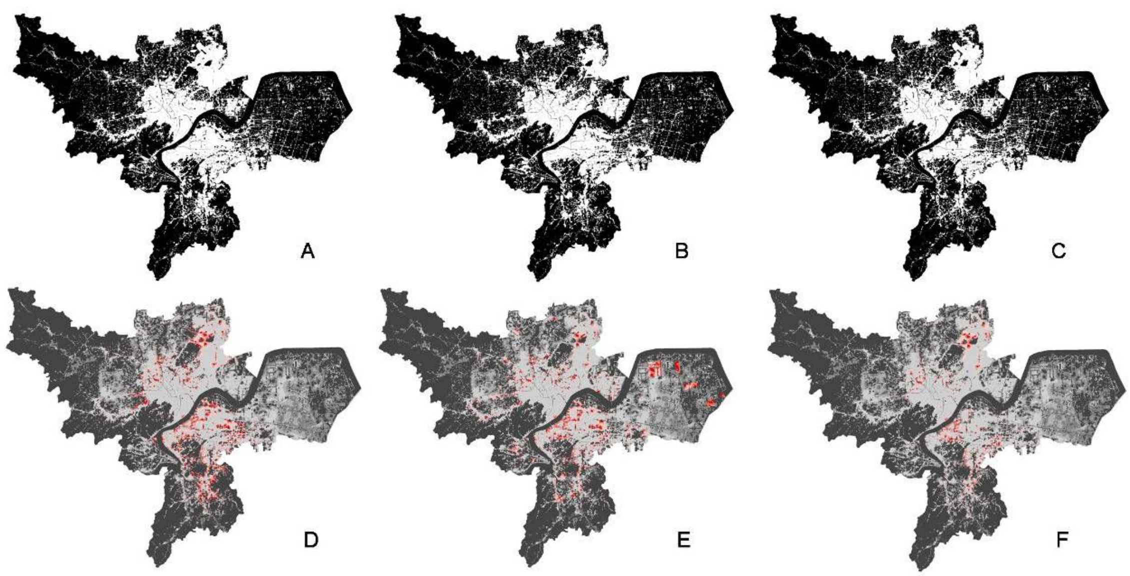


**Fig.4 urban growth scenarios and urban sprawl risk areas (Li Bo, 2008)**

**A) growth scenario without planning; B) growth scenario based on urban planning; C) growth scenario based on ecological infrastructure; D) sprawl risk areas based on scenario A; E) sprawl risk areas based on scenario B; F) sprawl risk areas based on scenario C**

## 4 Conclusions

The general conclusion of this research is that urban sprawl risk assessment could be an approach to smart conservation under great pressure of urban expansion. This approach not only provides idealizing blueprints to guide urban growth, but also give solutions to deal with conflicts between protection and development during the process of realizing the blueprints. Various risk areas based on different growth scenarios give decision-makers comparison for alternative future. Whatever growth policy they choose, the most important regions needing to manage will be identified through risk assessment.

The urban sprawl risk assessment is based on analysis of spatial “game-playing” of various landscape processes. Individual dynamic processes are simulated to define their demands of space, and then the overlay space will be the sprawl risk areas, since the negative effects of sprawl are induced by expansion process disturbing other landscape processes. Therefore, management sprawl risk areas could coordinate spatial demands of processes including urban growth process.

Urban growth is a fast and strong process, but abiotic, biotic, and cultural processes are slow and weak compared with expansion. Especially in China, there are stronger dive of urban expansion and more limited capability of conservation. Sprawl risk assessment could provide a smarter way for land conservation with focus on the risk areas where minimization of management attains maximization of protective effect.

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Li Bo, Candidate of PHD, Certified Planner in China. Graduate School of Landscape Architecture, Peking University, China.