IMPACTS OF MEGA PROJECTS ON THE RESILIENCE OF ISTANBUL CITY-REGION

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ABSTRACT

IMPACTS OF MEGA PROJECTS ON THE RESILIENCE OF ISTANBUL CITY-REGION

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Impacts of Mega Projects (3rd Bosporus Bridge and Northern Marmara Motorway Project, 3rd Airport Project, Canal Istanbul Project and New Istanbul Project) on the resilience of Istanbul City-Region was investigated in this research. For this reason, an exclusive resilience assessment framework was developed for Istanbul City-Region case. Through this framework, a conceptual model of the system was developed. Therefore, the focal system was described in terms of its boundaries, main issues and key components, first. In this context, key resources of the system were determined with possible disturbances on them. Then, a historical profile of the system was developed with various scales and domains in order to determine the thresholds of the system with their interactions. After determining the trends of change in the system, five scenario alternatives were developed for analysing the impacts of Mega Projects on the resilience of the system. These scenario alternatives were simulated through SLEUTH cellular automaton model for the year of 2050. Following the predictions of urban growth for Istanbul City-Region the possible impacts of the Mega Projects on the system's resilience were analysed in terms of the loss of natural resources.

Keywords: Istanbul City-Region, Resilience, Resilience Assessment, Social-Ecological Systems, SLEUTH Cellular Automaton, Urban Growth Simulation

ÖZ

MEGA PROJELERİN İSTANBUL KENT-BÖLGESİ'NİN UYUM SAĞLAMA KAPASİTESİNE ETKİLERİ

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Bu araştırmada İstanbul'un Mega Projelerinin (3. Boğaz Köprüsü ve Kuzey Marmara Otoyolu Projesi, 3. Havalimanı Projesi, Kanal İstanbul Projesi ve Yeni İstanbul Projesi) İstanbul Kent-Bölgesinin varlığını sürdürme kapasitesi üzerindeki olası etkileri incelenmiştir. Bu nedenle, İstanbul Kent-Bölgesine özel bir varlığını sürdürme kapasitesinin ölçümü çerçevesi oluşturulmuştur. Bu çerçeve kapsamında, sistemin sınırları, temel konuları ve anahtar bileşenleri tanımlarak kavramsal bir modeli oluşturulmuştur. Oluşturulan model kapsamında sistemin temel kaynakları ile olası tehditler tespit edilmiştir. Ayrıca tarihsel bir model oluşturularak sistemdeki eşikler ve bu eşikler arasındaki ilişkiler tanımlanmıştır. Sistemdeki değişim eğilimi tanımlandıktan sonra Mega Projelerin etkilerini analiz etmek için beş senaryo alternatifi oluşturulmuştur. Bu senaryo alternatifleri SLEUTH hücresel otomasyon modeli kullanılarak 2050 yılına projecte edilmiştir. Son olarak, kentsel büyüme tahminlerinin sonuçlarına dayanılarak Mega Projelerin sistemin varlığını sürdürme kapasitesi üzerindeki etkileri analiz edilmiştir.

Anahtar Kelimeler: İstanbul Kent-Bölgesi, Varlığını Sürdürme Kapasitesi, Varlığını Sürdürme Kapasitesinin Değerlendirmesi, Sosyal-Ekolojik Sistemler, SLEUTH Hücresel Otomasyon Modeli, Kentsel Büyüme Simulasyonu

To My Mother

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CHAPTER I

INTRODUCTION

Today, the world is dealing with shocks, disturbances and changes on the one hand, vulnerabilities on the other hand. Global and local drivers behind these changes trigger socio-spatial transformations like; social segregation, environmental degradation and economic disruption, which in various scales increase and intensify the vulnerabilities of urban and regional systems (Taşan-Kok & Stead, 2013). Accumulation of these vulnerabilities results in further shocks and disturbances on social and ecological systems. In spite of their deteriorating impacts, these transformations persist as a result of inefficiency or failure of existing policies and planning approaches in responding them.

It is getting clear that the policies and practices based on the conventional perceptions about the functioning of natural phenomena can no longer answer the needs of contemporary world (Berkes, Colding, & Folke, 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002). Contemporary sense of complexity, uncertainty and insecurity reveals the fallacy of conventional assumptions about the functioning of nature and its interaction with society (Christopherson, Michie, & Tyler, 2010; Eraydın & Taşan-Kok, 2013). Contrary to what was believed, nature responds in complex, unpredictable and uncontrollable manners and humans are dependent and co-evolving components of natural systems (Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002). Therefore, as Berkes and colleagues (2003, p. 382) claim; the "situation requires a shift to a view of the world as consisting of complex systems”. This understanding of world as consisting of complex adaptive systems or social-ecological systems, that are self-organising complex adaptive systems composed of socio-spatial processes among nature and society, requires a change in the ways of making plans and policies (Alberti et al., 2003; Berkes et al., 2003; Chapin, Folke, & Kofinas, 2009; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Pike, Dawley, & Tomaney, 2010; Portugali, Meyer, & Stolk, 2012; Simmie & Martin, 2010).

Sustainable development depends on sustaining the essential functions of social-ecological systems in this era of increasing complexity, uncertainty and insecurity. Therefore, capacities of social-ecological systems to withstand and tackle with existing vulnerabilities and foreseen or unforeseen shocks and disturbances should be improved. Planning systems and practices should prepare urban and regional systems to deal with these vulnerabilities and changes. In other words, they should improve the resilience of social-ecological systems in their urban and regional contexts. However, increasing frequency and widening diversity of the problems in the contemporary world has revealed the failure of existing planning approaches in this context. In spite of their deteriorating impacts, these vulnerabilities and changes persist and worsen as a result of inefficiency or failure of existing policies and planning approaches in responding them. It is getting clear that the policies and practices of neoliberal agenda can neither answer the need of complex, uncertain and insecure conditions of today nor prepare the “cities for the future in an increasingly neoliberalising world” (Eraydın & Taşan-Kok, 2013). Focusing on short-term and fragmented projects or land-use regulations, market-driven and opportunity-led practices and policies of the neoliberal agenda intensify and worsen these socio-economic and ecological problems. Social, economic and ecological problems of the contemporary world unfold the impossibility of sustaining these measures of neoliberal agenda and as Eraydın (2013) points out; underline the need of a new theoretical perspective in planning and policy making. In this context, "resilience" concept and “resilience thinking” perspective provide new means and potentials for planning.

It is clear that resilience is a necessary attribute of social-ecological systems to tackle with existing vulnerabilities while getting prepared for foreseen or unforeseen disturbances. Therefore, improvement of the resilience of social-ecological systems should be a primary concern of plans, policies and projects. On the contrary, practice shows that market-driven partial projects of the neoliberal agenda intensify the vulnerabilities of these systems while decreasing their resilience. Although real life experiences support this assumption, it should be tested in a scientific manner. Therefore, possible impacts of the Mega Projects (3rd Bosporus Bridge and Northern Marmara Motorway, 3rd Airport, Canal Istanbul and New Istanbul Projects) on the resilience of Istanbul City-Region were evaluated through a resilience assessment framework in this research (Figure 1.1).

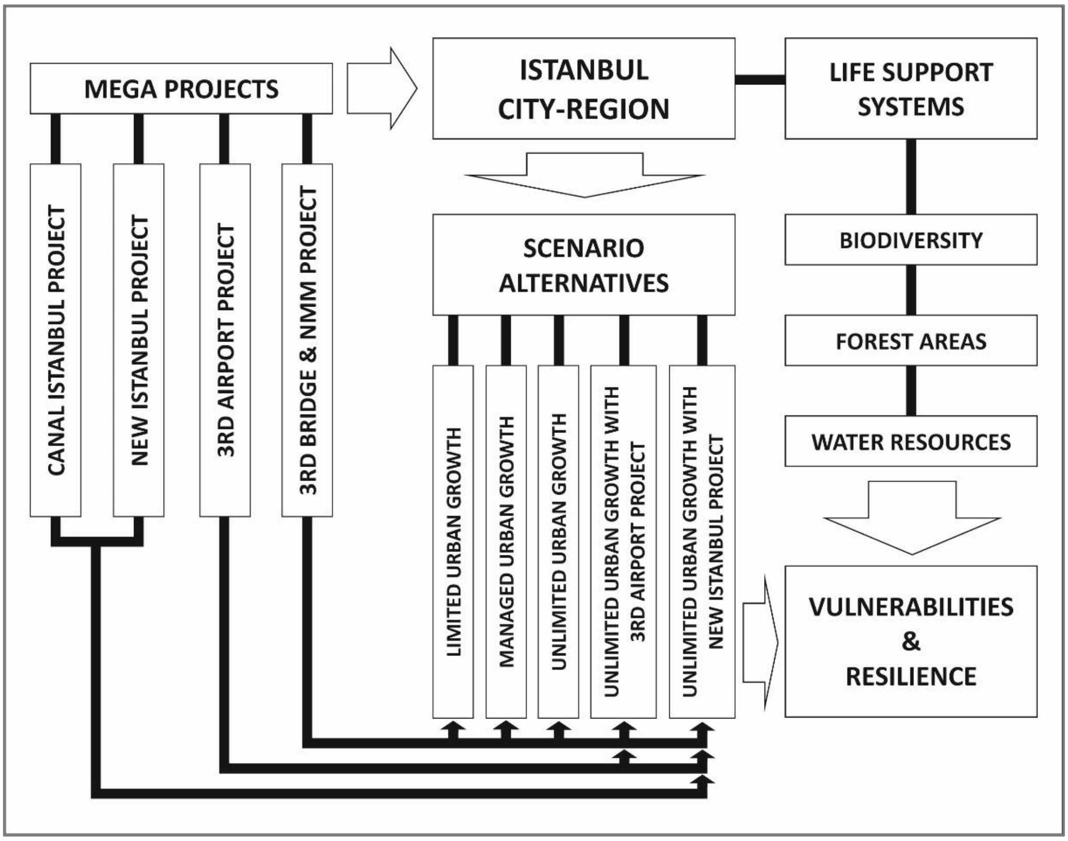

Figure 1.1: Logical Framework of Research

CHAPTER II

LITERATURE REVIEW

2.1 RESILIENCE

Concept of ‘resilience’ was first coined by Holling in his seminal paper in 1973. As a response to conventional, single equilibrium-centred views in ecology; Holling (1973, p. 14) distinguished resilience from stability, “the ability of a system to return to an equilibrium state after a temporary disturbance”, and introduced resilience as “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables”. As Folke and colleagues (2002, p. 5) point out resilience is the flip side of vulnerability which is the “propensity of social and ecological system to suffer harm from exposure to external stresses and shocks".

After its emergence in ecology, resilience concept continued its evolution and spread into various disciplines from physics to psychology (Klein, Nicholls, & Thomalla, 2003; Pendall, Foster, & Cowell, 2010; Taşan-Kok, Stead, & Lu, 2013). Following its proliferation with alternative definitions in ecology, resilience concept spread into physical and material sciences with cultural anthropology and environmental psychology. In 1980s, it was in social sciences and later spread in to disaster studies, economics, geography, political sciences, regional studies and planning (Klein et al., 2003; Taşan-Kok et al., 2013).

A comprehensive review of resilience literature reveals that the ‘fuzzy’ concept of resilience (Pendall et al., 2010) has various definitions and interpretations in different disciplines. As Klein et al. (2003) point out; in spite of this variety, the challenge of operationalizing the resilience concept still persists after three decades. They (Klein et al., 2003, p. 41) also claim that "there is limited scope for measurement, testing, and formalisation" of the concept. Nevertheless, some authors (Folke, 2006; Folke, Carpenter, Elmqvist, Gunderson, Holling, & Walker, 2002; Gunderson, 2000; Martin, 2012; Pendall et al., 2010) provide different classifications of resilience definitions in terms of behaviours of the system following a perturbation or shock.

2.1.1 Exploration of Resilience Concept

2.1.1.1 Definitions of Resilience

Classifications of resilience definitions mainly depend on the differences in perspectives about the behaviour of a system following a disturbance. Authors classify resilience definitions in terms of differences in the assumptions about system's relation with equilibrium. Some authors define two groups (single equilibrium and beyond equilibrium) while the others define three groups (single equilibrium, multiple-equilibria and beyond equilibrium) of definitions (Table 2.1).

Instead of single equilibrium and beyond equilibrium classification; Dovers and Handmer (1992) use reactive and proactive resilience; Folke et al. (2002) use engineering and ecological resilience; Raco and Street (2012) use conservative and radical resilience; Pickett et al. (2004) use equilibrium and non-equilibrium view, respectively. On the other hand, Folke (2006) uses engineering, ecological and social-ecological resilience; Gunderson (2000) uses global equilibrium ("return time"), multiple equilibrium and adaptive capacity; Martin (2012) uses engineering, ecological and adaptive resilience; Pendall et al. (2010) use single equilibrium ("bounce back" or "return to normalcy"), multiple-equilibria and complex systems classifications, instead of single equilibrium, multiple-equilibria and beyond equilibrium, respectively (Table 2.2).

Table 2.1: Classifications of resilience definitions

AUTHORS	CLASSIFICATIONS	ATTRIBUTES
Dovers and Handmer, 1992	1. reactive resilience 2. proactive resilience	1. resistance 2. adaptation
Folke et al., 2002 (following Holling, 1986, 1996)	1. engineering resilience 2. ecological resilience	1. approaching steady state, return time 2. remaining within the same state of attraction, self-organization, adaptation, recovery, reorganization
Raco and Street, 2012	1. conservative 2. radical	1. return to steady state 2. no return, rejection of status quo
Pickett et al., 2004	1. equilibrium view 2. non-equilibrium view	1. return to equilibrium 2. adaptability, adjustment
Folke, 2006	1. engineering resilience (following Holling) 2. ecological, ecosystem or social resilience 3. social-ecological resilience	1. return time, resistance, stability, conservation 2. absorption, re-organization, retaining, robustness 3. opportunity, renewal, emergence, adaptive capacity
Gunderson, 2000	1. global equilibrium ("return time") 2. multiple equilibrium 3. adaptive capacity	1. stability 2. absorption 3. adaptability
Martin, 2012	1. engineering resilience ("bounce back" or "plucking model" of economic fluctuations) 2. ecological resilience (multiple stability domains) 3. adaptive resilience (complex adaptive systems)	1. stability, resistance, return time 2. Tolerance 3. adaptation, evolution
Pendall et al., 2010	1. single equilibrium ("bounce-back" or "return to normalcy") 2. multiple equilibria (bridge to complexity) 3. complex systems (beyond equilibrium)	1. recovery, maintaining stability, resistance 2. absorption, robustness, buffering capacity 3. adaptation, change, adjustment

Table 2.2: Distinguishing attributes of definition groups

CLASSIFICATIONS	DISTINGUISHING ATTRIBUTES
(I) Single Equilibrium	stability, resistance, recovery, return time, conservation, approaching steady state
(II) Multiple-Equilibria	persistence, absorption, tolerance, reorganization, robustness, buffering capacity, retaining
(III) Beyond Equilibrium	adaptation (adaptability/adaptive capacity), renewal, self-organization, adjustment, change, opportunity, emergence, evolution

2.1.1.1.1 Single-Equilibrium Definitions

Single equilibrium definitions depend on the assumption that the system is consisting of a single steady state or equilibrium and stays close to this equilibrium. Following a perturbation or disturbance the system moves apart from the equilibrium and turns back to former steady state unless a threshold was passed. This recovery or return time to equilibrium after a disturbance is defined as resilience (Folke, 2006; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000; Martin, 2012; Pickett et al., 2004). In other words, resilience is an ability of the system to recover successfully and maintain stable conditions after a perturbation. Holling (1973) defines this ability of the system as 'stability' and later (Holling, 1996) names this kind of definitions as "engineering resilience". Gunderson (2000, p. 427) determines engineering resilience as the slopes in stability landscapes in Figure 2.1 below. Main focus being on the recovery or bounce-back ability of the system, authors emphasize different properties of the system. As Klein et al. (2003) declare; Pimm (1984) emphasizes "return speed" instead of return time of the system following perturbation, while Dovers and Handmer (1992) focus on the resistance of system to change and strength of status quo. In physics the emphasis is on the elasticity of materials (Taşan-Kok et al.,

2013) while in psychology it is on the ability of individuals to maintain their stable conditions (Bonanno, 2004).

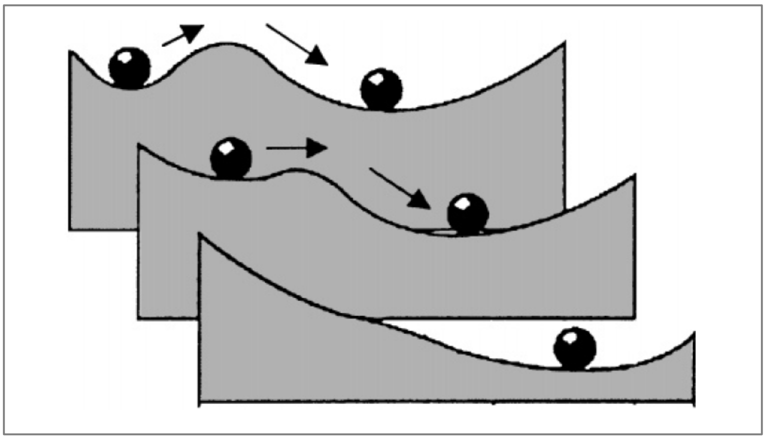

Figure 2.1: Stability domains and disturbances
["Valleys represent stability domains, balls represent the system, and arrows represent disturbances."] (Gunderson, 2000, p. 427)

2.1.1.1.2 Multiple-Equilibria Definitions

In this perspective, the system is composed of multiple basins or domains of attraction and the change is inevitable. System stays in one of these domains and until some threshold was passed it stays in that basin otherwise it passes to another basin. Here the emphasis is on the width or limits of these stability domains. Gunderson (2000, p. 427) determines this kind of resilience as the width of stability landscapes in the figure (Figure 2.1) above. Resilience is defined as the ability of a system to absorb and withstand disturbances and retain or maintain its essential functions and structures (Adger, 2000; Gunderson, 2000; Holling, 1973, 1996; Klein et al., 2003; Taşan-Kok et al., 2013; Brian Walker, Holling, Carpenter, & Kinzig, 2004). In other words, it is the tolerance of a system to disturbances or its ability to recover and persist after disturbances (Adger, 2000; Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Holling, 1973, 1996). It is also defined as the amount or magnitude of disturbance that the system can tolerate or absorb before changing its domain of attraction (Alberti et al., 2003; Berkes et al., 2003; Gunderson, 2000; Klein et al., 2003). Hence it is the ability to remain within the same basin of attraction (Folke, 2006; Klein et al., 2003; Brian Walker et al., 2004). In addition, Godschalk (2003) emphasizes the ability to accommodate change while authors like Holling et al. (1995 in Adger, 2000) with Berkes and Folke (1998 in Pendall et al., 2010) stress robustness and buffering capacity of the system.

2.1.1.1.3 Beyond Equilibrium Definitions

Similar to multiple-equilibria perspective, in this beyond equilibrium perspective the system is composed of multiple states of attraction and the change is inevitable. Yet, unlike the former perspective here the focus is on adapting to change instead of just absorbing or coping with it. Main distinguishing attribute of these definitions is the emphasis on the adaptability or adaptive capacity of the system. Some authors (Carpenter, Walker, Anderies, & Abel, 2001; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Klein et al., 2003) just attach self-organization, learning and adaptability capacities to the former (multiple-equilibria) definitions while others use novel descriptions. For example, Folke (2006) puts an emphasis on the opportunities provided by the disturbances and relates resilience with the ability of sustaining and developing with change. In a later study, he (Folke, 2009, p. 40) states that: “Resilience, above all, is about turning crisis into opportunity”. Folke (2009) also points out the capacity for catalysing renewal, novelty and innovation as another component of resilience. Berkes et al. (2003) emphasize the capacity to shape change in addition to adaptability. Pendal et al. (2010) use ‘continual adjustment’ term and highlight the ability to change or adapt. Martin (2012) also points out this binary behaviour of the system as the capacity to reconfigure or adapt. Gunderson (2000) focus on remaining within the stability domain while it is changing (Figure 2.1). Chapin et al. (2009) on the other hand emphasize reorganization in a new context.

Apart from these groups, authors also define resilience in terms of their disciplines (ecology, psychology, resource management, etc.) or subjects of their inquiries (ecological systems, individuals, society, etc.). As a result, each discipline provides a specialized derivative of resilience concept in terms of its context. Based on the subject of the disciplines there are various definitions for ecological, social, economic, urban, regional, community or social-ecological resilience in the literature. For example; Adger (2000, p. 347) defines 'social resilience' as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change". Taşan-Kok et al. (2013, p. 56) describe 'economic resilience' as the capacity of "coping with the slow and radical changes induced by the interaction of endogenous and exogenous economic and other related processes".

Comparison of these different classifications reveals the change or evolution in the definitions of resilience since its first emergence. It is clear that the definitions have evolved from a narrower and static meaning to a richer and dynamic one. In spite of the improvements in meaning, different definitions of resilience are still being used in contemporary theories and practices. Depending on the specific assumptions or goals of different studies or disciplines, different definitions of resilience are being used. For example, in theoretical studies on social-ecological systems (Berkes et al., 2003; Carpenter et al., 2001; Chapin et al., 2009; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000) beyond equilibrium kind of definitions are being used while in practical studies on urban resilience (Alberti et al., 2003; Godschalk, 2003; Klein et al., 2003) multiple-equilibria definitions are preferred. Narrower and equilibrium centred definitions of resilience are being used for the sake of efficiency and ease in analyses. Yet, as recent studies have proven, these conventional perspectives are not sufficient for understanding and responding to dynamics of the contemporary world as a complex adaptive system. Conceptualization (or representation) of the world as a complex adaptive system requires beyond equilibrium kind of a definition of resilience.

As it was mentioned before, the main distinguishing attribute of beyond equilibrium definitions is the adaptive capacity or adaptability of the system. There is also an emphasis on the renewal capacity of the system. System can change and selforganize in a new context (Chapin et al., 2009; Folke, 2006; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Pendall et al., 2010). In other words, it can transform after a perturbation. Therefore, transformability is another attribute of a resilient system in this perspective.

Although adaptability and transformability are accepted as important attributes of a resilient system, their relationship with resilience is controversial. Some authors (Folke, 2006; Taşan-Kok et al., 2013) describe adaptability and transformability as common attributes of resilience. Whereas others (Chapin et al., 2009; Klein et al., 2003; Brian Walker et al., 2004) distinguish adaptability and transformability from resilience and describe each of them as separate attributes of complex systems. For a better understanding of resilience concept these attributes should also be described in detail.

2.1.1.2 Resilience, Adaptability and Transformation

In resilience literature there is confusion about the interaction between the attributes of resilience, adaptability and transformability. Some authors (Folke, 2006; Taşan-Kok et al., 2013) claim that both adaptability and transformability are the attributes of resilience. Some of them (Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000) distinguish transformability from resilience while keeping adaptability as an attribute of resilience. Others (Chapin et al., 2009; Hassink, 2010; Brian Walker et al., 2004) describe each of them as separate attributes of the complex systems. Highlighting the distinction between resilience, adaptability, and transformability, Walker et al. (2004) argue that resilience and adaptability are about maintaining the functions of the system while transformability is about altering them. They (Brian Walker et al., 2004)claim that: “Resilience and adaptability have to do with the dynamics of a particular system, or a closely related set of systems. Transformability refers to fundamentally altering the nature of a system”. Apart from the differences in their perspectives about the interaction between these attributes, authors describe adaptability and transformability in similar ways.

2.1.1.2.1 Adaptability

Adaptability can simply be defined as the capacity of people or actors to adjust themselves to cope with changes or perturbations (Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Klein et al., 2003). Since it is a function of the system's social component (Brian Walker et al., 2004), adaptability is being described as a capacity of the 'actors' in the society (Chapin et al., 2009; Folke, 2006; Brian Walker et al., 2004). It is the capacity of people to build (Folke, 2006), influence or manage (Brian Walker et al., 2004) resilience of the system. In this context, adaptive capacity is also associated with learning and innovation abilities of the society (Carpenter et al., 2001; Chapin et al., 2009).

Adaptive capacity of the system depends on factors like: biological, economic and cultural diversity, learning capacity of individuals, institutions and networks, effective governance (Chapin et al., 2009; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002), experimentation and innovation, built, natural, human and social capital (Chapin et al., 2009).

2.1.1.2.2 Transformability

Transformability can simply be defined as the capacity of a system to change for survival. Walker et al. (2004) define it as: "The capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable". This definition of transformability is widely recognized and recapitulated by different authors (Chapin et al., 2009; Folke, 2006; Taşan-Kok et al., 2013) in resilience literature. In addition to this definition of Walker et al. (2004), Chapin et al. (2009) emphasize the capacity to reconceptualise whereas Taşan-Kok et al. (2013) stress the learning capacity. Walker et al. (2004) further elaborate their transformability definition and state that it "means defining and creating new stability landscapes by introducing new components and ways of making a living, thereby changing the state variables, and often the scale, that define the system".

Distinguishing transformability from resilience Walker et al. (2004) point out that resilience is not always a desirable attribute of the system. They emphasize the importance of transformability by claiming that: “Sometimes change is desirable, generally at larger scales, and then effective management requires overcoming the resilience in the system to precipitate changes at these scales”.

Walker et al. (2004) list attributes of transformability as; “novelty, diversity, and organization in human capital-diversity of functional types (kinds of education, expertise, and occupations); trust, strengths, and variety in institutions; speeds and kinds of cross-scale communication, both within the panarchy and between other systems elsewhere”. Panarchy is an important concept for understanding reorganization and transformation processes in a system hence it is well-recognized in resilience literature. First coined by Holling, panarchy simply means the hierarchical structure of nested adaptive cycles interacting across spatial and temporal scales (Berkes et al., 2003; Chapin et al., 2009; Holling, 2001; Brian Walker et al., 2004). These important components of complex adaptive systems; adaptive cycles and panarchy concepts are explained in detail below.

2.1.1.3 Adaptive Cycles and Panarchy

2.1.1.3.1 Adaptive Cycles

Adaptive cycles are the sequential and cyclical development paths of complex systems. They are the four-phase trajectories of a system's development. Folke (2006, p. 258) defines adaptive cycle as "a heuristic model, generated from observations of ecosystem dynamics, of four phases of development driven by discontinuous events and processes". Pendall et al. (2010, p. 76) also describe adaptive cycle as the "four phase cycle of system adaptation and change". Adaptive cycles (Figure 2.2) are composed of four sequential phases of; r (exploitation or growth), K (conservation or steady state), Ω (release or collapse), and α (reorganization or renewal) (Carpenter et al., 2001; Chapin et al., 2009; Folke, 2006; Holling, 2001; Brian Walker et al., 2004). Holling (2001) also calls these phases as ecosystem functions. Since changes are inevitable, system constantly follows; exploitation, conservation, release and reorganization phases, in various scales.

Authors underline the importance of adaptive cycles in understanding the dynamics of social-ecological systems (Carpenter et al., 2001; Chapin et al., 2009; Folke, 2006; Brian Walker et al., 2004). Exploitation (r) phase is the period of exponential change (Folke, 2006) and growth (Pendall et al., 2010). Seizing the opportunity (Pendall et al., 2010), system settles into a new trajectory (Carpenter et al., 2001) in this phase. High resilience of the system starts to decrease in this growth phase. Conservation (K) phase follows the exploitation phase. In this period of accumulation (Holling, 2001) system becomes more complex (Carpenter et al., 2001), stable and rigid (Pendall et al., 2010). With increasing rigidity and diminishing novelty (Carpenter et al., 2001; Pendall et al., 2010) system becomes less flexible and adaptive to disturbances (Brian Walker et al., 2004). In this phase of "growing stasis and rigidity" (Folke, 2006) resilience of the system is very low and it is vulnerable to perturbations. Hence, following a perturbation, system passes into a collapse (Carpenter et al., 2001; Folke, 2006; Pendall et al., 2010) or release (Ω) phase. Referring to the well-known economist J. A. Schumpeter (1950), Holling (2001) and Pendall et al. (2010) define this phase as a time of 'creative destruction'. In this uncertain and unpredictable period of collapse, resilience of the system starts to increase. This relatively shorter and faster phase of collapse leads to reorganization (α) phase. In this period of renewal (Folke, 2006; Holling, 2001) the system reaches to a higher level of resilience with increasing uncertainty and novelty (Carpenter et al., 2001; Pendall et al., 2010). Authors (i.e., Holling, 2001; Pendall et al., 2010; Walker et al., 2004) also emphasize the increasing possibility of innovation and new opportunities in this period.

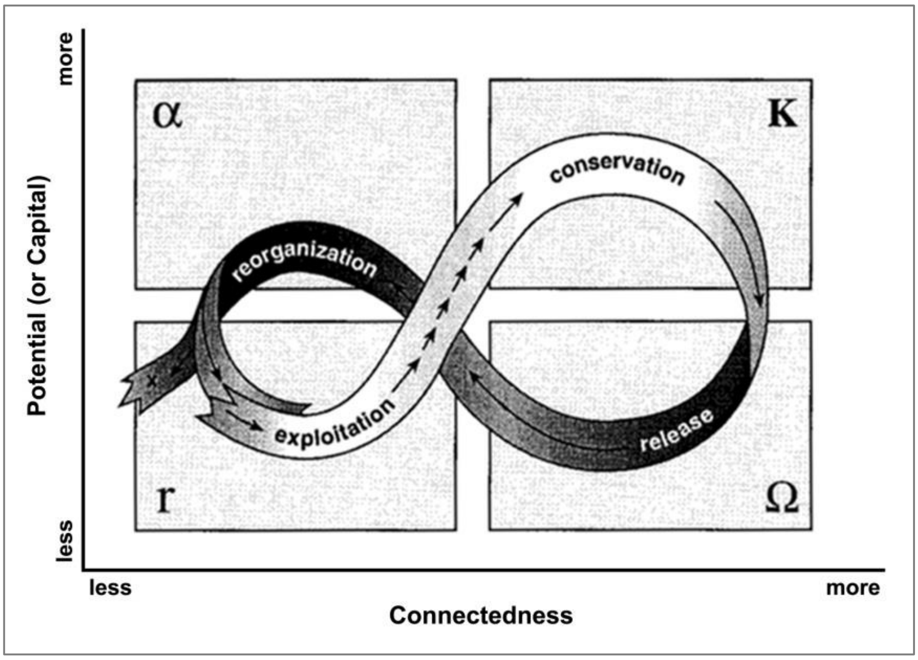

Figure 2.2: Adaptive cycle
(Adapted from Chapin et al., 2009 and Holling, 2001)

Relatively slower and longer trajectory from exploitation to conservation phase is named as "forward loop" (Carpenter et al., 2001) or "front loop" (Holling, 2001) of the adaptive cycle. In this process of growth and accumulation, predictability and certainty increases. On the contrary, during the "back loop" (Holling, 2001) between release and reorganization phases of adaptive cycle, system becomes unpredictable and uncertain. Holling (2001, p. 395) points out the opportunities created for innovation by back loop of the cycle and states that; in back loop process, "the previously accumulated mutations, inventions, external invaders, and capital can become re-assorted into novel combinations, some of which nucleate new opportunity".

2.1.1.3.2 Panarchy

Various adaptive cycles of social-ecological systems operate and interact through cross-scale linkages among them (Figure 2.3). These interactions and linkages among adaptive cycles at different temporal and spatial scales are called 'panarchy' (Berkes et al., 2003; Chapin et al., 2009; Folke, 2006; Holling, 2001; Pendall et al., 2010; Brian Walker et al., 2004). As it was mentioned before, panarchy concept was first coined by Holling and he explains the birth of panarchy concept as follows:

> “Because the word 'hierarchy' is so burdened by the rigid, top-down nature of its common meaning, we decided to look for another term that would capture the adaptive and evolutionary nature of adaptive cycles that are nested one within each other across space and time scales. Our goal was to rationalize the interplay between change and persistence, between the predictable and the unpredictable. We therefore melded the image of the Greek god Pan as the epitoma of unpredictable change with the notion of hierarchies across scales to invent a new term that could represent structures that sustain experiment, test its results, and allow adaptive evolution. Hence, 'panarchy'” (Holling, 2001, p. 396).

In other words, panarchy is the hierarchical structure of the cross-scale interactions among 'nested adaptive cycles' (Berkes et al., 2003; Folke, 2006). As Pendall et al. (2010, p. 17) state; in panarchy, smaller and larger, or lower and upper cycles "affect one another through continual response and adaptation". These interactions among cycles "combines learning with continuity" (Holling, 2001, p. 402) hence panarchy provides both creative and conservative structure (Berkes et al., 2003; Holling, 2001).

Walker et al. (2004) describe panarchy as one of the four aspects of resilience and state that: “At any particular scale, the system is actually a sub-system of the whole panarchy, and the first three aspects of resilience are influenced by what is happening in the panarchy at scales above and below the scale of interest". They describe panarchy (Pa) in relation to other three aspects of resilience (L = latitude, R = resistance, Pr = precariousness) as in the figure above (see Figure 2.4).

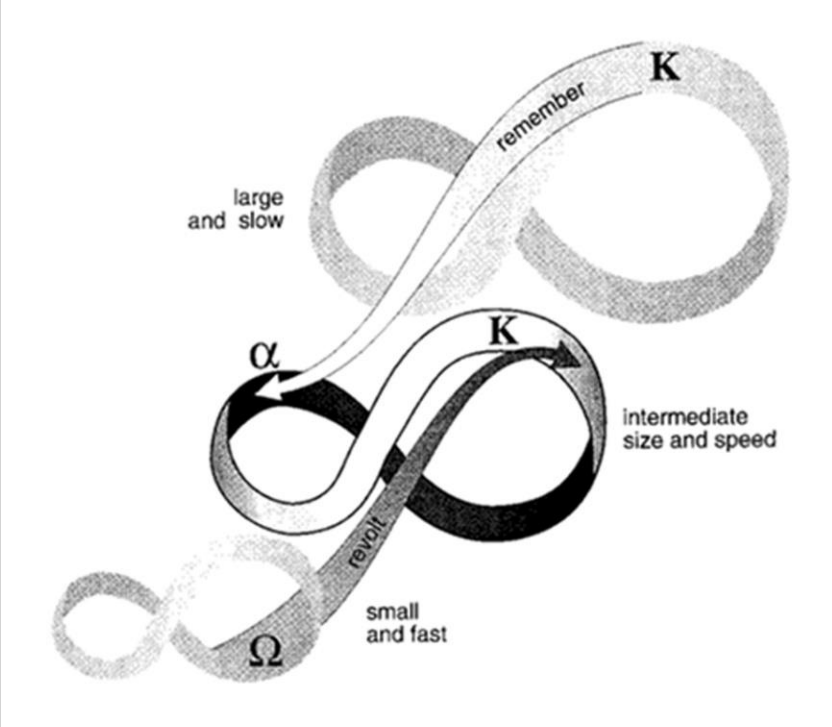

Figure 2.3: Panarchy
(Holling, 2001, p. 398)

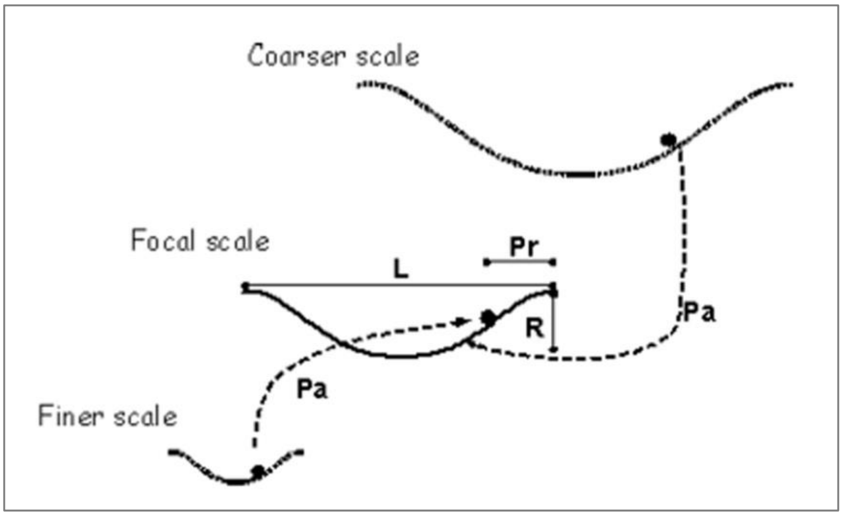

Figure 2.4: Panarchy in relation to three aspects of resilience
(Brian Walker et al., 2004)

Cross-scale linkages or 'panarchial connections' (Holling, 2001) among adaptive cycles (Figure 2.3) are classified as revolt and remember connections (Berkes et al., 2003; Chapin et al., 2009; Folke, 2006; Holling, 2001; Pendall et al., 2010; Brian Walker et al., 2004). Holling (2001, p. 398) stresses that, revolt and remember connections are "critical in creating and sustaining adaptive capability". An adaptive cycle in its conservation (K) phase can be affected by a smaller or lower cycle in release (Ω) phase. This "invigoration from below" (Holling, 2001) in the panarchy is called revolt connection (Chapin et al., 2009; Folke, 2006; Holling, 2001; Pendall et al., 2010). Also a larger or superior cycle in its conservation (K) phase can influence a lower cycle in its reorganization (α) phase. Upper cycle provides the needed experience and memory for the lower cycle. This protection and support from above is called remember connection (Chapin et al., 2009; Folke, 2006; Holling, 2001; Pendall et al., 2010). Pendall et al. (2010, p. 78) state that: "Remembering often serves to mitigate revolts that would otherwise cascade upwards through the multi-scale system".

2.1.2 Applications of Resilience

2.1.2.1 Resilience in Ecosystem Management

Resilience and adaptability concepts are widely accepted in ecosystem or natural resources management theories and practices (Berkes et al., 2003; Carpenter et al., 2001; Chapin et al., 2009; Folke, 2006; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000; Holling, 1996; Brian Walker et al., 2004). As a response to the conventional command-and-control (Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002) or steady-state (Chapin et al., 2009) resource management approaches, an adaptive management approach is being claimed by various authors and researchers from ecosystem or resource management disciplines (Berkes et al., 2003; Carpenter et al., 2001; Chapin et al., 2009; Folke, 2006; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000; Holling, 1996). They criticise the conventional approach for being efficiency-driven (Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002) and having a linear and mechanistic view of nature (Berkes et al., 2003). Berkes et al. (2003, p. 8) state that this command-and-control approach "aims to reduce natural variation in an effort to make an ecosystem more productive, predictable, economically efficient, and controllable". In another way, Chapin et al. (2009, p. 5) supports that these approaches aim to "reduce variability and prevent change, rather than to respond to and shape change in ways that benefit society". Presented as an alternative to this conventional management approach adaptive management approach is briefly explained below.

2.1.2.1.1 Adaptive Management

Accepting the inevitability of uncertainty, changes and surprises in nature (Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000), adaptive management approach takes management policies as hypotheses to be tested (Carpenter et al., 2001; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000; Holling, 1996). In this approach, various policies or hypotheses are being developed, evaluated and tested in terms of their ability to respond uncertainty and shape change (Carpenter et al., 2001; Chapin et al., 2009; Gunderson, 2000). Therefore, these management processes are also called as experiments (Berkes et al., 2003; Holling, 1996). Learning by doing and knowledge accumulation through these experiments are important components of this approach (Berkes et al., 2003; Carpenter et al., 2001; Folke, 2006; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Holling, 1996). Reversibility (Holling, 1996) and adjustability (Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002; Gunderson, 2000) of the policies are also important aspects of the success in this approach. In addition, Folke et al. (2002, p. 3) also emphasize the importance of the existence of "flexible and open institutions and organizations". Folke et al. (2002) describe this approach as a tool for building resilience in systems facing surprise. Chapin et al. (2009) call this approach as 'resilience-based ecosystem stewardship' and compare it with steady-state resource management and ecosystem management approaches (Figure 2.5).

In addition to adaptive management approach some authors also define Adaptive Co-management (Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002) and Adaptive Governance (Folke, 2006; Brian Walker et al., 2004) concepts as distinct management approaches. Adaptive co-management is defined (Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002) as a trial and error process driven by the participation of various interest groups or stakeholders from different scales and backgrounds. Generation and accumulation of ecological knowledge through interaction between theory and practice is also emphasized in this approach (Berkes et al., 2003; Folke, Carpenter, Elmqvist, Gunderson, Holling, Walker, et al., 2002). Here, there is a strong emphasis on learning through interaction between local and scientific knowledge. Berkes et al. (2003) define adaptive co-management process as a mutual learning process and underline the importance of social-ecological memory generated in this process. In another way, Folke et al. (2002) emphasize the importance of social-ecological experience accumulated in this process.

In addition, some authors prefer to use Adaptive Governance concept as another approach. However, the difference between adaptive co-management and governance is not so clear. Walker et al. (2004) define adaptive governance as "a process of creating adaptability and transformability in SESs [Social-Ecological Systems]". On the other hand, Folke (2006) define it as a collaborative process driven by the participation of a diverse set of stakeholders from different institutions and organizations. He also emphasizes the importance of social networks and learning in this participatory process and lists four essential parts of adaptive governance as; "understanding ecosystem dynamics; developing management practices that combines different ecological knowledge system to interpret and respond to ecosystem feedback and continuously learn; building adaptive capacity to deal with uncertainty and surprise including external drivers; and supporting flexible institutions and social networks in multi-level governance systems (Folke et al., 2005)." (Folke, 2006, p. 262).

Steady-state resource management	Ecosystem management	Resilience-based ecosystem stewardship
Reference state: historic condition	Historic condition	Trajectory of change
Manage for a single resource or species	Manage for multiple ecosystem services	Manage for fundamental social–ecological properties
Single equilibrium state whose properties can be sustained	Multiple potential states	Multiple potential states
Reduce variability	Accept historical range of variability	Foster variability and diversity
Prevent natural disturbances	Accept natural disturbances	Foster disturbances that sustain social–ecological properties
People use ecosystems	People are part of the social–ecological system	People have responsibility to sustain future options
Managers define the primary use of the managed system	Multiple stakeholders work with managers to define goals	Multiple stakeholders work with managers to define goals
Maximize sustained yield and economic efficiency	Manage for multiple uses despite reduced efficiency	Maximize flexibility of future options
Management structure protects current management goals	Management goals respond to changing human values	Management responds to and shapes human values

Figure 2.5: Contrasts between steady-state resource management, ecosystem management and resilience based ecosystem stewardship
(Chapin et al., 2009, p. 5)

2.1.2.2 Resilience in Urban and Regional Studies

Following the terrorist attacks of September 11, 2001, and Hurricane Katrina in 2005, resilience became an important concept in urban studies and planning in the 21th century (Hill, Wial, & Wolman, 2008). Increased frequency and magnitude of the disturbances coupled with increased permeability and interdependence of places attracted a great deal of attention to resilience concept from urban studies and planning disciplines (Christopherson et al., 2010).

In regional studies or economic geography disciplines, main concern is on the differences between the resilience levels of different places (Pike et al., 2010). Scholars and researchers try to find the reason why some regional economies are resilient while others are not (Christopherson et al., 2010; Hassink, 2010; Hill et al., 2008). Hence main focus is on the regional economic resilience of different geographies. Similar to resilience concept, there are different definitions and interpretations of regional economic resilience concept (Christopherson et al., 2010; Hassink, 2010; Hill et al., 2008; Martin, 2012; Pendall et al., 2010; Pike et al., 2010; Simmie & Martin, 2010). These definitions are mainly classified in terms of their assumptions about the existence and/or functioning of equilibrium in the system. There are two main groups of regional economic resilience definitions as equilibrium (equilibrium based or equilibrist interpretation) and evolutionary definitions (Christopherson et al., 2010; Pike et al., 2010; Simmie & Martin, 2010).

From an equilibrist point of view, Hill et al. (2008, p. 4) define regional economic resilience as "the ability of a region (defined roughly as a metropolitan area) to recover successfully from shocks to its economy that either throw it off its growth path or have the potential to throw it off its growth path but do not actually do so". Following this equilibrium based definition of regional economic resilience; they (Hill et al., 2008) describe three possible ways a regional economy can respond to internal or external shocks and disturbances. According to Hill et al., (2008) some regions, in short time periods, might return to or even exceed their previous growth paths following a disturbance. They describe these regions as economically resilient. Some regions might continue their growth paths without getting affected from those shocks. These regions are called as shock-resistant. On the other hand, some regions might be severely affected and thrown out of their growth path and cannot even return to their previous growth paths which might be called non-resilient.

Authors from the evolutionary perspective emphasize the adaptive capacity of regions in responding shocks or changes. From an evolutionary economic geography perspective these scholars stress the importance of history and geography in understanding the resilience capacity of regions. Transformation history or evolution of the economic landscape is an important component of resilience of the region. Martin (2012, p. 14) defines 'regional resilience' as "the capacity of a regional economy to reconfigure, that is adapt, its structure (firms, industries, technologies and institutions) so as to maintain an acceptable growth path in output, employment and wealth over time". As Simmie and Martin (2010, p. 31) point out, regional resilience "is considered as an ongoing process rather than a recovery to a (pre-existing or new) stable equilibrium state" in this evolutionary perspective.

2.1.3 Assessment of Resilience

Understanding the resilience of social-ecological systems is an important issue of interest in resilience literature. On the contrary there are a few frameworks for the assessment of resilience in social-ecological systems. These frameworks are represented below.

2.1.3.1 Resilience of SESs Assessment Framework by Walker and Colleagues, 2002 (Walker et al., 2002)

Walker et al. (2002) present a participatory approach for the assessment of resilience in social-ecological systems (Figure 2.6). They (Walker et al., 2002) develop this assessment framework as a basis for resilience management. Participation and stakeholder involvement is an important component of this framework which is composed of four successive steps of:

Step 1: Resilience of what?

Step 2: Resilience to what?

Step 3: Resilience analysis

Step 4: Resilience management

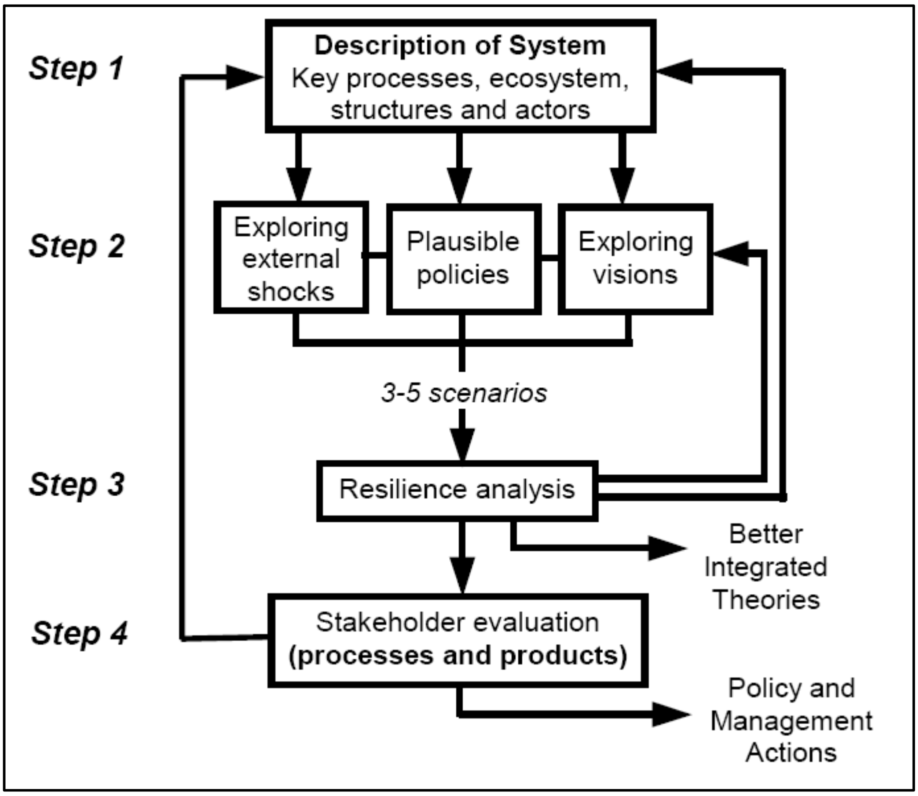

Figure 2.6: Resilience of SESs Assessment Framework
(Walker et al., 2002)

First step of the framework involves development of a conceptual model of the system through a participatory process including scientists, decision makers, local experts and stakeholders. This process includes identification of the historical profile of the system with driving forces of its ecosystem goods and services (Walker et al., 2002). In this context, key variables and important issues of the system are identified as objects of the assessment framework. In other words, this step gives an answer to the question of; "Resilience of what?" (Carpenter et al., 2001). Walker et al. (2002) provide following set of questions to be addressed for a better description of the systems.

- "What are the spatial boundaries of the SES?"
- "What are the key ecosystem services used by, and of concern to, people in the SES? What do they value?"
- "Who are the stakeholders?"

- “What are the key components of the SES, what are the natures and significance of their spatial patterns, what are their turnover times, and to what extent are their dynamics endogenous vs. influenced by exchange across the boundaries of the SES?”
- “What is the historical profile of the system? How did it get to be what it is now—what changes occurred through its history in terms of ecosystem, technology, society, economy, and so forth?”
- “What are the important, controlling variables that act as drivers of the key ecosystem goods and services people want?”
- “Which factors are controllable (e.g., land use policy) and which are not (e.g., climate)? What are the ambiguities in the system, the uncertainties that can be neither controlled nor quantified?”
- “How do the current institutional arrangements, property rights in particular, and the distribution of power and wealth influence formal and informal decision making and access to information?”

Second step deals with answering the question of; “Resilience to what. Therefore, the external disturbances of the system and their development processes are examined with drivers and interventions behind them. In addition, unpredictable drivers of the system are identified with contrasting policies and visions for the future. Following the identification of possible future policies and visions of different stakeholders, a limited set of scenario alternatives are developed for the future. Here, Walker et al. (2002) emphasize the importance of “establishing a range of possible trajectories” with at least one business-as-usual, one conservative and one aggressive scenario alternative. In this context, they (Walker et al., 2002) recommend considering the “external shocks and disturbances (physical, social, and economic); the visions, hopes, and fears that people have for the future; and a set of possible policies that might conceivably be imposed” for scenario development process.

Third step synthesises the outcomes of first and second steps and provide possible resilience pathways. Thresholds and nonlinearities of the system are explored through participatory discussions including scientists, local experts, policy makers and stakeholders. Simple models of system dynamics are developed as a result of the process (Walker et al., 2002).

In the fourth and final step of the framework, policy recommendations are developed as a result of the stakeholder evaluation of the entire assessment process (Walker et al., 2002). Developed policies of the process aims at enhancing "the system's ability to reorganize and move within some configuration of acceptable states" rather than attempting to keep the system on some predicted path (Walker et al., 2002).

2.1.3.2 Resilience Surrogates Approach by Bennett, Cumming and Peterson, 2005 (Bennett, Cumming, & Peterson, 2005)

Acknowledging the difficulty of understanding and assessing resilience of social-ecological systems, Bennett et al. (2005) underline the need and scarcity of practical resilience assessment methods or frameworks. With reference to the difficulty of measuring resilience, they (Bennett et al., 2005) introduce resilience surrogates and develop an approach for their determination. Bennett et al. (2005, p. 946) define resilience surrogates as; "proxies that are derived directly from theory for use in assessing resilience in a social-ecological system". In this approach, assessment of a social-ecological system's resilience depends on interpretation of the resilience surrogates of the system. Approach mainly depends on the identification of measurable resilience attributes of the system. This approach of Bennett et al. (2005) is composed of the four main steps of:

Step 1: Assessment and Problem Definition
Step 2: Identifying Feedback Processes
Step 3: Designing a Systems Model
Step 4: Using the Systems Model to Identify Resilience Surrogates

Bennett et al. (2005) provide questions to be used in these steps of the approach and give examples of answers from case studies (Table 2.3).

Table 2.3: Questions to be used in steps of the Determining Resilience Surrogates Approach
(Adapted from Bennett et al., 2005, pp.947-948)

Step	Question	Answer Defines
1	What aspects of the system should be resilient?	System boundaries, criteria for building system model
	What kind(s) of change would we like the system to be resilient to?	External drivers, disturbances, desired state of the system
2	What variables are changing?	System elements
	What processes and drivers are producing these changes?	System drivers
	What forces control the processes that are generating change?	Connections among processes and elements
3	What are the key elements and how are they connected?	Editing and refining connections among elements and processes
	What positive and negative feedback loops exist and which variables do they connect?	Identifying loops in model
	What (if anything) moves the system from being controlled by one feedback loop to another?	Identifying thresholds and leverage points in loops
4	As indicated by the feedback loops, what is the threshold value of the state variable?	Threshold conditions
	How far is the state variable from the threshold value?	Compare current state to threshold level
	How fast is the variable moving toward or away from the threshold?	Whether system is becoming more vulnerable or more resilient
	How do external controls and shocks affect the state variable and how likely are those shocks and controls?	Whether system is resilient to external shocks
	How are slow variables changing in ways that affect the threshold location?	Whether slow changes in the organization of the system is increasing or decreasing the resilience of the system
	What factors control the changing of these slow variables?	Controls of the resilience of the system

In first step of the approach, reason of the assessment is determined by problem definition. Key variables or issues of the system are determined here. In other words, object of the assessment, the focal system is defined in this step. Boundaries and desired state of the system are identified with external drivers and disturbances in this context (Bennett et al., 2005). ‘Resilience of what to what?’ question is answered in this step of the approach.

Following the problem definition, related positive and negative feedbacks of the system are identified in the second step. These feedback processes are identified in terms of the changes in the system. Therefore, changing variables (elements) of the system are identified with the drivers and processes behind them first. Then, interactions or connections among these variables and drivers (feedback loops of the system) are defined (Bennett et al., 2005).

Using the findings of the former steps, a model of the social-ecological system is designed in the third step of the approach. Identified elements and processes with the connections among them are used in this formalization process of the system. Bennett et al. (2005, p. 949) state that: “A good system model will include all the key elements of the system and the feedback processes and linkages among the elements”. They (Bennett et al., 2005) also claim that these models are best designed by small but diverse research teams.

	Resilience Surrogates				
Generic Description of Surrogates →	*The state of the system relative to the location of the threshold*	*The sensitivity of the system to further movement*	*The rate at which the system is moving toward thresholds*	*The location of the threshold*	*The rate of change in the movement of the threshold*
Archetypical Models ↓	*Dominated by fast variables*	*Dominated by feedback strength, internal to the system*	*Dominated by shocks or controls imposed from outside the system*	*Dominated by changes in the slow variables*	*Dominated by changes in the slow variables*
Limits to growth	N/a	N/a	N/a	N/a	N/a
Limits to growth with a threshold (for example, eutrophic lakes)	P concentration of lake relative to P concentration at which the rate of P recycling increases	Amount of P recycling relative to lake P dynamics	Rate of terrestrial input of P and factors that influence that rate, such as fertilizer use	N/a	N/a
Tipping point (for example, Longleaf pine habitat in Florida)	Longleaf pine density relative to threshold at which fire and longleaf savanna out competes hardwood regeneration	Relative sensitivity of fire frequency and spread to changes in longleaf pine density Relative mortality of oaks to fire	Management control of fires by fire control and prescribed fire Climate variation, dry and wet periods	N/a	N/a
Shifting tipping point (for example, elephant populations in Southern Africa)	Density of woodland relative to threshold density at which fire and grassland out competes woodland regeneration	Relative sensitivity of fire frequency and spread to changes in grassland density, Relative mortality of woodlands to fire	Amount of prescribed fire Climate variation: wet and dry periods Killing of elephants by people	Relative balance between woodland growth versus fire and elephant woodland elimination	Intensity of elephant elimination of woodlands, Rate of change in elephant population

The first three columns are determined by the fast variables in the system and relate to the state of the system relative to the location of the threshold. In these columns, the threshold itself is not changing. The last two columns are related to changes in the location of the threshold itself and are dominated by changes in slowly-changing variables. N/a indicates that this type of surrogate is not applicable for this system model. There are no resilience surrogates for the Limits to Growth system because this system does not exhibit alternate states.

Figure 2.7: Comparison of resilience surrogates with archetypal models (Bennett et al., 2005, p. 951)

Acknowledging the difficulty of designing a formalized model of the system, Bennett et al. (2005) provide archetypal systems models that can be used as templates in designing models of systems. They (Bennett et al., 2005, p. 950) define these system archetypes as “representations of patterns that appear repeatedly in many different system” and add that they are “general, formal, flexible, simple, and largely qualitative”. Bennett et al. (2005) present four generic archetypal systems models as; “limits to growth”, “limits to growth with a threshold”, “tipping point” and “shifting tipping point”. Except the first one, these models exhibit alternative stable states.

Following the design of systems model, resilience surrogates are identified in the last step of the approach. Bennett et al. (2005) present five main places to look for these surrogates and define them in terms of the relationship between state variables and the thresholds. The first three of these places “relate to the distance of the system from a threshold” whereas the final two “relate to movement of the threshold itself” (Bennett et al., 2005, p. 950). Bennett et al. (2005) provide an example of these surrogates with related archetypal models (Figure 2.7). In this context, they (Bennett et al., 2005) provide four generic system models archetypes of; limits to growth, limits to growth with a threshold, tipping point, and shifting tipping point, in order to extract potential resilience surrogates from the system models. Stressing the fact that all of these surrogates are not appropriate for all cases, they claim that these examples can help researchers in their specific studies.

2.1.3.3 Resilience Assessment Framework by Resilience Alliance, 2007 and 2010 (Resilience Alliance, 2007b, 2007a, 2010)

Being established by scholars that had already been developing and testing resilience theory since 1970s, Resilience Alliance is an international and multidisciplinary organization that has been providing and supporting resilience science related activities since its establishment in 1999 (Resilience Alliance, n.d.). Providing a strong network of researchers and leaders from the fields of social-ecological systems, resilience, adaptability and transformation, the organization aims at; "contributing toward theoretical advances in the dynamics of complex adaptive systems", "rigorous testing of theory", and "developing guidelines and principles" for the assessment and management of the resilience of social-ecological systems (Resilience Alliance, n.d.). In this context, Resilience Alliance provides workbooks to guide the practices of resilience assessment and management.

Up to the present, three versions of these workbooks (Resilience Alliance, 2007b, 2007a, 2010) were presented by the organization. First two versions of the workbooks (versions 1.0 and 1.1) were complementary. Building on the "Resilience of SESs Assessment Framework" by Walker et al. (2002) and emerging from the case-studies presented in the Special Future of Ecology and Society on "Exploring Resilience in Social-Ecological Systems" (Walker et al., 2006), these two versions were developed in parallel for practitioners and scientists, respectively (Resilience Alliance, 2007b, p. 4). Version 1.0 of the workbook was prepared for practitioners, "who make strategic decisions about resource policies and management" (Resilience Alliance, 2007b, p. 4). Assuming no prior scientific knowledge of resilience concepts, a more comprehensive version of the workbook was developed for practitioners. On the other hand, aiming scientist familiar with the concepts of resilience, the workbook for scientist was developed in a fairly concise structure. Later, revised version (2.0) of the workbook for practitioners was presented in 2010. The resilience assessment frameworks that were presented in these workbooks were explained in details below.

2.1.3.3.1 Assessing and Managing Resilience in Social-Ecological Systems: A Practitioners Workbook, 2007 (Version 1.0)

The first version (v.1.0) of the workbook for assessing and managing resilience in social-ecological systems was published for practitioners in 2007 (Resilience Alliance, 2007a). Main objective of the workbook was stated as; "to help guide a process of inquiry and action for those who are interested in applying the concept of resilience to complex resource problems within a region" (Resilience Alliance, 2007a, p. 4). Resilience Assessment Framework that was presented in this version of the workbook is composed of five main stages:

Stage 1: Resilience of What, to What?

Stage 2: Assessing Alternate States and Thresholds

Stage 3: Assessing Cycles of Change

Stage 4: Adaptability and Transformative Change

Stage 5: Interventions and Management

These stages of the framework are briefly explained below. In addition, a list of key questions and guiding principles that might be used in the assessment process is provided in the Appendices (see Appendix A).

Stage 1: Resilience of What, to What?

This first stage of the framework involves defining and understanding the social-ecological system with its main issues. In this context, spatial and temporal boundaries, critical components, valued attributes, and main disturbances of the focal system are determined within multiple scales (Resilience Alliance, 2007a).

Step 1.1 – Describing the present:

In this first step of the framework, the focal system is defined in terms of its boundaries, main issues and key components. Therefore, the main issues of the system and their valued attributes are determined first. Then, social, economic and ecological components of the focal system that are related to main issues and valued attributes are identified. In this context, ecosystem goods and services, stakeholders, organizations and institutions of the system are determined in this step (Resilience Alliance, 2007a).

Step 1.2 – Multiple scales:

In this step of the framework, social, economic and ecological scales above and below the focal system are identified and the interactions among these scales are analysed (Resilience Alliance, 2007a). A table to be used in determination of the multiple scales and cross-scale interactions (Table 2.4) is provided in the workbook.

Table 2.4: Multiple scales and cross-scale interactions
(Resilience Alliance, 2007a, p. 24)

Note: You may not find it necessary to fill in all cells; this will depend on how many scales and domains you are choosing to analyze.

Domain	Scale	Describe the scale	Describe processes that influence focal scale
Social	Larger		
	Large		
	Focal		
	Small		
	Smaller		
Economic	Larger		
	Large		
	Focal		
	Small		
	Smaller		
Ecological	Larger		
	Large		
	Focal		
	Small		
	Smaller		

Step 1.3 – Historical timeline:

In order to determine the long-term dynamics of the system, a historical profile or timeline of the system is constructed in this step of the framework. Therefore, the significant events and changes from different (coarser, focal, and finer) scales and (social, economic, and ecological) domains are placed on the historical timeline and the connections or interactions among these events are highlighted. Thereby, system drivers and regime shifts in social, economic, and ecological domains are determined by analysing the past disturbances and responses in the system. Effects of human interventions and management actions are also considered in this context (Resilience Alliance, 2007a).

Table 2.5: Summary of the historical profile of focal system (Resilience Alliance, 2007a, p. 26)

Era	Crisis or triggering event	Vulnerabilities that led to change

One method for developing a historical profile of the system is also explained in this part of the workbook (Resilience Alliance, 2007a). In this context, it is recommended to construct a diagram with three rows that are representing the focal, coarser, and finer scales of the system. Next, the length of the historical period (e.g., 100 years, 1000 years) and time intervals (e.g., 1 year, 5 years, 10 years) are determined and sketched as a line on the bottom of the diagram. Then, the significant triggering events are marked on the appropriate scales and cross-scale interactions among these events are highlighted. As a result, different eras of the focal system are identified by analysing the triggering events and regime shifts in the system (Resilience Alliance, 2007a). A table for summarizing the historical profile of the focal system (Table 2.5) is also provided in the workbook.

Step 1.4 – Disturbances:

Past, present and future (potential) disturbances of the focal system from social, economic and ecological domains are determined and "Resilience to what?" question is answered in this step of the framework. In this context, disturbance regime of the system is identified by analysing the frequency, duration, severity and predictability of determined disturbances. Managed or suppressed disturbances are also identified in this step (Resilience Alliance, 2007a). A table for summarizing the disturbances of the focal system (Table 2.6) is also provided in the workbook.

Table 2.6: Summary of focal system disturbances
(Resilience Alliance, 2007a, p. 34)

Disturbance	Pulse or Press?	Frequencies of occurrence (if pulse)?	Does the system have time to recover between occurrences (if pulse)?	Variable or component of the system most affected? (e.g., soil, markets, etc.)	Magnitude of impact (minor to severe)	Change in the past few years or decades? (none, little, less frequent, more intense, etc.)
Future						

Stage 2: Assessing Alternate States and Thresholds

In this stage of the framework, possible alternate states of the system are identified with potential transitions among them. In this context, critical thresholds and disturbances that underpin these transitions are determined and plausible future scenarios are considered.

Step 2.1 – Alternate states:

Possible alternate states of the system and potential transitions among them are described in this step of the framework. Social, economic and ecological characteristics of each alternate state described in terms of their key components and the processes or disturbances underlying a transition between these states are determined. Desirability of each alternate state for different stakeholders is also investigated in this step (Resilience Alliance, 2007a). For analysis of the possible alternate states and transitions of the system, construction of state-and-transition diagrams (Westoby, Walker, & Noy-meir, 1989) is recommended and examples of such diagrams (Figure 2.8) are presented in the workbook (Resilience Alliance, 2007a).

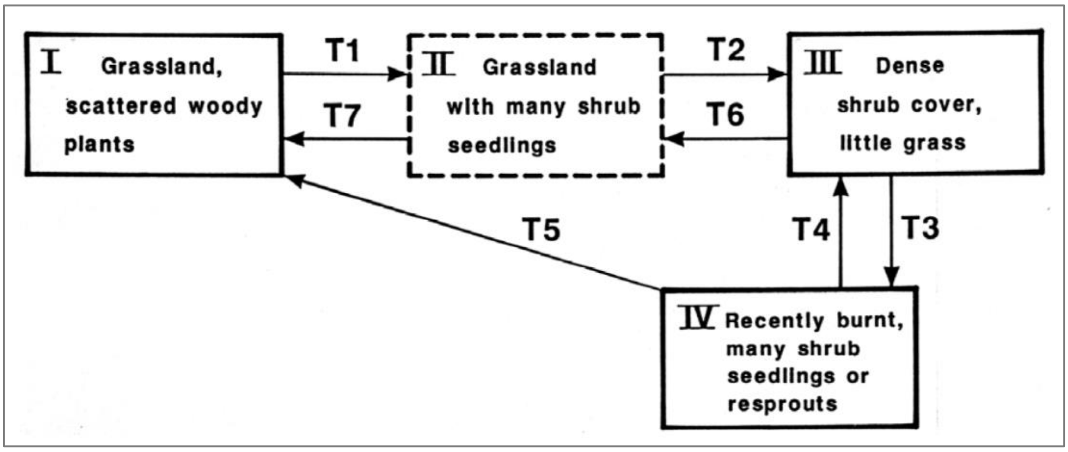

Figure 2.8: State-and-transition diagram for a savannah system (Resilience Alliance, 2007a, p. 37)

Step 2.2 – Thresholds:

Critical thresholds that are separating the alternate states of the system are identified in this step of the framework. Acknowledging the difficulty of knowing exact position of a threshold, importance of determining the change driving factors and potential disturbances of the system is emphasized. Therefore, the factors and disturbances that drive changes in slow-changing variables and influence the position of thresholds are determined (Resilience Alliance, 2007a)

Step 2.3 – Scenarios:

Three to five plausible future scenario alternatives are developed in this step of the framework. Being described as "ways of helping to understand aspects of system dynamics by imagining a range of plausible futures and the processes that lead to them", scenarios provide a foresight for uncertainties and assumptions of the system (Resilience Alliance, 2007a, p. 47). These scenario alternatives are developed by analysing the information about main components and drivers of the system and determining plausible alternatives for future system states or trajectories (Resilience Alliance, 2007a). Then, the mechanisms or processes behind these scenario alternatives are analysed by the indicators of change in the system (Resilience Alliance, 2007a).

Stage 3: Assessing Cycles of Change

Patterns of change in the focal system and cross-scale interactions with the surrounding systems are investigated through the general systems model of adaptive cycles and panarchy in this stage of the framework.

Step 3.1 – Cycles of change:

Adaptive Cycle Model is applied to the focal system in this step of the framework. In this context, the focal system is represented as an adaptive cycle and its current phases in social, economic and ecological domains are determined (see Table 2.7). Then, the key factors or disturbances that drive change in the system are analysed through this adaptive cycle (Resilience Alliance, 2007a). Past adaptive cycles of the system are also identified and analysed for determining the disturbances and vulnerabilities of the system (see Table 2.8).

Table 2.7: Current phases of the system
(Resilience Alliance, 2007a, p. 54)

Domain	Current Phase	(Approximate) Length of current phase
Ecological		
Economic		
Social		
Focal (overall) System		

Table 2.8: Past adaptive cycles of the system
(Resilience Alliance, 2007a, p. 54)

Past Cycles (Name)	Dominant Characteristics	Length of Adaptive Cycle	What triggered a release or shift?	What are the system vulnerabilities?	What characteristics changed among cycles?

Step 3.2 – Cross-scale interactions:

In this step of the framework, cross-scale interactions of the system are represented in a model of panarchy. In this context, current adaptive cycle phases of the larger and smaller scale systems are described and their potential (desirable and undesirable) influences on the focal system are analysed. Thus, resulting system vulnerabilities at the focal scale are identified (Resilience Alliance, 2007a).

Stage 4: Adaptability and Transformative Change

Adaptability and transformability of the focal system is evaluated in this stage of the framework. Therefore, the capacities of the system's social, economic and ecological components to respond changes and disturbances are analysed. Also, capitals (human, natural, economic, social, political, and cultural) of the system and the trade-offs among them are determined. Especially, for determining the adaptability of the system, capacities of the system’s human and social capitals are examined. In this context, relationships among key stakeholders and institutions of the system are described (Resilience Alliance, 2007a).

Stage 5: Interventions and Management

Management interventions and adaptive management approaches are developed in this last stage of the framework. Using the information gathered in the assessment stages of the framework, interventions are developed for the thresholds of the system. Types and sequence of the interventions are determined in terms of the dynamics of adaptive cycle and panarchy of the system. A brief explanation of the adaptive management approach is also presented in this stage of the workbook (Resilience Alliance, 2007a).

2.1.3.3.2 Assessing Resilience in Social-Ecological Systems: A Workbook for Scientists, 2007 (Version 1.1)

The second, complementary version (v.1.1) of the workbook for assessing and managing resilience in social-ecological systems was published for scientist in 2007 (Resilience Alliance, 2007b). This version of the workbook is composed of three main sections of; (i) Outline of Process, (ii) Resilience Assessment, and (iii) Interventions for Resilience Management. Key questions and activities for guiding the practices in following sections are listed in the first section of the workbook. Resilience Assessment Framework and resilience management interventions are explained in the second and third sections of the workbook, respectively. The Resilience Assessment Framework that was presented in this version of the workbook is composed of four main stages:

Stage 1: Defining and Understanding the System

Stage 2: Assessing Resilience

Stage 3: Implications for Management Interventions

Stage 4: Synthesis of Resilience Understanding

These stages of the framework are briefly explained below. Summary questions and activities that were listed in the first section of the workbook are presented in the appendices (see Appendix B).

Stage 1: Defining and Understanding the System

This first stage of the framework involves defining and understanding the social-ecological system with its main issues. In this context, spatial and temporal boundaries, critical components, important variables, and main disturbances of the focal system are determined within multiple scales (Resilience Alliance, 2007b).

Step 1.1 – Resilience of what?

In this first step of the framework, significant issues and relevant scales of the system are determined for defining the focal system. Therefore, the main issues of the system are determined in terms of the variables of concern. In this context, ecosystem goods and services, stakeholders (key groups), organizations and institutions of the system are determined. Relevant scales above and below the focal system in social, economic and ecological domains are identified and the interactions among these scales are analysed. In addition, potential challenges, conflicts, vulnerabilities and opportunities are described (Resilience Alliance, 2007b).

Step 1.2 – Resilience to what?

Drivers, disturbances and controlling variables of the system are identified in this step of the framework. Hence, a historical profile of the system is developed and the trends in major resources and resource uses are investigated in order to determine the main shocks or disturbances that drive change in the social, economic and ecological domains of the system in different scales. In this context, important events of each scale are determined with the cross-scale interactions among them. In addition, changes in the frequency and intensity of determined disturbances are also determined (Resilience Alliance, 2007b).

Step 1.3 – People and governance:

In this step of the framework, key actors or stakeholders of the system are described with the power relations and conflicts among them. Thus, individuals and organisations with key leadership roles and power are identified for each scale. Then, relations and conflicts among these actors are investigated. Policies, rules and regulations about the major resource uses are also determined in this step (Resilience Alliance, 2007b).

Stage 2: Assessing Resilience

Step 2.1 – Developing conceptual models:

Using the knowledge that was gathered in the first stage of the framework, a conceptual model of the social-ecological system is developed in this step. Therefore, mental models of different stakeholders are analysed for determining the dynamics of social-ecological system. The focal system is represented as an adaptive cycle and its current phase is determined. Also, the systems above and below the focal system are determined with their cross-scale influences on the focal system. Referring back to the historical profile of the system, alternative states and possible transitions among them are described on a conceptual state-and-transition model. Examples of such state-and-transition models (Figure 2.9) are also presented in the workbook. In this context, critical assumptions are also developed about the possible alternate states of the system (Resilience Alliance, 2007b).

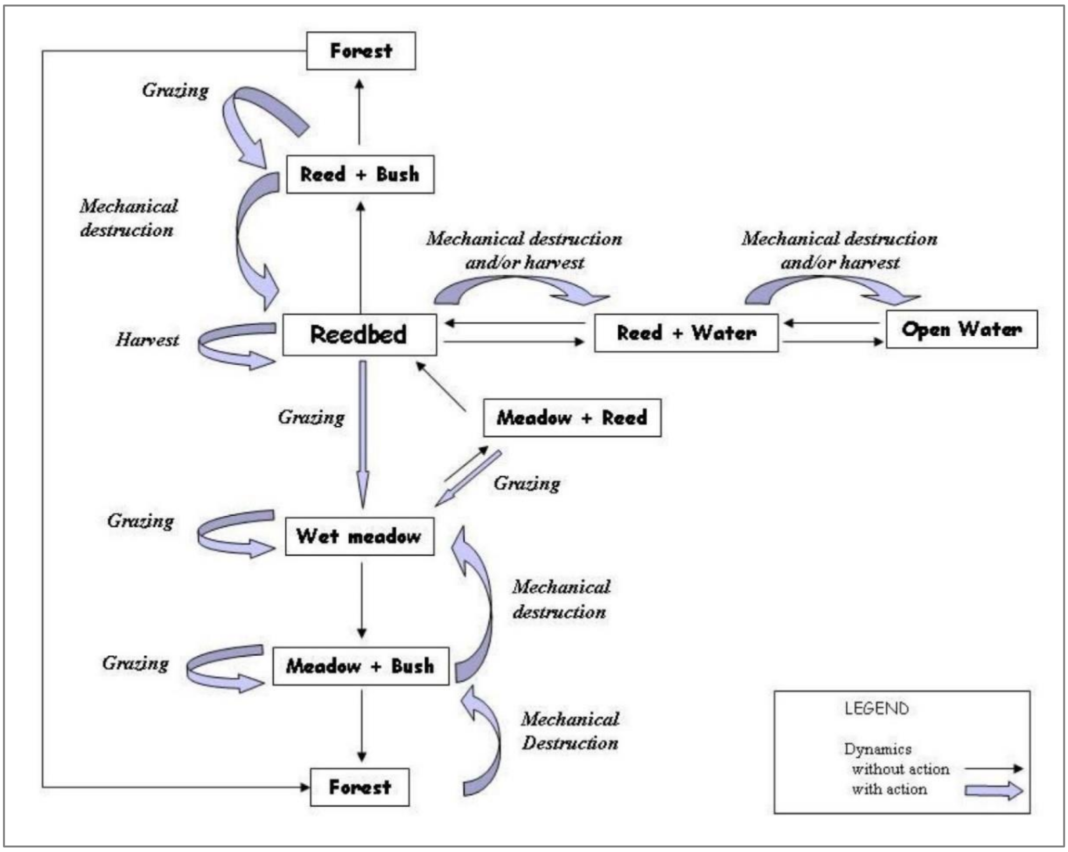

Figure 2.9: State-and-transition model of Camargue reed-bed system in the Rhone delta
(Mathevet et al., 2006 in Resilience Alliance, 2007b, p. 28)

Step 2.2 – Alternate system regimes:

Alternative "basins of attraction" or regimes of the system and the patterns of change among these alternate regimes are determined in this step of the framework. Therefore, thresholds or tipping points on controlling variables are analysed and alternate regimes of the system are determined with possible regime shifts. A "model" template for summarizing the multiple interacting thresholds (Figure 2.10) is provided in this part of the workbook (Resilience Alliance, 2007b). Desirability of the determined regimes or trajectories are also considered. Additionally, possible regime shifts are investigated through scenario development. In this context, possible pathways are described for the future.

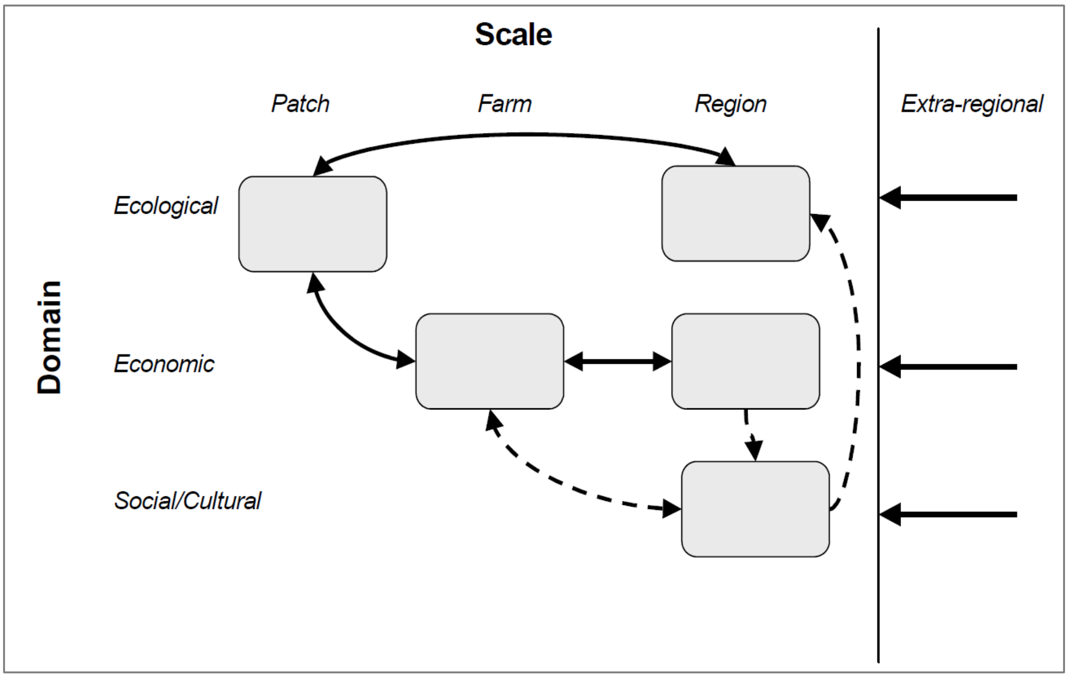

Figure 2.10: Template model for multiple interacting thresholds (Kinzig et al., 2006 in Resilience Alliance, 2007b, p. 31)

Step 2.3 – Likely interactions among thresholds:

Following the determination of thresholds and regime shifts of the system, existing and potential interactions among the thresholds are determined in this step. Therefore, connections among the thresholds from different scales and domains are described here (Resilience Alliance, 2007b).

Step 2.4 – Cross-examination of the model with system attributes:

In this step of the framework, "attributes of the system that determine the positions of thresholds" are described (Resilience Alliance, 2007b, p. 35). Thus, attributes of the system's resilience and adaptability are investigated.

In this context, response diversity, feedback strength, spatial heterogeneity, modularity, social capacity, governance systems, learning, memory, etc. of the system are analysed. In addition, the conditions of system capitals (natural, financial, built, human, social, etc.) and the changes in them are determined (Resilience Alliance, 2007b).

Step 2.5 – Cycles of change and cross-scale interactions

Current phases of adaptive cycles at each scale and domain of the system are reviewed in this step of the framework. Cross-scale interactions among these adaptive cycles are represented in a panarchy model and influences from the scales above and below the focal system are determined (Resilience Alliance, 2007b).

Stage 3: Implications for Management Interventions

In this stage of the framework, implications of the assessment process for policy and management are described without providing any policy recommendations (Resilience Alliance, 2007b).

Stage 4: Synthesis of Resilience Understanding

Results of the assessment process are synthesized in this final stage of the framework. In this context, "the key determinants of the system's resilience, and its present state" are described in terms of the attributes of resilience and adaptability (Resilience Alliance, 2007b, p. 40). Trade-off between the general and specified resilience of the system are also examined in this stage (Resilience Alliance, 2007b).

2.1.3.3.3 Assessing Resilience in Social-Ecological Systems: A Workbook for Practitioners, 2010 (Revised Version 2.0)

The final version (v.2.0) of the workbook for assessing and managing resilience in social-ecological systems was published in 2010 (Resilience Alliance, 2010). Resilience Assessment Framework that was presented in this final version of the workbook is composed of five main stages (Figure 2.11):

Stage 1: Describing the System

Stage 2: Understanding System Dynamics

Stage 3: Exploring System Interactions

Stage 4: Evaluating System Governance

Stage 5: Acting on the Assessment

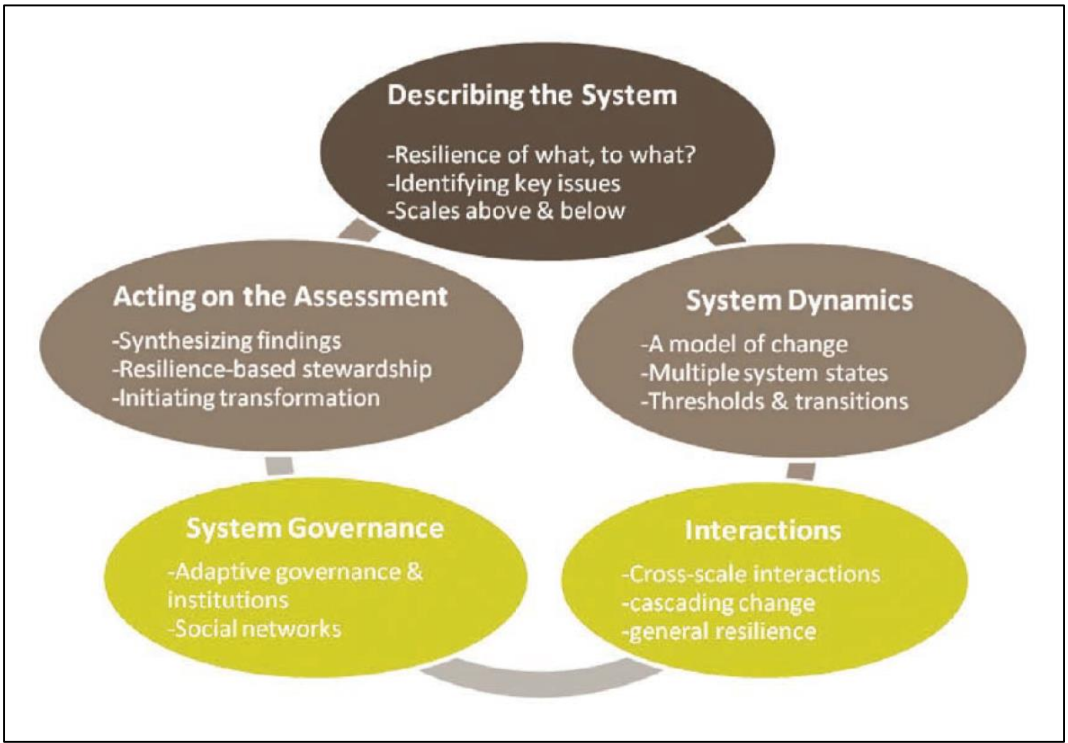

Figure 2.11: Resilience Assessment Framework
(Resilience Alliance, 2010, p. 5)

These stages of the framework are briefly explained below. A set of worksheets and guiding questions to be used in the iterative steps of the assessment process are also provided in the workbook. Provided worksheets were presented under the headings of related steps, below. On the other hand, the guiding questions were listed and presented in the appendices (see Appendix C).

Stage 1: Describing the System

The first stage of resilience assessment framework involves defining the focal social-ecological system by setting its soft boundaries in spatial and temporal scales. Since, these boundaries are defined in terms of the main issues of the social-ecological system, key territorial issues and valued attributes of those issues are identifies in this stage. In this context, the critical components of the system (e.g.; key resource uses, ecosystem services, stakeholders) are determined with potential disturbances and a historical profile of the system is developed with scales above and below the focal scale (Resilience Alliance, 2010).

Step 1.1 – Identifying the main issues:

In this first step of the framework, main issue or issues of the system are identified. In this context, main issue(s) of concern for assessment are determined in terms of valued attributes of the system (Resilience Alliance, 2010). A worksheet (Table 2.9) to be used in determination of main issue(s) and valued attributes of the system is provided in this step of the workbook.

Step 1.2 – Resilience of what?

In this step, key components (including social, economic, political and ecological factors) and stakeholders of the social-ecological system are identified. "Resilience of what?" question is answered in this step of the framework. In this respect, important resources of the focal system are determined with their direct and indirect benefits. Therefore, main uses of natural resources are determined with the key stakeholders in the focal system. In other words, ecosystem goods and services of the social-ecological system are identified (Resilience Alliance, 2010). A worksheet (Table 2.10) to be used in determination of the main natural resource uses with related stakeholders of the system is provided in this step of the workbook.

Table 2.9: Worksheet for determination of main issues and valued attributes of the system
(Resilience Alliance, 2010, p. 12)

Issues	*Main issue(s) of concern for the assessment*	*Valued attributes of the system*
Issue 1		
Issue 2		
Issue 3		

Table 2.10: Worksheet for determination of natural resource uses and key stakeholders
(Resilience Alliance, 2010, p. 14)

Natural resource uses	***Stakeholders***
Direct uses	Inside focal system
Indirect uses	Outside focal system

Step 1.3 – Resilience to what?

Past, present and future (potential) disturbances of the social-ecological system are determined in this step. "Resilience to what?" question is answered in this step of the framework. In this context, disturbance regime of the system is identified by analysing the frequency, duration, severity and predictability of determined disturbances. Managed or suppressed disturbances are also identified in this step (Resilience Alliance, 2010). A worksheet (Table 2.11) to be used in determination of focal system disturbances and their attributes is provided in this step of the workbook.

Table 2.11: Worksheet for determination of focal system disturbances and their attributes
(Resilience Alliance, 2010, p. 17)

Disturbance (past or present)	Pulse or Press	Frequency of occurrence	Time for recovery between occurrences	Components most affected (e.g., soil, markets)	Magnitude of impact (minor to severe)	Any change in past years or decades? (none, less frequent, more intense, etc.)
Future disturbances						

Step 1.4 – Expanding the system:

A historical profile of the system is developed in this step of the framework. In this context, change drivers or trigger events of the system are identified in a historical timeline. Thus, the significant historical events and their influences are presented in historical timeline of the social-ecological system. The scales above and below the focal scale are also included within the historical profile and critical interactions between these scales were determined (Resilience Alliance, 2010). A worksheet (Table 2.12) for determining the cross-scale interactions between social and ecological dimensions of the system is provided in this step of the workbook.

Table 2.12: Worksheet for determination of the cross-scale interactions between social and ecological dimensions of the system (Resilience Alliance, 2010, p. 20)

	Social dimensions that influence the focal system	*Ecological dimensions that influence the focal system*
Larger-scale systems		
Focal System		
Smaller-scale systems		

Stage 2: Understanding System Dynamics

In this stage of the framework adaptive cycle model is applied to the focal system for understanding the cycles of change. Therefore, current phase of the focal system in adaptive cycle is identified. In this context, current, historical and potential alternate states of the focal system are determined with the thresholds and transition phases between them. Reversibility of transitions is also investigated while describing the strengths and weaknesses of alternative states (Resilience Alliance, 2010).

Step 2.1 – A conceptual model of change:

In first step of this stage, a conceptual model of change is developed for the focal system. In this respect, the focal system is represented as an adaptive cycle and its current phase is determined. Key factors that drive change in the system are analysed through this adaptive cycle. Also, possible vulnerabilities and opportunities that are introduced by the adaptive cycle are also determined (Resilience Alliance, 2010).

Step 2.2 – Multiple states:

Current, historical and potential states of the focal system are described in this step. Each alternate state described in terms of their key components or variables and the transition phases between those states are determined. Then, desirable and undesirable traits (strengths and weaknesses) of alternate states are determined while investigating the reversibility of those transitions (Resilience Alliance, 2010).

Step 2.3 – Thresholds and transitions:

In this step of the framework, the thresholds or tipping points of the system and potential interactions between them are determined. In this context, the types of formerly determined transition phases and the system drivers behind them are analysed in this step (Resilience Alliance, 2010).

Stage 3: Exploring System Interactions

In this stage of the framework, the panarchy model is applied to the cross-scale interactions between the focal system and surrounding systems. Therefore, desirable and undesirable impacts from larger and smaller scale systems are investigated in terms of the cross-scale interactions among thresholds. In addition, the trade-offs between specified and general resilience of the focal system are described in this stage (Resilience Alliance, 2010).

Step 3.1 – Cross-scale interactions:

In the first step of this stage, cross-scale interactions of the system are represented in a model of panarchy. In this context, current adaptive cycle phase(s) of the larger and smaller scale systems are described and their potential (desirable and undesirable) influences on the focal system are analysed. Thus, resulting system vulnerabilities at the focal scale are identified (Resilience Alliance, 2010).

Step 3.2 – Interacting thresholds and cascading change:

*C*ross-scale interactions between the thresholds of key system variables are determined in this step of the framework. Certainty levels of thresholds and their cascading effects are also identified (Resilience Alliance, 2010). In this respect, a worksheet (Figure 2.12) for determining the potential interactions between the thresholds of slow variables is provided in the workbook. On this worksheet, assigning a level of certainty for each threshold (between 1 and 3) and drawing lines between interacting thresholds are also recommended (Resilience Alliance, 2010).

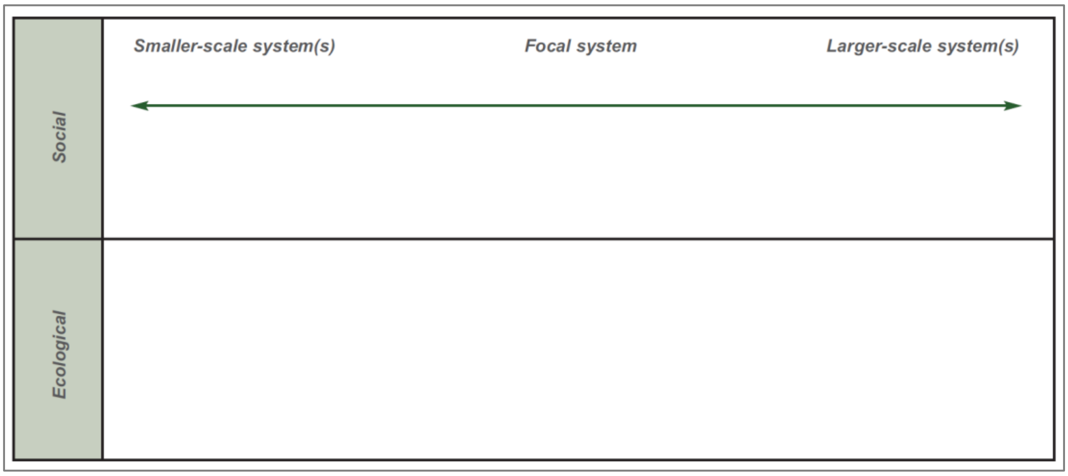

Figure 2.12: Worksheet for determining the potential interactions between the thresholds of slow variables
(Resilience Alliance, 2010, p. 33)

Step 3.3 - General and specified resilience:

In the step, trade-offs between the specified resilience of focal system and the general resilience of whole social-ecological system are identified. In this context, critical attributes of general resilience (e.g., diversity, openness, tightness of feedbacks, system reserves, and modularity) of the system are identified. Then, the trends in these attributes are investigated for determining the feedbacks that might undermine general resilience of the system (Resilience Alliance, 2010).

Stage 4: Evaluating System Governance

Key institutions and stakeholders of the social-ecological system are determined in this stage of the framework. Power dynamics and conflicts between stakeholders are also described by analysing the interactions among individuals, organizations, rules and traditions of the system in this stage (Resilience Alliance, 2010).

Step 4.1 - Adaptive governance and institutions:

Key formal and informal institutions of the system are identified with the levels and scales of decision making processes, in this step of the framework. In this context, the power relations and conflicts between the decision-makers from different scales are investigated. Effectiveness of rule enforcement and compliance is also identified (Resilience Alliance, 2010). A worksheet (Table 2.13) for determining the institutions and decision-making processes of the system is provided in this step of the workbook.

Step 4.2 - Social networks among stakeholders:

In this step of the framework, social networks of the system are determined by analysing the linkages and social relations among stakeholders. Central actors of the system and their potential roles in the network are also identified. In addition, the structure of the networks is described by investigating the number of linkages or relations among actors, the degree of centrality of actors, and the existence of cohesive subgroups (Resilience Alliance, 2010).

Table 2.13: Worksheet for determining the institutions and decision-making processes of the system
(Resilience Alliance, 2010, p. 38)

Key formal and informal institutions			
	List of institutions	*Enhance flexibility (Yes/No)*	*Restrain flexibility (Yes/No)*
Main issue 1			
Main issue 2			
Overarching			

Level of decision-making			
	Local, municipal, provincial, national, regional	*Appropriate given ecological processes? (Yes/No)*	*Suggested improvements*
Main issue 1			
Main issue 2			

Rule enforcement and compliance		
	Is it effective? (Yes/No)	*Suggested improvements*
Main issue 1		
Main issue 2		

Mapping power relations and conflicts				
List of Stakeholders	*Formal power (strong, intermediate, weak)*	*Informal power (strong, intermediate, weak)*	*Conflicts with other stakeholders? Specify.*	*Conflict resolution mechanisms in place?*

Stage 5: Acting on the Assessment

Findings of the assessment process are synthesized in this final stage of the framework. A conceptual model of the social-ecological system and a diagram of system thresholds and interactions are developed for synthesizing and summarizing the findings. In this context, templates of a conceptual model (Figure 2.13) and a diagram of thresholds and interactions (Figure 2.14) are provided with the lists of guiding questions (Table 2.14 and Table 2.15) for case studies, respectively. Possibilities of a resilience-based stewardship and transformation of the system are also discussed in this synthesizing stage (Resilience Alliance, 2010).

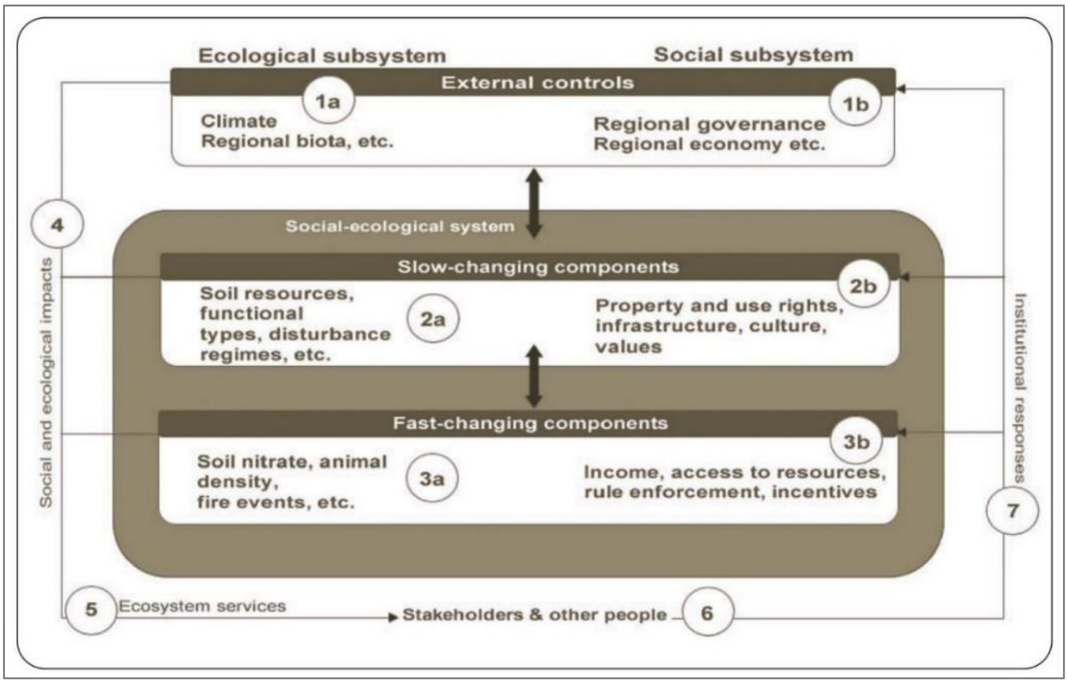

Figure 2.13: Template conceptual model of a social-ecological system (Resilience Alliance, 2010, p. 43)

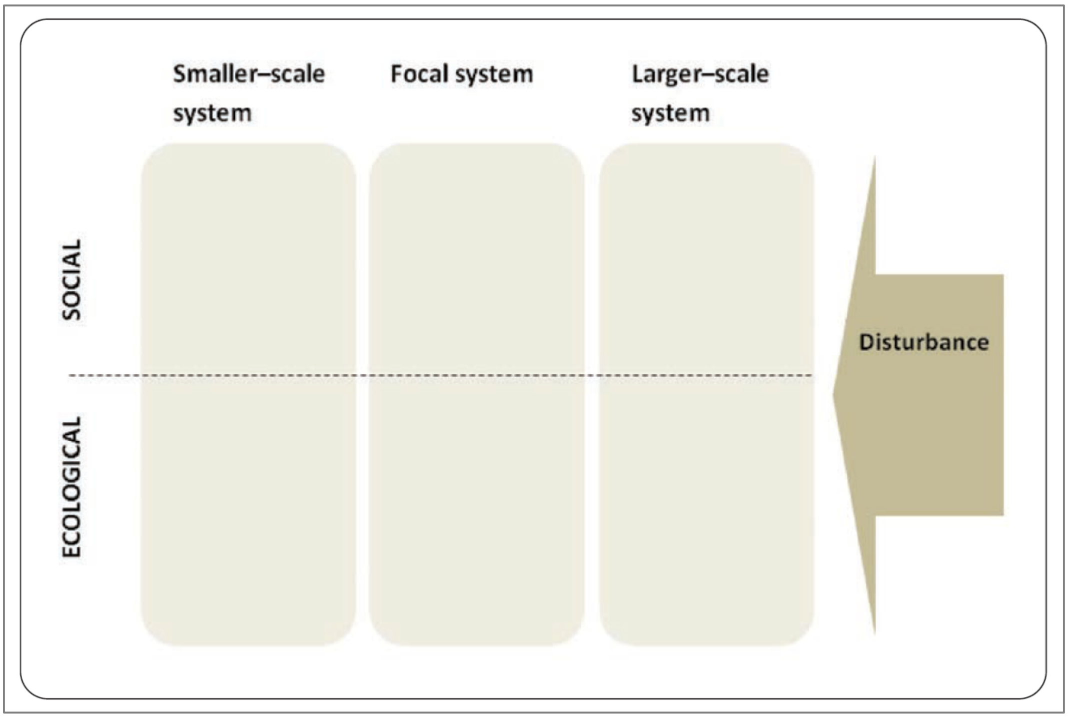

Figure 2.14: Template guide for a thresholds and interactions diagram (Resilience Alliance, 2010, p. 45)

Table 2.14: Guiding questions for the conceptual model of a social-ecological system
(Resilience Alliance, 2010, p. 44)

Refer to Section	*Guiding questions for reflection*
1.1	What are the environmental and social impacts of the main issue(s) that was identified? *[4]*
1.2	Considering the main resource use(s) that is central to the main issue, what are the key ecological components of the natural resource that change relatively slowly over time (e.g., trees are a slow variable relative to fire or pest invasions)? *[2a]* What are the key ecological components of the natural resource that change relatively fast over time? *[3a]* Who are the key stakeholders and what role(s) do they play in the system? *[6]* What are the main ecosystem services that are most important to stakeholders and others? *[5]*
1.3	What is known (in summary) about the main disturbance regime(s) of the system? *[2a]* What are the main disturbance events? *[3a]* What are the social and ecological impacts of disturbances in the system? *[4]*
1.4	What are the larger-scale external controls that interact in a significant way with the focal system? *[1a & 1b]* Are there smaller nested systems that affect any of the faster-changing components of the focal system? *[3a & 3b]* How do current institutional responses differ from those in the past? *[7]*
2.1	Referring to the adaptive cycle diagram developed in Section 2.1, are there key system components that change relatively slowly or quickly and that should be added to the SES model? *[2a&b, 3a&b]* If the adaptive cycle exercise revealed any new insights into social and ecological impacts or institutional responses, add these to the model. *[4 & 7]*
2.2	The rule of hand challenges the analyst to reduce the number of key variables that define a system state. Without oversimplifying, are there components of the SES that you might want to remove or set aside from the model? *[2a&b, 3a&b]*
4.1	Is decision-making taking place at larger scales (external to the focal system) that significantly impacts your focal system? *[1b]* Are there power dynamics in the social domain of your focal system that significantly influence how the system is structured and how it functions? *[2b, 3b, 7]*

Table 2.15: Guiding questions for the diagram of thresholds and interactions (Resilience Alliance, 2010, p. 46)

Refer to Section	*Guiding questions for reflection*
2.2	What are the key slow variables associated with thresholds that are (or would be) responsible for a shift between the alternate states that you identified previously? At what scale do these slow variables operate?
2.3	Reviewing your list of potential thresholds of concern, identify the thresholds associated with slowly changing variables. If your list of slow-variable potential thresholds includes primarily social or primarily ecological variables, challenge yourself to consider additional potential thresholds in the ecological domain. Are there any thresholds that you may have overlooked because of the level of expertise of those conducting the assessment? What are the system disturbances identified earlier that might move the system closer to a threshold? Indicate on the thresholds and interactions diagram any potential interactions that you identified previously.
3.1	Do any of the cross-scale interactions that you identified previously in Section 3.1 involve the slowly changing variables included on your draft interactions and thresholds diagram?
3.2	Review your list of thresholds and interactions from Section 3.2 and apply this information to a full revision of your diagram thus far. You may want to codify the thresholds to indicate the level of certainty associated with each threshold or to vary the weight of the interaction lines based on your understanding of the likelihood or impact of specific interactions.
3.3	Are there potential slow-variable thresholds that you previously identified with respect to general system resilience?
4.0	What role does the governance of your focal system play in the potential for crossing or avoidance of slow-variable thresholds in your diagram?

2.1.3.4 Resilience Assessment Framework by Walker and Salt, 2012 (Walker & Salt, 2012)

Acknowledging the importance of being in a "resilience frame of mind" or having a general understanding of resilience concept, Walker and Salt (2012, p. 1) outline the essence of resilience thinking before explaining the steps of applying that thinking or putting it into practice. In this context, they (Walker & Salt, 2012, p. 3) provide a framework for the assessment and management of resilience after explaining 10 key points of resilience thinking as:

1. "The systems we are dealing with are self-organizing."
2. "There are limits to a system's self-organizing capacity."
3. "These systems have linked social, economic, and biophysical domains."
4. "Self-organizing systems move through adaptive cycles."
5. "Linked adaptive cycles function across multiple scales."
6. "There are three related dimensions to resilience: specified resilience, general resilience, and transformability.
7. "Working with resilience involves both adapting and transforming."
8. "Maintaining or building resilience comes at a cost."
9. "Resilience is not about knowing everything."
10. "Resilience is not about not changing."

The framework that was presented by Walker and Salt (2012) is composed of three main steps of: describing the main system, assessing its resilience and managing it. These steps of the framework are briefly explained below and a list of guiding questions is presented in the Appendices (see Appendix D).

Step 1: Describing the System

A simple description of the system is developed in this step of the framework. Therefore, critical scales and people of the system are determined with the interactions among them. Acknowledging the importance of stakeholder involvement for the accuracy and acceptance of results of the framework, Walker and Salt (2012, p. 36) emphasize the necessity of "identifying and engaging the critical set of stakeholders" in this first step of the framework. Depending on the perspectives of different stakeholders, critical scales of the system are determined with their social and spatial boundaries and cross-scale interactions among the scales above and below the focal scale are examined. Interactions or relations between different actors or stakeholders are also examined in this step and the governance system is determined with the formal and informal institutions of the system.

In addition, big issues and important components of the system are identified with the possible disturbances and shocks influencing them. Therefore, important goods and services of the system are identified with the possible trade-offs among them. Characteristic, infrequent, and unknown disturbances or shocks of the system are also determined with their possible impacts on the valued components of the system. In this context, a historical timeline of the system is developed and the specific events are presented with possible changes following them. The scales above and below the focal scale are presented in the timeline and cross-scale interactions among specific events or drivers are determined. Hence, current or plausible states or trajectories of the system are determined with the trends of change in the system. As a result, a general understanding of the social-ecological system is developed at the end of this step of the framework (Walker & Salt, 2012).

Step 2: Assessing Resilience

This assessment step of the framework involves analysing specified and general resilience of the system with its capacity for transformative change (see Figure 2.15). In this respect, a conceptual model of the system is developed with known and possible thresholds on controlling variables (at different scales and domains) and interactions among them. Thus, alternative states of the system are determined with potential transitions among them. In addition to the assessment of specified resilience of the focal system, its relations with the adaptive and transformative capacities of the entire social-ecological system is also analysed and the trade-off between them are determined (Walker & Salt, 2012).

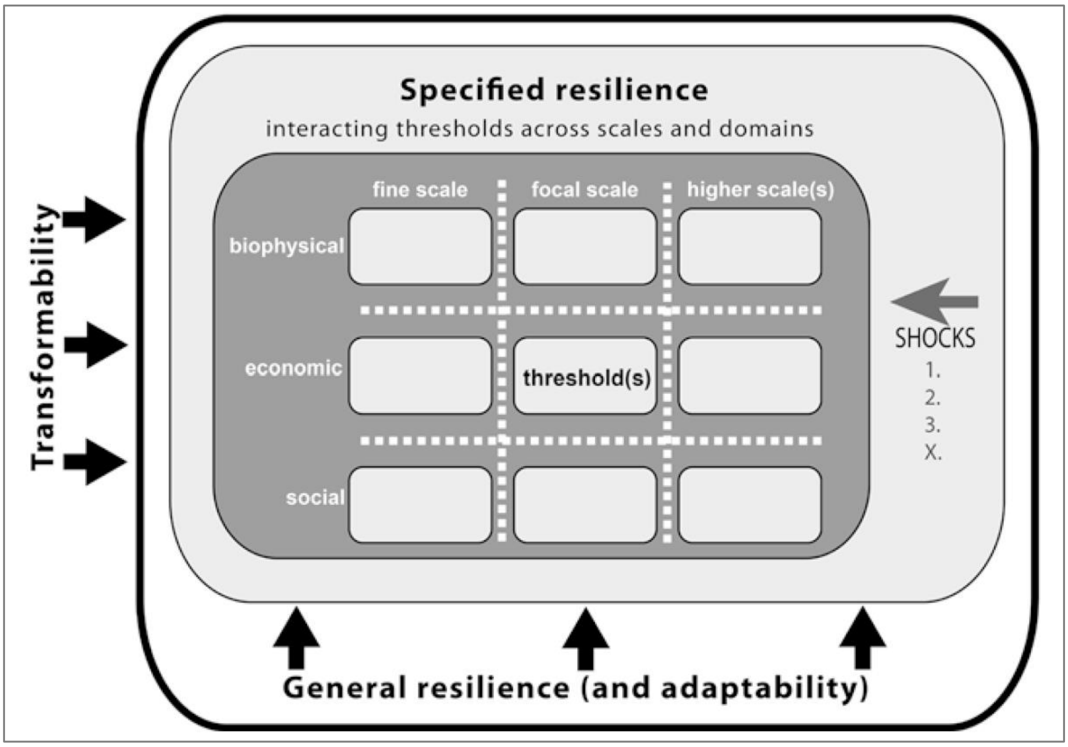

Figure 2.15: Specified Resilience, General Resilience and Transformability (Walker & Salt, 2012, p. 104)

Specified Resilience

Specified resilience is defined as "the resilience of some part of the system to particular kinds of disturbance" by Walker and Salt (2012, p. 68). It is the resilience of a particular part of the system to a particular set of disturbances. Assessment of the specified resilience involves identifying the alternative states of the system with associated thresholds. Therefore, known and possible thresholds on controlling variables are identified for each scale and each domain (social, economic and ecological) in this step. Hence, thresholds at each scale in each domain are presented in a conceptual model and the interactions between them are determined with their cascading effects. In this respect, Walker and Salt (2012) present an idealised 3x3 version of thresholds matrix (Figure 2.16) for determining the thresholds of the system. Thresholds at each scale in each domain are presented in this scales X domains matrix with interactions among them (Kinzig et al., 2006).

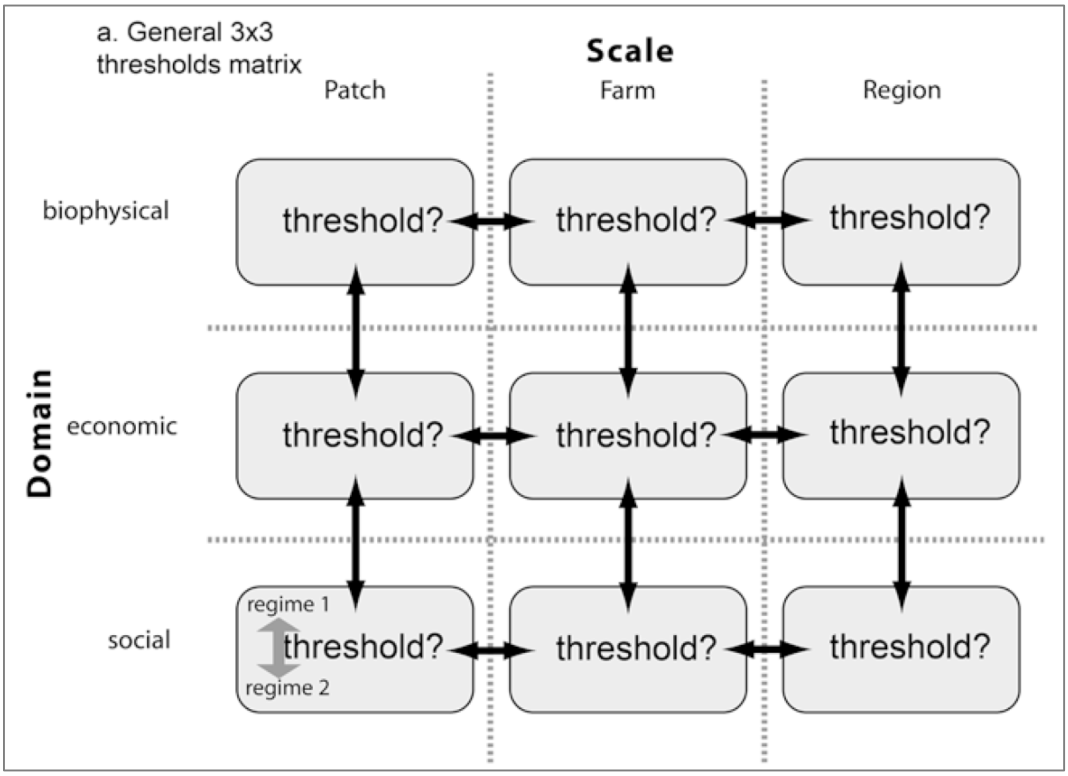

Figure 2.16: General 3x3 thresholds matrix
(Walker & Salt, 2012, p. 70)

Walker and Salt (2012) emphasize that depending on the dynamics of each case study, some slots could be empty while some slots include more than one threshold. In this context, they (Walker & Salt, 2012) provide examples of more complex matrices from former case studies of: Madagascar Dry Forest (Figure 2.17) and Goulburn-Broken Catchment in Australia (Figure 2.18). A list of slow variables with the thresholds and alternative regimes on them, is also provided for the case of Goulburn-Broken Catchment (Figure 2.19). In this list, slow variables of the system are presented in bold and the thresholds in parenthesis.

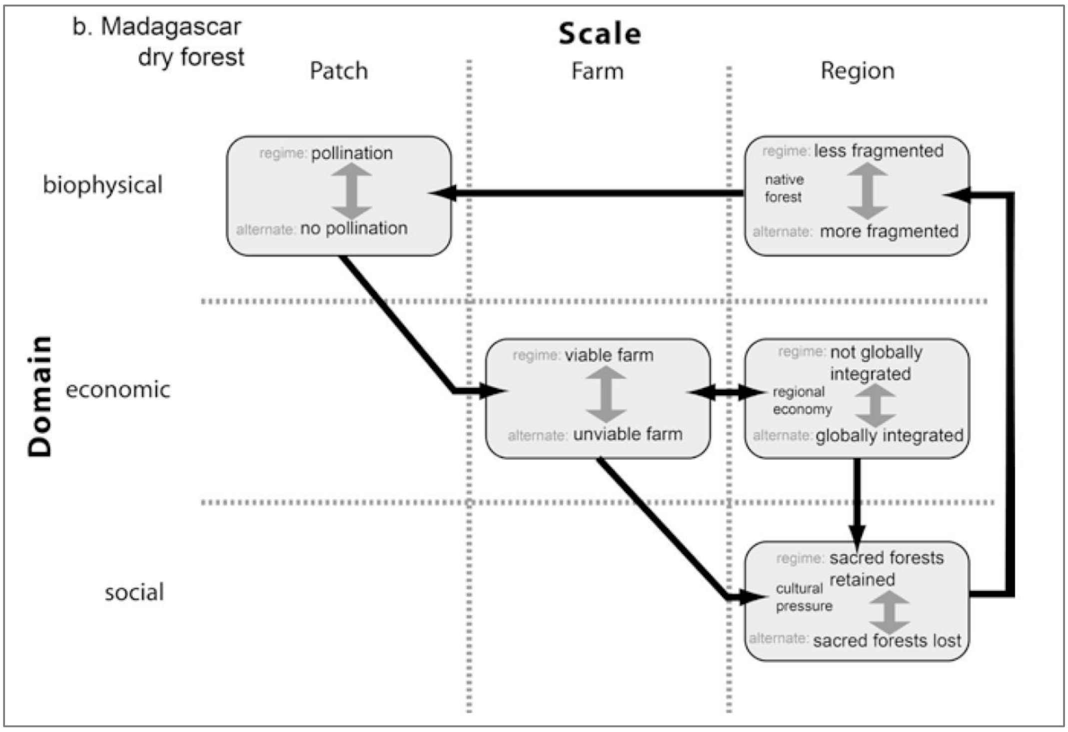

Figure 2.17: Thresholds matrix for the Madagascar Dry Forest
(Based on Bodin et al., 2006 and modified from Kinzig et al., 2006 in Walker & Salt, 2012, p. 70)

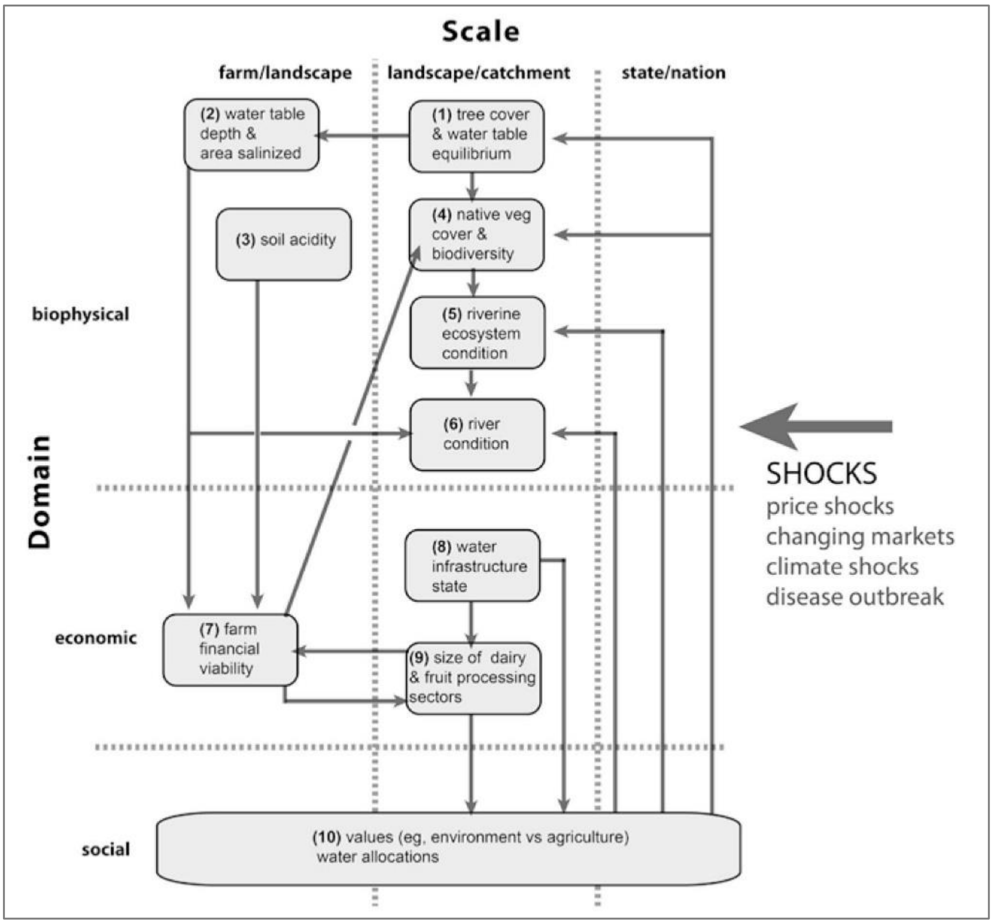

Figure 2.18: Thresholds matrix for the Goulburn-Broken Catchment (Modified from Walker et al., 2009 in Walker & Salt, 2012, p. 71)

1. Landscape tree cover (10 - approx 15%) water table deep vs. water at surface
2. Water table depth (approx 2m under surface) fertile top soil vs. salinized soil
3. Soil acidity (approx pH 5.5) high crop production vs. crop failure
4. Native vegetation cover (5%, 30%) fauna groups present vs. absent
5. N and P content in water bodies (concentration level threshold) clear water, high biodiversity vs. eutrophic, low biodiversity
6. River flow regime (flow level threshold) wetland/floodplain biodiversity persists vs. different species
7. Farm income:debt ratio (debt ratio threshold) farm viable vs. non-viable
8. Funds for infrastructure from water sales (level of funds threshold) infrastructure good vs. declining, non-viable
9. Size of dairy & fruit processing (level of industry activity) viable processing plants vs. non-viable
10. Balance of values for water for environment vs agriculture (availability of water threshold) farmer income: debt positive vs. negative

Figure 2.19: Controlling variables of the Goulburn-Broken Catchment (Modified from Walker et al., 2009 in Walker & Salt, 2012, p. 71)

For identifying thresholds and developing threshold matrices, Walker and Salt (2012) suggest considering the known and potential thresholds of the system. For this, they (Walker & Salt, 2012) recommend developing conceptual and analytical models of the system to examine its dynamics. In this context, they suggest using "state-and-transition" models (Westoby et al., 1989) for developing the conceptual model of the system and provide an example developed for Camargue Wetland System (Figure 2.20). In state-and-transition model, the boxes represent alternative states of the system while the lines represent transitions among them. In addition to conceptual models, Walker and Salt (2012) also recommend developing quantitative, analytical models of the system with participation of experts (i.e., specialists and scientists).

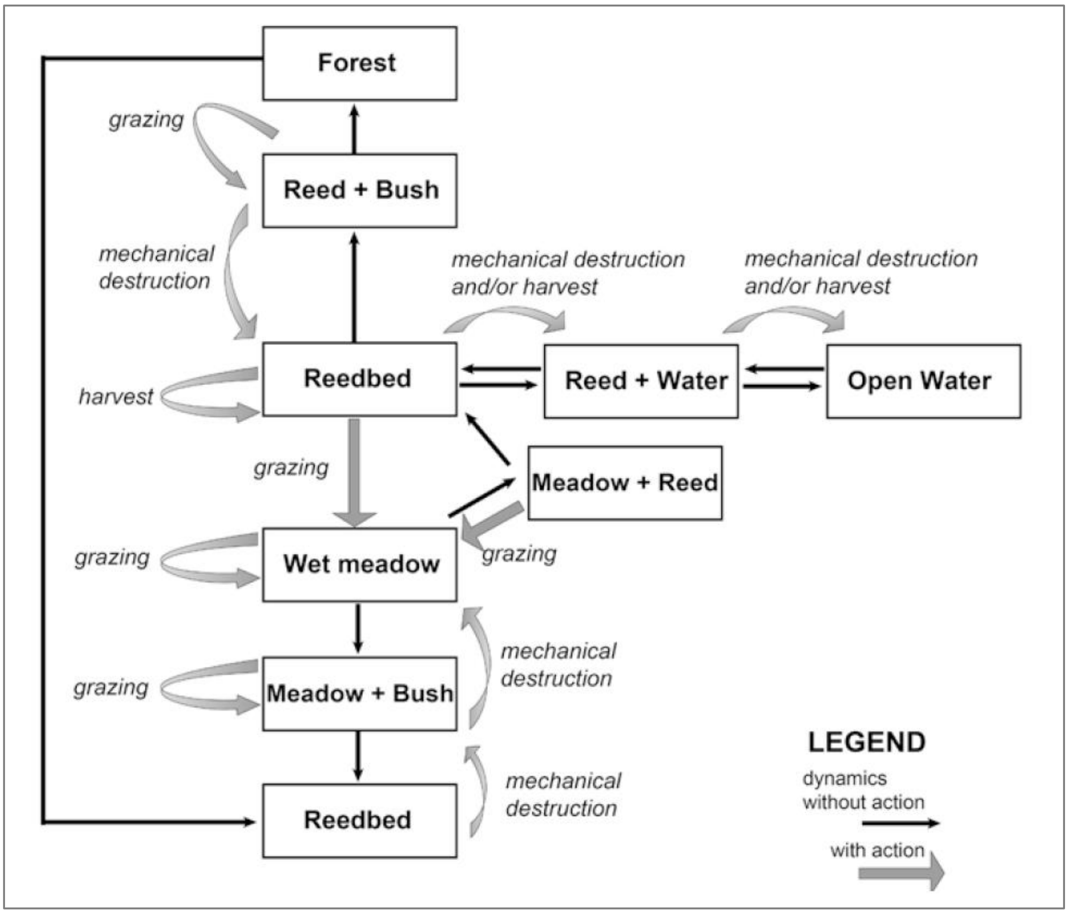

Figure 2.20: State-and-transition model of the Camargue Wetland System (Modified from Mathevet et al., 2007 in Walker & Salt, 2012, p. 80)

As emphasized by Walker and Salt (2012, p. 90): "making your system resilient in particular ways can cause it to become less resilient in other ways", therefore general resilience of the system should also be considered in the assessment process.

General Resilience

Walker and Salt (2012, p. 90) define general resilience as "the capacity of a system that allows it to absorb disturbances of all kinds, including novel, unforeseen ones, so that all parts of the system keep functioning as they were" and emphasize the importance of assessing general resilience in addition to the specified resilience. In this context, they (Walker & Salt, 2012) recommend analysing the changes in main attributes of the system and determine; diversity, openness, reserves, feedbacks, modularity, and levels of different types of capital as the main attributes of general resilience.

Transformability

Describing transformability as "the capacity to effect transformational change", Walker and Salt (2012, p. 100) state that it "is part of the suite of capacities that add up to a system's resilience". Additionally, they (Walker & Salt, 2012) emphasize that the resilience of system in one scale could depend on the transformation in another scale. Therefore, transformability or transformative capacity of the system is also assessed in this step of resilience assessment. To that end, three main attributes of the system's transformability, that were described as: "Getting beyond the state of denial", "Creating options for transformational change" and "Having the capacity for transformative change" by Walker and Salt (2012, p. 101), are analysed and transformative capacity of the system is determined (see Figure 2.21).

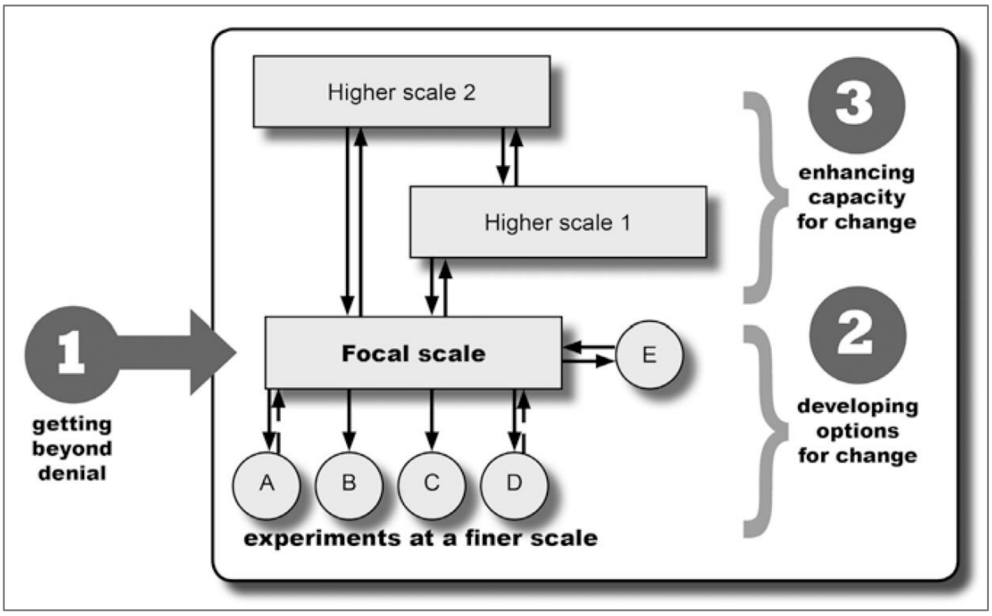

Figure 2.21: The Components of Transformability
(Walker & Salt, 2012, p. 102)

Step 3: Managing Resilience

Following the description of the system and assessment of its resilience, all possible interventions for its management are determined with their sequence in this step of the framework. Walker and Salt (2012, p. 118) describe four main kinds of interventions as: "Management (changes in recommended management)", "Financial intervention (assistance, investments, subsidies, taxes)", "Governance/institutions (including laws and regulations, policies)" and "Education/information (to influence behavior)", and underline the importance of determining these interventions and their sequence with participation of a group of stakeholders from different disciplines and positions. They (Walker & Salt, 2012) also emphasize the importance of analysing existing plans and policies with a resilience thinking perspective for identifying their shortcomings. After identifying the shortcomings of existing interventions, an adaptive management framework is developed for the system. In this context, all possible interventions are determined with their target phases on the adaptive cycles of the system. Hence, when and where to intervene in an adaptive cycle is identified for each scale. Options for transformability are also considered in this step (Walker & Salt, 2012).

2.1.3.5 Resilience Thinking in Planning (RTP) Framework by Pinho, Oliveira and Martins, 2013 (Pinho, Oliveira, & Martins, 2013)

Acknowledging the lack of evaluation of resilience-based planning in the literature Pinho et al. (2013) develop an evaluation methodology for SUPER-Cities (Sustainable Land Use Policies for Resilient Cities) project. They propose "Resilience Thinking in Planning (RTP)" model for investigating a resilience perspective in planning processes (of case studies in Lisbon, Oporto, İstanbul, Stockholm and Rotterdam). As an integrated evaluation approach, RTP evaluates planning documents and processes with their implementation and impacts on the territory and society (Pinho et al., 2013). RTP follows seven integrated stages (Pinho et al., 2013, p. 139):

1. "Identification of key territorial issues"
2. "Selection of relevant planning documents"
3. "Identification of resilience-related policies and measures"
4. "Selection of appropriate resilience attributes"
5. "Formulation of the evaluation questions"
6. "Selection of the dimensions of resilience and corresponding indicators"
7. "Synthesis and critical appraisal of the evaluation results"

Key territorial issues or problems of the system are identified in the first stage of RTP. This stage includes identification of former changes and current vulnerabilities of the system. In second stage, planning documents about the identified issues are selected. Resilience related policies and measures, that will be the main object of evaluation, are explored from the selected documents in the third stage. In the fourth stage, resilience attributes which are relevant to the case study and key territorial issues will be selected. Pinho et al. (2013, p. 140) present these attributes as; "recovery, connectivity, capital building, adaptability, robustness, flexibility and transformability". In the fifth stage, evaluation questions are formulated for the selected attributes. These questions are operationalized in the sixth stage. Resilience indicators are defined for each question in this stage. Finally, results of the evaluation are synthesized in the last stage of RTP.

2.2 -SLEUTH CELLULAR AUTOMATON MODEL

SLEUTH is a self-modifying, scale-independent and universally applicable cellular automaton (CA) model that was based on the growth principles of Clarke wildfire model (Clarke, Brass, & Riggan, 1994). It was developed by Keith C. Clarke (Professor of Geography) as a computer program in C programming language for UNIX operating systems. Initially the model (then called the Clarke Cellular Automaton Urban Growth Model) was developed for understanding and predicting the dynamics of urban growth (Clarke, Hoppen, & Gaydos, 1996). Later, with the inclusion of land-use layers (Clarke, 1997), model gained another ability for modelling the land-use change dynamics and took the name of SLEUTH as an acronym for the capital letters of its input layers (Slope, Land-use, Exclusion, Urban, Transportation and Hill-shade).

Today, SLEUTH is composed of two tightly coupled models for simulating urban growth (Clarke Urban Growth Model - UGM) and land-use change (Deltatron Land Cover Model - LCM). These two sub-models run in sequence and land cover change in Deltatron LCM follows the urbanization in Clarke UGM. Although these two components could be used for understanding the dynamics of urban growth and land cover change, only Clarke UGM provides a prediction mode. Deltatron LCM does not run in prediction mode. Thus land cover changes could not be forecasted by the model.

2.2.1 Clarke Urban Growth Model

2.2.1.1 Input Data

As it was mentioned before, SLEUTH is a universally applicable model. Application of the model for different case areas could be achieved through adaptation of its scenario files and input layers. Input layers provide spatial attributes of the case area (locality) while scenario files determine the parameters of the model. Therefore, input layers should be prepared for each case area in terms of the format required by the model while scenario files should be edited for each model run. Sample scenario files for Democity case, which was provided in the

SLEUTH folder, could be adapted for different case areas through text editors of UNIX. Main properties of input layers and scenario files are explained in details below.

2.2.1.1.1 Input layers

Current version of the model requires at least five types of input layers (six if land cover changes would also be simulated). One slope, one exclusion, one hill-shade, at least two transportation and four urban images are needed to simulate urban growth. Also, to simulate land cover changes, at least two land-use images should be added. All input images should be in 8-bit unsigned greyscale GIF (Graphics Interchange Format) image format to be recognized by the model. They should also have a consistent number of rows and columns with same resolution. In addition, they should be derived from grids of same map extent and projection. At last, input images should be named in the required naming format and placed under a defined input directory.

Having an 8-bit greyscale image format, input images provide 256 different cell values between 0 and 255. In all input images, 0 is a non-existent value, whereas values from 1 to 255 are existing values. However, classification and range of the values vary for each input layer.

- ***Urban layer:*** The model requires at least four urban images of different time periods with a binary classification of urban and non-urban grids. Cell values of urban images range between 0 and 255. Non-urban fields take the value of 0 while the values of urban pixels range between 1 and 255. Cell values of urban areas are generally set to 255.
- ***Transportation layer:*** The model requires at least two transportation images for different time periods. Transportation images could have a binary classification of road and non-road grids. But also, road cells could have relative values depending on the weighting of accessibility. Therefore, the values of road cells could range between 1 and 100 or have relative values

(like 25, 50 and 100 for low, medium and high accessibility, respectively) while non-road cells should have the value of 0.

- ***Slope layer:*** The model requires one slope image with cell values denoting percent slopes. Cell value range for slope layer is defined as 0 to 100 and therefore cell values higher than 100 are read as 100 by the model.
- ***Exclusion layer:*** The model requires one exclusion image with cell values ranging between 0 and 100. Exclusion image provides the information about the areas that urban growth is restricted. Level of exclusion might vary depending on the level of restrictions on the excluded areas. Therefore, depending on the level of exclusion, values of the excluded cells might range between 1 and 100 while cells without any restriction would take the value of 0.
- ***Hill-shade layer:*** The model requires one hill-shade image as background for the output images of the model.
- ***Land-use layer:*** The model requires at least two land-use images of different time periods with same number of land-use classes. Cell values of land-use images range between 0 to 255 and values of land-use classes could be arranged in terms of the land cover colour-table (provided in the Scenario Files).

2.2.1.1.2 Scenario files

Scenario files provide main guidelines of the model. They present adaptable parameters of the model that could be edited in terms of the attributes of each case. Preferences of implementers could also be reflected in scenario files. They are simply text files that include information about key parameters of the model. Main sections of a scenario file are outlined below. Under each title, instructions and information about different sets of model parameters are provided.

I. Path Name Variables: This section provides the instructions and information about location and naming of input and output file folders.

II. Running Status (Echo): This section provides the instructions and information about running status preferences.

III. Output ASCII Files: This section provides the instructions and information about output file preferences.

IV. Log File Preferences: This section provides the instructions and information about log file preferences.

V. Working Grids: This section provides the instructions and information about working grid numbers.

VI. Random Number Seed: This section provides the instructions and information about random seed numbers.

VII. Monte Carlo Iteration: This section provides the instructions and information about Monte Carlo Iteration numbers.

VIII. Coefficients: This section provides the instructions and information about start, step and stop values of control parameters (diffusion, breed, spread, slope-resistance and road-gravity coefficients) for both calibration and prediction modes.

IX. Prediction Date Range: This section provides the instructions and information about start and stop dates of the prediction period.

X. Input Images: This section provides the instructions and information about naming of input images (layers).

XI. Output Images: This section provides the instructions and information about output image preferences.

XII. Colour Table Settings: This section provides the instructions and information about colour preferences for output images.

XIII. Self-Modification Parameters: This section provides the instructions and information about values of self-modification parameters such as; road gravity sensitivity, slope sensitivity, critical low, critical high, critical slope, boom and bust.

Compressed folder of the model, which could be downloaded from the web page of Project Gigalopolis, includes sample scenario files for test, calibration and prediction modes of the Democity case. These scenario files could be edited in terms of the attributes and preferences of the specific case, by one of the text editors of UNIX (such as “Nano” or “Pico”).

2.2.1.2 Growth Cycles

The model simulates urban growth through iterative growth cycles. Each growth cycle is equivalent of a year. Total number of the growth cycles depends on the number of growth years (from seed year to final year) and Monte Carlo iterations, which are determined in the scenario files of the model. In other words, the total number of growth cycles is a product (multiplication) of the numbers of growth years and Monte Carlo iterations. A growth cycle is composed of four phases that are the growth types in sequence. Spontaneous, diffusive (new spreading centres), organic (edge) and road-influenced growth types take place sequentially (Figure 2.22). Five behavioural parameters (diffusion, breed, spread, slope-resistance and road-gravity coefficients) control the execution of these growth types. After each cycle, the growth rates are calculated and if they pass a critical threshold (upper or lower limits of growth) than the behavioural factors are adjusted in terms of the self-modification[1] parameters in the scenario files (Candau, 2000; Candau, Rasmussen, & Clarke, 2000; Clarke, Hoppen, & Gaydos, 1997; Jantz, Goetz, & Shelley, 2003).

[1] "Self-modification" function of the model is explained below.

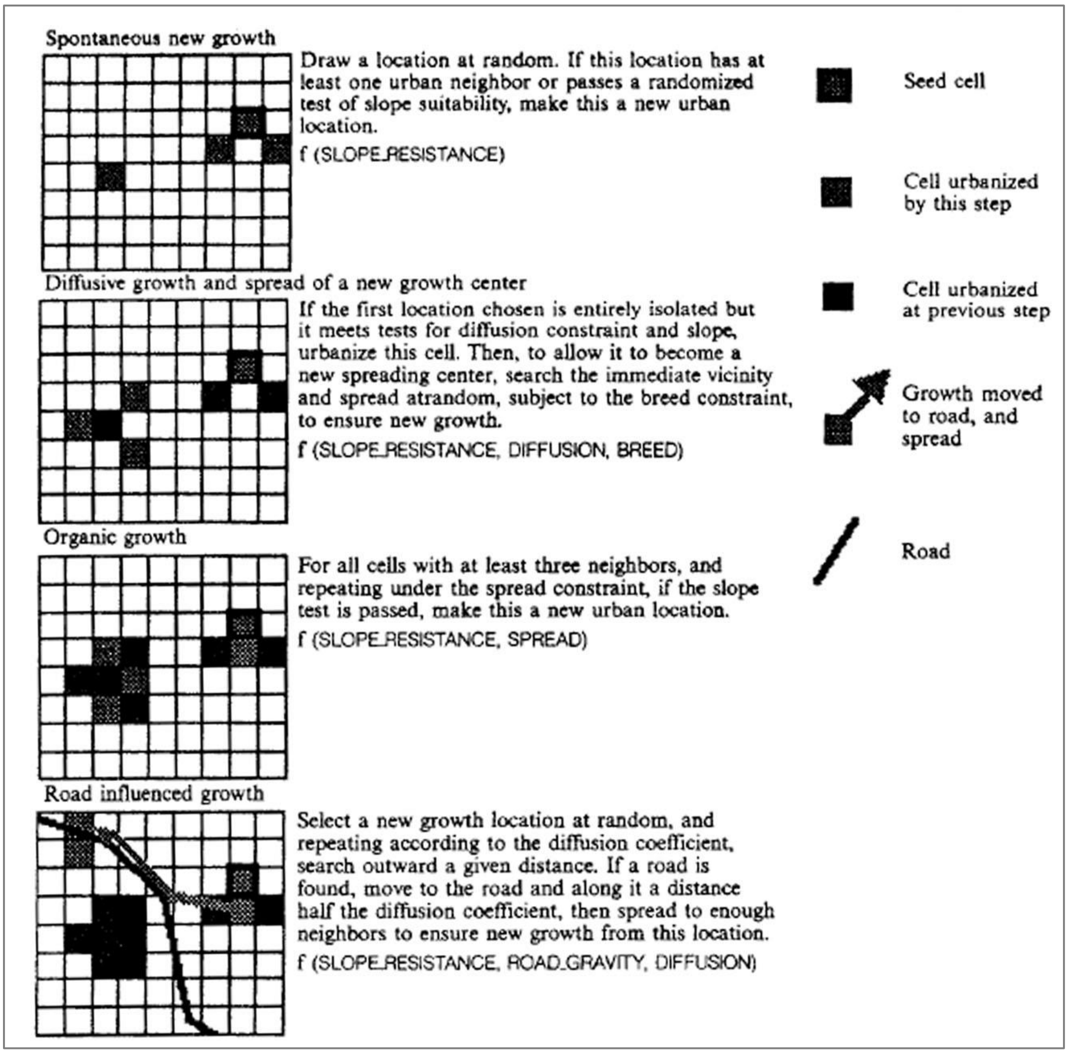

Figure 2.22: Growth types
(Clarke et al., 1997, p. 253)

2.2.1.2.1 Growth coefficients (control parameters)

Set by the user for every model run, following coefficients (with values ranging between 0 and 100) control the behaviour of the system (Clarke & Gaydos, 1998; Clarke et al., 1997; Dietzel & Clarke, 2004; Jantz et al., 2003; Silva & Clarke, 2002):

- *Diffusion (or dispersion) coefficient* controls the level of dispersion or distribution of the change (urbanization) in landscape. It determines the probability of a non-urbanized cell to urbanize randomly.

- *Breed coefficient* determines the probability of a newly generated urban cell to start its own growth cycle.
- *Spread coefficient* controls the level of spread or "organic" expansion of urbanization from the existing or newly established settlements.
- *Slope-resistance (or slope) coefficient* determines the probability of urbanization in steep slopes. Higher values of slope resistance factor mean lower probability of urbanization in steeper slopes.
- *Road-gravity coefficient* determines the influence of transportation systems on attracting/drawing new settlements or development.

2.2.1.2.2 Growth types

As it was mentioned before, each growth cycle is composed of four sequential phases of; spontaneous, diffusive (new spreading centres), organic (edge) and road-influenced growth types. Different sets of growth coefficients control the process of urban growth in each growth phase (Table 2.16). These phases of urban growth and their relations with the growth coefficients are explained in details below.

Table 2.16: Growth types and coefficients
(Jantz et al., 2003, p. 254)

Growth cycle order	Growth type	Controlling coefficients	Summary description
1	spontaneous	dispersion	Randomly selects potential new growth cells.
2	new spreading center	breed	Growing urban centers from spontaneous growth.
3	edge	spread	Old or new urban centers spawn additional growth.
4	road-influenced	road-gravity dispersion, breed	Newly urbanized cell spawns growth along transportation network.
Throughout	slope resistance	slope	Effect of slope on reducing probability of urbanization.
Throughout	excluded layer	user-defined	User specifies areas resistant or excluded to development.

Phase 1 - Spontaneous (Neighbourhood) Growth

This first phase of the Clarke UGM simulates random urbanization of the land. In this growth type, a randomly chosen cell becomes urban if it is suitable for urbanization (Figure 2.23). Suitability of the selected cell is determined by the current condition of the cell with dispersion and slope coefficients. If the cell is already urban or defined as excluded it is not suitable for a change. Dispersion coefficient determines the probability of spontaneous urbanization for any given cell while slope coefficient determines the influence or weight of local slope on urbanization (Candau, 2000; Clarke & Gaydos, 1998; Clarke et al., 1997; Jantz et al., 2003; Silva & Clarke, 2002).

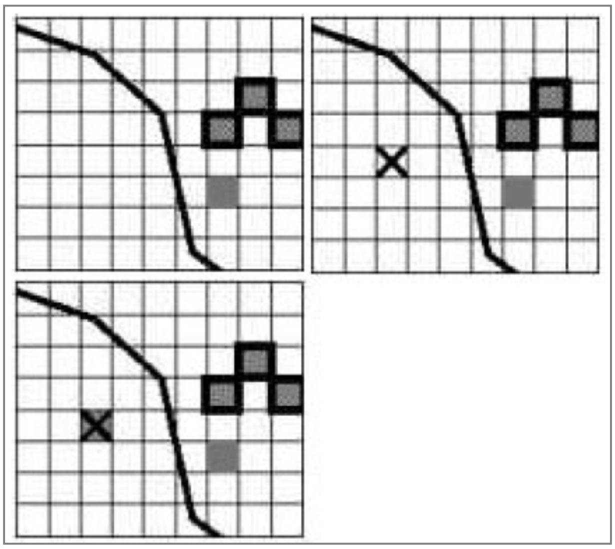

Figure 2.23: Spontaneous growth process
(Adapted from Candau et al., 2000)

Phase 2 - New Spreading Centre (Diffusive) Growth

Urbanization spreads through newly urbanized cells from spontaneous growth phase of the model (Figure 2.24). Depending on the breed coefficient and availability of neighbouring cells for urbanization, newly urbanized cells could become the centres of spreading growth in this second phase. Breed coefficient determines the probability of newly urbanized cells to be the centres of spreading growth. It determines the amount (percentage) of the cells that could become new growth centres. In addition, at least two neighbours of the newly urbanized cells should be suitable for urbanization. In other words, their slopes and current conditions should be available (Candau, 2000; Jantz et al., 2003; Silva & Clarke, 2002).

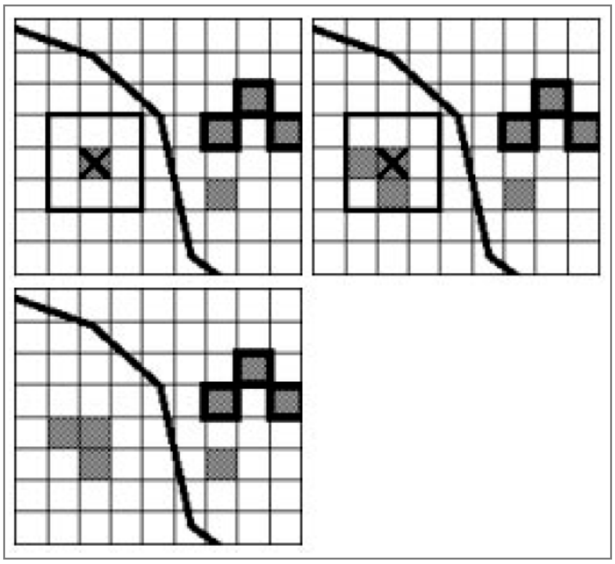

Figure 2.24: New spreading centre growth process
(Adapted from Candau et al., 2000)

Phase 3 – Organic (Edge) Growth

Organic growth phase of the model simulates outward (expansion) and inward (infill) growth from both the new and the existing urban centres (Figure 2.25). Organic growth takes place in the edge of urban centres and depends on the spread coefficient. Spread coefficient determines the probability of non-urbanized cells with at least three urban neighbours to become urban. These neighbours could be urbanized in this time step (*t+1*) or earlier. As always, urbanization of non-urban cells depends on the slope coefficient and slopes of the selected cells (Candau, 2000; Candau et al., 2000; Clarke & Gaydos, 1998; Clarke et al., 1997; Jantz et al., 2003; Silva & Clarke, 2002).

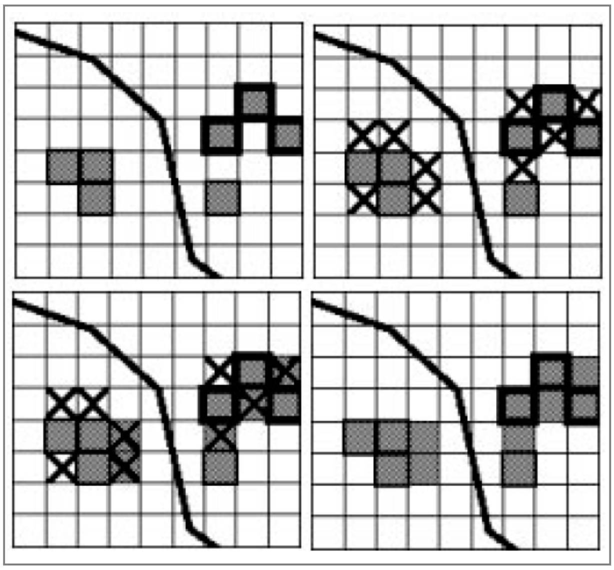

Figure 2.25: Edge growth process
(Adapted from Candau et al., 2000)

Phase 4 - Road Influenced Growth

Influence of transportation networks on the urbanization process is simulated in this phase of the model (Figure 2.26). Urban growth is drawn towards existing roads through a complex process in the road influenced growth phase (Candau, 2000; Clarke & Gaydos, 1998; Clarke et al., 1997; Silva & Clarke, 2002). First, depending on the breed coefficient some percent of the newly urbanized cells (at time $t+1$) are selected. Then, existence of a road within a maximum radius of the selected cell is searched. This maximum radius or distance is defined by the road gravity coefficient. If there is a road within the radius than a temporary urban cell is generated at the closest location of the selected cell adjacent to the road. Than depending on the dispersion coefficient, temporary urban cell searches for a permanent location and becomes a new spreading growth centre. One or two suitable neighbours of the permanent cell also become urban (Candau et al., 2000; Jantz et al., 2003). Suitability of the cells depends on their current conditions and the slope coefficient as always.

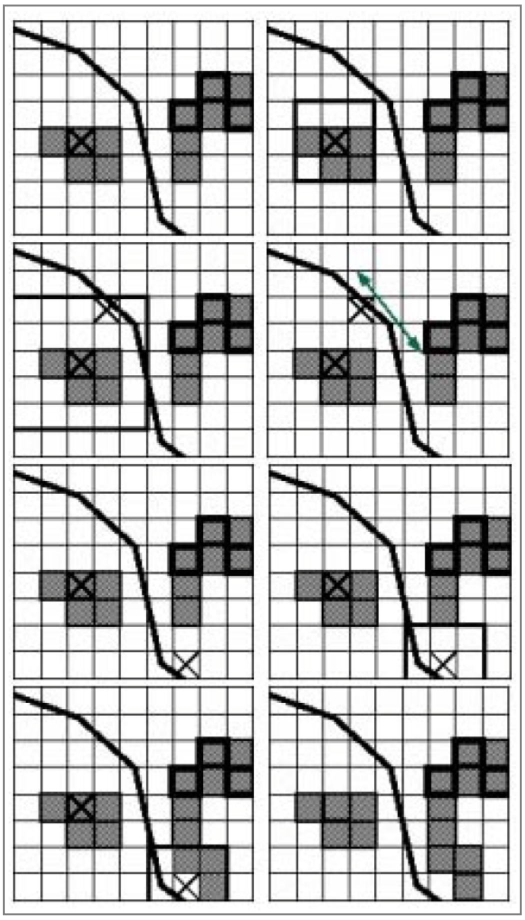

Figure 2.26: Road-influenced growth process
(Adapted from Candau et al., 2000)

2.2.1.2.3 Self-modification

At the end of each growth cycle, the model modifies itself based on the pre-determined parameters of self-modification. Self-modification parameters could be classified as thresholds and multipliers. The thresholds are the limit values that the self-modification is based on, whereas the multipliers are the growth constants that the model uses for modification. These parameters could be listed as follows:

- *road gravity sensitivity* (a multiplier with “0.01” default value)
- *slope sensitivity* (a multiplier with “0.1” default value)
- *critical low* [lower limit of growth] (a threshold with “0.97” default value)
- *critical high* [upper limit of growth] (a threshold with “1.3” default value)

- *critical slope* [maximum value of the percent slope that urbanization can take place] (a threshold with “15.0” default value)
- *boom* [constant value higher than “1.0”] (a multiplier with “1.01” default value)
- *burst* [constant value lower than “1.0”] (a multiplier with “0.09” default value)

If annual growth rate (new urbanized pixels over total existing urban pixels) exceeds the upper limit of growth (critical high), than the diffusion, breed and spread coefficients are multiplied by a (boom) constant higher than 1.0 (Figure 2.27a). Thus, the model imitates “the tendency of an expanding system to grow ever more rapidly" (Clarke & Gaydos, 1998, p. 705). For controlling the rate of growth and preventing uncontrolled exponential growth, applied multiplier is decreased each year. On the other hand, if the growth rate for any year (growth cycle) falls below the lower limit of growth (critical low), the diffusion, breed and spread factors are multiplied by a (burst) constant lower than 1.0 (Figure 2.27c). In addition to these modifications, the road-gravity factor increases with the developing road network, while the slope-resistance factor is decreased with decreasing amount of areas suitable for development (Figure 2.27b).

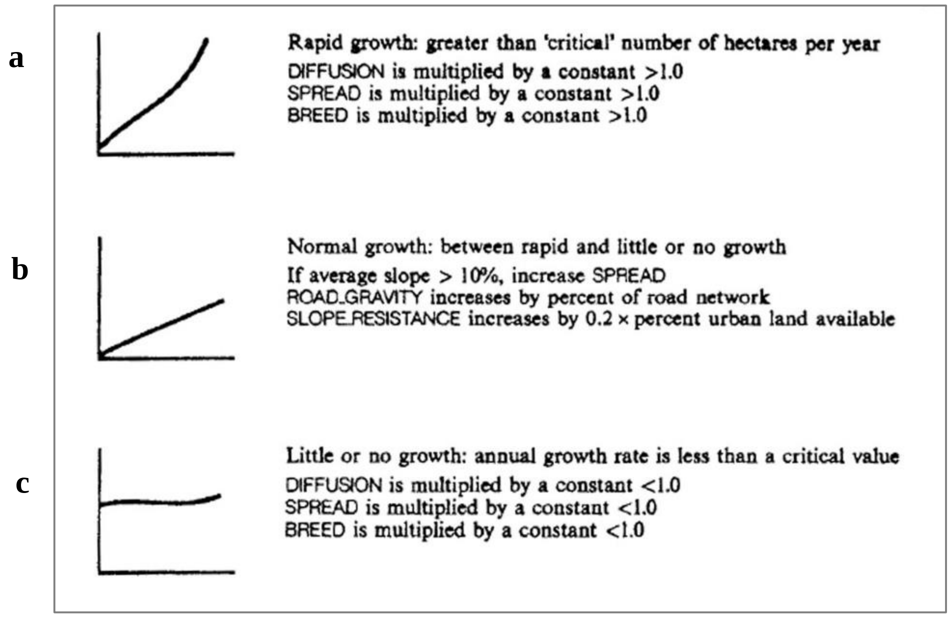

Figure 2.27: Self-modification adjustments
(Clarke et al., 1997, p. 255)

In self-modification process, values of the parameters rapidly increase in the beginning of the cycle and decrease with the decreasing level of land available for urbanization. Thus, self-modification attribute of the model provides S-curve growth patterns while traditional CA models provide linear or exponential growth patterns (Clarke & Gaydos, 1998; Clarke et al., 1996, 1997; Jantz et al., 2003; Silva & Clarke, 2002)

2.2.1.2.4 Calibration

Application of the model to different urban settings or cases is achieved by the calibration process. It allows the model to be modified for different localities. Calibration is a process of determining the best parameter values for the model to simulate the case area. In this context, observed historical values are compared with the model values until the best fit is reached (Candau, 2000; Clarke & Gaydos, 1998; Clarke et al., 1996, 1997; Silva & Clarke, 2002). Silva and Clarke (2002, p. 529) quotes from Birkin et al. (1996, p.93) and stress that "the key component of the modeling process [...] is calibration: the process by which numerical values are assigned to the model parameters in such a way that the model accurately reproduces the real patterns". They (Silva & Clarke, 2002, p. 529) also add that an "absence of a calibration phase in model development and application reflects poorly on a model's applicability, verifiability, portability and robustness".

In the first (original) version of the model (Clarke et al., 1996, 1997), calibration process was composed of two phases; visual and statistical. Similarity of the shapes and extents of real and modelled urban cover was visually tested in the first phase. Two different programs were developed and used for illustrating the results of different parameter value combinations. Using the Silicon Graphics tools (graphical user-interface tools), the first program "allowed easy animation and display of the resulting images" (Clarke et al., 1996). The second program, which was an X Window System version using XView toolset, provided slide bars for controlling the parameter values during the model run and allowed starting and stopping the execution when necessary (Clarke et al., 1996). A set of measures were used for visual comparison of the observed and predicted urban extent. Centres of gravity for observed and predicted distributions were determined by symbols and compared. In addition, circles were drawn on the mean centres of predicted distributions for following the temporal change of the distribution. Also "urban pixels were color-coded by which cellular automaton rule had invoked their transition" (Clarke et al., 1996).

In the second "graphics-free" phase of the calibration, observed and predicted distributions are compared in terms of statistical measures and scores. Four statistical measures of; total area, number of edge pixels, number of clusters and Lee-Sallee shape index were recorded into a set of log files for further calculations and comparisons (Clarke et al., 1996).

Later, Clarke and Gaydos (1998) provided multi-scale calibration process to speed up the calibration process [for the first time]. They run a two-step (coarse and fine) calibration process for four different resolutions (210 m (486 x 720 pixels), 420 m (243 x 360 pixels), 840 m (121 x 180 pixels), 1680 m (60 x 100 pixels)). At the end, the processing time decreases from 252 hours to 6 hours of CPU time for 210 m to 1640 m resolutions, respectively (Clarke & Gaydos, 1998). Candau (2000) uses a three-step (coarse, fine and final) calibration process that requires "all input images to be rescaled to half and one quarter of their original resolution" (Table 2.17). She (Candau, 2000) uses a special C program called "halfgif" to rescale the input data. This program also rescales the road data to twice of its original size to preserve its linearity during the change of resolution.

Success of prediction mode of the model highly depends on the performance of the calibration mode (Silva & Clarke, 2002). Through three phases of calibration (coarse, fine, final), known as 'brute force calibration', values of the model parameters are tested and adjusted for the study area (Table 2.18). Determined in the calibration phase, the values of the parameters are used for predicting the future of the study area (Silva & Clarke, 2002).

Table 2.17: Three phases of calibration in Candau, 2000 (30 m binary grids)

	Full Resolution	Half Resolution	Quarter Resolution
Calibration Phase	Final	Fine	Coarse
Rows x Columns	428 x 1751	214 x 875	107 x 437
Pixel Count	749 428	187 250	46 759

Table 2.18: Calibration results for Lisbon and Porto Metropolitan Areas (Silva & Clarke, 2002, p. 543)

	AML			AMP		
Score/resolution	784×836	392×4181	196×209	347×563	173×281	86×140
Composite score	0.15	0.19	0.23	0.48	0.47	0.41
Compare	0.90	0.88	0.97	0.97	0.99	0.94
r^2 Population[a]	0.91	0.91	0.92	0.99	0.99	0.99
Edges r^2	0.78	0.99	0.98	0.98	0.99	0.98
Cluster r^2	0.85	0.85	0.93	0.99	0.95	0.97
Leesalle	0.35	0.34	0.32	0.58	0.57	0.53
Diffusion	16	20	1	20	40	1
Breed	57	51	100	20	1	100
Spread	50	50	50	40	35	50
Slope	25	25	25	45	40	50
Roads	30	30	20	20	25	75

[a] Population indicates no. of urban oixels.

Jantz et al. (2003) entitle three (course, medium and fine) phases calibration process as 'brute force Monte Carlo method'. They (Jantz et al., 2003) only mention compare, population and Lee and Sallee statistics as the comparison metrics of calibration process (Table 2.19). Also they did not use the hierarchical scale approach of changing resolutions.

Table 2.19: Calibration results Baltimore-Washington Metropolitan Area (Jantz et al., 2003, p. 262)

	Growth parameter				
	dispersion	breed	spread	slope	road growth
Coarse calibration					
Range	1-100	1-100	1-100	1-100	1-100
Step	25	25	25	25	25
Monte Carlo iterations = 4					
Total number of simulations = 3 125					
Compare statistic = 1.00					
Population statistic (r^2) = 0.86					
Lee and Sallee statistic = 0.67					
Medium calibration					
Range	40-90	30-75	20-30	1-5	0-25
Step	10	15	2	1	5
Monte Carlo iterations = 7					
Total number of simulations = 3 600					
Compare statistic = 1.00					
Population statistic (r^2) = 0.86					
Lee and Sallee statistic = 0.68					
Fine calibration					
Range	50-60	45-55	23-28	3-8	15-20
Step	2	2	1	1	1
Monte Carlo iterations = 9					
Total number of simulations = 7 776					
Compare statistic = 1.00					
Population statistic (r^2) = 0.86					
Lee and Sallee statistic = 0.68					
Final coefficient values	52	45	26	4	19

For comparison of observed and modelled distributions four statistical measures were used in the initial applications (Clarke & Gaydos, 1998; Clarke et al., 1996, 1997) of the urban growth model. These were the Pearson's r^2 values of (r-squared fit between (Clarke & Gaydos, 1998)) modelled and real distributions for: total area (converted to urban use), number of edge pixels (pixels with non-urban cell neighbours), and number of pixel clusters with Lee-Sallee shape index (ratio of intersection of modeled and observed urban layers over their union (Lee & Sallee, 1970)). A combined score is calculated by multiplying the Lee-Sallee index with the sum of first three measures. First three measures are the r^2 values of correlations between observed (actual) and predicted values while Lee-Sallee index is a measure of spatial fit between the shapes of observed and predicted distributions (Clarke & Gaydos, 1998; Clarke et al., 1996).

In Portuguese application by Silva and Clarke (2002), the model computes 13 different measures (scores) [for all scores, value of 1.0 is equal to exact match of modelled to control data]:

1. Composite score: all 12 scores multiplied together
2. Compare: comparison of the final urban pixels in the modelled to real distributions
3. r^2 Population (number of urban pixels): "least squares regression score for modeled urbanization compared with actual urbanization for the control years" (Silva & Clarke, 2002, p. 549)
4. Edge_r^2: "least squares regression score for modeled urban edge count compared with actual urban edge count for the control years" (Silva & Clarke, 2002, p. 549)
5. r^2_Cluster: "least squares regression score for modeled urban clustering compared with known urban clustering for the control years" (Silva & Clarke, 2002, p. 549)
6. Mean_cluster_size_r^2: "least squares regression score for modeled average urban cluster size compared with known mean urban cluster size for the control years" (Silva & Clarke, 2002, p. 549)
7. Lee-Sallee: "a shape index, a measurement of spatial fit between the model's growth and the known urban extent for the control years" (Silva & Clarke, 2002, p. 549)

8. Average_slope_r^2: "least squares regression of average slope for modeled urbanized cells compared with average slope of known urban cells for the control years" (Silva & Clarke, 2002, p. 550)
9. pct_Urban_r^2: "least squares regression of percent of available pixels urbanized compared with the urbanized pixels for the control years" (Silva & Clarke, 2002, p. 550)
10. xmu_r^2 (centre of gravity [x]): "least squares regression of average x_values for modeled urbanized cells compared with average x_values of known urban cells for the control years" (Silva & Clarke, 2002, p. 550)
11. ymu_r^2 (centre of gravity [y]): "least squares regression of average y_values for modeled urbanized cells compared with average y_values of known urban cells for the control years" (Silva & Clarke, 2002, p. 550)
12. sdist_r^2: "standard deviation averaged over (XY)" (Silva & Clarke, 2002, p. 550)
13. lu_Value: "a proportion of goodness of fit across landuse classes" (Silva & Clarke, 2002, p. 550)

In their application of Deltatron land cover change model, Dietzel and Clarke (2004) use five different metrics of: compare statistic, population statistic (least squares regression score (r^2) for modelled to actual urban pixels), Lee-Sallee metric, F-match statistic (proportion of goodness of fit across land-use classes) and a composite score (a product (multiplication) of the former four metrics).

2.2.2 Deltatron Land Cover Change Model

Tightly coupled to and driven by the Clarke UGM, the Deltatron LCM uses same calibration process with the UGM. Unlike UGM, Deltatron LCM requires at least two land-use images to be activated (Candau & Clarke, 2000; Clarke, 1997). Deltatron LCM operates through three different types of land use transitions that are; state changes, neighbourhood transitions and discrete location changes (Dietzel & Clarke, 2004). Transitions from one land-use class to another (e.g. from forest to agriculture) are the state changes. Neighbourhood transitions take place when the transition of a cell influences the transition of similar neighbouring cells. On the other hand, discrete location change occurs when a specific cell transforms on an individual level due to the influence of neighbouring cells (Dietzel & Clarke, 2004). For example, a transition from forest to agriculture in the neighbouring cells of a water cell would trigger a transition to wetland from water. Thus, the land cover might change in three different ways. First, a new and different land cover type might be introduced in a homogenous neighbourhood. Second, a land cover type might expand into another one when two meet. In another word, it might grow into its neighbours. The third way is the spread of change. Once started, land cover transition might continue and spread across the landscape (Candau & Clarke, 2000; Candau et al., 2000). These transitions are driven and influenced by three parameters that are referred to as; (1) transition matrices, (2) topography (principally slope), and (3) urbanization (Candau & Clarke, 2000; Dietzel & Clarke, 2004).

2.2.2.1 Control Parameters

2.2.2.1.1 Transition matrices

In Deltatron LCM, two transition matrices are used for estimating the probabilities of transitions among different land use classes (Clarke, 1997). First, the transition matrix L is computed depending on the numbers of land use changes between each couple of land use classes. It is assumed that there are same numbers of land use classes for at least two identical land cover maps with same extent and resolution at different time periods (Clarke, 1997). Assuming that there are "n" number of land use classes at time 0 and time 1, an "n x n" transition matrix L can be computed. Counts of transitions among each couples of land use types are entered in the related cells of the L matrix.

Example:

"n" (number of land use classes at time 0 and time 1) = 3, Land use classes: a, b, c

Δt = time 1 - time 0

L matrix (#)

	a	b	c	∑
a	# (a, a)	# (a, b)	# (a, c)	A
b	# (b, a)	# (b, b)	# (b, c)	B
c	# (c, a)	# (c, b)	# (c, c)	C

T matrix (%)

	a	b	c	
a	# [(a, a) / A] / Δt	# [(a, b) / A] / Δt	# [(a, c) / A] / Δt	1
b	# [(b, a) / B] / Δt	# [(b, b) / B] / Δt	# [(b, c) / B] / Δt	1
c	# [(c, a) / C] / Δt	# [(c, b) / C] / Δt	# [(c, c) / C] / Δt	1

Then, dividing each cell by its row sum, the T matrix of transition probabilities is computed. Each cell of the T matrix defines the probability of transition among each couples of land use types (Clarke, 1997). T matrix is normalized by the number of years between land cover layers (or control years) so that it gives the annual probability of change between land-use classes (Candau & Clarke, 2000; Dietzel & Clarke, 2004). This T matrix is also known as the Markov transition matrix (Dietzel & Clarke, 2004).

2.2.2.1.2 Topography

In addition to the Markov transition matrix, slopes of the cells also influence the transitions between land-use classes (Dietzel & Clarke, 2004). Prior to probability testing for transition, average slopes of randomly selected land use classes are compared with slope of the selected cell and the class with most similar slope to the selected cell pasts the test (Candau & Clarke, 2000; Dietzel & Clarke, 2004).

2.2.2.1.3 Urbanization

In a land cover context of the cities, urbanization is the driving force of other land cover transitions. Converting unsettled lands to settlement areas, urbanization triggers further land use transitions in the vicinity (Clarke, 1997). Thus, urban growth output from UGM determine the level of land cover transition in this part of the model (Candau & Clarke, 2000; Dietzel & Clarke, 2004). Additionally, when a cell is urbanized it will not transform to another use throughout the model run. Hence urban is an "absorbing class" (Candau & Clarke, 2000) and the end state of any cell (Dietzel & Clarke, 2004). Since land cover transitions are driven by urbanization process, more deltatrons are created and spread during periods of rapid urbanization. On the other hand, during periods of slower urban growth, deltatron creation also slows down (Clarke, 1997, 2008). Controlled by these parameters, deltatrons ensure spatial and temporal autocorrelation of land cover transitions (Candau & Clarke, 2000; Candau et al., 2000). However, this is only true for the time period between two land use layers. Since these parameters are not updated, they cannot reflect future transitions (Clarke, 2008).

2.2.2.2 Deltatrons

Pixels or cells of changing land-use classes are called as "deltatrons" and they are established or "born" with any land-use transition (Dietzel & Clarke, 2004). A deltatron tends to stay in its new state for its lifetime. Therefore, the probability of an immediate state transition in a newly established deltatron is low (Dietzel & Clarke, 2004). As products of land-use change, deltatrons are also the “bringers" (Clarke, 1997, 2008) or "agents" (Candau & Clarke, 2000) of change within the landscape (Dietzel & Clarke, 2004, p. 527). They influence the neighbouring cells and promote similar transitions in them. Hence, change clusters are established in the vicinity of deltatrons and the probability of another class change is low in these clusters (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 1997). Deltatrons "die" when their lifetime ends or no further transition occur in their neighbourhood but some are also "killed" randomly (Clarke, 1997). Lifetime of the deltatrons is determined by the modeller therefore it can be used for calibration of the model (Candau & Clarke, 2000). Deltatrons occupy a separate space (deltatron space or deltaspace) and track the spatial and temporal locations of land cover transitions (Candau et al., 2000; Clarke, 2008). Deltatrons do not hold land use class values but they provide age and location values (Figure 2.28). In other words, they provide information about when and where has a land-use transition occurred (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 1997).

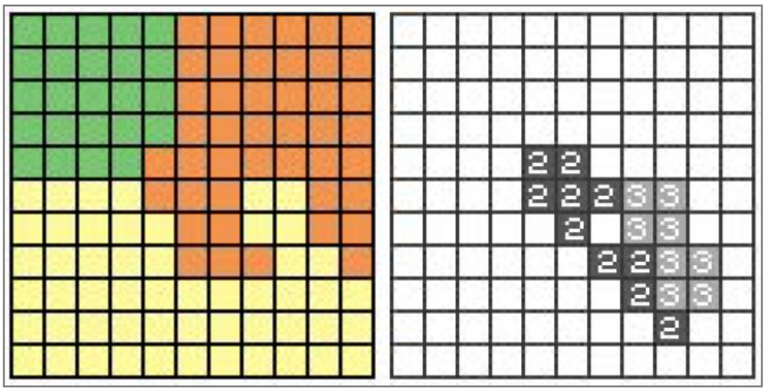

Figure 2.28: Land cover space (lattice) and deltatron space (deltaspace) (Candau et al., 2000)

2.2.2.3 Phases of Land Cover Transition

As a result of these attributes of the deltatrons, Deltatron LCM operates through two subsequent phases. Change is created in the first phase and it is spread into the landscape in the second phase (Dietzel & Clarke, 2004). Candau and Clarke (2000) explain these consecutive phases of the transition process with the metaphor of a stone dropped in a pool of water. First, the change was created then it was spread across the landscape as the spread of ripples following the drop of a stone into the water. On the other hand, Candau et al. (2000) and Clarke (2008) define land cover transition as a four-step process: (1) initiate change, (2) create change cluster, (3) propagate change, and (4) age deltatrons. Nevertheless, two phases are composed of these four steps. First two steps constitute 'Phase I' while the last two constitute 'Phase II'.

2.2.2.3.1 Phase 1 – Creation of landscape change

In first phase of Land Cover Transition model new deltatrons are born and aggregate in their vicinity. This phase of the model is composed of two sequential steps: initiate change and create change cluster (Figure 2.29).

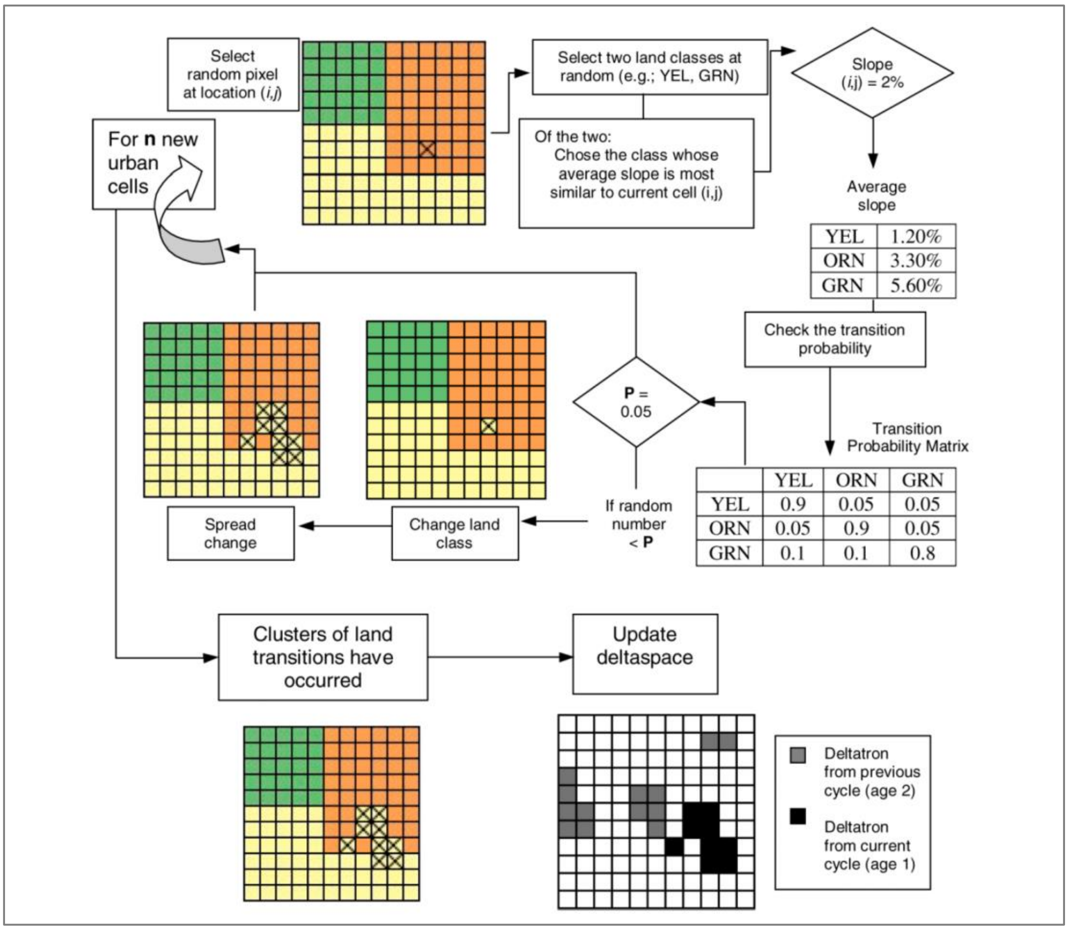

Figure 2.29: Phase I - Creation of landscape change
(Dietzel & Clarke, 2004, p. 528)

Step I: Initiate Change

Urbanization drives land cover transition in its vicinity. Therefore, landscape change starts following the urbanization in the current growth cycle of UGM. Newly urbanized cells trigger land cover change in their neighbourhood. Change starts with random selection of a non-urbanized cell. For a land cover change to occur, this cell: (i) should contain a land-use class value, (ii) should not be urbanized, (iii) should not have a present Deltatron (this should be the first land cover change), and (iv) should not be excluded from change (land-use classes like water, sea or protected areas) (Candau & Clarke, 2000; Candau et al., 2000; Dietzel & Clarke, 2004). Probability of land cover change is determined by the average slopes of each land use class, slopes of randomly selected cells and the history of land cover change (in terms of Markov transition probability matrix) (Candau et al., 2000; Clarke, 2008). Following the selection of suitable cell, two land use classes are chosen randomly. Average slopes of these classes are compared with the slope of current cell and the land-use class with the closest slope chosen. Then, transition probability from current land use class to chosen one is tested against a randomly chosen number. If the transition probability is higher than this number, then transition takes place and a new deltatron is created or "born". On the other hand, if the probability is lower than the selected number, transition fails and another cell is selected randomly (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 2008; Dietzel & Clarke, 2004). Each deltatron holds the information about its location and age (Figure 2.30).

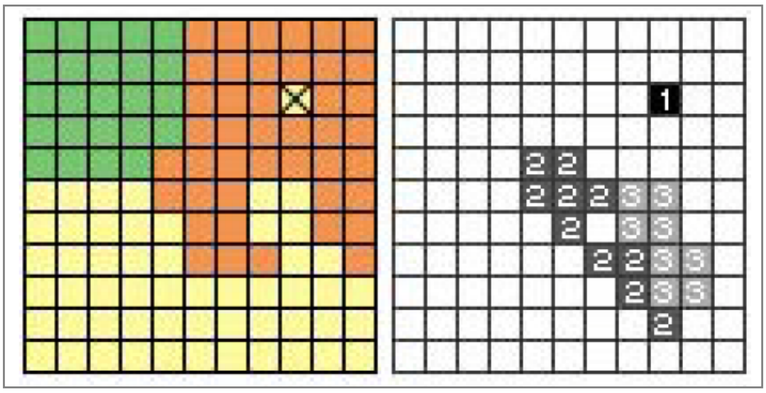

Figure 2.30: Step I - Initiate change
(Candau et al., 2000)

Step II: Create Change Cluster

Following the birth of new deltatrons in the first step, land cover transition aggregates through creation of change clusters. A *cluster-size* parameter controls the size of these clusters (Candau et al., 2000; Clarke, 2008). In this step, land cover change spreads to the neighbours of currently changed cell (Figure 2.31). Therefore, randomly selected neighbours are tested for transition to the land-use class of the currently changed cell. Unlike the first step, transition probability of the selected cells is tested for only the land-use class of the new deltatron. Hence, classes of the selected cells whether change to the associated deltatron's class or remain unchanged (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 2008; Dietzel & Clarke, 2004). At the end of this step, a deltaspace was created or updated with newly born deltatrons and their clusters. Deltaspace monitors age and location of each deltatron. Newly created deltatrons of this first phase take a value of 1 (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 2008; Dietzel & Clarke, 2004).

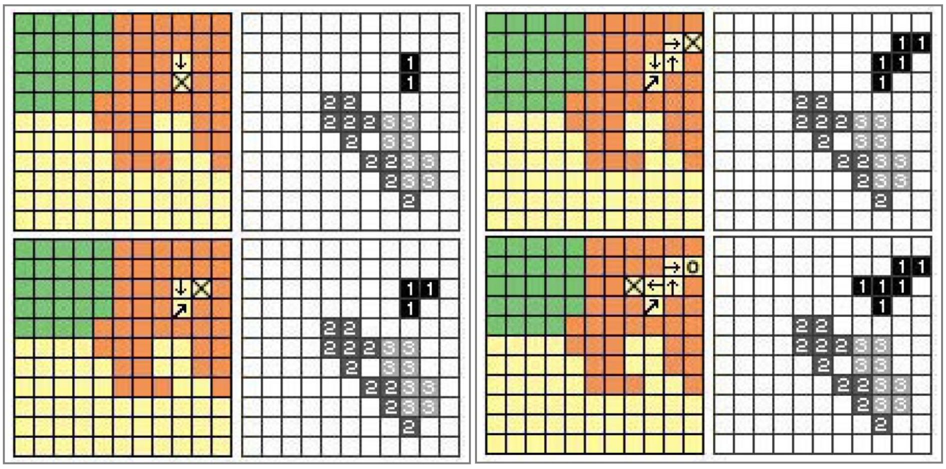

Figure 2.31: Step II - Create change cluster
(Candau et al., 2000)

2.2.2.3.2 Phase 2 – Propagation of landscape change

Depending on the landscape changes in previous time steps, transition propagates in this second phase of the model and the growth cycle of the current time step closes in the end. This phase of the model is composed of two sequential steps: propagate change and age deltatrons (Figure 2.32).

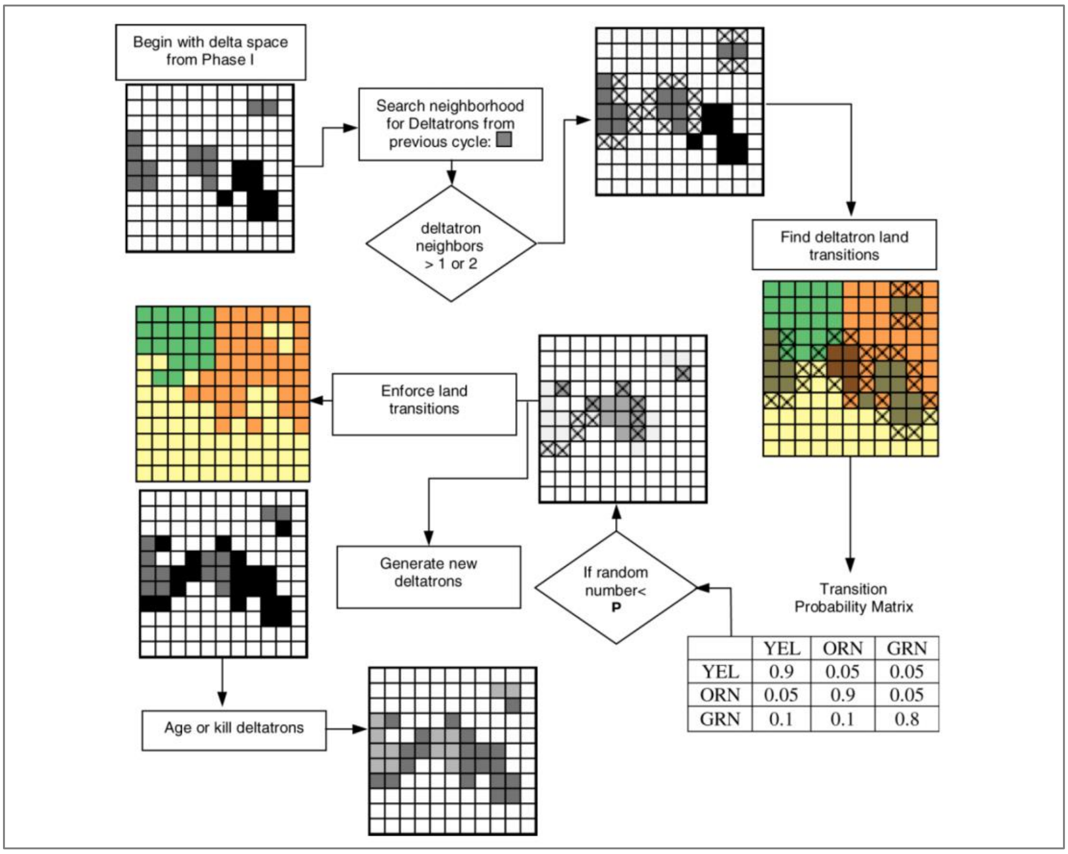

Figure 2.32: Phase II - Proliferation of landscape change
(Dietzel & Clarke, 2004, p. 529)

Step III: Propagate Change

Landscape change propagates with a similar way to the Organic (Edge) Growth of the UGM model (Figure 2.33). A randomly selected cell is first tested for its neighbours. If the cell has two or more deltatron neighbours that were created in the previous time steps (in other words, with an age of 2 or more) than a transition could take place. After a suitable cell was selected, its probability of transition to land use class of the neighbouring cells is tested. If transition probability is higher than a randomly drawn number, land use class of the cell changes to its neighbours' class, otherwise remains unchanged. With the update of deltaspace, newly created deltatrons take the value of 1 (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 2008; Dietzel & Clarke, 2004).

2004).

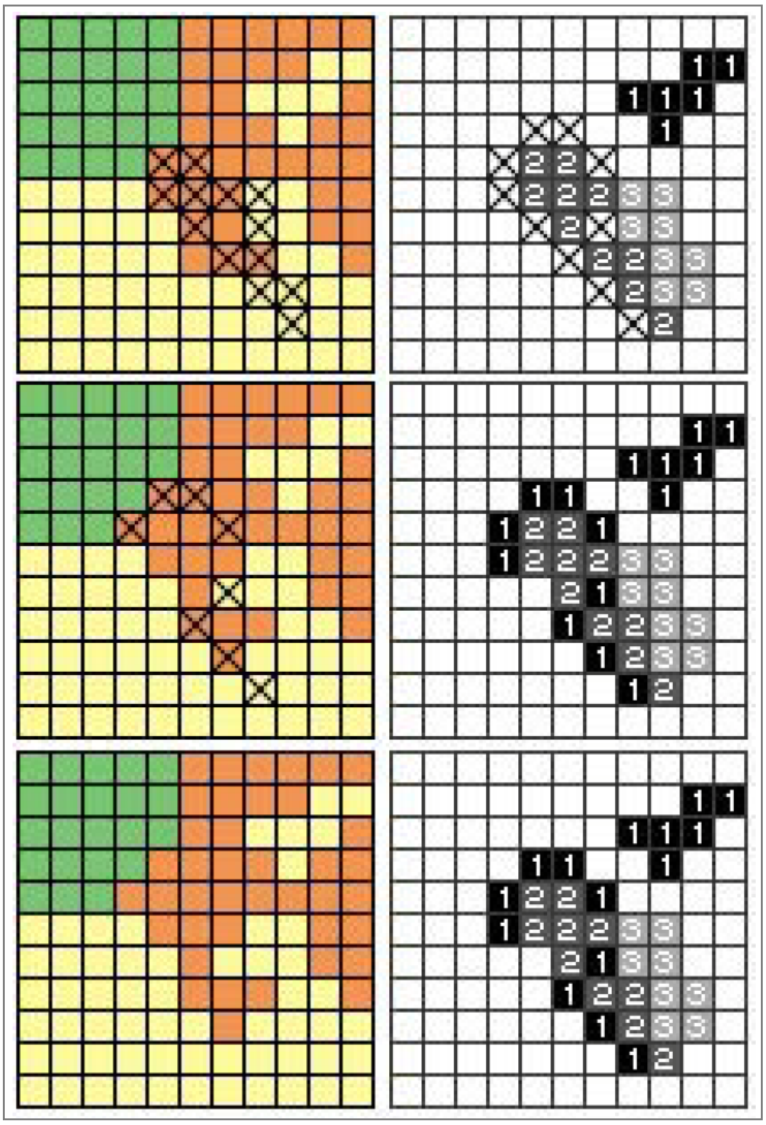

Figure 2.33: Step III - Propagate change
(Candau et al., 2000)

Step IV: Age Deltatrons

In this final step of the model, all deltatrons are aged one year (Figure 2.34 and Figure 2.35). Therefore, the deltatrons that were created in the previous steps of this growth cycle becomes 2 years old. If they become older than a determined lifetime, they die and become available for land cover transitions in the following growth cycles. Hence at the end of the second phase Deltatrons are either aged or killed (Candau & Clarke, 2000; Candau et al., 2000; Clarke, 2008; Dietzel & Clarke, 2004).

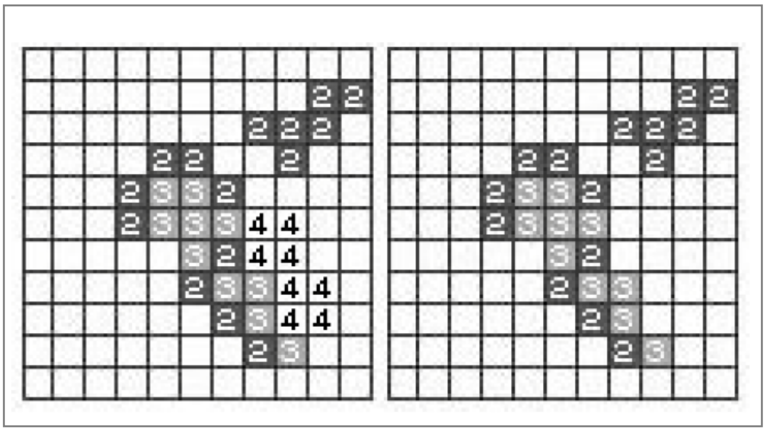

Figure 2.34: Step IV - Age deltatrons
(Candau et al., 2000)

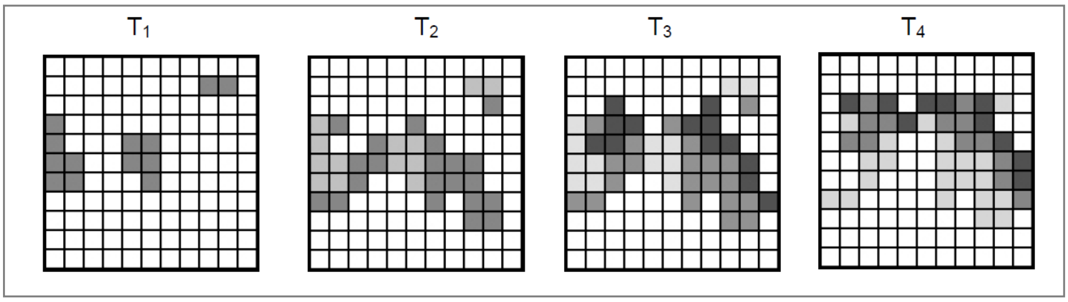

Figure 2.35: Aging deltatrons
(Candau & Clarke, 2000)

2.2.3 Applications of SLEUTH Cellular Automaton Model

SLEUTH (then called Clarke Urban Growth Model) was first developed as a scale-independent cellular automaton urban growth model, as a part of the USGS (U.S. Global Change Research Program) Human Induced Land Transformations (HILT) project, for understanding the urban transition from a historical perspective hence predicting urban extent for assessment of the impacts of urbanization (Clarke et al., 1996, 1997). Developed model was first calibrated for San Francisco Bay area and used for predicting the urban growth in 100 years into the future. Growth principles of the Clarke wildfire model (Clarke et al., 1994) were modified and used in the model (Clarke et al., 1996). In this archetype of the SLEUTH model, influence of topography, adjacency and transportation networks on urbanization were simulated by the inclusion of; land cover, slope, transportation and protected lands data (Candau & Clarke, 2000; Clarke et al., 1996, 1997). Examples of these data layers are presented in the figure below (see Figure 2.36).

C-language computer program of the model was written by Keith C. Clarke and runs in the UNIX operating systems (Clarke et al., 1997). The program is composed of a set of nested loops (Clarke & Gaydos, 1998). The outer control loop “repeatedly executes each growth ‘history’, retaining statistical and cumulative data for the Monte Carlo application” (Clarke et al., 1997, p. 254). The inner loop on the other hand “executes the CA [Cellular Automata], with each application cycle processing the whole layer once and considered equivalent to one year or one time cycle” (Clarke et al., 1997, p. 254).

Following San Francisco Bay area application of the Urban Growth Model (UGM) a second model, which is called Deltatron Land Cover Change Model (Deltatron LCM), was developed for simulating sequential land cover change (Clarke, 1997). Tightly coupled to and driven by the UGM, Deltatron LCM uses the same calibration process with UGM. Unlike UGM, Deltatron LCM requires at least two land-use layers to be activated (Candau & Clarke, 2000; Clarke, 1997). In the first application of Deltatron LCM, Clarke (1997) uses synthetic examples in "delta" space instead of real world data but he mentions that the model will be calibrated for San Francisco Bay area in further applications.

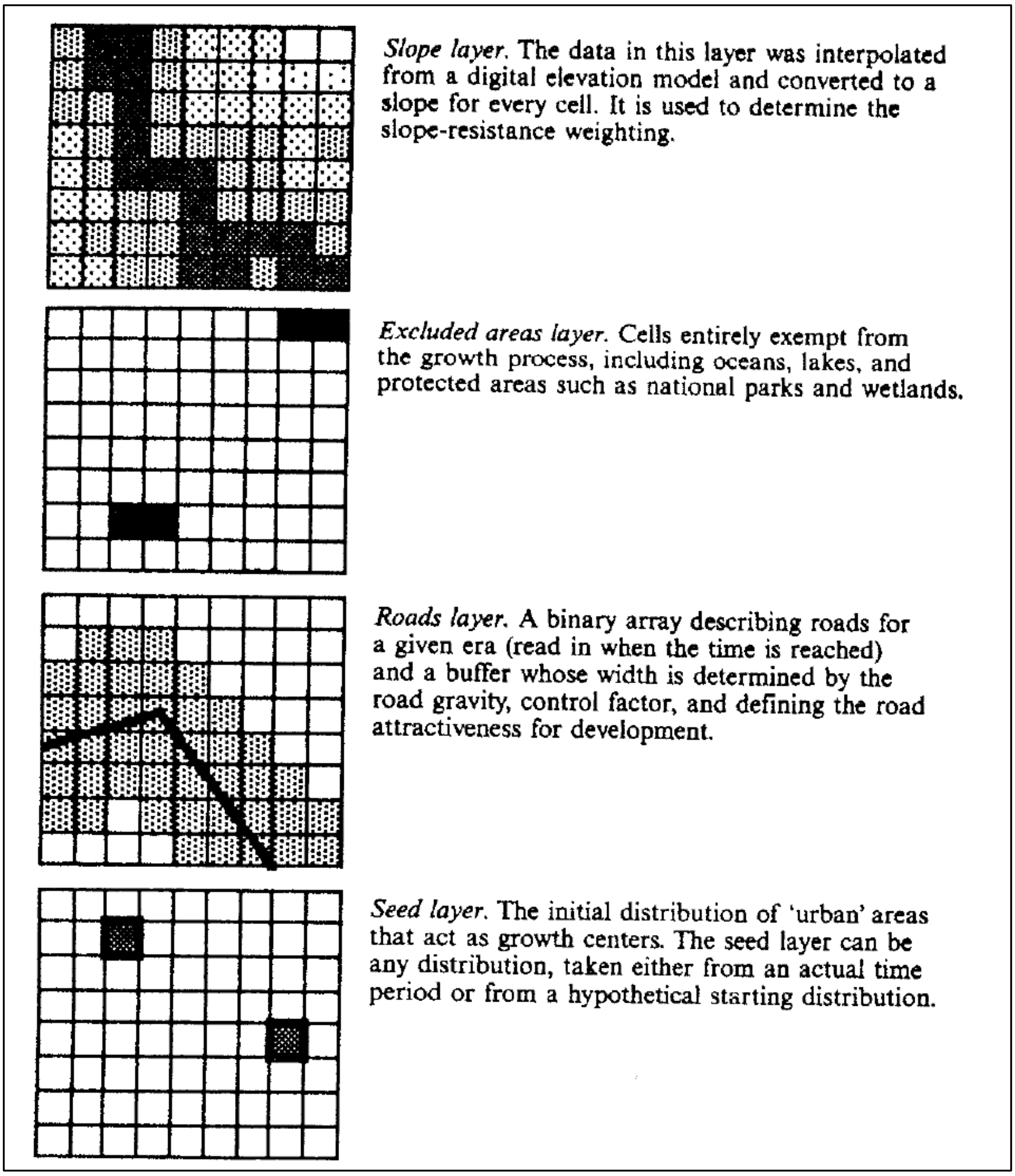

Figure 2.36: Input layers for the urban growth model
(Clarke et al., 1997, p. 252)

After San Francisco Bay area application of the UGM, it was calibrated and implemented to Washington/Baltimore region (Clarke & Gaydos, 1998). Same four data layers of; land cover, slope, transportation, and protected lands (excluded areas), were used for both San Francisco Bay area and Washington/Baltimore region and the results of the model were compared (Clarke & Gaydos, 1998). Also, the model was loosely coupled with GIS for this application.

Later, a "hill-shade" data layer (for visualization) was included in the coupled model and its name changed to SLEUTH (an acronym for input data layers of; Slope, Land-use, Exclusion, Urban extent, Transportation and Hill-shade) urban growth and land cover change model (Candau & Clarke, 2000). This was the first time that the SLEUTH abbreviation was used. Candau and her colleagues (Candau & Clarke, 2000; Candau et al., 2000) applied SLEUTH model (version 2.1) to the Mid-Atlantic Integrated Assessment (MAIA) study area. MAIA is an EPA designated research area that includes Delaware, Maryland, Pennsylvania, Virginia, West Virginia, New York, North Carolina states and District of Columbia of USA (Candau & Clarke, 2000; Candau et al., 2000). In this application of the model, five input data of; urban (1950, 1970, 1980, 1990), road (1950, 1970, 1980), land-cover (1975, 1992), slope and excluded layers were used with a data resolution of 1km. Land cover maps were classified in terms of Anderson Level I (Anderson, Hardy, Roach, & Witmer, 1976) classification and transition matrix was computed from them (Candau & Clarke, 2000; Candau et al., 2000). Following the calibration of urban growth and land-cover change models for MAIA study area, they were run to the year 2050.

Later on, the temporal sensitivity of the model was tested by Candau (2000) and it was proved that the model gives better results with recent data and short-term predictions. The assumption that the performance of calibration enhances with the increased number of historical data layers raises time need (Candau, 2000). Therefore, Candau (2000) investigates the optimal number of historical data needed for a calibration process in Santa Barbara area, California. She (Candau, 2000) runs the calibration process for three times with different time intervals using the land cover layers for the years of: 1929, 1943, 1954, 1967, 1976, 1986, 1997 (Cal1 – using all data layers), 1929, 1954, 1976, 1997 (Cal2 – using minimum number of layers with maximum temporal intervals), and 1967, 1976, 1986, 1997 (Cal3 – using minimum number of the recent data layers), respectively.

After its applications in various cities of North America, SLEUTH leaped to Europe and UGM was calibrated for the metropolitan areas of Lisbon and Porto, Portuguese (Silva & Clarke, 2002). This was the first time that SLEUTH model implemented in Europe. Silva and Clarke (2002) downloaded version 2.1 of the model from the web site of Project Gigalopolis (US Geological Survey & Department of Geography, 2005) and calibrated it for the two Portuguese metropolitan areas.

Later, the SLEUTH model was used for the comparison of the impacts of different policy scenarios on Baltimore-Washington metropolitan area (Jantz et al., 2003). In this application, Jantz et al. (2003) used 3.0 Beta version of the SLEUTH model (downloaded from the web site of Project Gigalopolis). Impacts of three different policy scenarios; current trends, managed growth and ecologically sustainable development, were compared for the year 2030 (Jantz et al., 2003). Differences between the scenarios were mainly based on the changes in exclusion levels (exclusion layer) and transportation networks (transportation layers).

Then, Dietzel and Clarke (2004) examined the ability of the SLEUTH model to replicate historical land-use change for three different levels of land-use classification. Model was calibrated for San Joaquin County, California case for 8 years period (between 1988 and 1996) and tested for 5, 10 and 15 different land-use classes. Land cover data were obtained for the years of 1988 and 1996 while urban extent data were taken for 1988, 1992, 1994 and 1996. Although there were 20 land use classes in the original of land use data they were reclassified to 5, 10 and 15 classes for comparison. Results of this application showed that the model was able to simulate 93% (F-match statistic) of land use change accurately for 5 land use classes. Accuracy levels of the model for 10 and 15 land use classes were 77% and 72%, respectively.

Later on, Clarke (2008) examined the SLEUTH model for its accuracy in simulating land use change with more than two land use layers and tested Markov assumption of linear transition. He (Clarke, 2008) applied the model first on the hypothetical city of Demo City with land use (Anderson Level I classification) layers for the years of 1930, 1950, 1970, 1980 and 1990. Results of Demo City application revealed that land use transition is a non-linear process. Then, Clarke (2008) applied the model for the Santa Barbara, California region with land use (Anderson Level II classification) layers for the years of 1954, 1975, 1986 and 1998. The results of Santa Barbara application also supported the fact that land use transition is a non-linear process. Variation in the paths of land use transition violates the assumption of linear transition (Clarke, 2008). Therefore, Clarke (2008) emphasizes the need of modifications for developing a more complex model to accommodate non-linear changes and claims that this could be achieved by the inclusion of as many land use layers as possible. He (Clarke, 2008) also underlines the fact that urban land is not an end state in real life. An urban land can change to different land use classes and even get de-urbanised. Thus, he proposes a third model to include land-use change in urban areas. Clarke (2008) suggests that an aged urban space (like Deltatron space) could be created where each urban class (residential, commercial, industrial, etc.) has an associated lifetime.

CHAPTER III

METHODOLOGY

3.1 Case Study Description

3.1.1 Case Selection Criteria

Accommodating nearly 18.6% of the total population of Turkey (TurkStat, 2017) and providing nearly 30% of the Gross Domestic Product (GDP) of Turkey (TurkStat, 2017), Istanbul City-Region is the most important industrial and commercial centre of Turkey. Also, accommodating nearly 15 million people (TurkStat, 2017), it is one of the largest urban agglomerations in Europe. In addition to its economic, cultural, historical and natural potentials, Istanbul City-Region's geographical location connecting Europe and Asia increases its attraction.

As a result of these potentials, Istanbul City-Region attracts major development projects of the neoliberal agenda. Especially with 2010s, Mega Projects like; 3rd Bosporus Bridge and Northern Marmara Motorway, 3rd Airport, Canal Istanbul and New Istanbul were brought to the agenda of central government. Contradicting with the principles and objectives of the existing plans and policies of the City-Region, these projects generate pressure on the life support systems of Istanbul City-Region. In other words, these Mega Projects influence the resilience and vulnerabilities of Istanbul City-Region. Therefore, the case of Istanbul City-Region was selected as the study area for analysing the possible impacts of mega projects on the resilience of a social-ecological system.

3.1.2 Istanbul City-Region, Turkey

Being located in north-western part of Turkey, Istanbul City-Region connects Europe to Asia (Figure 3.1). The entire surface area of the City-Region covers nearly 5.461 km² with half of the city in Europe and Asia separated by the Bosporus strait. Today, three bridges connect the eastern and western parts of the city.

Figure 3.1: Location of Istanbul City-Region

One of the largest urban agglomerations in Europe, Istanbul City-Region, is the most important industrial and commercial centre of Turkey with a population of 15 029 231 in 2017 (TurkStat, 2017). Nearly 18,6% of the total population of Turkey

(80 810 525) lives in Istanbul City-Region (TurkStat, 2017). Accommodating nearly 2892 people per km², Istanbul City-Region has the highest population density in Turkey (TurkStat, 2017).

Employing nearly 32% (Gülersoy & Yazıcı Gökmen, 2014, p. 9) of the total employed population of Turkey, Istanbul City-Region provides nearly 30% (TurkStat, 2017) of the Gross Domestic Product (GDP) of Turkey. Accommodating nearly 55% of total trade volume of Turkey, Istanbul City-Region draws migration from all over Turkey (Gülersoy & Yazıcı Gökmen, 2014).

Population increase starts to accelerate in this period (Table 3.1 and Figure 3.2). During 30 years between 1970 and 2000 total population of Istanbul City-Region increases from 3 million to 10 million (TurkStat,1970 and TurkStat, 2000). In 2017, total population of the City-Region reaches 15 million (TurkStat, 2017). The share of Istanbul City-Region in the total population of Turkey also increases in this period. While nearly 8,48% of the population was living in Istanbul City-Region in 1970, the share of population reached nearly 18,60% in 2017 (TurkStat, 2017).

Table 3.1: Population Change in Istanbul City-Region and Turkey

	Turkey	**Istanbul**	**Rate**
1970*	35.605.176	3.019.032	8,48%
1980*	44.736.957	4.741.890	10,60%
1990*	56.473.035	7.309.190	12,94%
2000*	67.803.927	10.018.735	14,78%
2010**	73.722.988	13.624.240	18,48%
2017**	80.810.525	15.029.231	18,60%

* General census of population by TurkStat
** Address Based Population Registration System (ABPRS) by TurkStat

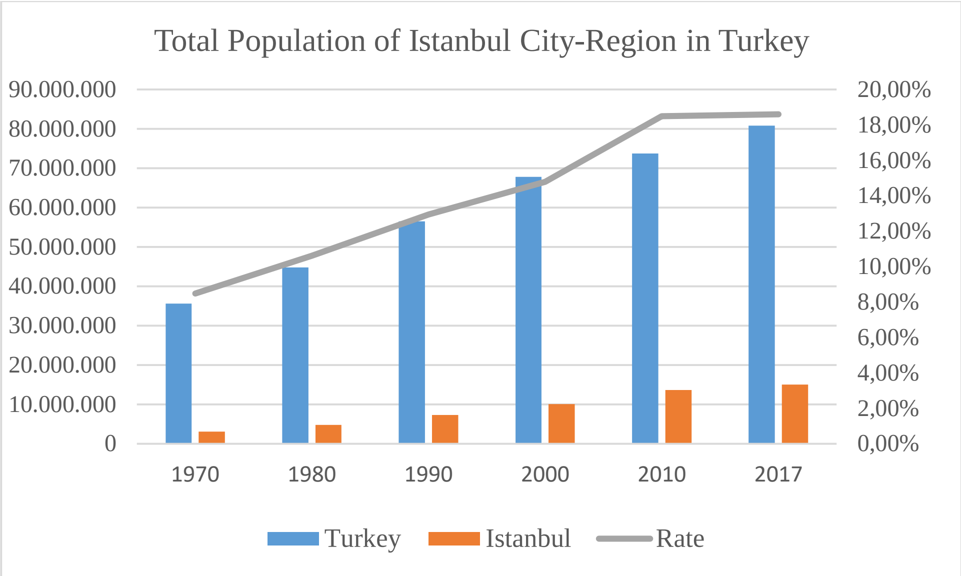

Figure 3.2: Share of Istanbul City-Region's Population in Turkey's Total Population
(TurkStat, 2017)

Accompanying the existing road networks, urban areas are mainly located in the southern shores of Istanbul City-Region. On the other hand, a mixture of rural patterns with agriculture and forested lands characterizes the northern part of the City-Region. This pattern of urban development parallel to Marmara Sea on the southern coasts of the city was mainly characterised by water and railway transportation systems until the 1950s. With increasing use of road motor vehicles in transportation and developing industrial production, urban growth starts to expand towards northern parts of the City-Region. Construction of the first (Boğaziçi) bridge and connected motorways in 1973 accelerates this growth towards north (Çalışkan, 2010). Later, with construction of the second (Fatih Sultan Mehmet - FSM) bridge to the north of Boğaziçi bridge in 1988, urban and industrial development further expands towards the forest areas and water resources of Istanbul City-Region in the north (WWF Turkey, 2015). Following the 1990s, gated communities were developed in the northern forest areas of Istanbul City-Region (Çalışkan, 2010). Later, a third (Yavuz Sultan Selim -YSS) bridge was constructed on Bosporus strait in 2016.

In 2017, total number of cars in Istanbul City-Region reaches 2.8 million while total number of motor vehicles reaches 4 million (Table 3.2). Total number of cars in Istanbul City-Region increases 14 times between 1980 and 2017 while total population increases 3 times in this period. In spite of this rapid increase in the number of car ownership in Istanbul City-Region, only 187 persons out of a thousand owns a car in 2017 (TurkStat, 2017).

Table 3.2: Total Number of Cars in Istanbul City-Region

	1950s[γ]	1970s[ϙ]	1980s[ϙ]	2000s[ϙ]	2017[ϕ]
Total Population	1 million	3.5 million	4.8 million	12.9 million	15.0 million
Total Number of Cars	2.000	60.000	200.000	1.800.000	2.813.027
Number of Cars Per One Thousand Persons	2	17	42	140	187

γ WWF Turkey, 2015, p.6
ϙ ŞPO, 2010, p.11
ϕ TurkStat, Road Motor Vehicles, December 2017

Acknowledging the negative impacts of urban growth on the northern parts of Istanbul City-Region, 1/100.000 scaled Istanbul Environment Plan controls urban growth and limits the total population at 16 million for the year of 2023.

3.1.3 Life Support Systems of Istanbul City-Region

3.1.3.1 Forest Areas

Forest areas are mainly concentrated on the north of Istanbul City-Region, where most of the water resources are located. As a result, forest areas protect water basins and regulate water quality. Preserving their integrity, these forest areas provide habitat for wildlife of the City-Region. Holding important amounts of carbon, forest areas regulate the air quality of City-Region. Northern winds carry the clear and cool air over the forests into the urban areas in the south (Tolunay, 2014, p. 24).

According to the manually digitized land-use data of Istanbul City-Region, forest areas were covering nearly 237 481 ha area in 2017. Following the industrial developments in 1950s, population of Istanbul starts to increase rapidly with migration from all over Turkey. With 1970s, especially after the construction of first Bosporus bridge in 1973, city starts to expand towards forest areas in the north. According to Tolunay (2014, p. 24), forest areas were covering nearly 264 800 ha area in 1971. Based on the manually digitized data, forest areas were covering nearly 255 430 ha area in 1987. Thus, with construction of the first bridge on Bosporus strait, nearly 9370 ha (3.54 %) of forest areas were lost in 16 years. Following the construction of second Bosporus bridge in 1988, urban expansion towards north increases and nearly 17 949 ha (7.03 %) of forest areas were lost in 30 years between 1987 and 2017.

Forest areas of Istanbul City-Region provides various goods and services. In addition to raw materials like timber, forest areas provide various regulation functions. They prevent disturbances while providing habitat for living organisms. Forest areas also regulate climate and control air quality. Covering water resources, they also control the water quality. Therefore, forest areas are important components of Istanbul City-Region's life support systems.

3.1.3.2 Water Resources

Istanbul City-Region accommodates water basins of: Terkos, Büyükçekmece, Küçükçekmece, Alibeyköy, Sazlıdere, Elmalı and Ömerli, that are also important for wildlife and biodiversity. Except for Küçükçekmece Lake, all of these resources provide drinking water for Istanbul City-Region. In spite of their importance as scarce water resources, urban areas surround and populate these areas. Especially after the construction of second Bosporus bridge in 1988, built up areas increases in the catchment areas of Elmalı and Ömerli Lakes. Küçükçekmece Lake losses its drinking water provision function as a result of urbanization and pollution. In spite of the laws and regulations, urban growth continues to threaten these water basins of Istanbul City Region.

Drinking Water Basins Regulation of Istanbul Water and Sewerage Administration protects the drinking water basins of Istanbul City-Region. In terms of Drinking Water Basins Regulation of Istanbul, the water basins are divided into four preservation areas. These preservation areas are the buffer zones of drinking water sources and they are named as: strict (0-300m), short distance (300-1000m), medium distance (1000-2000m) and long distance (2000m to basin border) preservation areas.

In terms of Drinking Water Basins Regulation, strict preservation areas should be absolutely excluded from urbanization whereas short-distance preservation areas could harbour traditional settlements Medium-distance preservation areas on the other hand could be urbanized with low density settlements. Analysis of the urban growth trends in preservation areas between 1987 and 2017 revealed that in spite of the regulations; 0.40, 2.86 and 7.24 percentages of strict, short distance and medium distance preservation areas were lost in 30 years' period, respectively.

In addition to provision of drinking water, water resources provide various services. They prevent disturbances while providing habitat for living organisms. They also regulate nutrients and water quality. Therefore, water resources are important components of Istanbul City-Region's life support systems.

3.1.4 Mega Projects of Istanbul City-Region

After the first decade of 21th century, four Mega Projects were brought to the agenda Istanbul City-Region by the central government of Turkey. These Mega Projects of the neoliberal agenda are briefly explained below.

3.1.4.1 3rd Bosporus Bridge and Northern Marmara Motorway Project

Being separated by the Bosporus strait, eastern and western parts of Istanbul City-Region were connected with bridges over the Bosporus. Today, three bridges connect the European side of the City-Region to the Anatolian side. The first (Boğaziçi) bridge over the Bosporus was constructed in 1973 for connecting two sides of the city. Soon afterwards, the bridge and connected motorways attracted urban development and created their own traffic. Thus, in order to decrease the volume of traffic on the first bridge by directing transit traffic to the north, a second (Fatih Sultan Mehmet - FSM) bridge was constructed in 1988. On the contrary, the new bridge created its own traffic and attracted new urban developments on its route. As a result, in just 5 years, a third bridge project was brought to the agenda with the investment programme of State Planning Organisation in 1993 (Çalışkan, 2010). Later, the project was again brought to agenda by the Minister of Public Works and Settlement in 1988 and the route was announced to take place between Arnavutköy and Kandilli (Gülersoy & Yazıcı Gökmen, 2014).

Later, acknowledging the importance of protecting the life support systems in the north of the City-Region, a linear growth in the south parallel to Marmara Sea was planned with 1/100.000 scaled Environment Plan of Istanbul in 2009. However, just one year later, route of the 3rd Bosporus bridge between Garipçe and Poyrazköy became definite with the affirmance of 1/25.000 scaled "Istanbul Province Northern Marmara Motorway General Plan" in 2010. In addition, a planning note, that was saying the additional crossings of the Bosporus strait would be considered in the lower scale plans", was also added to 1/100.000 scaled Environment Plan of Istanbul in 2010 (Gülersoy & Yazıcı Gökmen, 2014). Three years later, the construction of 3rd (Yavuz Sultan Selim) bridge was started with a ground breaking ceremony on 29 May 2013. During the construction period, route of the Northern Marmara Motorway was changed four times (see Figure 3.3) and the final expropriation map of the project was presented with 05.01.2015 dated and 2015/7158 numbered Decree of the Council of Ministers (Figure 3.4). After three years of construction process the 3rd Bosporus bridge was brought into service on 26 August 2016.

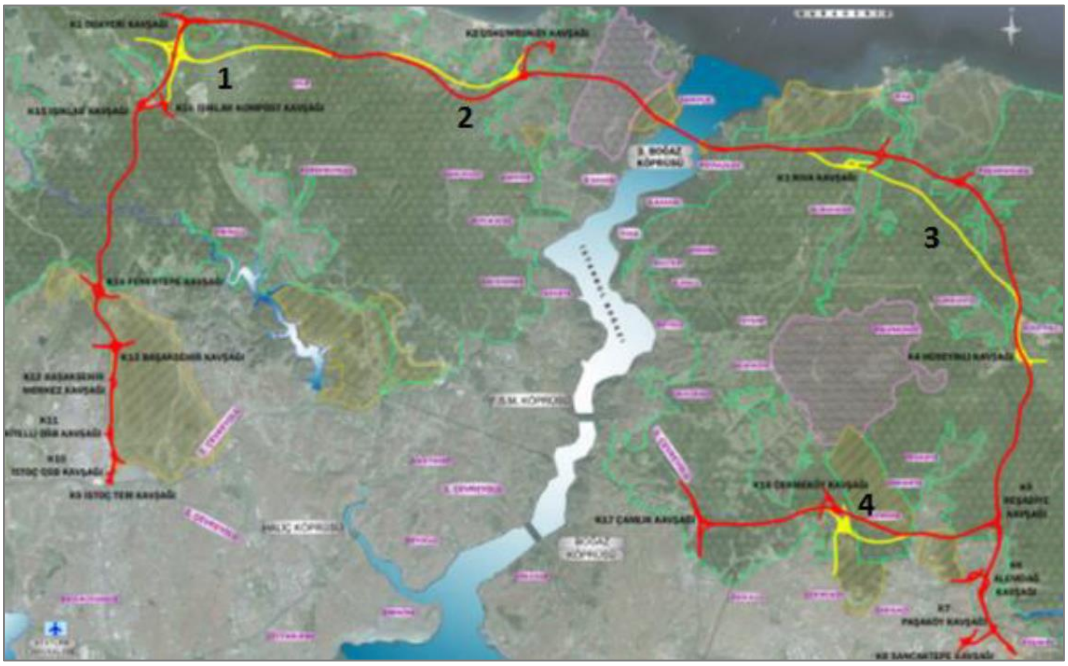

Figure 3.3: Route Changes of 3rd Bosporus Bridge and Norther Marmara Motorway
(AECOM, 2013, p. 2–8)

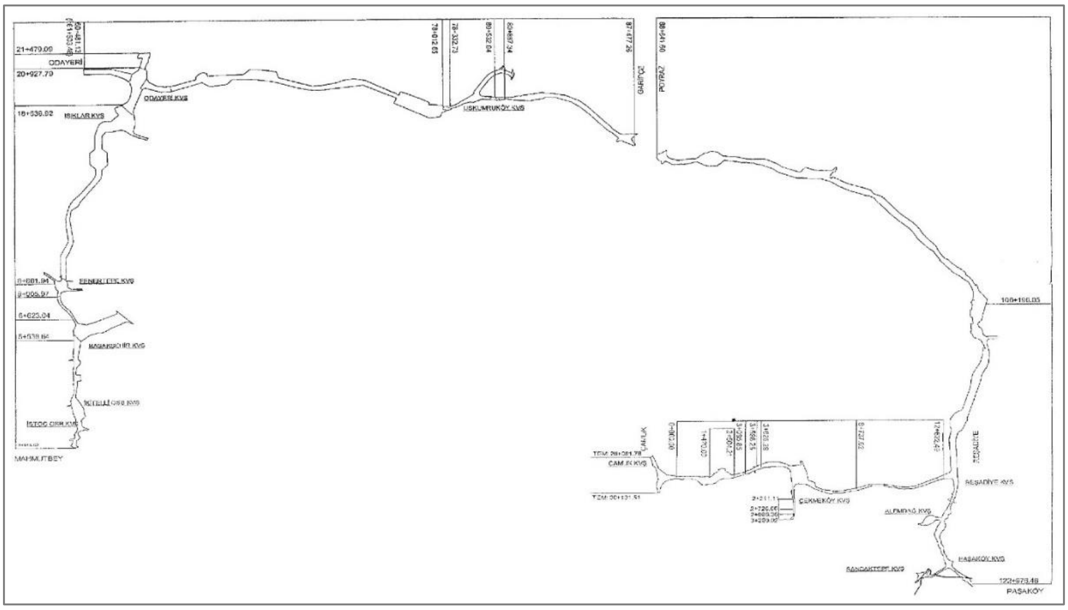

Figure 3.4: Expropriation Map of the 3rd Bosporus Bridge and Northern Marmara Motorway Project
(05.01.2015 dated 2015/7158 numbered Decree of the Council of Ministers)

3.1.4.2 3rd Airport Project

Today, two airports at two sides of Istanbul City-Region serve domestic and international passengers (Figure 3.5). First airport of Istanbul was constructed for military purposes on Yeşilköy district of European side in 1912. Later, construction of the first commercial airport of Istanbul City-Region was started at Yeşilköy in 1949 and Yeşilköy Airport was opened in 1953 ("Istanbul Ataturk Airport," n.d.). In 1972, a second runway was opened in the airport and after construction of new terminal and service buildings in 1985, the airport was renamed as Atatürk Airport ("Istanbul Ataturk Airport," n.d.). With increasing demand on air transportation, second airport of Istanbul City-Region was constructed on the Anatolian side and Sabiha Gökçen Airport was opened in 2001.

Figure 3.5: Locations of the Airports of Istanbul City-Region

In 2009, the third airport of Istanbul City-Region was planned to be constructed on the south-western part of the city near Silivri with 1/100.000 scaled Environment Plan of Istanbul. However, just three years later, the central government announced that the 3rd Airport would be constructed on the mine fields at the northern coasts of European side (Gülersoy & Yazıcı Gökmen, 2014). Following the tendering of 3rd Airport Project at 3 May 2013, construction of the 3rd Airport on the northern coast of Istanbul City-Region was started in 2013 (Gülersoy & Yazıcı Gökmen, 2014).

Coordinates of the location of 3rd Airport were provided with the Final Environmental Impact Assessment (EIA) Report of 3rd Airport Project in 2013 (AK-TEL Mühendislik, 2013). According to the Final EIA Report of the project, 3rd Airport covers nearly 7650 ha area and nearly 6172 ha of the airport takes place on forest areas. 3rd Airport area covers nearly 1180 ha of mining fields, 236 ha of pasture and 60 ha of agricultural areas (AK-TEL Mühendislik, 2013, p. 1). On the other hand, 3rd Airport area covers forest areas, coastal rehabilitation areas, rural settlement areas and geologically unfavourable areas on 1/100.000 scaled Environment Plan of Istanbul (Figure 3.6).

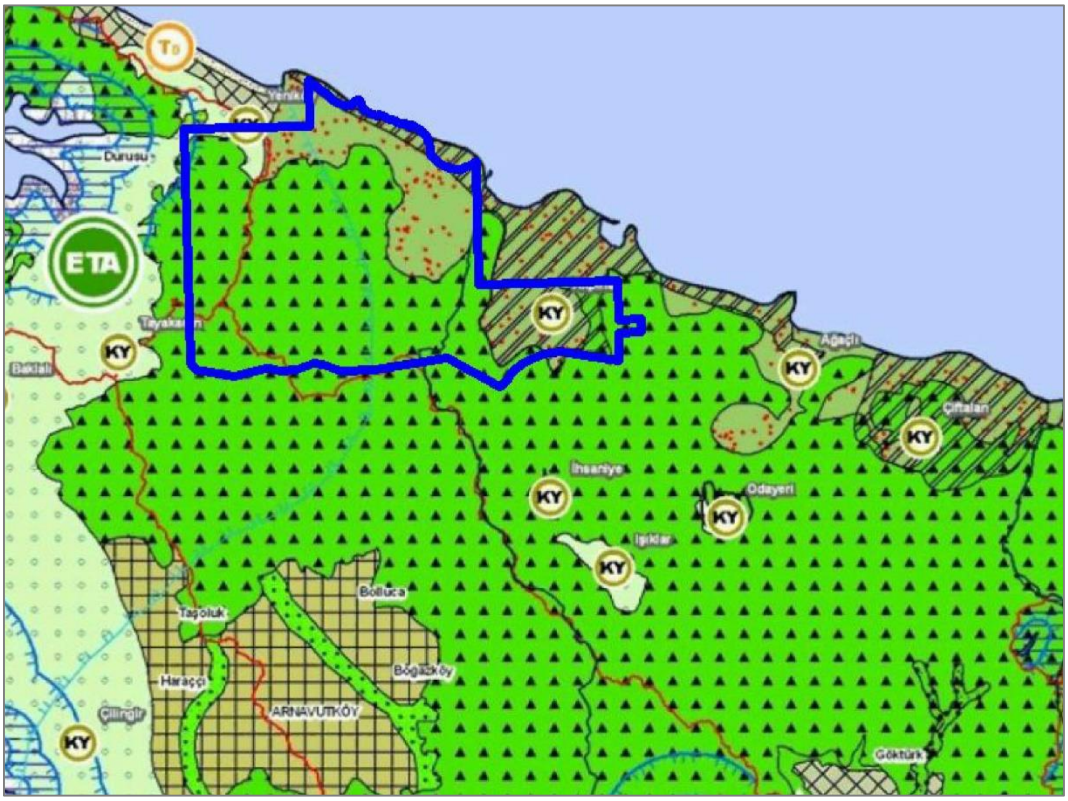

Figure 3.6: Location of 3rd Airport on 1/100.000 scaled Environment Plan of Istanbul
(AK-TEL Mühendislik, 2013, EK-22)

According to the Final EIA Report of the project, the construction process of 3rd Airport complex will be completed in four stages (Figure 3.7). Main terminal building, 2 runways and a cargo runway will be constructed in the first stage. In the second stage, the fourth runway on the east side of airport will be constructed with the terminal building. The fifth runway and terminal building on the west side of airport will be constructed in the third stage. In the fourth and final stage of construction process sixth runway and terminal building will be constructed. First stage of the construction process was planned to be completed at the end of 2018. On the other hand, final date of the construction process determined as 2039 (AK-TEL Mühendislik, 2013, p. 6).

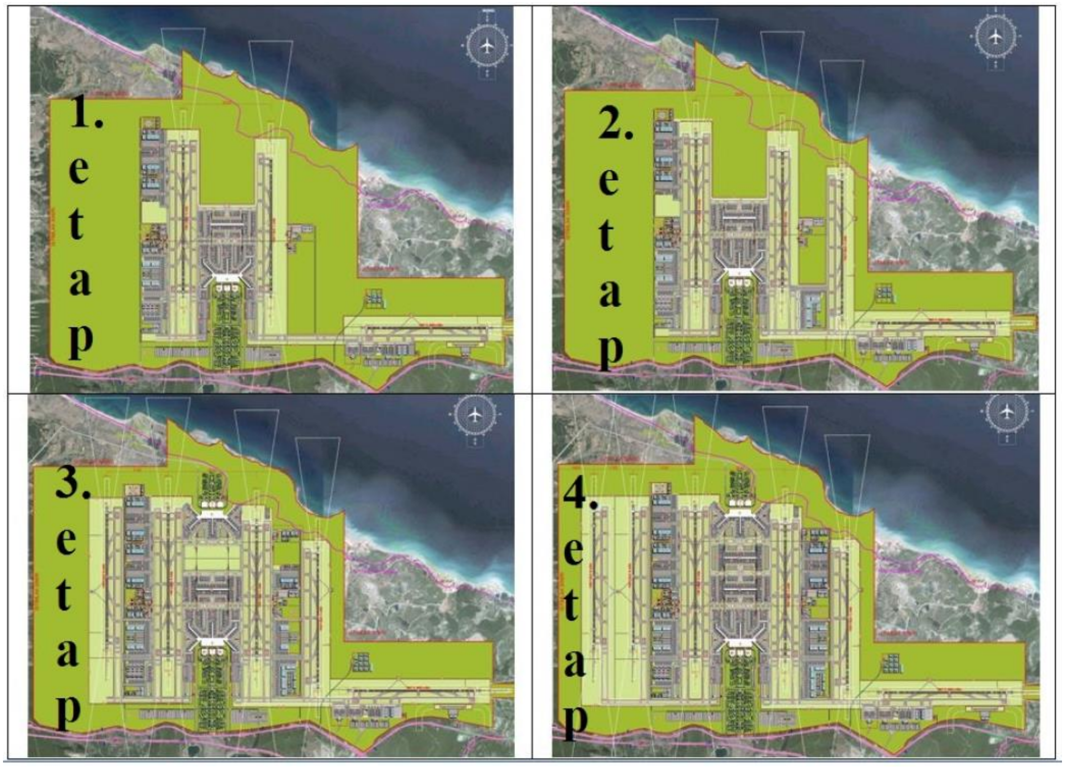

Figure 3.7: Stages of 3rd Airport Construction Process
(AK-TEL Mühendislik, 2013, p. 285)

3.1.4.3 Canal Istanbul and New Istanbul Projects

A canal connecting Marmara Sea to Black Sea on the European side of Istanbul was first proposed on a scientific journal article in 1990 (Önem, 1990). Route of the proposed canal was starting from Büyükçekmece Lake on the south and end on the west of Terkos Lake on the north. According to Önem (1990), the canal would be 47 km long and its width and depth would be 100 and 25 meters, respectively. Later, canal project was brought to the agenda by Democratic Left Party (DSP) leader Bülent Ecevit in 1994 during the municipal elections but did not draw public attention (WWF Turkey, 2015, p. 13).

Later, in 2011, the then Prime Minister Recep Tayyip Erdoğan was again brought the Canal Istanbul Project to the agenda with the aim of decreasing the volume of ship traffic on the Bosporus strait (Gülersoy & Yazıcı Gökmen, 2014; WWF Turkey, 2015). Although an exact location was not announced for the Canal Project, three alternatives (Silivri-Black Sea route, Büyükçekmece-Terkos route and Küçükçekmece-Sazlıdere-Terkos route) were appeared on the media (see Figure 3.8). According to the media, the canal would be 40-45 km long and its width and depth would be 150 and 25 meters, respectively (WWF Turkey, 2015, p. 6).

Figure 3.8: Route Alternatives of Canal Istanbul Project
(Adapted from Damalı, 2014, p. 87; WWF Turkey, 2015, p. 14)

In 2012, nearly 38 500 ha of area on the European side of Istanbul was determined as "Reserve Construction Area" and the Ministry of Environment and Urbanisation was authorised to develop new urban areas in this reserve area with 08.09.2012 dated 2012/3573 numbered Decree of the Council of Ministers (Figure 3.9). Taking place on the Küçükçekmece-Sazlıdere-Terkos route alternative of Canal Istanbul, this “Reserve Construction Area” was accepted as the location of New Istanbul Project covering the Canal Istanbul Project (WWF Turkey, 2015, p. 83). Later, in 2014, the boundaries of New Istanbul Project area were rearranged with 24.02.2014 dated 2014/6028 numbered Decree of the Council of Ministers (Figure 3.10). As a result, possible route of Canal Istanbul Project was determined within the boundaries of New Istanbul Project, for this research (Figure 3.11).

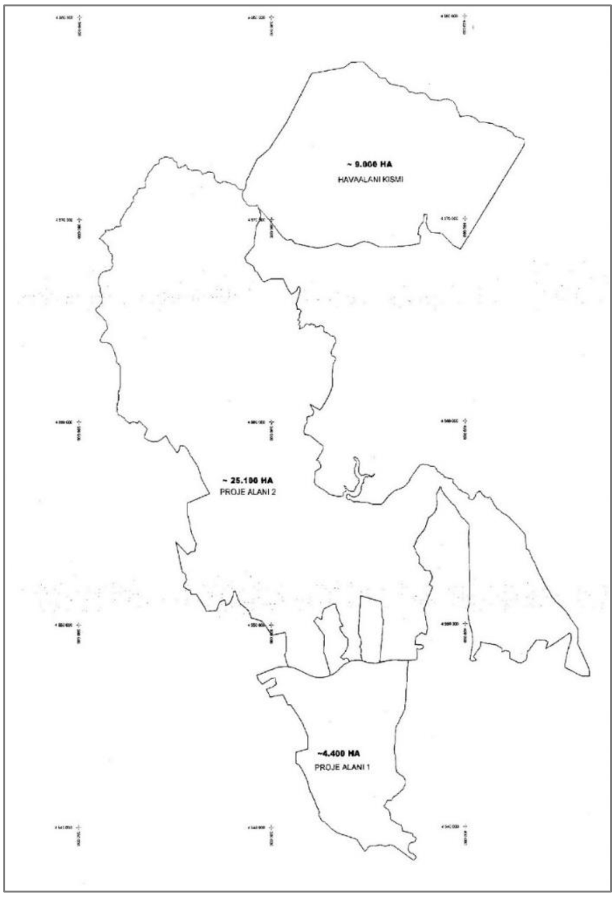

Figure 3.9: Boundaries of Reserve Construction Area
(08.09.2012 dated 2012/3573 numbered Decree of the Council of Ministers)

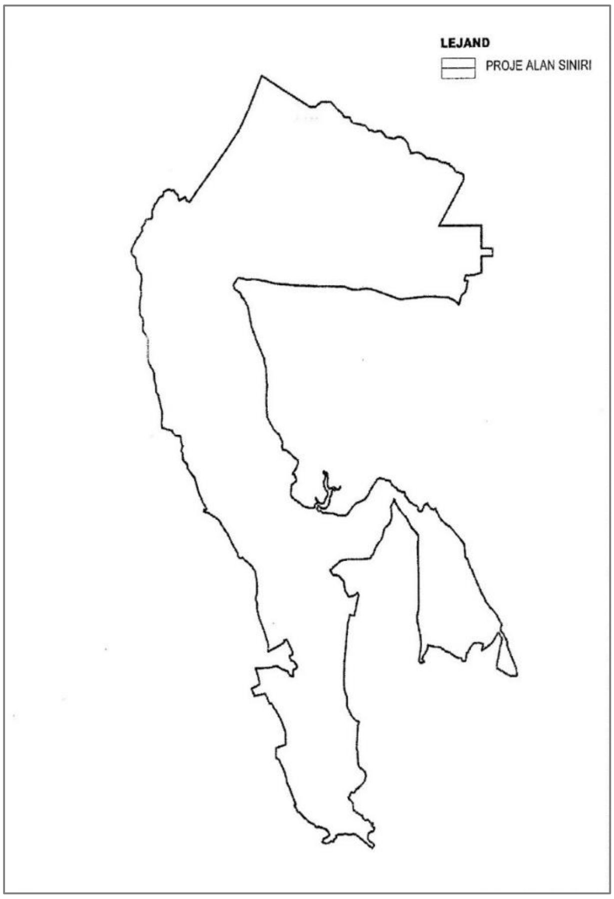

Figure 3.10: Rearranged Boundaries of Reserve Construction Area
(24.02.2014 dated 2014/6028 numbered Decree of the Council of Ministers)

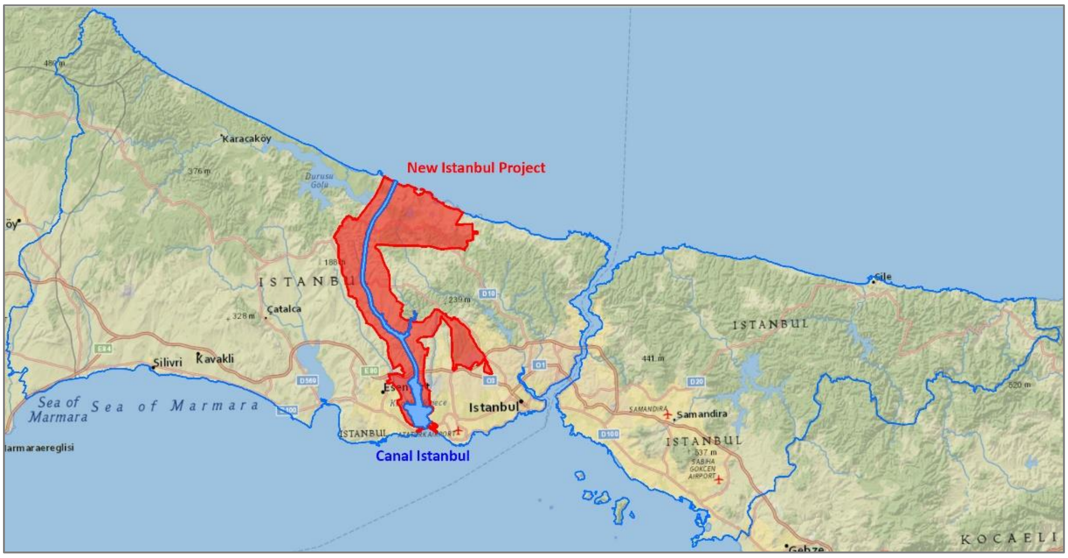

Figure 3.11: Location of New Istanbul Project with Canal Istanbul

3.2 Data, Data Sources and Collection Process

3.2.1 SLEUTH Cellular Automaton Model

As an easy to apply, freeware urban growth simulation model; SLEUTH Cellular Automaton Model was employed for simulating the urban growth process of Istanbul City-Region. With the long-term goal of developing SLEUTH urban and land use change model to best predict urban growth on a regional, continental and eventually global scale, Project Gigalopolis shares the code of the model for free[2]. In this context, 2005 release of SLEUTH 3.0 Beta code with the necessary patch and libraries were downloaded from the web page of Project Gigalopolis (US Geological Survey & Department of Geography, 2005).

3.2.2 Cygwin DLL

Cygwin is a Linux-like environment for Windows Operating Systems that makes it possible to port software running on Linux systems to Windows. In other words, Cygwin emulates the Linux environment in Windows Operating Systems and enables Windows to run Linux based software. In 2005, SLEUTH 3.0 Beta code was released with a functionality to be executed on Windows through Cygwin DLL. Therefore, 2.7.0 version of the freeware emulator Cygwin DLL was downloaded and installed on Windows 10 Pro operating system to run SLEUTH Cellular Automaton Model. Although, both 32 and 64 bit versions of the program were available on web page of Cygwin DLL[3], 32 bit version was downloaded to comply with SLEUTH.

3.2.3 ArcMAP

ArcMAP application of ESRI's ArcGIS Desktop software was employed as the GIS software of the research. In this context, 10.5.1 version of ArcGIS Desktop Basic[4]

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[2] In addition to the complete code of the model, web page of the Project Gigalopolis also provides the necessary information and resources about the implementation of the model.
[3] [https://www.cygwin.com]
[4] ArcGIS Desktop Basic software and Spatial Analyst extension with Concurrent Use License for Aydın Metropolitan Municipality was used in this research.

software was used with Spatial Analyst extension for the preparation of input images and examination of output images of the SLEUTH cellular automaton model.

3.2.4 Satellite Images:

Satellite images of Istanbul City-Region for the years of 1987, 2000, 2006, 2013 and 2017 provided the main data source of this research (Figure 3.12 - Figure 3.17 below). Suitable Landsat images of Istanbul City-Region were acquired from the archives of U.S. Geological Survey (USGS)[5] Agency. USGS archives of Landsat provide "the longest temporal record of moderate resolution multispectral data of the Earth's surface" for free[6]. Earth Explorer (EE)[7] tool of USGS was used for finding and downloading the proper images of Istanbul. In terms of Worldwide Reference System (WRS2) of Landsat data, Istanbul City-Region takes place in two Landsat scenes that are located on row 31 and row 32 of path 180. Therefore, images of Landsat scenes in rows 31 and 32 of path 180 were downloaded and combined for each year. Downloaded folders of each Landsat scene contain spectral bands of Landsat data in 8-bit greyscale Geo-referenced Tagged Image File Format (GeoTIFF). Since each Landsat sensor (TM, ETM^+, OLI or TIRS) collects data at different spatial and spectral resolutions, varying number and size of images were provided in downloaded folders of each year. In other words, number and size of single band images included in each Landsat data differs depending on the sensor on the satellite. In this context, 7 bands of Landsat 5 TM (Thematic Mapper) data for 1987, 9 bands of Landsat 7 ETM^+ (Enhanced Thematic Mapper Plus) data for 2000 and 2006, and 11 bands of Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensors) data for 2013 and 2017 were downloaded for each Landsat scene in rows 31 and 32 of path 180 (in WRS2). Properties of the Landsat images of Istanbul City-Region are listed in the table (Table 3.3) below.

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[5] [https://www.usgs.gov/]
[6] [https://landsat.usgs.gov/about-landsat]
[7] [https://earthexplorer.usgs.gov/]

Figure 3.12: Landsat images of Istanbul City-Region for 1987, 2000, 2013 and 2017

Table 3.3: Properties of the Landsat images of Istanbul City Region

Years	Acquisition Date	Satellite & Instrument	Bands	Resolution	
				Spectral (µm)	Spatial (m)
1987	25.09.1987 (path 180 row 31)	Landsat 5	B10 (Blue)	0.45-0.52	28.5 x 28.5
		Thematic Mapper (TM)	B20 (Green)	0.52-0.60	28.5 x 28.5
			B30 (Red)	0.63-0.69	28.5 x 28.5
			B40 (NIR)	0.76-0.90	28.5 x 28.5
	05.06.1987 (path 180 row 32)		B50 (SWIR-1)	1.55-1.75	28.5 x 28.5
			B60 (Thermal)	10.40-12.50	28.5 x 28.5
			B70 (SWIR-2)	2.08-2.35	28.5 x 28.5
2000	02.07.2000 (path 180 row 31)	Landsat 7	B10 (Blue)	0.45-0.52	28.5 x 28.5
		Enhanced Thematic Mapper Plus (ETM+)	B20 (Green)	0.52-0.60	28.5 x 28.5
			B30 (Red)	0.63-0.69	28.5 x 28.5
			B40 (NIR)	0.76-0.90	28.5 x 28.5
	02.07.2000 (path 180 row 32)		B50 (SWIR-1)	1.55-1.75	28.5 x 28.5
			B61 (Thermal)	10.40-12.50	57 x 57
			B62 (Thermal)	10.40-12.50	57 x 57
			B70 (SWIR-2)	2.08-2.35	28.5 x 28.5
2006	20.08.2006 (path 180 row 31)	Landsat 7	B10 (Blue)	0.45-0.52	30 x 30
		Enhanced Thematic Mapper Plus (ETM+)	B20 (Green)	0.52-0.60	30 x 30
			B30 (Red)	0.63-0.69	30 x 30
			B40 (NIR)	0.76-0.90	30 x 30
			B50 (SWIR-1)	1.55-1.75	30 x 30
	04.08.2006 (path 180 row 32)		B61 (Thermal)	10.40-12.50	60 x 60
			B62 (Thermal)	10.40-12.50	60 x 60
			B70 (SWIR-2)	2.08-2.35	30 x 30
			B80 (PAN)	0.52-0.90	15 x 15
2013	30.07.2013 (path 180 row 31)	Landsat 8	B01 (Coastal)	0.43-0.45	30 x 30
		Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS)	B02 (Blue)	0.45-0.51	30 x 30
			B03 (Green)	0.53-0.59	30 x 30
			B04 (Red)	0.64-0.67	30 x 30
			B05 (NIR)	0.85-0.88	30 x 30
			B06 (SWIR-1)	1.57-1.65	30 x 30
	30.07.2013 (path 180 row 32)		B07 (SWIR-2)	2.11-2.29	30 x 30
			B08 (PAN)	0.50-0.68	15 x15
			B09 (Cirrus)	1.36-1.38	30 x 30
			B10 (Thermal-1)	10.60-11.19	30 x 30
			B11 (Thermal-2)	11.50-12.51	30 x 30
2017	09.07.2013 (path 180 row 31)	Landsat 8	B01 (Coastal)	0.43-0.45	30 x 30
		Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS)	B02 (Blue)	0.45-0.51	30 x 30
			B03 (Green)	0.53-0.59	30 x 30
			B04 (Red)	0.64-0.67	30 x 30
			B05 (NIR)	0.85-0.88	30 x 30
			B06 (SWIR-1)	1.57-1.65	30 x 30
	09.07.2013 (path 180 row 32)		B07 (SWIR-2)	2.11-2.29	30 x 30
			B08 (PAN)	0.50-0.68	15 x15
			B09 (Cirrus)	1.36-1.38	30 x 30
			B10 (Thermal-1)	10.60-11.19	30 x 30
			B11 (Thermal-2)	11.50-12.51	30 x 30

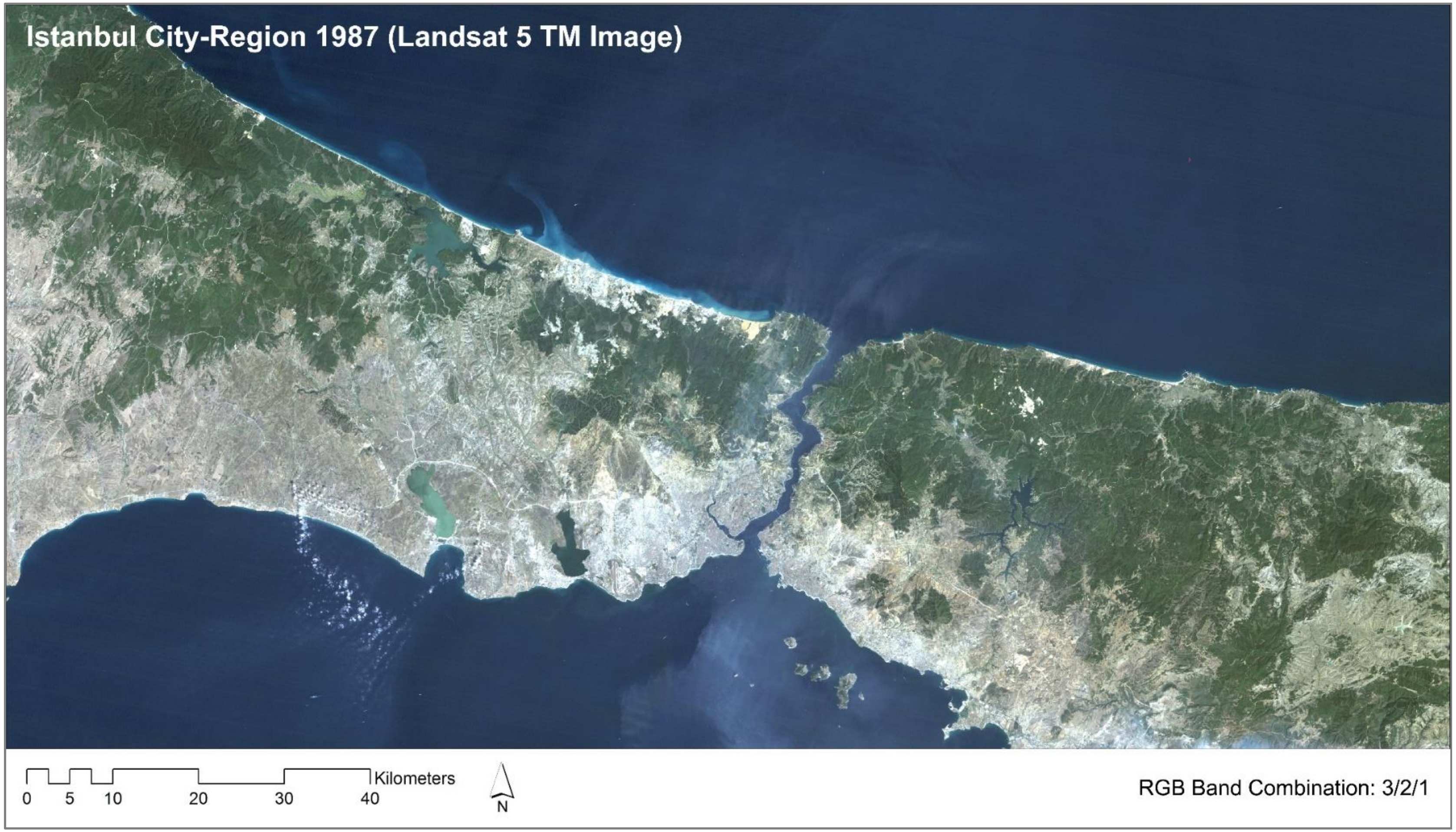

Figure 3.13: Landsat 5 TM image of Istanbul City-Region for the year of 1987

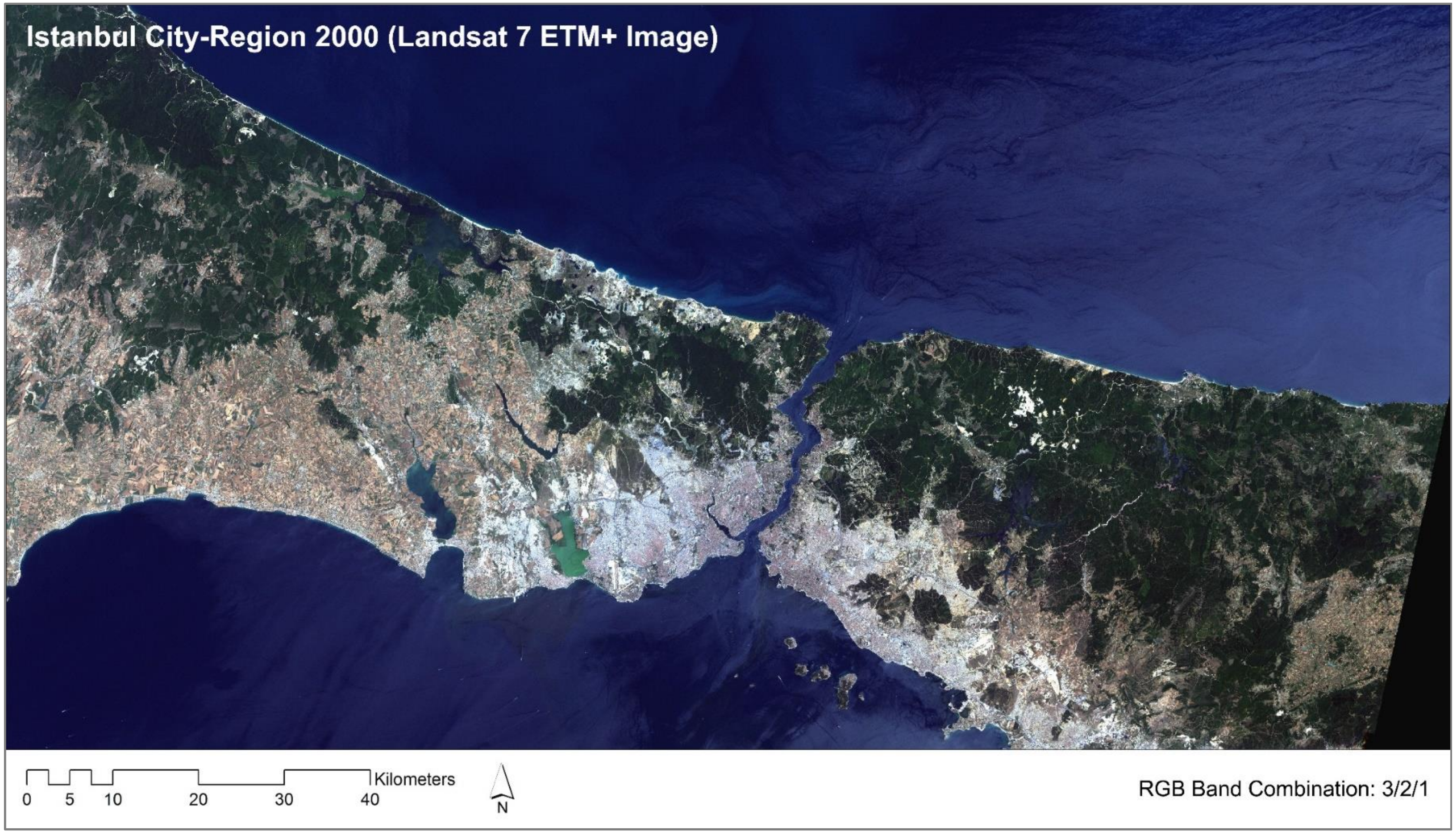

Figure 3.14: Landsat 5 TM image of Istanbul City-Region for the year of 2000

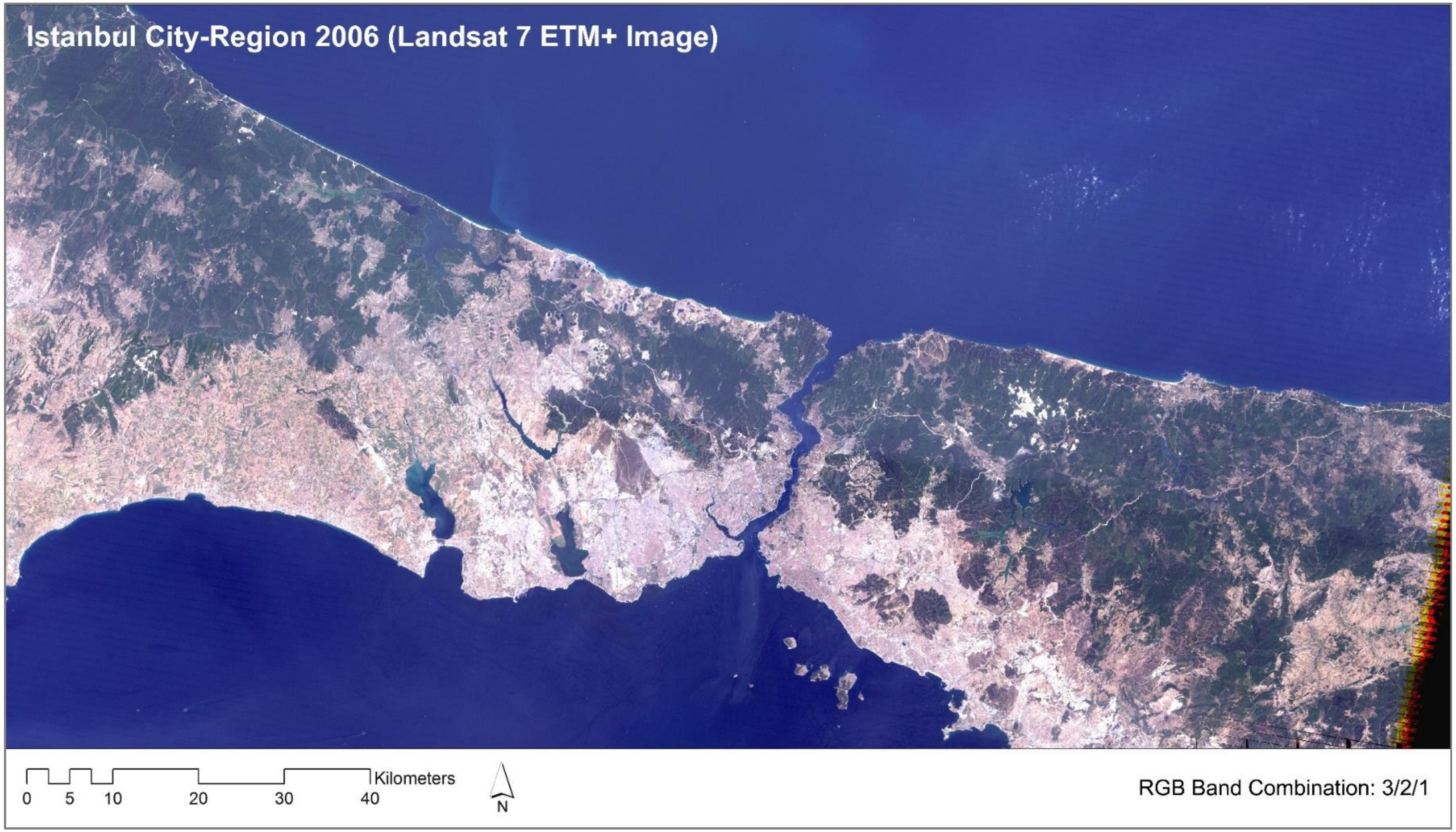

Figure 3.15: Landsat 7 ETM+ image of Istanbul City-Region for the year of 2006

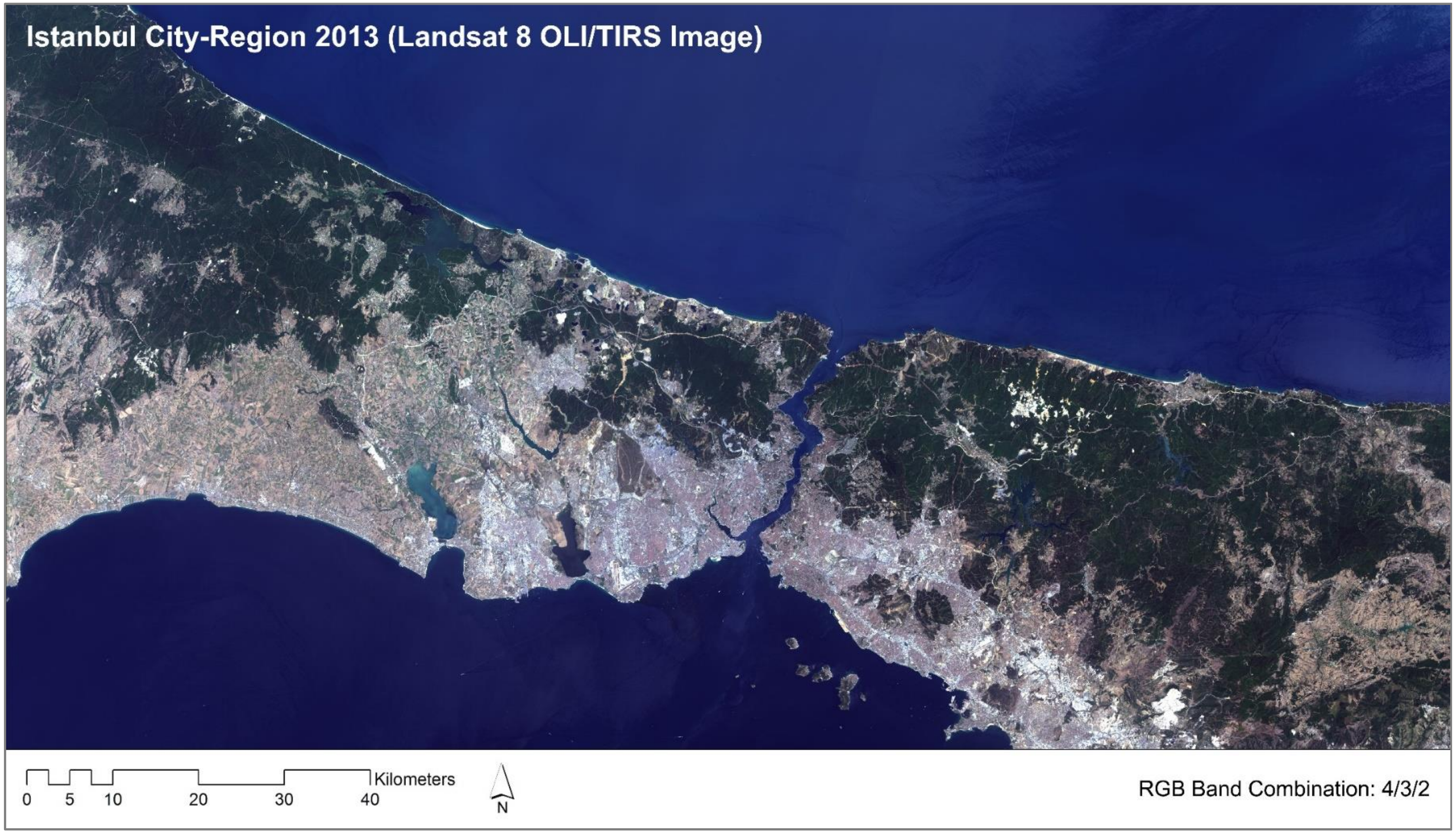

Figure 3.16: Landsat 8 OLI/TIRS image of Istanbul City-Region for the year of 2013

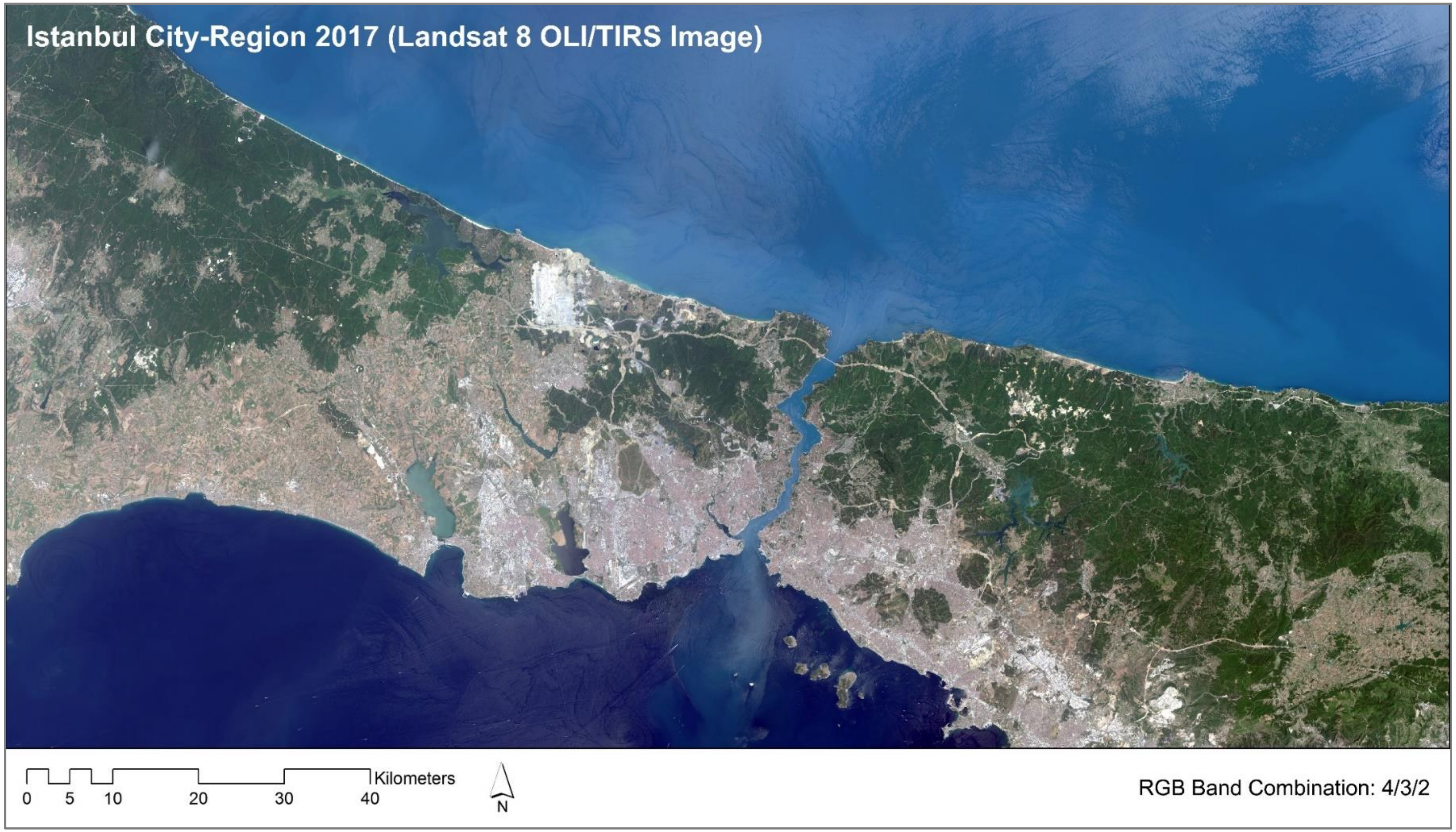

Figure 3.17: Landsat 8 OLI/TIRS image of Istanbul City-Region for the year of 2017

3.2.5 CORINE Land Cover Data

CORINE (Co-ordination of Information on the Environment) Land Cover (CLC) maps were used for ensuring the accuracy of manually operated classification of the satellite images. As a part of the CORINE Programme of European Commission, CORINE Project provides an inventory of the land cover of Europe in 44 classes, for the years of 1990, 2000, 2006 and 2012. These land cover maps of Europe could be downloaded in raster and vector format from the web pages of European Environment Agency (EEA)[8] or The Copernicus Programme[9]. So, land cover maps of Europe were downloaded and edited to be used in the manually operated classification of the satellite images of Istanbul City-Region. In this context, the maps were cropped, re-projected and reclassified for comparison purposes (see Figure 3.18 - Figure 3.21 below).

3.2.6 Land Use Classes and Conservation Areas

Vector data of land use classes and conservation areas of Istanbul City-Region were acquired from Istanbul Metropolitan Municipality (IMM) during the field survey in August 2014. In addition to vector data, analysis and synthesis maps prepared by Istanbul Metropolitan Planning and Urban Design Centre (IMP) for the Territorial Plan of Istanbul were also acquired in digital data format.

3.2.7 Location, Form and Size of the Mega Projects

Information about the location, form and size of the Mega Projects of Istanbul were acquired through synthesis of the news releases, political statements and cabinet decrees of the government. Web pages of NGOs and chambers about the Mega Projects of Istanbul were also used as a source of information.

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[8] [http://www.eea.europa.eu/]
[9] [http://land.copernicus.eu/pan-european/corine-land-cover]

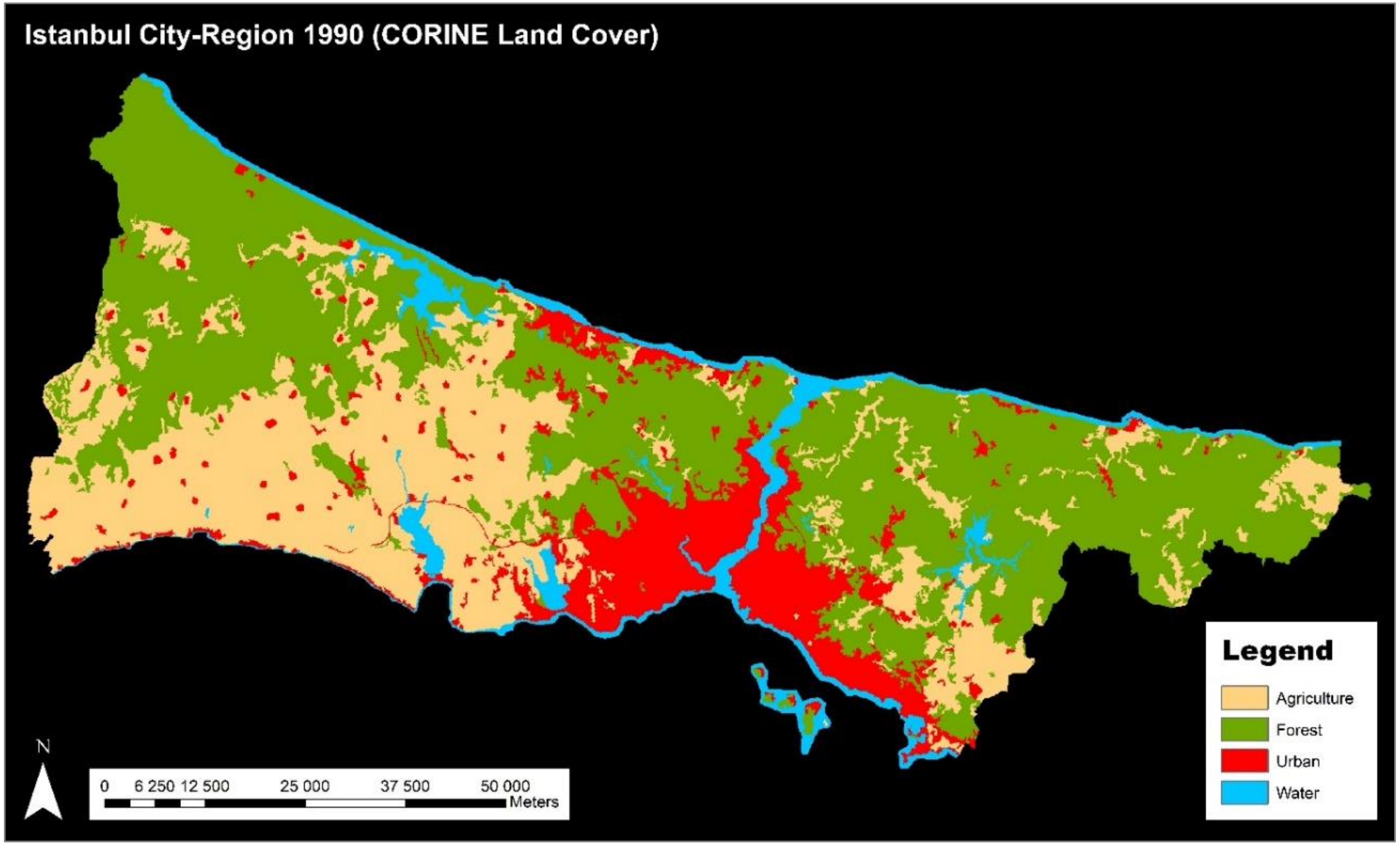

Figure 3.18: Istanbul City Region in CORINE land cover map of 1990

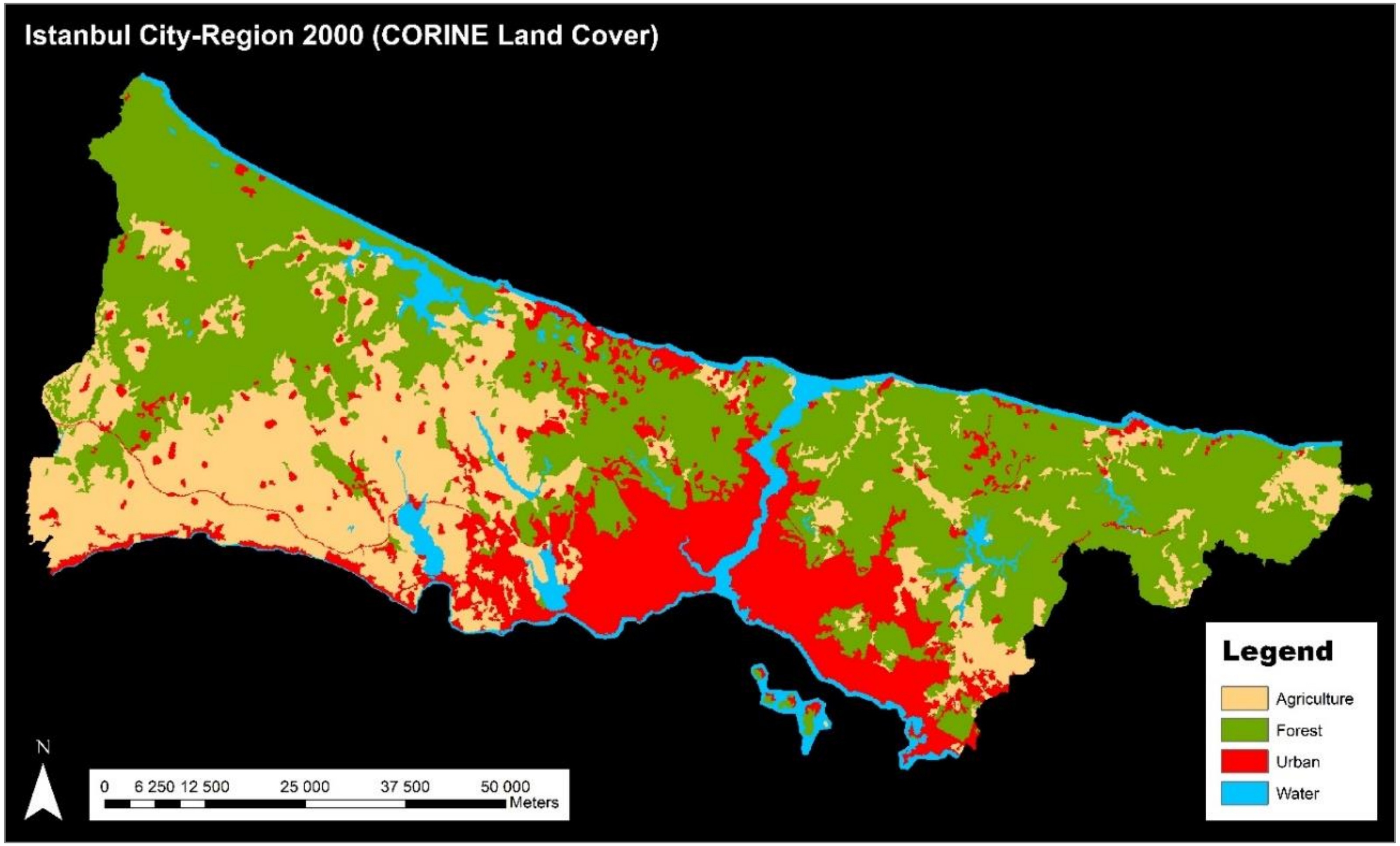

Figure 3.19: Istanbul City Region in CORINE land cover map of 2000

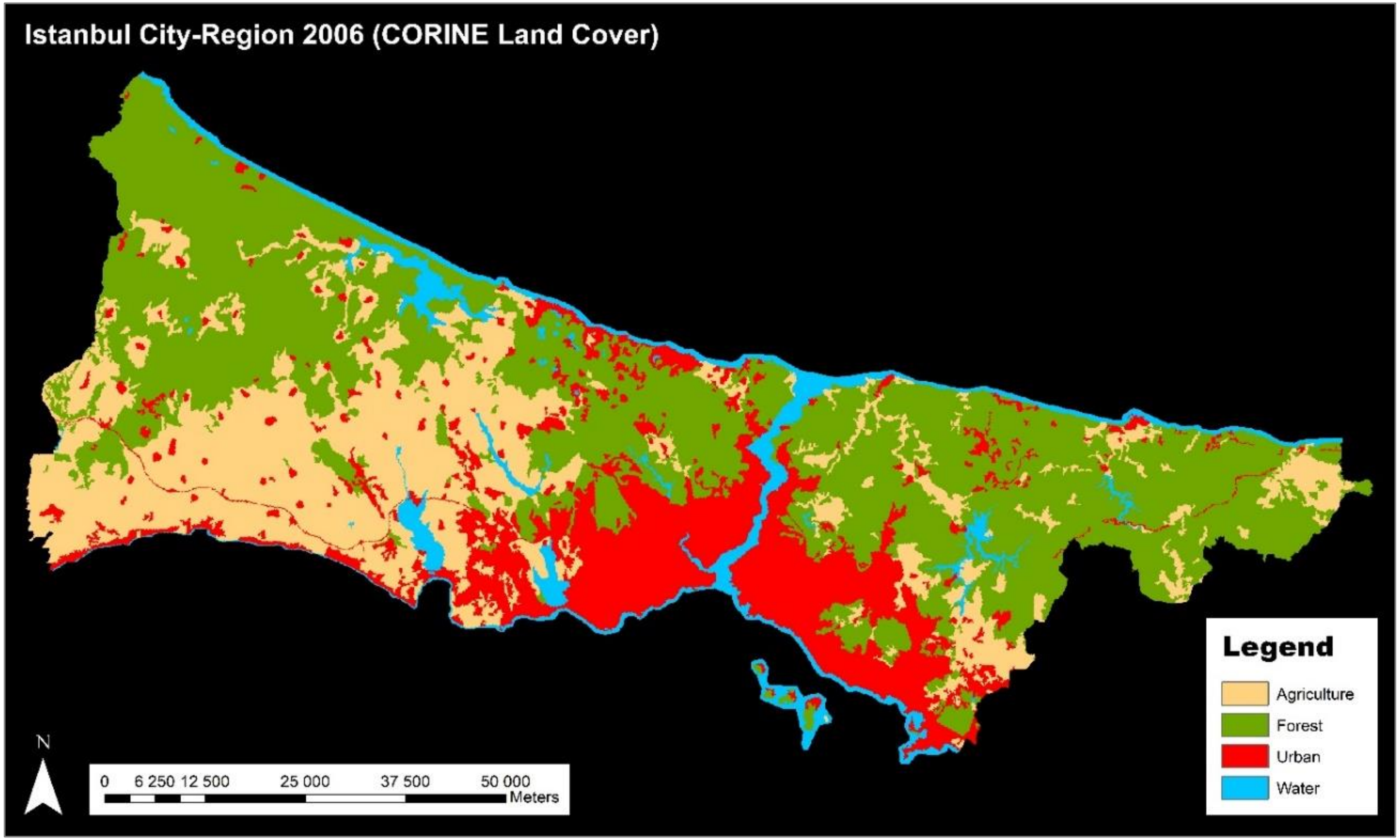

Figure 3.20: Istanbul City Region in CORINE land cover map of 2006

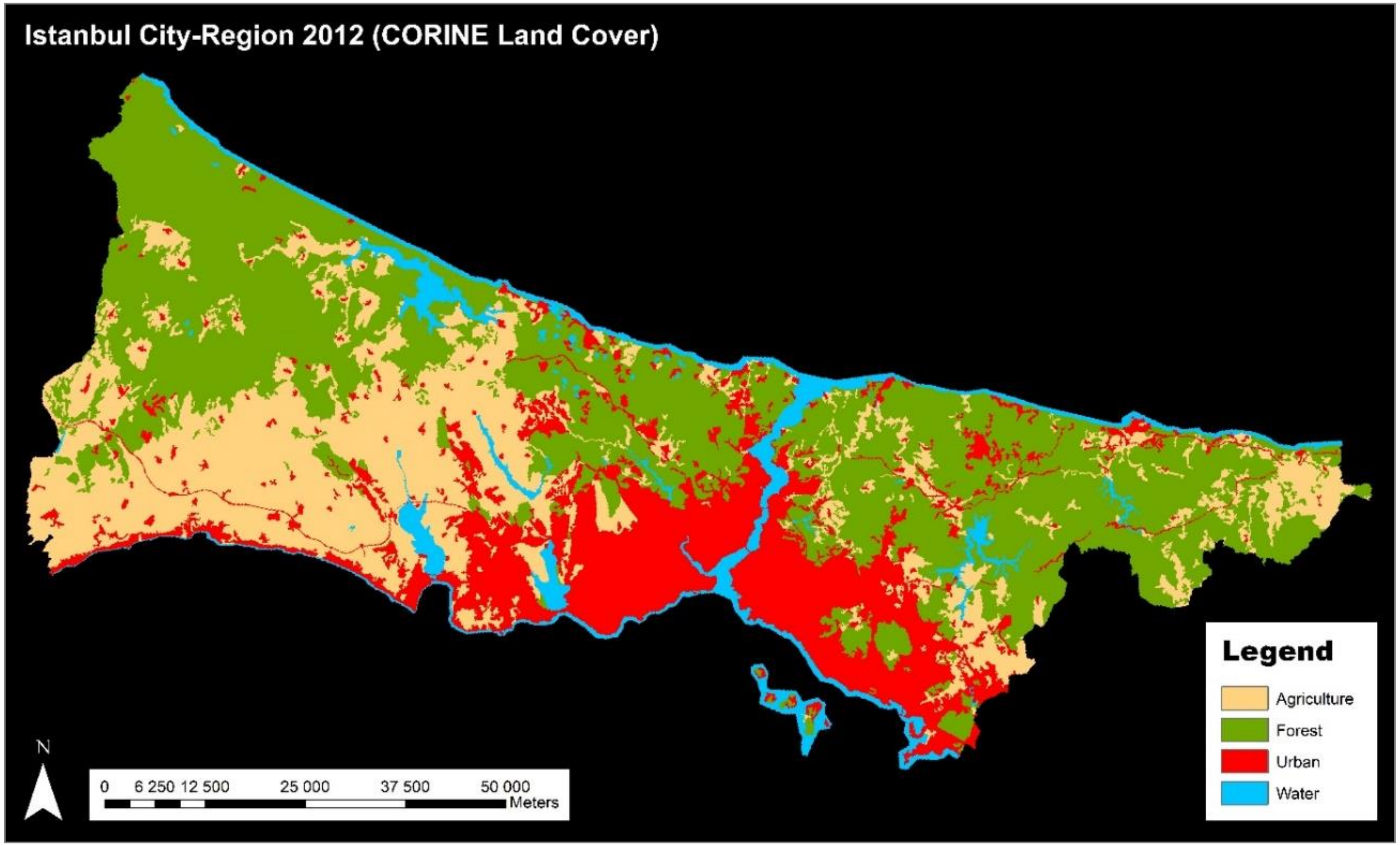

Figure 3.21: Istanbul City Region in CORINE land cover map of 2012

3.2.8 General Information and Statistics

Information about the natural, physical, social and economic properties of Istanbul City Region were gathered mainly from the research (analysis and synthesis) reports of 1/100.000 scale Territorial Plan of Istanbul City Region. In addition, statistical data about Istanbul were acquired from the web page of TUIK (Turkish Statistical Institute).

3.3 Resilience Assessment Framework for Istanbul City-Region

Building on the resilience assessment frameworks that were explained in the literature review chapter, an exclusive resilience assessment framework was developed for Istanbul City-Region case. Possible impacts of Mega Projects on the resilience of Istanbul City-Region were analysed through implementation of this framework. This exclusive framework for assessing the resilience of Istanbul City-Region is composed of three main steps (Figure 3.22):

Step 1: Describing the System

Step 2: Identifying the System Dynamics

Step 3: Synthesizing the Assessment Findings

3.3.1 Step 1: Describing the System

This step of the framework involves defining the focal social-ecological system by setting its soft boundaries in spatial and temporal scales. Since, these boundaries are defined in terms of the main issues of the social-ecological system, key territorial issues and valued attributes of those issues are identifies in this stage. In this context, the critical components of the system (e.g.; key resource uses, ecosystem services, stakeholders) are determined with potential disturbances and a historical profile of the system is developed with scales above and below the focal scale.

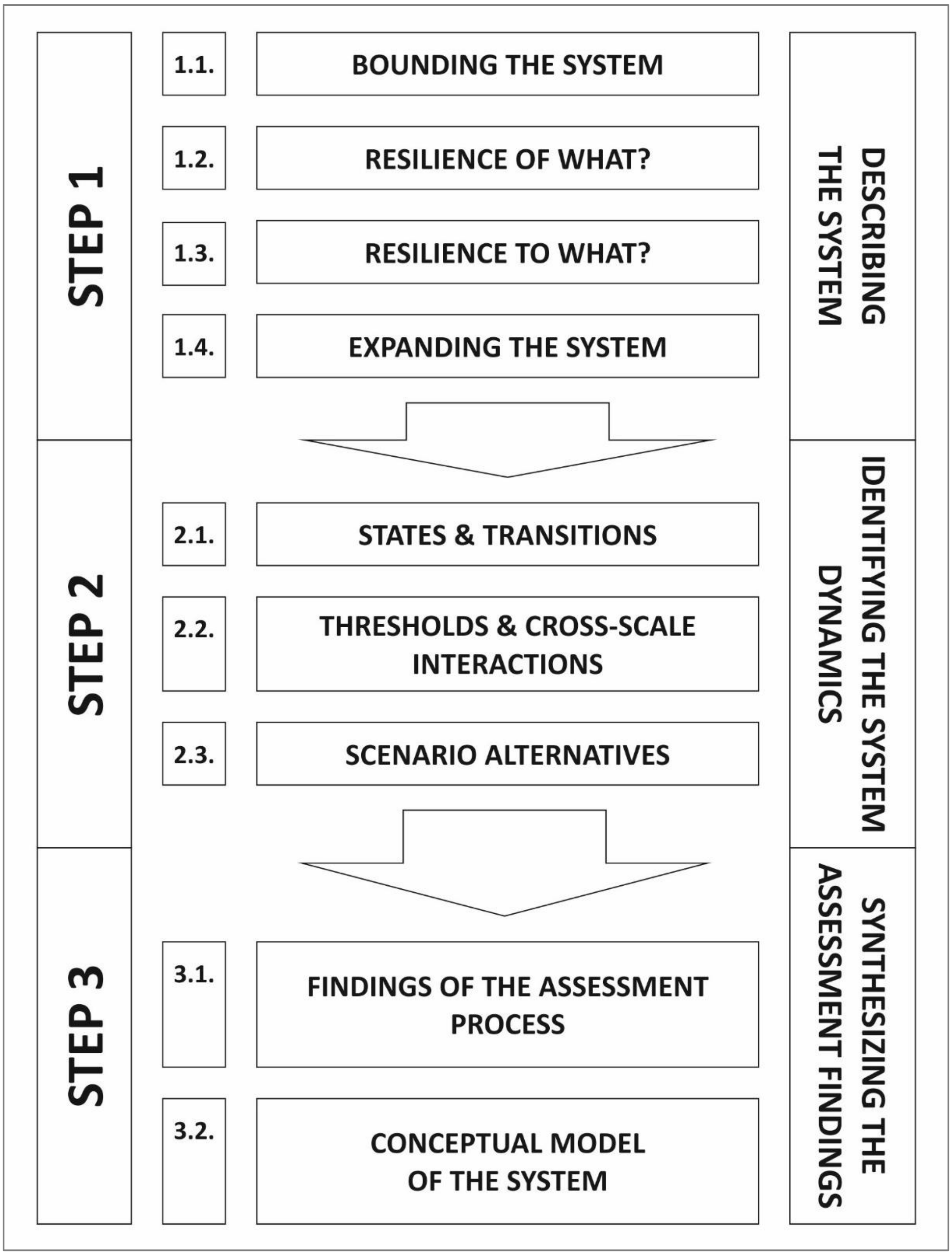

Figure 3.22: Resilience Assessment Framework for Istanbul City-Region

3.3.1.1 Step 1.1: Bounding the System

The focal system is defined in terms of its boundaries, main issues and key components in this first step of the framework. Therefore, the main issues of the system and their valued attributes are determined first. Then, social, economic and ecological components of the focal system that are related to main issues and valued attributes are identified.

3.3.1.2 Step 1.2: Resilience of What?

In this step, key components and stakeholders of the social-ecological system are identified and "Resilience of what?" question is answered. In this respect, important resources of the focal system are determined with their direct and indirect benefits. Therefore, main uses of natural resources are determined with the key stakeholders in the focal system. In other words, ecosystem goods and services of the social-ecological system are identified. Also, key actors or stakeholders of the system are described with the power relations and conflicts among them. Thus, individuals and organisations with key leadership roles and power are identified for each scale. Then, relations and conflicts among these actors are investigated. Policies, rules and regulations about the major resource uses are also determined in this step.

3.3.1.3 Step 1.3: Resilience to What?

Past, present and future disturbances of the social-ecological system are determined in this step. In this context, disturbance regime of the system is identified by analysing the frequency, duration, severity and predictability of determined disturbances. Managed or suppressed disturbances are also identified in this step.

3.3.1.4 Step 1.4: Expanding the System

A historical profile of the system is developed in this step of the framework. In this context, change drivers or trigger events of the system are identified in a historical timeline. Thus, the significant historical events and their influences are presented in historical timeline of the social-ecological system. The scales above and below the focal scale are also included within the historical profile and critical interactions between these scales were determined.

3.3.2 Step 2: Identifying the System Dynamics

In this step, possible alternate states of the system are identified with potential transitions among them. Therefore, critical thresholds and disturbances that underpin these transitions are determined and plausible future scenarios are considered.

3.3.2.1 Step 2.1: States and Transitions

Possible alternate states of the system and potential transitions among them are described in this step of the framework. Social, economic and ecological characteristics of each alternate state described in terms of their key components and the processes or disturbances underlying a transition between these states are determined. In this context, state-and-transition diagrams are constructed for analysing the possible alternate states and transitions of the system.

3.3.2.2 Step 2.2: Thresholds and Cross-scale Interactions

Critical thresholds that are separating the alternate states of the system are identified in this step of the framework. In this context, the factors and disturbances that drive changes in slow-changing variables and influence the position of thresholds are determined. After determination of thresholds and regime shifts of the system, existing and potential interactions among the thresholds are also determined in this step. Therefore, connections among the thresholds from different scales and domains are described here. Certainty levels of thresholds and their cascading effects are also identified.

3.3.2.3 Step 2.3: Scenario Alternatives

In this step of the framework, five plausible scenario alternatives were developed for investigating possible disturbances and regime shifts in the future. SLEUTH Cellular Automaton Model was implemented on Istanbul City-Region to predict the urban growth in the future and determine the possible impacts of Mega Projects on the urbanization process of Istanbul. With purpose of simulating the influence of Mega Projects on the urbanization process of Istanbul City-Region, only Clarke

UGM was executed in this research. In this context, future trajectories of the system were analysed for limited, managed and unlimited urban growth scenario alternatives. With two more scenario alternatives of unlimited urban growth, possible impacts of 3rd Airport and New Istanbul Projects were analysed.

In this context, 2005 release of the SLEUTH 3.0 Beta code was downloaded from the web page of Project Gigalopolis. Then, Cygwin program was downloaded and installed in order to execute the model in a Windows operating system. After modifying the system environment for SLEUTH application, successful execution of the model was verified by running a test run with the input images of Democity sample case. In parallel with the arrangement of SLEUTH environment, input images of the model were prepared for Istanbul City-Region case. Before implementing the model for Istanbul City-Region, accuracy of the prepared images verified by running a test run with the images. Verifying the successful run of the model for Istanbul City-Region, a brute-force calibration process was implemented for determining the best fitting values of the growth coefficients. In this context, the range of coefficient values was narrowed by running the model in coarse, fine and final calibration modes in sequence. Then, final (best fitting) values of the growth coefficients for forecasting were determined by running the model in calibration mode for the last time (with the values derived from final calibration). Once the best fitting coefficient values were determined, the model was executed in prediction mode to estimate the urbanization pattern/process of Istanbul City-Region for the year of 2050. These steps of the application process of SLEUTH Urban Growth Model are explained in detail below (see Figure 3.23 below).

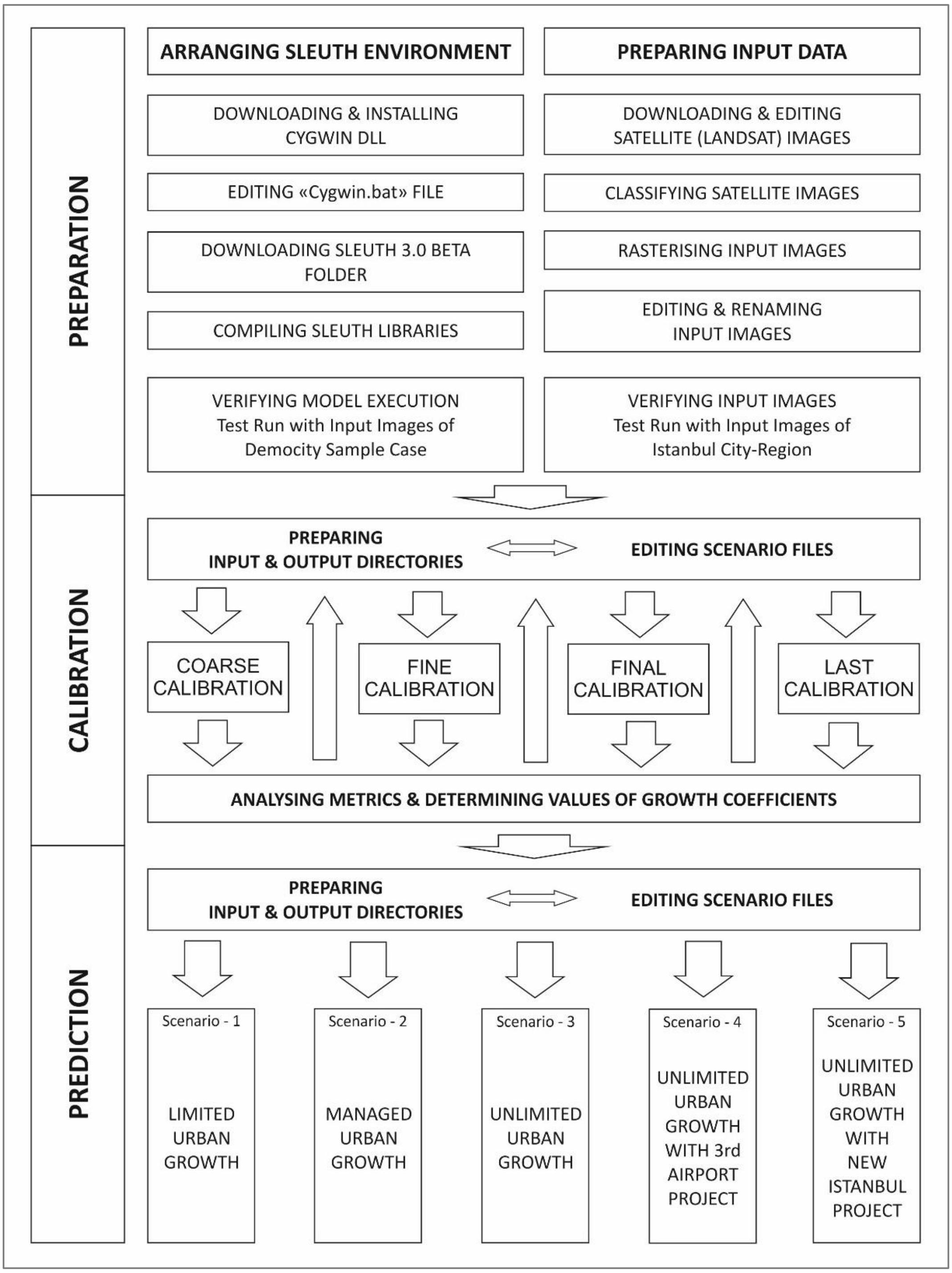

Figure 3.23: Application Process of SLEUTH Urban Growth Model

3.3.2.3.1 Preparation

Arranging SLEUTH Environment

Being developed for UNIX operating system, first releases of the SLEUTH could only be executed in UNIX or UNIX-like systems/environments. Later, the 2005 release of the model provided a functionality to be executed in Windows operating systems through Cygwin software. As an emulation software, Cygwin provides a UNIX-like environment on Microsoft Windows user APIs (Application Programming Interfaces) to compile and run open source software. Hence, 2.7.0 version of Cygwin was utilized to execute the 2005 release of the SLEUTH 3.0 beta code in Windows 10 Pro OS. Although, both 32 and 64 bit versions of Cygwin were available on web page of the software[10], 32 bit version was downloaded to comply with SLEUTH (Since SLEUTH is also a 32 bit program). Following the installation of Cygwin package (by running "setup_x86.exe" file), system environment was arranged for SLEUTH application. In this context, "Cygwin.bat" file was edited for SLEUTH through "nano" text editor of Cygwin and SLEUTH libraries were compiled through Cygwin Terminal. A detailed explanation of the steps of arranging SLEUTH environment is provided in the Appendices. Following the arrangement of SLEUTH environment, the model was executed in test mode with Democity sample data to verify successful operation of the model.

Preparing Input Data

In order to simulate urban growth and land cover changes, (current version of) the SLEUTH Cellular Automaton Model requires six types of input layer in predefined format. Scenario files aside, input layers are the main components of the model that enable its modification and implementation to different case areas. Since the model requires input data in specific and predefined format, they should be produced for each different case. Therefore, preparation of the input data in predefined format requires special attention. Especially, since the required data are generally not available at hand, they should be produced from scratch. The model requires Urban,

[10] [https://www.cygwin.com]

Land-use and Transportation data to be derived from different time periods. Urban images of at least 4, Land-use images of at least 2 and Transportation images of at least 3 different time periods are required to execute the model. In Istanbul City-Region case, land-use data for the year of 2006 [that were produced and used during the preparation of 1/100.000 scale Territorial Plan of Istanbul] were acquired from the archives of Istanbul Metropolitan Municipality. Since, data of only one time period (2006) was not enough to execute the model, input images of different time periods were produced from the satellite (Landsat) images of Istanbul City-Region.

In this context, first, Landsat images of Istanbul City-Region (for the years of 1987, 2000, 2006, 2009, 2013 and 2017) were downloaded and edited for classification. Then, supervised and unsupervised classifications were performed to the multi-band images of 2006 and 2013 in first step. Following the completion of classification processes, overall accuracy and Cohen’s Kappa coefficients were calculated for each classified image to assess the accuracy of their classification. Although, admissible values of overall accuracy and Cohen’s Kappa (higher than 80% and 70%, respectively) were obtained from accuracy assessment of the classified images, their resemblance to the actual (Google Earth and Landsat) imagery was not accurate enough to be directly used in the model. Consequently, in addition to the classified images of Istanbul; multiband Landsat images, CORINE land cover maps and Google Earth aerial photography were used as templates to manually digitize the land-use classes of Istanbul City-Region. Once the land-use classes of Istanbul City-Region were created in vector data format, they were edited to generate the input images of the model. Following their preparation, input images were verified by running the model in test mode. Steps of the input data preparation process are explained in detail, below.

Acquiring Satellite Images

As it was mentioned before, satellite images of Istanbul City-Region were utilised for generating input data of the model. In this context, Landsat images of Istanbul City-Region were downloaded from the archives of U.S. Geological Survey

Agency (USGS). Landsat archives of USGS provide the longest temporal record of moderate resolution multispectral data of the Earth's surface on a global basis ("Landsat Missions," 2016). USGS also provides a number of tools or web sites [EarthExplorer (EE), Global Visualization Viewer (GloVis), LandsatLook Viewer] for searching and downloading the intended images of the Earth's surface, free of charge. In this research, Earth Explorer (EE) web site[11] (tool) was used for acquiring the Landsat images of Istanbul City-Region.

Earth Explorer web site provides a set of sequential steps to reach appropriate image of the search area for the intended time period. Registration and login are required to access all system features and download data from the web site. Search process starts after signing in to the system. Search criteria, such as location and date range of the intended images are entered in the first step of search. In this step, search area could be narrowed or defined by typing in an address or place name, entering coordinates or path/row numbers, or clicking the area on the provided online map of the Earth's surface. After entering the search criteria, data sets to be searched are selected in the second step. Then, additional criteria, such as cloud cover, spacecraft identifier, path/row range and day/night indicator could be selected in the next step. After submitting the additional criteria, search results are listed in the final step of the search. Appropriate images of the search area could be examined and downloaded from the list of results (see Figure 3.24).

For case study of Istanbul City-Region, search area was narrowed down to the administrative boundaries of Istanbul Province and time periods are defined as the years of 1987, 2000, 2006, 2009, 2013 and 2017. Since, provincial borders of Istanbul City-Region fall in two scenes of Landsat in Worldwide Reference System (WRS), Landsat scenes in rows 31 and 32 of path 180 were searched for each year. In this context, collections of Landsat Archive were selected as the data set to be searched and in terms of additional criteria; levels/percentages of land and scene

[11] [https://earthexplorer.usgs.gov/]

cloud covers, types of spacecraft identifiers and periods of the day were defined. Then, listed results of each search examined for the appropriate images and the selected ones were downloaded in compressed folders.

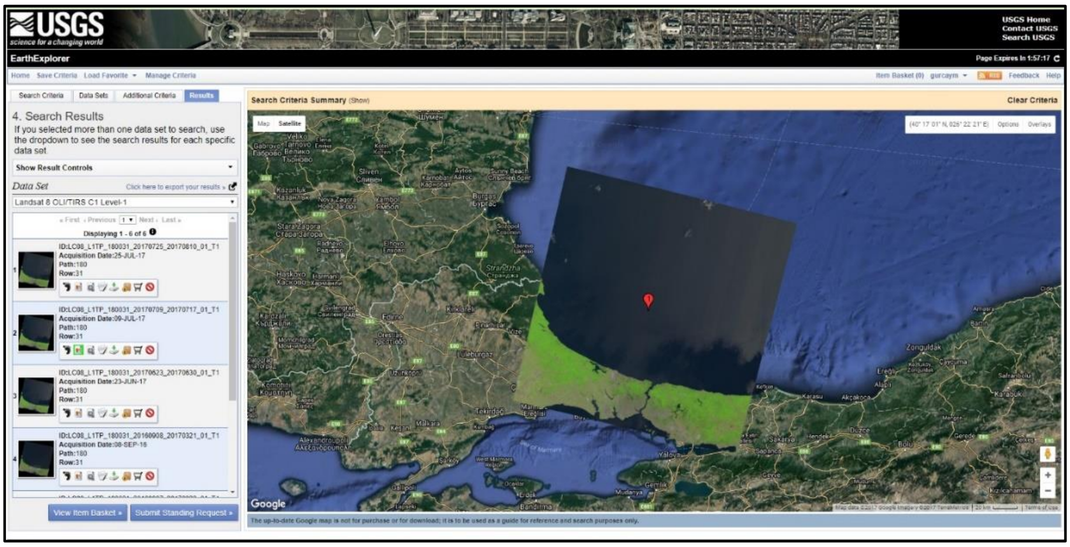

Figure 3.24: Screenshot of Earth Explorer web page (EarthExplorer, 2018)

Editing/Organising Satellite Images

Because of its location and magnitude, entire area of Istanbul City-Region does not fit into a single Landsat scene. Instead, two intersecting scenes in rows 31 and 32 of path 180 (WRS2) contain the northern and southern parts of Istanbul City-Region, respectively. Therefore, in order to obtain the entire area of Istanbul City-Region (within provincial borders of Istanbul), two sets of Landsat data were downloaded for each year. Since each Landsat sensor collects data at different (spatial and spectral) resolutions, varying numbers of single band images with distinctive spectral ranges were provided in downloaded folders of Landsat data.

In order to generate multi-band images of Istanbul City-Region for each year, downloaded single-band images of each Landsat scene were edited and combined by using ArcMap 10.3.1. In this context, "null" values of each single band image were eliminated, first. Next, image pairs of each spectral band were joined to produce single band images of the entire area of Istanbul City-Region. Then, multi-band images of Istanbul City-Region were generated by combining the single band images of different spectral layers for each year. Finally, multi-band images of each year were clipped to the borders of Istanbul City-Region to eliminate the redundant parts.

Classifying Satellite Images

After their preparation, multi-band images of Istanbul City-Region were classified to determine the land-use patterns of each year. In this context image classification methods were applied to multi-band images of Istanbul City-Region by ArcMap 10.3.1. Image classification methods generate preferred or defined number of informational classes from multi-band images of an area. They (image classification methods) basically group the pixels (of an image) with uniform or homogeneous spectral values (identities) together and sort them into defined/preferred number of informational classes (such as land-use or soil classes).

Supervised and unsupervised classifications are the two main types of image classification methods. In supervised classification, operator could train or supervise the computer system to identify the pixels with similar characteristics whereas in unsupervised classification system the computer performs automatically. Since each method has different advantages, both supervised and unsupervised classifications were applied to the images of Istanbul City-Region and the accuracy of their results was evaluated. Although admissible values of overall accuracy and Cohen's Kappa were obtained from classification of the images of 2006 and 2013, resemblance of the classified images to the actual imagery was not accurate enough to be used in the model. Therefore, images of 1987, 2000, 2009 and 2017 were not classified with image classification methods. Instead, all of the images were manually digitized to determine the land-use classes of Istanbul City-Region. Processes of performing supervised and unsupervised classification and the assessment of their accuracies are briefly explained below.

Supervised Classification: In supervised classification the operator supervises the classification of pixels by selecting (or drawing) training samples from the image. Training samples are the groups (or clusters) of pixels with similar characteristics or values that will be assigned to specific informational classes. For Istanbul City-Region case, pixels of the images were classified into four informational (land-use) classes of urban, agriculture, forest and water. Therefore, for each informational class multiple training samples were created from different areas of the image in ArcMap. In order to determine the different values of each informational class, different combinations of the spectral bands of multi-band images were used. Following their creation, training samples were evaluated in terms of their normality, separability and partitioning. Next, the evaluated training samples were re-organised and a single signature file was generated from the re-organised training samples. Finally, Maximum Likelihood Classification was applied with the generated signature file and the results were re-classified into the informational classes of urban, agriculture, forest and water. Output images of supervised classification are presented in the Figure 3.25 and Figure 3.26 below.

Unsupervised Classification: In unsupervised classification the pixels are clustered together automatically. The operator could only set the number of spectral classes to be classified and then the computer determines which informational class contains each one of the spectral classes. For Istanbul City-Region case, ISO Cluster Unsupervised Classification was applied to the images of 2006 and 2013 and the number of spectral classes was set to 200. Following the classification of images into 200 spectral classes, they were compared with actual images (multi-band satellite images and Google Earth imagery) to determine which informational classes contain each spectral class. Then spectral classes were reclassified into the informational classes of urban, agriculture, forest and water. Output images of unsupervised classification are presented in the Figure 3.27 and Figure 3.28 below.

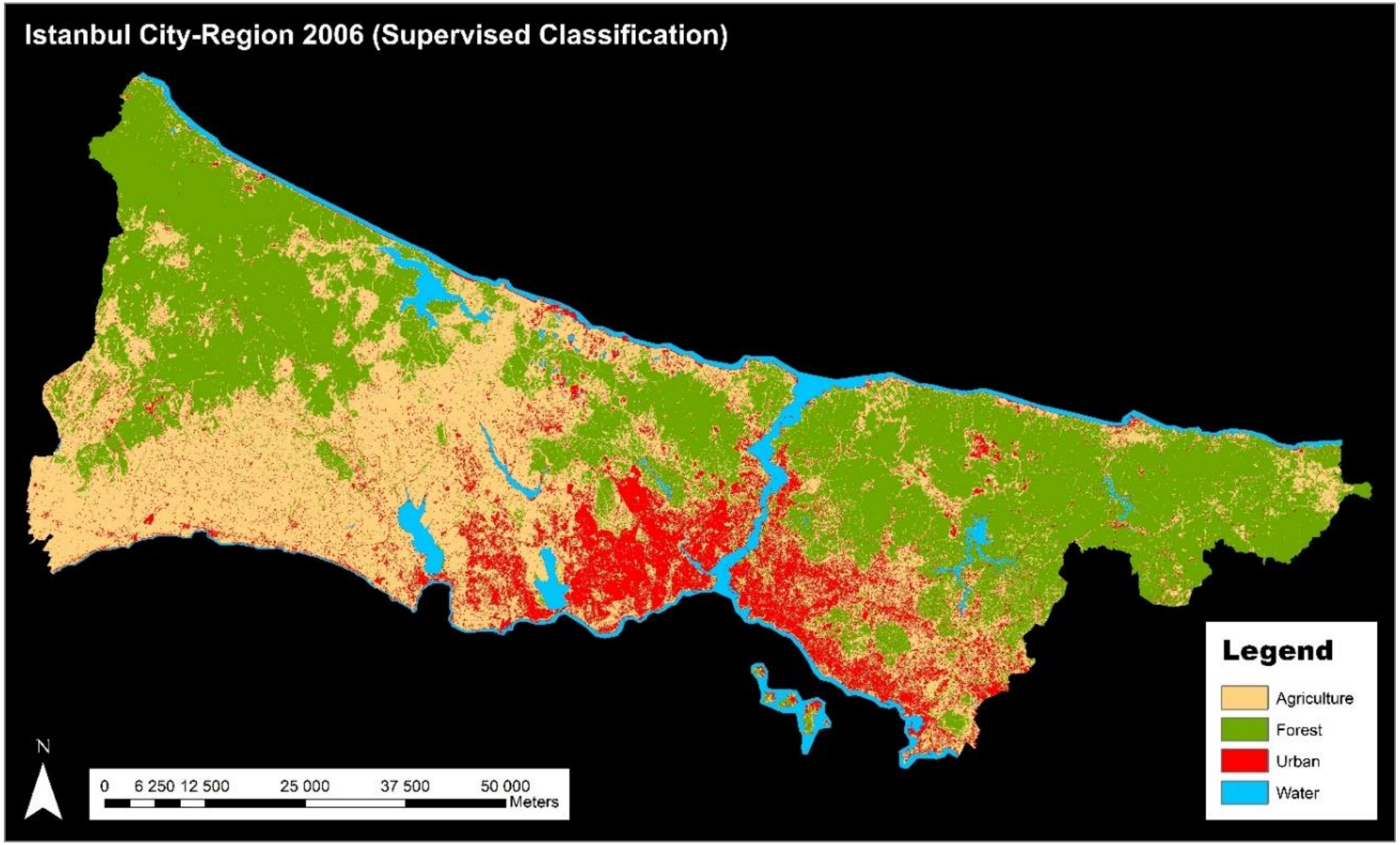

Figure 3.25: Classified image of Istanbul City-Region for 2006 (Supervised classification)

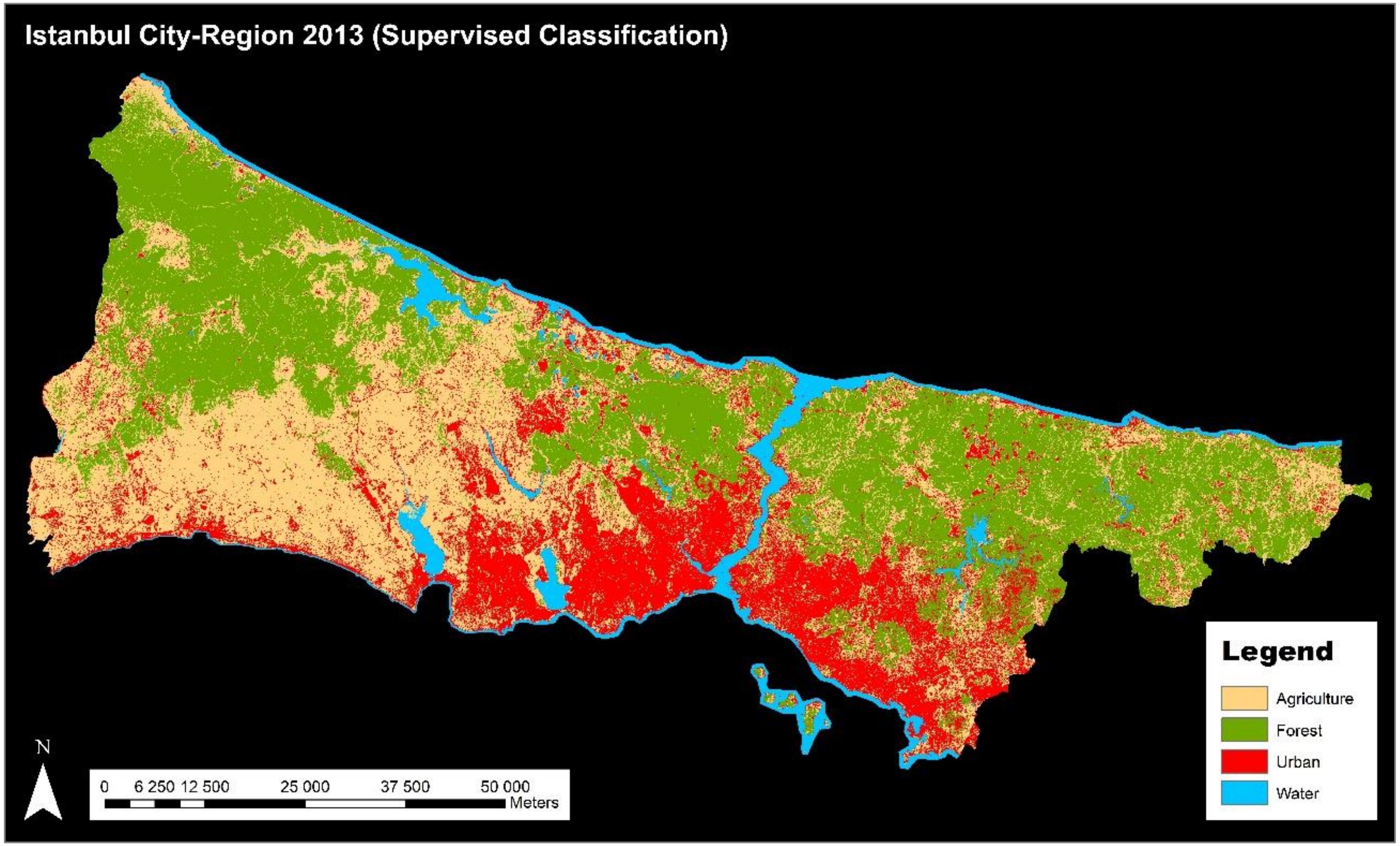

Figure 3.26: Classified image of Istanbul City-Region for 2013 (Supervised classification)

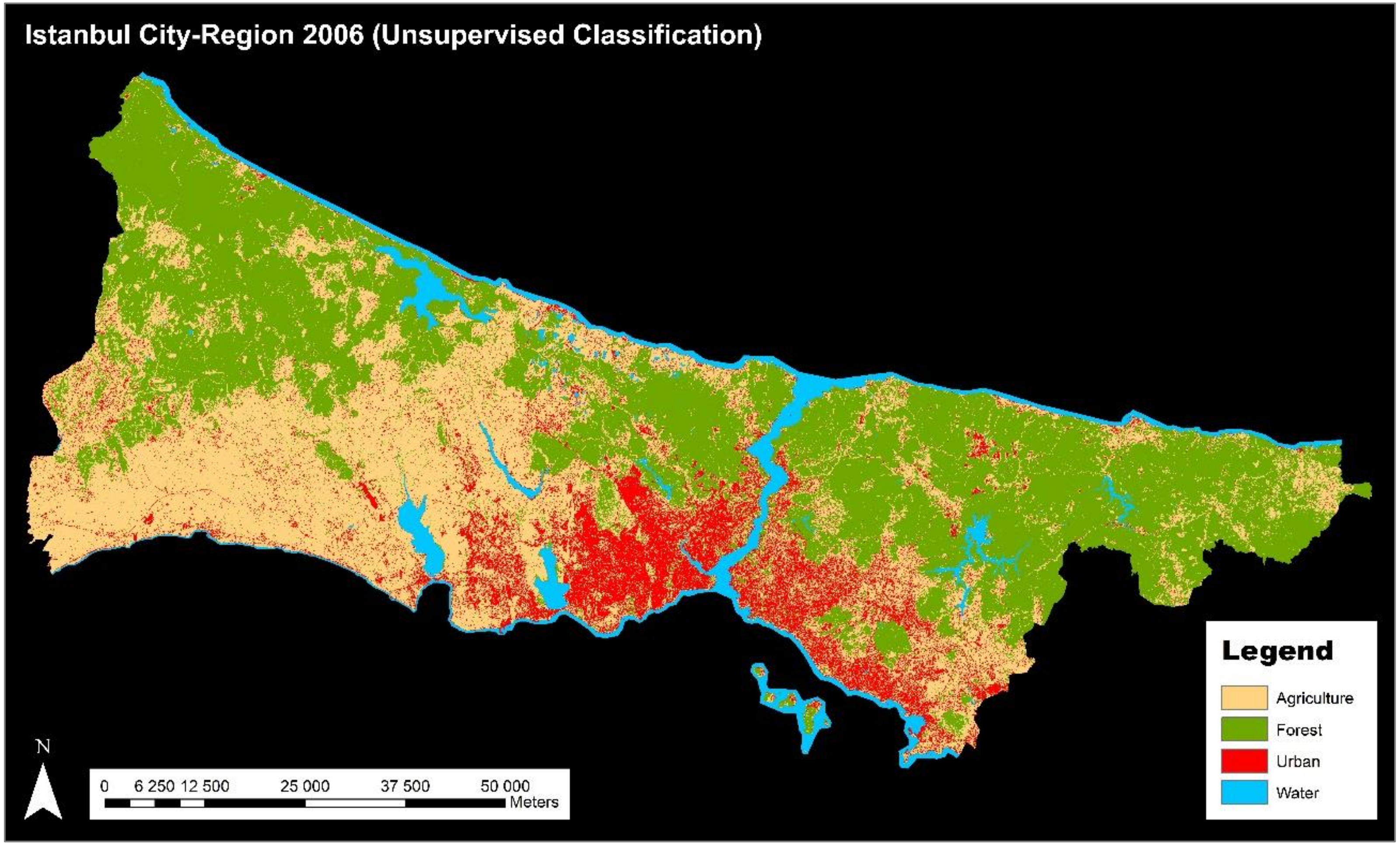

Figure 3.27: Classified image of Istanbul City-Region for 2006 (Unsupervised classification)

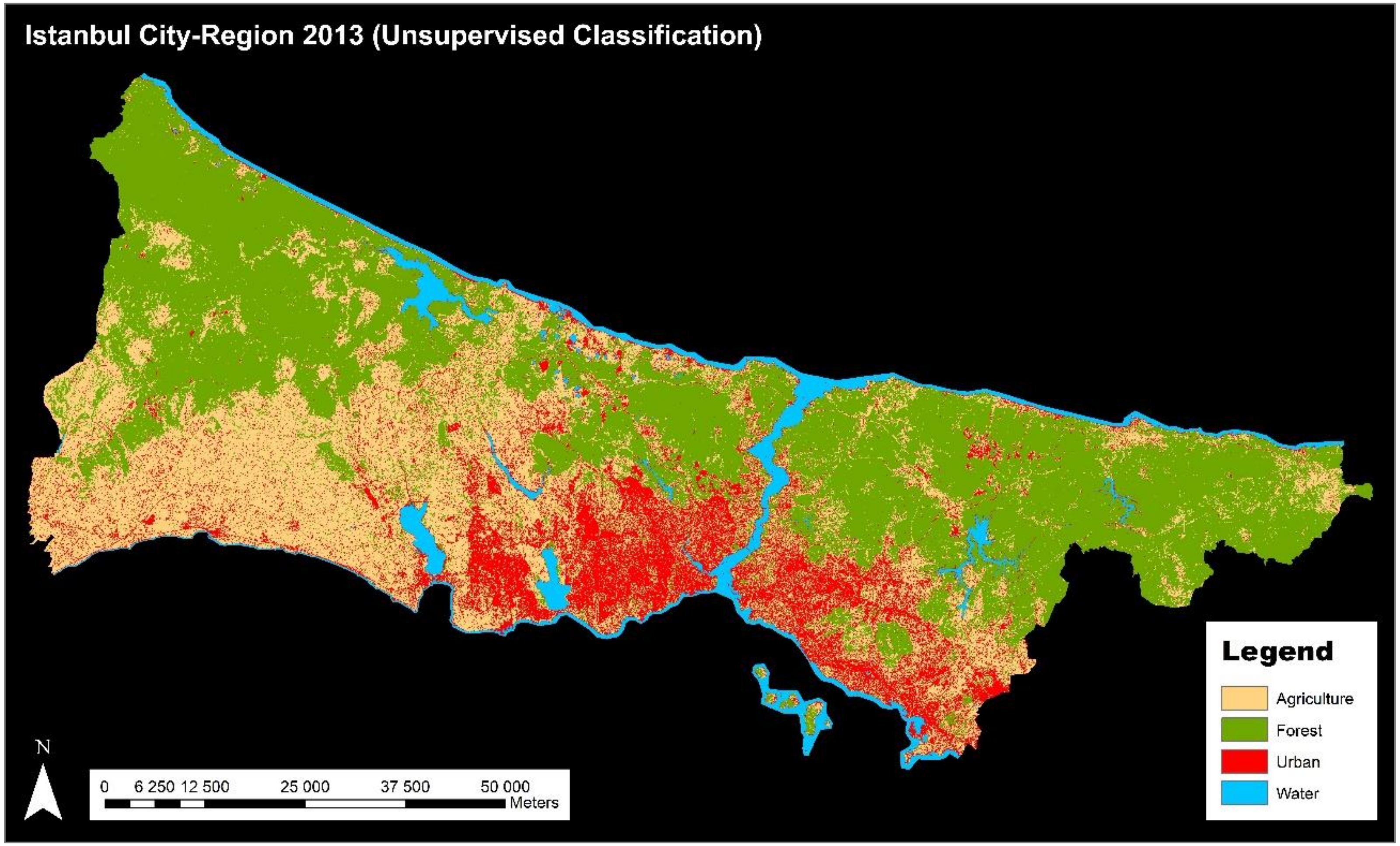

Figure 3.28: Classified image of Istanbul City-Region for 2013 (Unsupervised classification)

Accuracy Assessment: After classification of the images of 2006 and 2013, resemblance of classified images to actual images was tested in order to determine the accuracy of classifications. In this context, overall accuracy and Cohen's Kappa coefficients were calculated by compiling an error matrix for each classification. An error matrix is a table of values that compares the resemblance of classified images to actual ones (Campbell and Wynne, 2011; Story and Congalton, 1986). In order to prepare an error matrix, random set of points are generated over the entire area of classified images. Then, values of each point for classified and actual images are entered into error matrix for comparison. Next, overall accuracy and Cohen's Kappa coefficients are calculated from the error matrix. Overall accuracy denotes the ratio of the number of points with same values in both images to the number of all random points. To put it another way, it is the percentage of random points with correct values (see Table 3.4). On the other hand, Cohen's Kappa presents how well the results were achieved by classification compared to randomly assigning values (Campbell and Wynne, 2011).

Table 3.4: Error Matrix for Supervised Classification of 2013 Images of Istanbul

		classification				
		urban	**rural**	**forest**	**water**	**TOTAL**
real world	**urban**	24	8	0	0	32
	rural	13	45	1	0	59
	forest	4	12	79	1	96
	water	1	0	0	12	13
	TOTAL	42	65	80	13	160

Number of points: 200

Overall Accuracy: 160/200 (0.8)

Cohen's Kappa is calculated by the formula of: $\frac{observed - expected}{1 - expected}$. In this formula, observed is the overall accuracy of classification whereas expected is the product of row and column values of error matrix. In order to calculate the value of "expected", a product matrix is generated from the row and column totals of error matrix. In this context, the values in each cell are multiplied with total of the related column. Then, "expected" is calculated by dividing the sum of diagonals to cumulative sum of all values from product matrix (see Table 3.5).

Table 3.5: Product Matrix for Supervised Classification of 2013 Images of Istanbul

		classification				
		urban	**rural**	**forest**	**water**	**TOTAL**
real world	**urban**	1344	2080	2560	416	32
	rural	2478	3835	4720	767	59
	forest	4032	6240	7680	1248	96
	water	546	845	1040	169	13
	TOTAL	42	65	80	13	13 028

Sum of Diagonals: 13 028
Cumulative Sum: 40 000
Observed (Overall Accuracy): 0.80
Expected: 13 028/40 000 (0.33)
Kappa: 0.70

In Istanbul City-Region case, 200 random points were generated for each classified image by ArcMap. Then, classified and actual values of each point were determined and listed in the error matrix. In this respect, desktop application of Google Earth Pro was utilised for acquiring reference images to identify the actual values of random points. Google Earth Pro provides historical imagery of the Earth's surface and allows to move between images of different acquisition dates with time-slider. Therefore, shapefiles of random points were exported into "kml" format to be opened in Google Earth. Then, actual values of each point were identified from Google Earth imagery of that year and noted into the attribute table of shapefiles. Later, classified values of each point were extracted from the classified image to attribute table of same shapefiles. Using the acquired values of random points, error matrices were generated for each classification. At the end, overall accuracy and Cohen's Kappa values were calculated for each classification and acquired values are listed in the Table 3.6 below. As a result, similar values of overall accuracy and Cohen's Kappa were acquired for supervised and unsupervised classifications of each image.

Table 3.6: Overall Accuracy and Kappa values of supervised and unsupervised classifications.

	Supervised Classification		**Unsupervised Classification**	
Years	**Overall Accuracy**	**Cohen's Kappa**	**Overall Accuracy**	**Cohen's Kappa**
2006	0.78	0.67	0.79	0.67
2013	0.80	0.70	0.81	0.71

Although, admissible values of overall accuracy and Cohen's Kappa were obtained from accuracy assessment of the classified images, visual comparison of classified images with actual images (historical imagery) revealed that resemblance to actual imagery was not detailed enough to be used in the model. Therefore, the land-use classes of Istanbul City-Region were also digitized manually.

Manually Digitising Land-use Classes

In spite of the fact that statistically accurate results were obtained from the supervised and unsupervised classifications of satellite images, the resulting images were not corresponding to the actual (multi-band and Google Earth) images. Especially, urban and agricultural areas were dispersed within each other in the classified images. Therefore, in order to increase the accuracy of classifications, land-use classes were digitised from the multi-band images of Istanbul City-Region. In other words, the land-use classes were manually drawn over the multi-band images. In addition to the satellite images of Istanbul City-Region; recently classified images and CORINE land cover maps were also utilised as base maps. Additionally, historical imagery was also used for comparison.

For manually digitising the land-use classes; multi-band satellite images, recently classified images and CORINE land cover images of Istanbul City-Region were opened in ArcMap and overlapped. CORINE land cover images were classified in terms of label 2 classes and multi-band satellite images were displayed with different combinations of spectral bands. Since the recent images have higher resolutions, land-use classes of 2013 were digitised first[12]. Examining the base maps and Google Earth images, land-use classes were identified and drawn in ArcMap. In this context, land-use classes of; urban areas, forests, agricultural areas, meadows (range lands), construction sites, barren lands, water bodies and roads were determined and digitised from the 2013 images of Istanbul City-Region. Additionally, vector data of military zones were imported from the land-use data of 2006 that was acquired from Istanbul Metropolitan Municipality. Once the vector data of land-use classes of 2013 were generated, they were modified for other years by examining the base maps and historical satellite images of each year. At the end, vector data of land-use classes for the years of 1987, 2000, 2006 and 2013 were generated from raster images. Land-use classes of 2017 were also generated through same process, later.

Finalising (Rasterising, Editing and Renaming) Input Images

As it was mentioned before, SLEUTH Cellular Automaton Model requires input images to be prepared in predefined data format. In order to execute the model successfully, input images should be prepared in 8 bit unsigned greyscale GIF format with consistent numbers of rows and columns. They should also be named in the required naming format of the model. Therefore, after digitisation of land-use data for the years of 1987, 2000, 2006, 2013 and 2017 input images were prepared in the required raster format in ArcMap. Images of slope and hill-shade layers were produced from the Digital Elevation Model (DEM) of Istanbul City Region that was provided with 2009 images of Landsat. On the other hand, images

[12] Input data preparation process was started in 2014 therefore the most recent image was the image of 2013. Later, 2017 image was acquired and digitized to update the research.

of urban, transportation and excluded layers were generated from the digitised data of land use classes in addition to the vector data acquired from Istanbul Metropolitan Municipality. Since Deltatron Land Cover Change Model was not employed, land-use images were not prepared for this research. In order to achieve the correspondence (or overlapping) of input images, (feature class of) a rectangular data frame covering the entire area of Istanbul City-Region was created in ArcMap. In addition, a smaller data frame covering the central urban areas of the city was also created to be used in calibration processes. Once the input images were prepared in ArcMap, they were extracted by these data frames and exported from ArcCatalog in 8-bit unsigned TIF format. Next, to be used in coarse and fine calibration steps of brute-force calibration process, the prepared images were exported one more time with spatial resolution of 100x100m[13]. Then, format of the exported images was converted to GIF in PhotoShop (software) and their naming was reorganised in terms of the required naming format. Preparation processes of input images for each input layer are briefly explained below.

Slope Image: Slope image of the model was generated from the Digital Elevation Model (DEM) of Istanbul City Region in ArcMap. A DEM image covering the boundaries of Istanbul City-Region was provided with the 2009 images of Landsat 5. Acquired DEM image was opened in ArcMap and clipped to the provincial borders of Istanbul City Region by Extraction Tool of ArcToolbox. Next, an image of percent slope was created from DEM by Slope Tool of ArcToolbox. Then, generated image of percent slope was combined with the raster image of larger data frame in order to achieve the correspondence among input images. Thereafter, created image was clipped to (the feature classes of) large and small data frames with Extraction Tool of ArcToolbox and exported in 8-bit unsigned TIFF format. After that, format of the exported images was converted to GIF in Photoshop (see Figure 3.29).

[13] Since a smaller frame was also used in brute-force calibration process, images with a quarter of the original resolution were not prepared.

Figure 3.29.a) Large frame (column/row: 3368x1736)

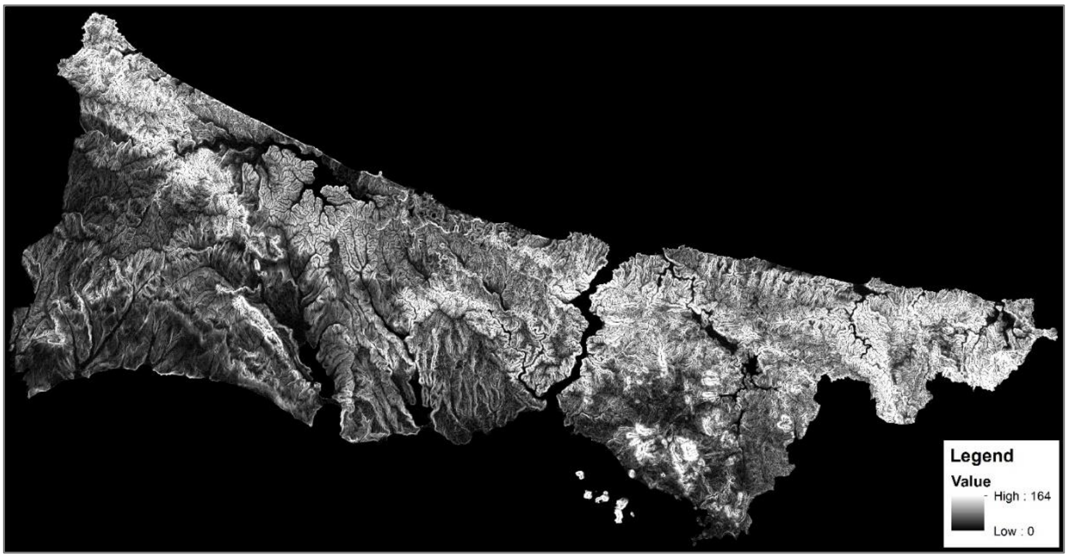

Figure 3.29.b) Small frame (column/row: 1744x1419)

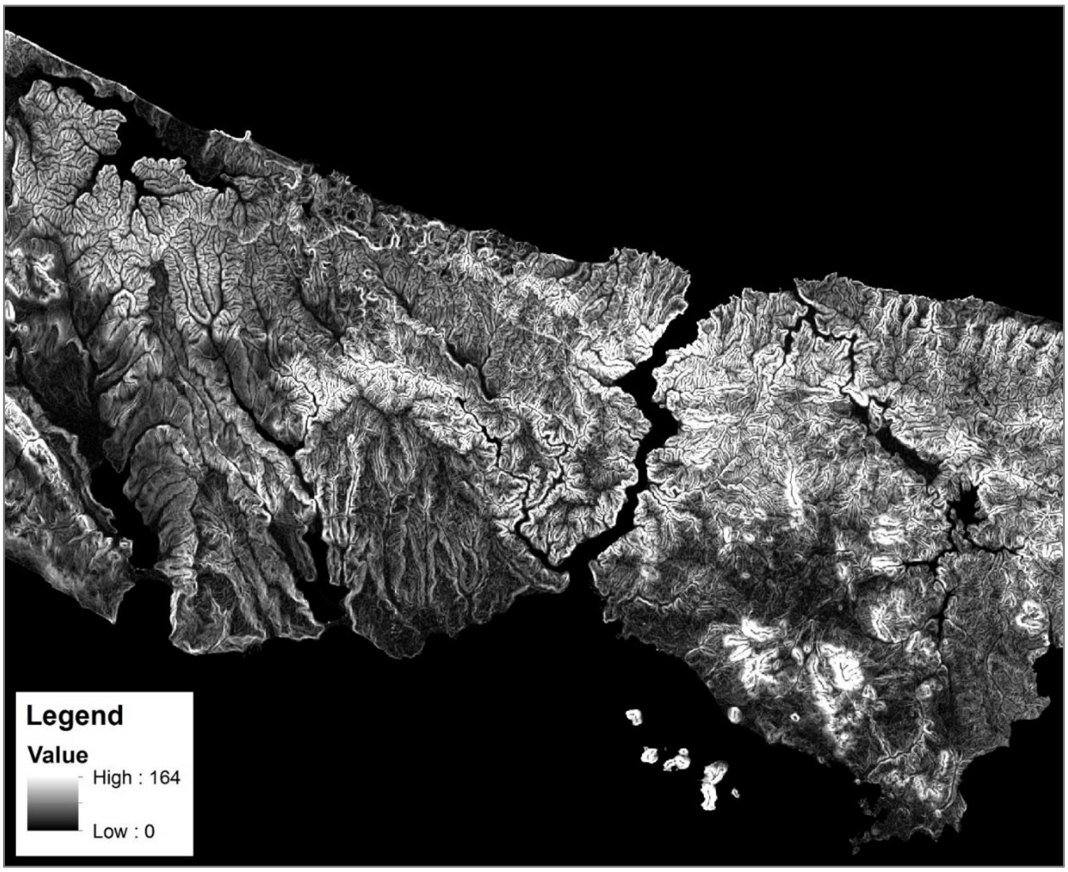

Figure 3.29: Slope image

Figure 3.30.a) Large frame (column/row: 3368x1736)

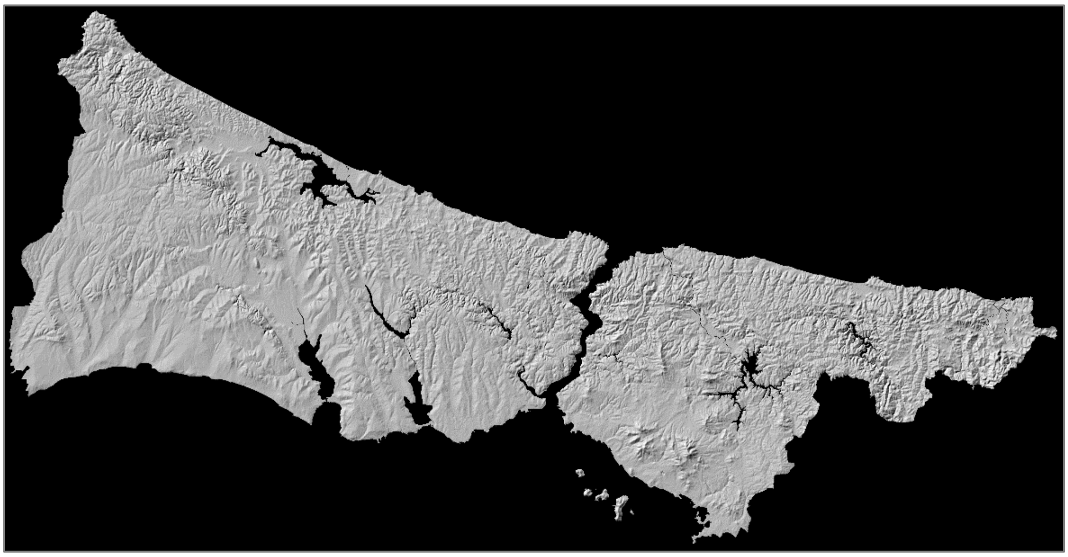

Figure 3.30.b) Small frame (column/row: 1744x1419)

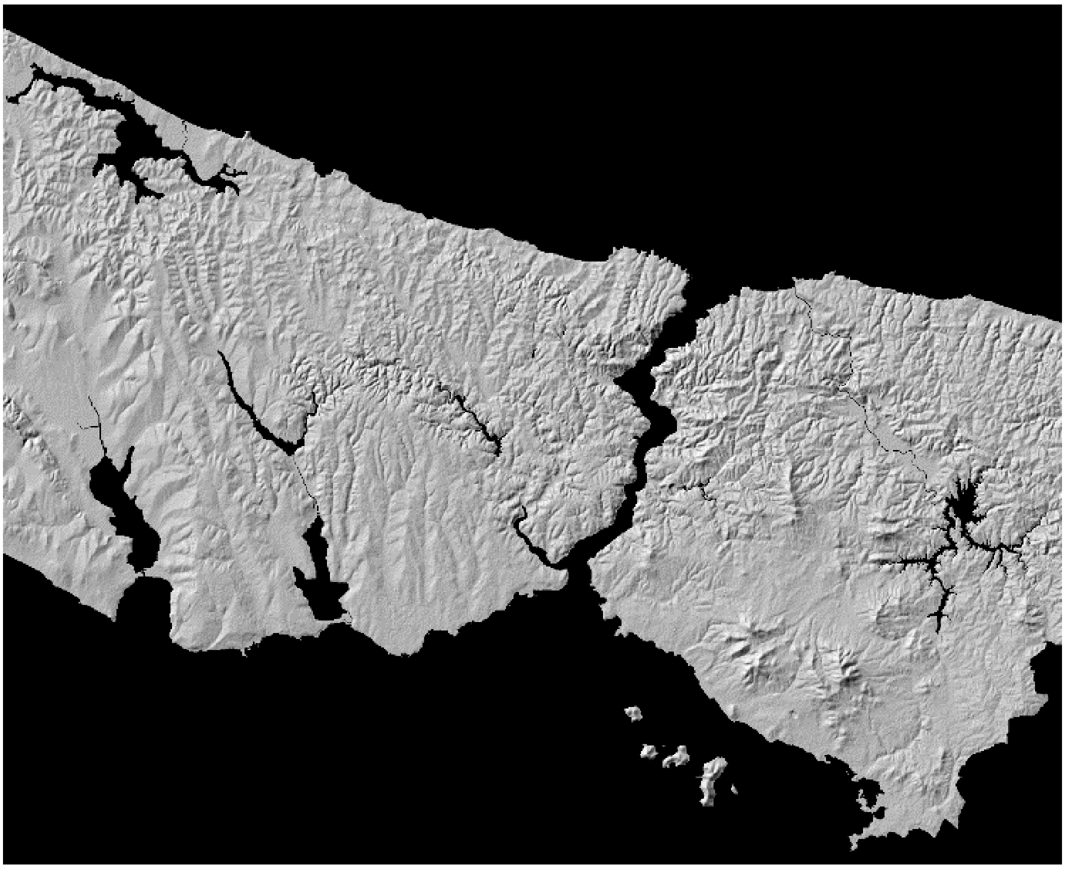

Figure 3.30: Hill-shade image

Hill-shade Image: Like slope image, hill-shade image of the model was generated from the DEM of Istanbul City-Region. In this context, edited DEM image was opened in ArcMap and a shaded image of Istanbul City-Region was created with Hillshade Tool of ArcToolbox. Then, created image was combined with raster images of the water bodies and data frame to produce a background image with lakes and rivers. Next, created image was clipped to (the feature classes of) large and small data frames with Extraction Tool of ArcToolbox and exported in 8-bit unsigned TIFF format. After that, format of the exported images was converted to GIF in Photoshop (see Figure 3.30 above).

Urban Images: Urban images of the model were generated from the digitized data of land-use classes. Accordingly, feature class of urban areas was converted to raster image in TIFF format with Conversion Tool of ArcToolbox. In this process, cell size (resolution) of the output image was determined as 50m. After being rasterised, image of urban areas was combined with the image of data frame. Then, using Reclassify Tool of ArcToolbox, values of the image were reclassified as 255 and 0 for urban and non-urban areas, respectively. Next, reclassified image was clipped to (the feature classes of) large and small data frames with Extraction Tool of ArcToolbox and exported in 8-bit unsigned TIFF format. After that, format of the exported images was converted to GIF in Photoshop and the process was repeated for other years (see Figure 3.31).

In addition to urban images of 1987, 2000, 2006, 2013 and 2017, two more images were generated for scenario alternatives. For the scenario of “Unlimited urban growth with New Istanbul Project”, an urban image including the “New Istanbul Project” as urban area was prepared. In this context, expropriation area of “New Istanbul Project” (Retrieved from the appendix of 2014/6028 numbered Decree of the Council of Ministers), including the areas of 3rd Airport and Canal Istanbul Projects was digitised.

Figure 3.31.a) Large frame (column/row: 3368x1736)

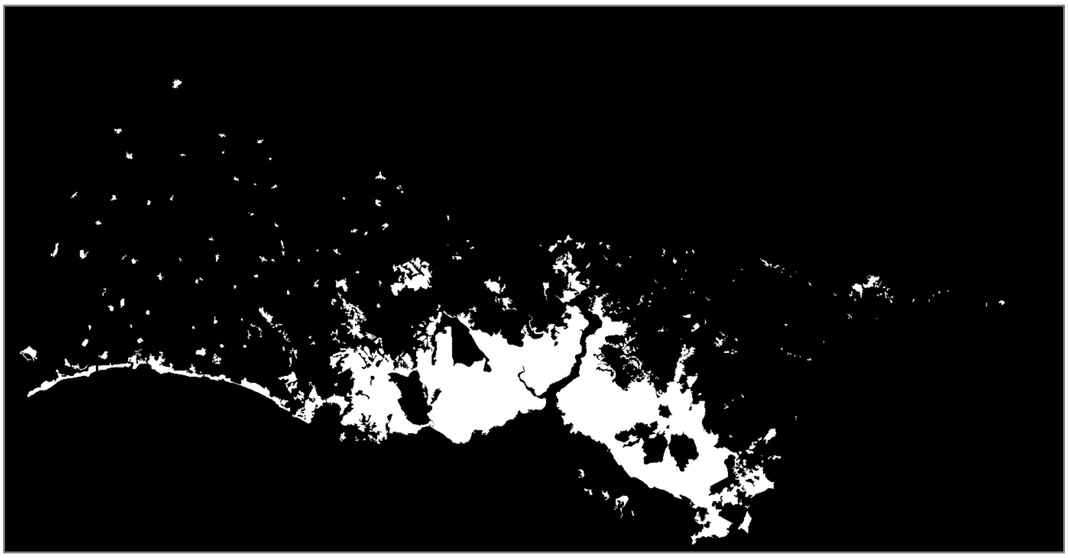

Figure 3.31.b) Small frame (column/row: 1744x1419)

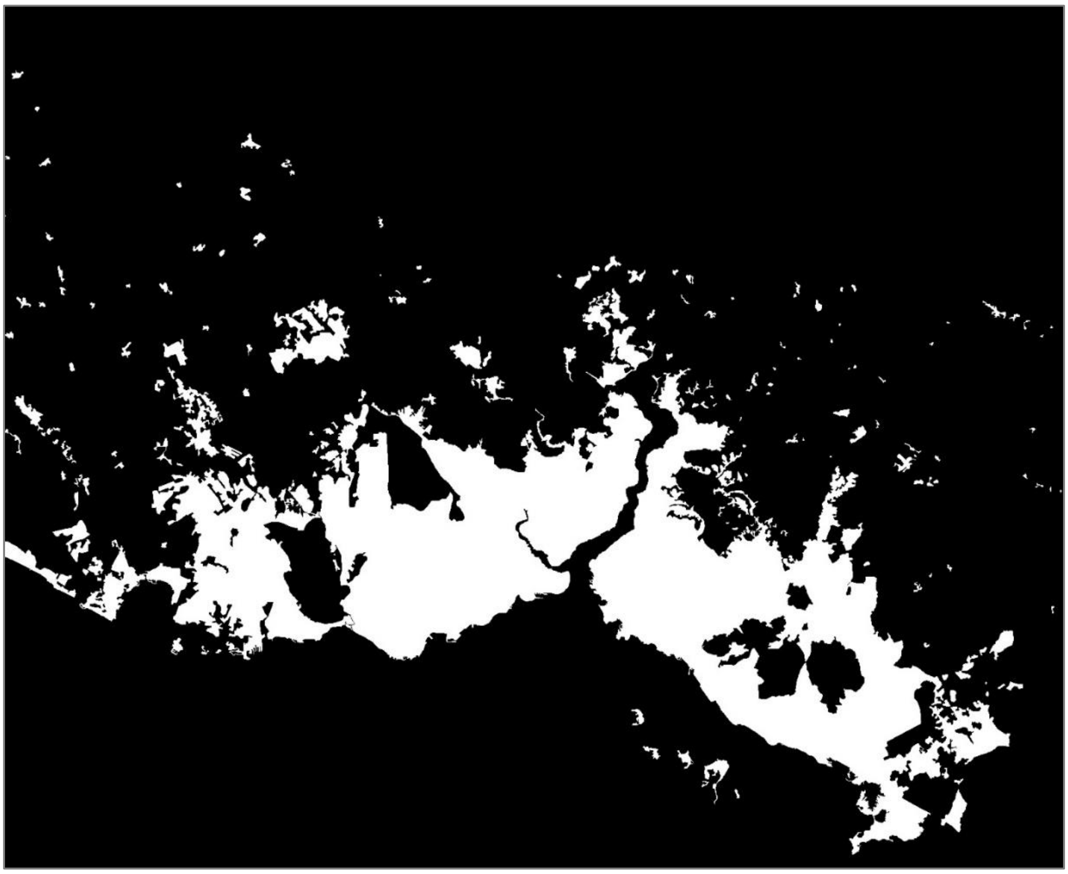

Figure 3.31: Urban image for 2017

Since, implementation or completion date of the project had not been revealed yet, it was speculated (predicted) for the research. Because of the fact that 2023 is the target year of AKP government for large-scale investments, it was assumed that the New Istanbul Project would be started in 2023 and completed in 2030. Therefore, digitised expropriation area of “New Istanbul Project” was rasterised and attached to the predicted urban areas of 2030. In this context, predicted image of 2030 was acquired from the results/outputs of “Unconstrained urban growth scenario” (see Figure 3.32).

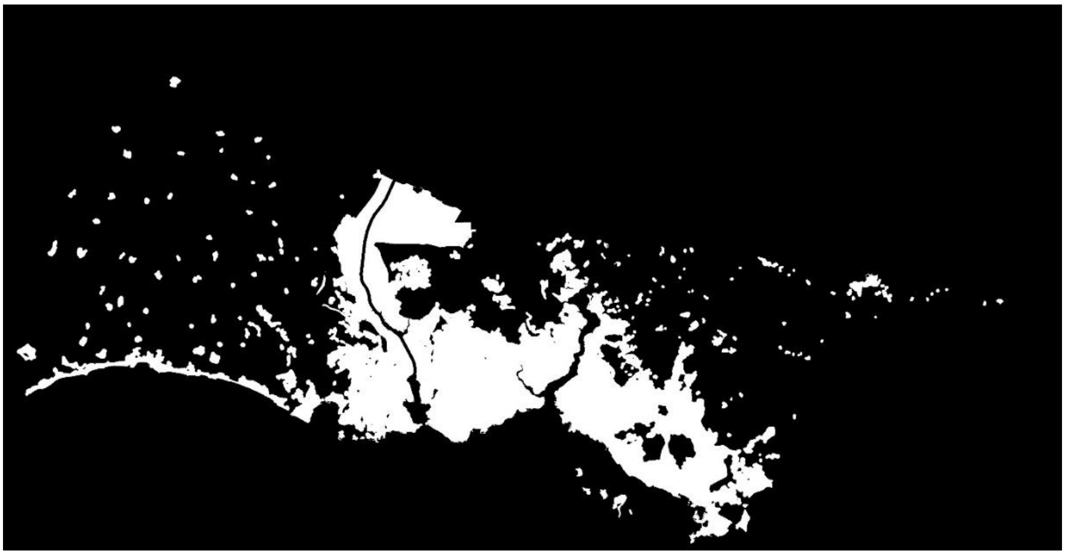

Figure 3.32: Urban image for 2030

Additionally, an urban image containing the expropriation area of “3rd Istanbul Airport Project” as urban areas was prepared for the scenario of “Unconstrained urban growth with 3rd Airport”. Accordingly, expropriation area of 3rd Airport Project was digitised and attached to the urban areas of 2017. Year of this urban image with 3rd Airport Project was set to 2018 (see Figure 3.33).

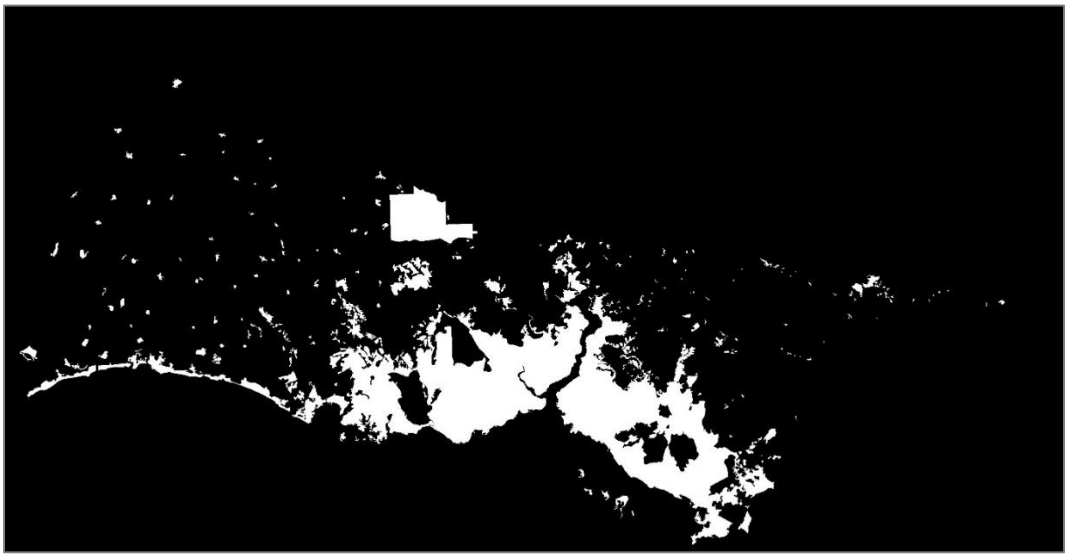

Figure 3.33: Urban image for 2018

Exclusion Images: Exclusion images of the model were generated mainly from the digitized data of land-use classes and acquired data of conservation areas from Istanbul Metropolitan Municipality and Ministry of Forestry and Water Affairs. Although, only one image of excluded areas was enough for the model, two more images were prepared for scenario alternatives. Therefore, three different exclusion images were prepared for the scenario alternatives of conservative, moderate and aggressive urban growth (see Figure 3.34, Figure 3.35 and Figure 3.36). In addition to these three main images of excluded areas, a fourth was also prepared for the scenario alternative of Unlimited Urban Growth Including New Istanbul Project. For this fourth exclusion image, speculated border of Canal Istanbul Project was added to the exclusion image of aggressive scenario alternatives (see Figure 3.37).

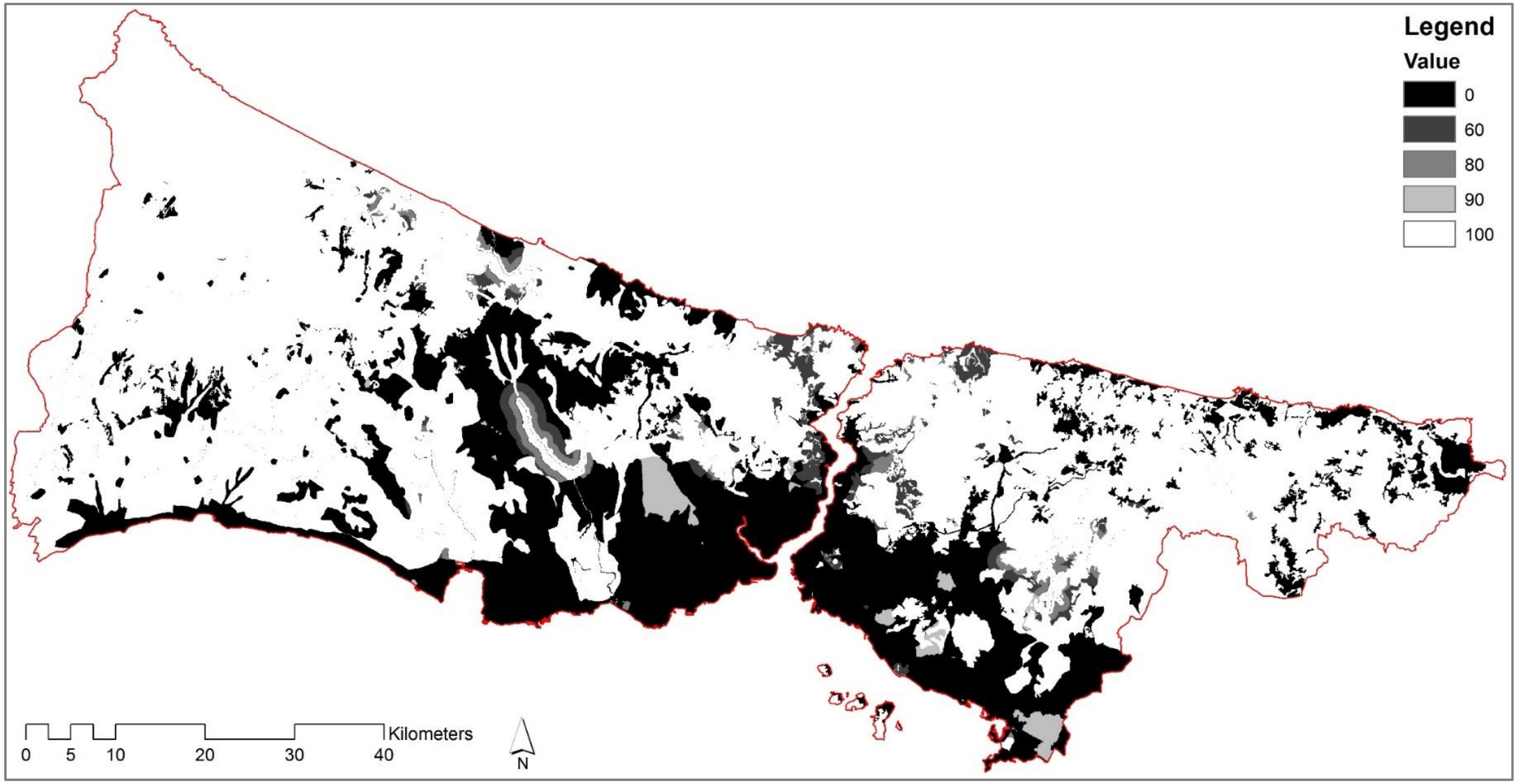

Figure 3.34: Exclusion image for conservative scenario alternative (large frame: 3368x1736)

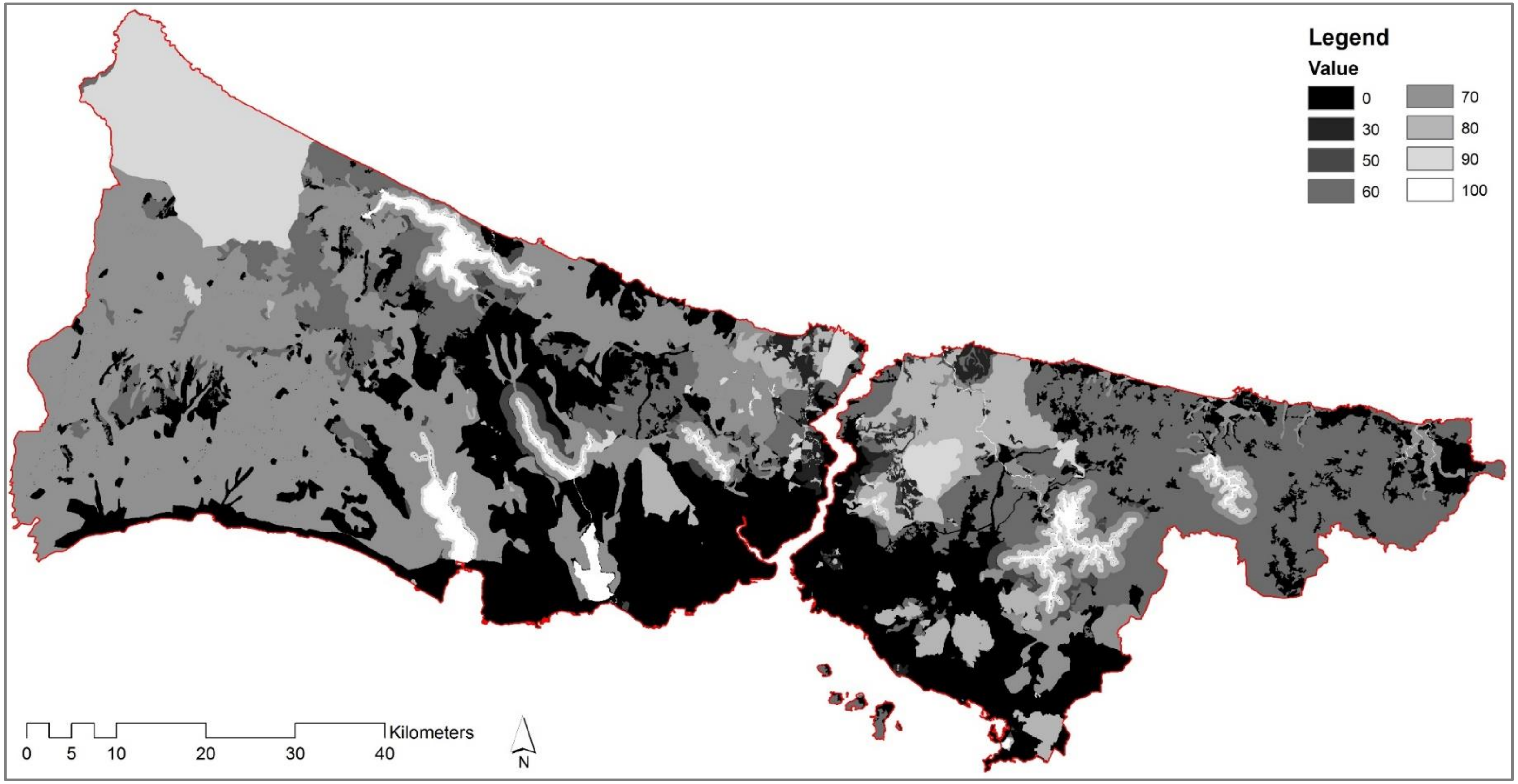

Figure 3.35: Exclusion image for moderate scenario alternative (large frame: 3368x1736)

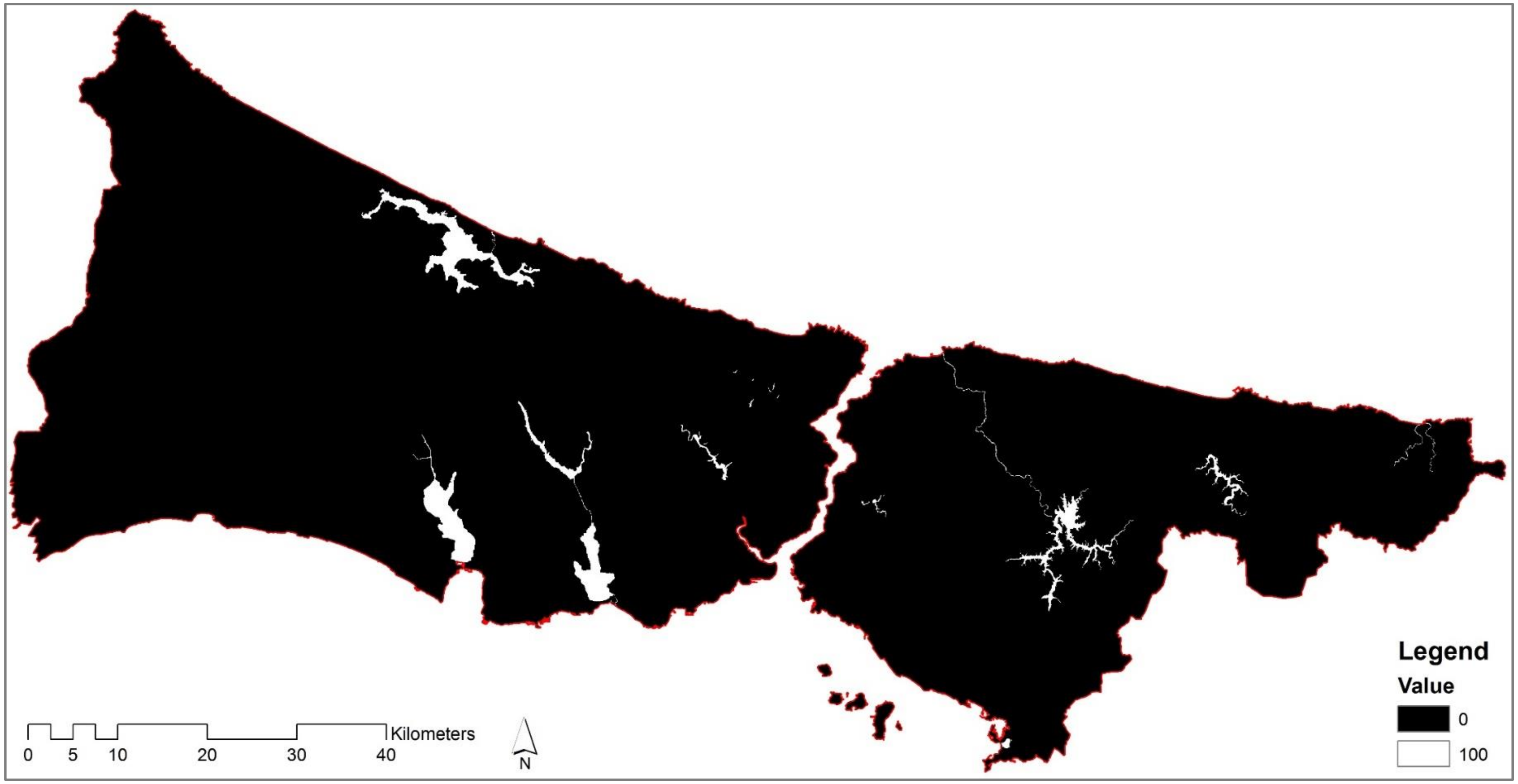

Figure 3.36: Exclusion image for aggressive scenario alternative (large frame: 3368x1736)

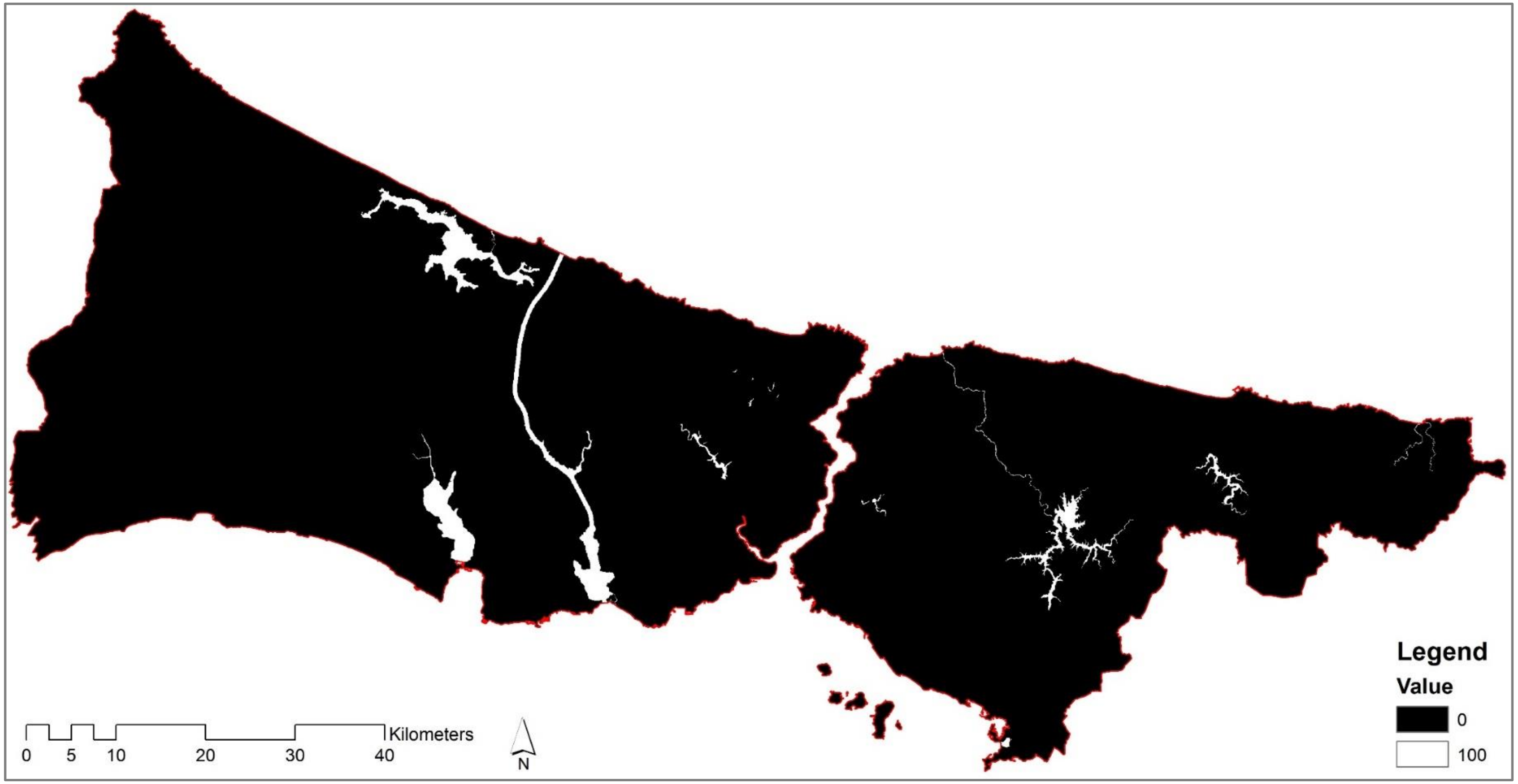

Figure 3.37: Exclusion image for aggressive scenario alternative including Canal Istanbul Project (large frame: 3368x1736)

Feature classes of military zones, natural conservation sites (1st, 2nd and 3rd degree), archaeological conservation sites, historical and natural conservation sites and agricultural soil classes (1st, 2nd and 3rd degree) were acquired from the archives of Istanbul Metropolitan Municipality. On the other hand, feature classes of the borders of nature reserve areas, natural parks and wildlife improvement areas were acquired from the Ministry of Forestry and Water Affairs (with 20.11.2017 dated 246406 numbered letter). Feature class of water bodies was digitised from satellite images of Istanbul City Region and distance buffers were created around lakes in ArcMap. In terms of the provisions of "Domestic Water Catchment Areas Regulations of Istanbul Water and Sewerage Administration (IWSA)"[14], 1st, 2nd and 3rd degree buffer zones were created around the lakes with distances of 300m, 1000m and 2000m, respectively. In addition, feature class of the forest areas of Istanbul Islands was digitised from the satellite images.

Exclusion images of the model were created from the combination of these feature classes. In this context, vector data or feature classes of each conservation area were converted to raster by Conversion Tool of ArcToolbox. Then, these created raster images of conservation areas were combined together by Mosaic to New Raster Tool of ArcToolbox. Next, created image of conservation areas was combined with the image of larger data frame. After that, values of each conservation (or exclusion) layer were reclassified for scenario alternatives by Reclassify Tool of ArcToolbox. Finally, reclassified images were clipped to (the feature classes of) large and small data frames with Extraction Tool of ArcToolbox and exported in 8-bit unsigned TIFF format. After that, formats of the exported images were converted to GIF in Photoshop.

Levels of exclusion for each area in the exclusion image of each scenario alternative are listed in Table 3.7, below. Rationale of setting these values for exclusion areas is also explained below. As it was mentioned before, in exclusion images, a value

[14] İSKİ (İstanbul Su ve Kanalizasyon İdaresi), İçmesuyu Havzaları Yönetmeliği

of "100" represents 100% exclusion from development whereas a value of "0" represents no exclusion. Therefore, in exclusion image of aggressive urban growth only the water bodies were set to value of “100”. In other words, only the water bodies were excluded from the urban growth.

Table 3.7: Pixel values of exclusion images

Excluded (Conservation) Areas	**Scenario Alternatives**		
	Conservative	**Moderate**	**Aggressive**
water bodies	100	100	100
military zones	90	80	0
forest areas	100	60	0
absolute agricultural lands (1st, 2nd and 3rd degree agricultural soils)	100	70	0
nature reserve areas	100	90	0
nature parks	100	90	0
wildlife improvement areas	100	90	0
1st degree natural conservation sites	100	80	0
2nd degree natural conservation sites	80	50	0
3rd degree natural conservation sites	60	30	0
Strict preservation areas of drinking water basins	100	90	0
Short distance preservation areas of drinking water basins	80	70	0
Medium distance preservation areas of drinking water basins	60	50	0

Natural Conservation Sites: Natural Conservation Sites of Turkey are protected by laws and regulations. In this context; “21.07.1983 dated and 2863 numbered Cultural and Natural Heritage Conservation Law”[15], “19.06.2007 dated and 728 numbered Resolution of Cultural and Natural Heritage Conservation Board”

[15] Kültür ve Tabiat Varlıklarını Koruma Kanunu

(revised with 12.03.2008 dated and 740 numbered Resolution)[16], "19.07.2012 dated Regulation About Procedures and Principles Regarding the Determination, Registration and Certification of Protected Areas"[17], "05.01.2017 dated and 99 numbered Resolution of the Ministry of Environment and Urbanization"[18] determine the procedures and principles for protection of these sites.

In terms of these regulations, 1st degree natural conservation sites are sensitive/fragile areas that should strictly be protected. Also, 2nd degree natural conservation sites are qualified natural areas that could harbour traditional modes of living. On the other hand, 3rd degree natural conservation areas are sustainable protection and controlled use areas that could host low density settlements.

In this context, 1st degree natural conservation sites should be absolutely excluded from urbanization whereas 2nd degree natural conservation sites could harbour traditional settlements. 3rd degree natural conservation sites on the other hand could be urbanized with low density settlements. Therefore, for exclusion image of the conservative scenario alternative the values of 1st, 2nd and 3rd degree natural conservation areas were set to 100, 80 and 60, respectively.

In order to determine the exclusion levels of natural conservation sites for the exclusion image of moderate scenario alternative, current trends of urban growth in these areas were analysed. In this respect, urban growth in these conservation areas between 1987 and 2017 was examined. Analysis of the urban growth trends in conservation areas revealed that 2.00, 10.48 and 21.70 percentages of 1st, 2nd and 3rd degree natural conservation areas were lost in 30 years' period, respectively. Therefore, for exclusion image of the moderate scenario alternative the values of 1st, 2nd and 3rd degree natural conservation areas were set to 80, 50 and 30, respectively.

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[16] Kültür ve Tabiat Varlıklarını Koruma Yüksek Kurulunun Doğal (Tabii) Sitler, Koruma ve Kullanma Koşulları ile ilgili İlke Kararı
[17] Korunan Alanların Tespit, Tescil ve Onayına İlişkin Usul ve Esaslara Dair Yönetmelik
[18] Çevre ve Şehircilik Bakanlığı İlke Kararı

Conservation Areas: Special conservation areas of nature reserve areas, natural parks and wildlife improvement areas are also protected by laws and regulations in Turkey. In this context; "09.08.1983 dated and 2873 numbered National Parks Law"[19] and "08.11.2004 dated Regulation About Wildlife Protection and Improvement Areas"[20] determine the procedures and principles for protection of these areas.

In terms of these regulations, nature reserve areas, natural parks and wildlife improvement areas are sensitive areas that should strictly be protected. Therefore, in exclusion image of the conservative scenario alternative these areas were 100 percent excluded from urban growth. However, since day-trip activities could take place in these areas their values were set to 90 for the exclusion image of moderate scenario alternative.

Drinking Water Basins: Drinking water basins of Istanbul are protected by "23.01.2011 dated Drinking Water Basins Regulation of Istanbul Water and Sewerage Administration"[21]. In terms of Drinking Water Basins Regulation of Istanbul, the water basins are divided into four preservation areas. These preservation areas are the buffer zones of drinking water sources and they are named as: strict (0-300m), short distance (300-1000m), medium distance (1000-2000m) and long distance (2000m to basin border) preservation areas. Protection procedures and principles of the first three of these preservation areas are similar to natural conservation areas whereas the fourth (long distance) preservation areas are not protected from urban growth. Therefore, for exclusion image of the conservative scenario alternative the values of strict (0-300m), short distance (300-1000m) and medium distance (1000-2000m) preservation areas were set to 100, 80 and 60, respectively.

[19] Milli Parklar Kanunu
[20] Yaban Hayatı Koruma ve Yaban Hayatı Geliştirme Sahaları ile ilgili Yönetmelik
[21] İSKİ İçme Suyu Havzaları Yönetmeliği

In order to determine the exclusion levels of drinking water basins for the exclusion image of moderate scenario alternative, current trends of urban growth in these areas were analysed. In this respect, urban growth in these preservation areas between 1987 and 2017 was examined. Analysis of the urban growth trends in preservation areas revealed that 0.40, 2.86 and 7.24 percentages of strict, short distance and medium distance preservation areas were lost in 30 years period, respectively. Therefore, for exclusion image of the moderate scenario alternative the values of strict, short distance and medium distance preservation areas were set to 90, 70 and 50, respectively

Agricultural Lands: Agricultural lands of Turkey are protected by laws and regulations. In this context; "03.07.2005 dated and 5403 numbered Soil Protection and Land-Use Law"[22] and "15.12.2005 dated Regulation for Implementation of Soil Protection and Land-use Law"[23] determine the procedures and principles for protection of these sites. Boundaries of 1st, 2nd and 3rd degree agricultural soils of Istanbul were acquired from the archives of Istanbul Metropolitan Municipality. In terms of "Technical Order About Soil and Terrain Classification Standards"[24] these soils are could be classified as strict/absolute agricultural lands[25] that should be excluded from urban development. Therefore, these agricultural soils were utilized as absolute agricultural lands and 100 percent excluded from urban growth in exclusion image of the conservative scenario alternative.

In order to determine the exclusion level of absolute agricultural lands for the exclusion image of moderate scenario alternative, current trends of urban growth in these areas were analysed. In this respect, urban growth in these areas between 1987 and 2017 was examined. Analysis of the urban growth trends in agricultural lands revealed that 4.29 % of absolute agricultural lands (1st, 2nd and 3rd degree agricultural soils) were lost in 30 years' period. Therefore, for exclusion image of

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[22] Toprak Koruma ve Arazi Kullanımı Kanunu
[23] Toprak Koruma ve Arazi Kullanımı Kanunu Uygulama Yönetmeliği
[24] Toprak ve Arazi Sınıflaması Standartları Teknik Talimatı ve İlgili Mevzuat
[25] Mutlak Tarım Arazisi

the moderate scenario alternative the values of absolute agricultural lands were set to 70.

Forest Areas: Forests of Turkey are protected by "31.08.1956 dated and 6831 numbered Forest Law"[26] and related regulations. In terms of Forest Law and related regulations, forest areas should be strictly protected. Therefore, forest areas of Istanbul were 100 percent excluded from urban growth in exclusion image of the conservative scenario alternative.

In order to determine the exclusion level of forest areas for the exclusion image of moderate scenario alternative, current trends of loss in forest areas were analysed. In this respect, total loss of forest areas between 1987 and 2017 was examined and revealed that 7.03 % of forest areas were lost in 30 years' period. Therefore, for exclusion image of the moderate scenario alternative the values of forest areas were set to 60.

Military Zones: "18.12.1981 dated and 2565 numbered Prohibited Military Zone and Security Zones Law"[27] and "Prohibited Military Zone and Security Zones Regulation"[28] determine the procedures and principles about military zones of Turkey. In terms of these law and regulation military zones could only be used for military purposes. Since military zones could include military settlements, values of military zones were set to 90 and 80 for exclusion images of conservative and moderate scenario alternatives, respectively.

Transportation Images: Transportation images of the model were generated from the digitized data of roads for 1987, 2000, 2006, 2013 and 2017. In this context, feature classes of 1st, 2nd and 3rd degree roads were combined together to create a single feature class of roads. Then, created feature class of roads was converted to

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[26] Orman Kanunu
[27] Askeri Yasak Bölgeler ve Güvenlik Bölgeleri Kanunu
[28] Askeri Yasak Bölgeler ve Güvenlik Bölgeleri Yönetmeliği

raster image in TIFF format with Conversion Tool of ArcToolbox. After being rasterised, image of transportation was combined with the image of data frame. Then, using Reclassify Tool of ArcToolbox, values of the image were reclassified as 100, 90 and 80 for 1st, 2nd and 3rd degree roads, respectively. Next, reclassified image was clipped to (the feature classes of) large and small data frames with Extraction Tool of ArcToolbox and exported in 8-bit unsigned TIFF format (see Figure 3.38 and Figure 3.39). After that, format of the exported images was converted to GIF in Photoshop and the process was repeated for other years.

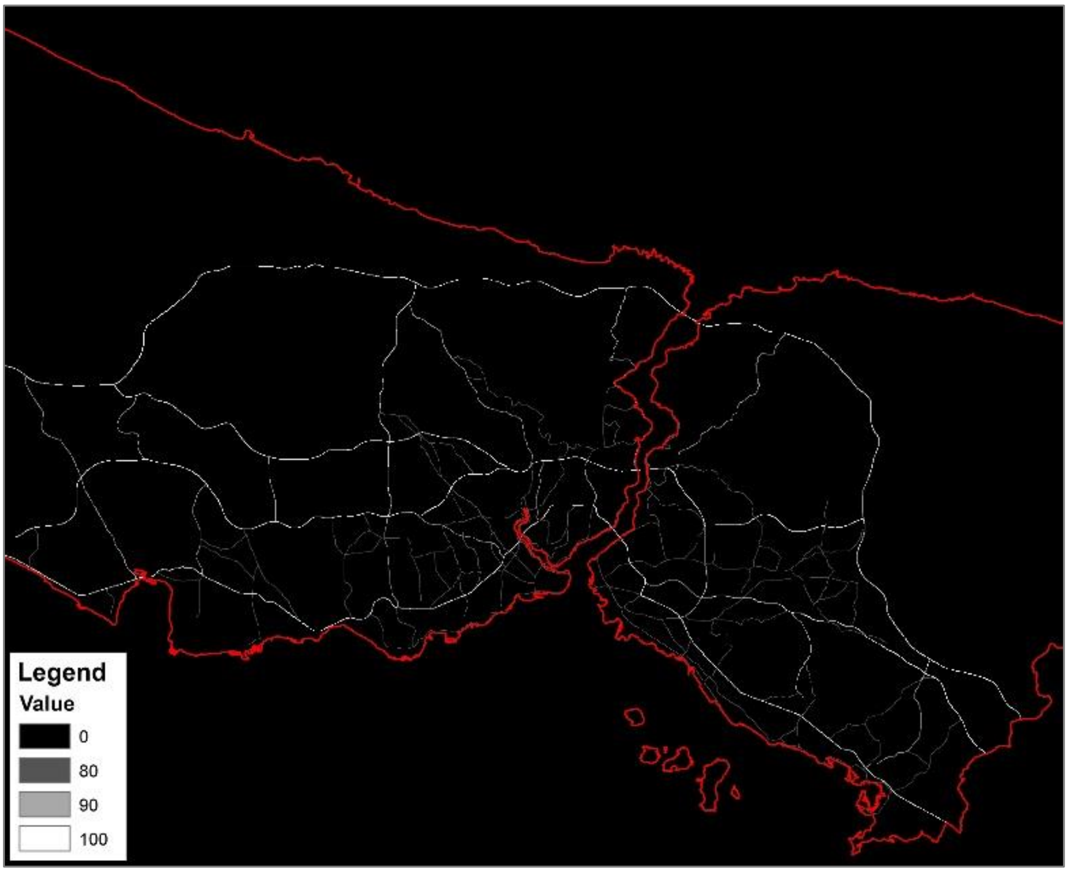

Figure 3.38: Small frame transportation image for 2006 (column/row: 1744x1419)

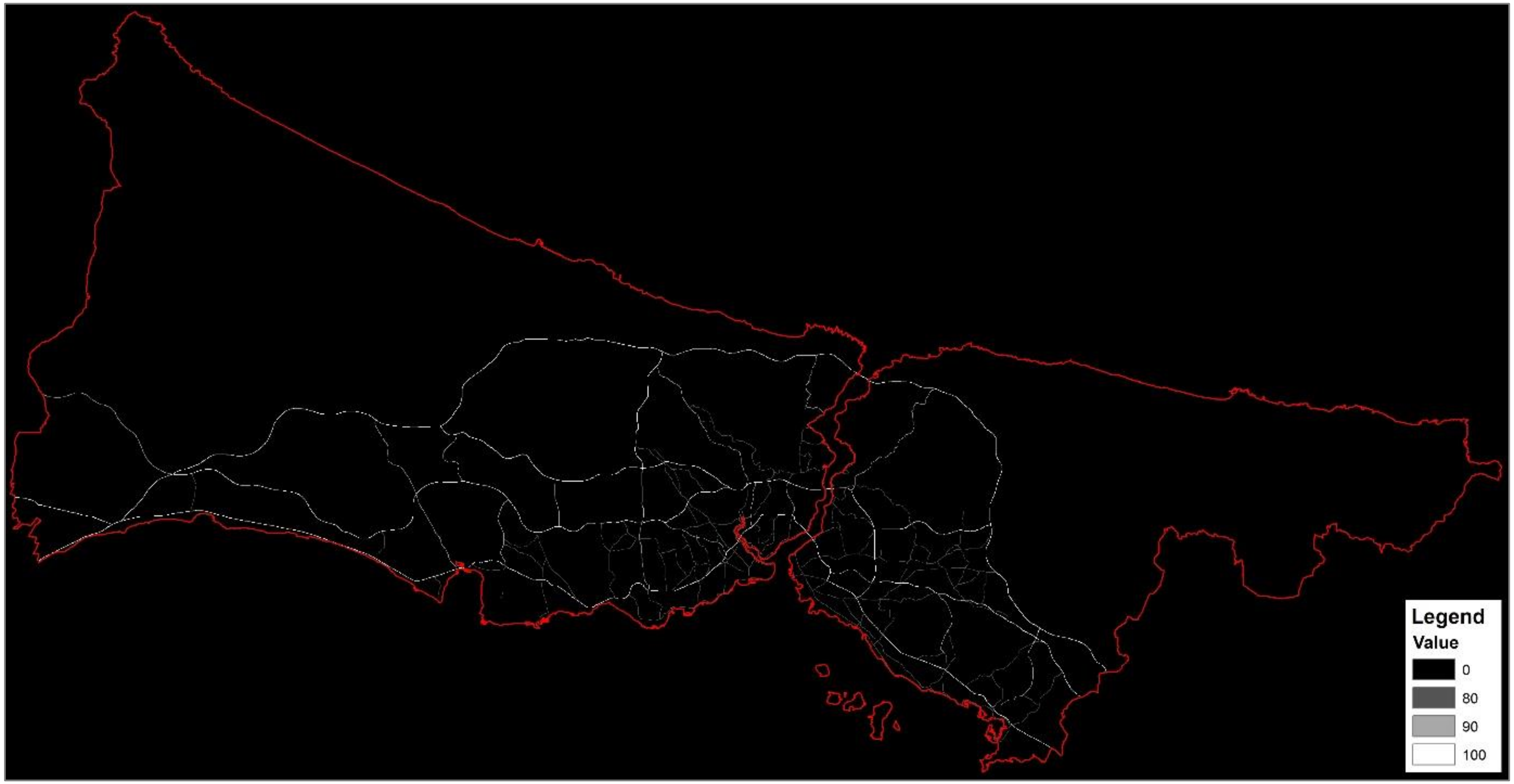

Figure 3.39: Large frame transportation image for 2006 (column/row: 3368x1736)

Verifying Input Data

After preparation of the input images for Istanbul City-Region, the model was executed in test mode with the prepared images to verify their accuracy. Therefore, input and output directories were prepared and the prepared images were moved into the input directory. Next, sample scenario file of Democity case was modified to Istanbul City-Region. Then, the model was executed in test mode and terminated properly.

3.3.2.3.2 Calibration

After preparation and verification of the SLEUTH environment and input images for the case study of Istanbul City-Region, SLEUTH Urban Growth Model was executed in calibration mode in an effort to determine the coefficient values that best simulate the urban growth in Istanbul (through time). In order to decrease the duration of calibration process while increasing its accuracy, a brute-force calibration process was applied to the input images of Istanbul City-Region.

Brute-force calibration is a three steps calibration process that is composed of the successive phases of coarse, fine and final calibration. Through these successive steps of the brute-force calibration process the range of coefficient values were narrowed down (while enhancing the resolution of images) step by step. Then, with a fourth and last step of calibration the best fitting (forecasting) values of the growth coefficients were derived.

In order to decrease the duration of this process, resolutions of input images are lowered for coarse and fine calibration phases. In general, resolutions of the images are reduced to one half and one quarter of the original images for fine and coarse calibration phases, respectively. For Istanbul City-Region case, in addition to the original frame size of the area, a smaller frame covering mainly the urbanised areas was also created. Since using this smaller frame decreased the duration of entire calibration process (from nearly 7 days to 2.5 days), only one half of the original resolution of input images was used for both coarse and fine calibration phases.

Phase 1 - Coarse Calibration

Coarse calibration is the first phase of brute-force calibration process. In this initial phase of the process, input images with one half resolution of the original images were used with the entire range of coefficient values (between 0 and 100).

Before running the model in calibration mode for the first time, input and output directories and scenario file were prepared for coarse calibration. For this purpose, input and output directories of coarse calibration were created under the related folders of SLEUTH directory (in Local Disk C of the PC), first. Second, the input images with small data frame (872x710 cells) and lower resolution (100x100 m cell size) were copied into the input directory. Then, a copy of the scenario file that was provided for the calibration process of Democity (sample) case was created and modified for Istanbul City-Region case. In this context, "scenario.demo200_calibrate" file was copied and renamed as "scenario.istanbul_coarseS". Next, it was opened in "Nano" text editor of Cygwin and pathnames, input image flags and coefficient values were modified for coarse calibration phase of Istanbul City-Region case.

Once the "scenario.istanbul_coarseS" file was customised/modified for coarse calibration phase, the model was executed in calibration mode with this scenario file. Coarse calibration process took 3 hours 40 minutes and the log files of the model were saved into the output directory of coarse calibration.

Later, "control_stats.log" file, which was containing r^2 values of the control metrics, was opened in Microsoft Office Excel and the values of growth coefficients were analysed in terms of control metrics. In addition to 13 metrics provided by the model, two more metrics were calculated from the literature. In previous studies, different combinations of the metrics were used. The main two of these combinations are Combined Metric (Clarke et al., 1996, 1997) and Optimum SLEUTH Metric (OSM) (Dietzel & Clarke, 2007). Combined Metric is calculated by multiplying the sum of Pop, Edges and Clusters metrics with LeeSalee metric

(Clarke & Gaydos, 1998; Clarke et al., 1996, 1997; Dietzel & Clarke, 2004). On the other hand, OSM is a product of Compare, Pop, Edges, Clusters, Slope, X Mean and Y Mean metrics (Dietzel & Clarke, 2007).

After calculating the Combined and Optimum SLEUTH Metrics for each run, values of Combined, OSM, Pop, Edges, Clusters, LeeSalee and %Urban metrics were sorted in descending order and averages of top 5, 10, 20, 50 and 100 coefficient values were calculated for each metric (Table 3.8). Then, examining these average values with the top 5 values of the coefficients for each metric, value range of each coefficient was narrowed down. As a result of the examination, value range of the growth coefficients were narrowed down to 1-41, 55-95, 50-90, 40-80 and 40-80 for Diffusion, Breed, Spread, Slope and Road-Gravity coefficients, respectively. Thus, for a range of 40, STEP values were set as 8 for fine calibration phase.

Table 3.8: Analysis of Growth Metrics for Coarse Calibration

	Diff	Brd	Sprd	Slp	RG	#_run: 3125		Diff	Brd	Sprd	Slp	RG
OSM	1	50.2	70	5.8	45.4	**Top5**	**1st**	1	100	50	1	50
	20.8	65.1	55	8.2	57.7	**Top10**	**2nd**	1	25	50	1	100
	40.6	63.9	52.5	15.45	46.6	**Top20**	**3rd**	1	1	100	1	75
	40.6	65.62	55.5	18.48	42.8	**Top50**	**4th**	1	25	75	25	1
	35.35	64.84	58.75	26.61	44.77	**Top100**	**5th**	1	100	75	1	1
Combined	1	75	60	50.4	70	**Top5**	**1st**	1	100	25	1	75
	1	72.5	50	35.6	55.2	**Top10**	**2nd**	1	100	25	1	100
	1	73.75	58.75	44.15	50.2	**Top20**	**3rd**	1	100	100	75	25
	1	61.08	61.5	36.4	50.24	**Top50**	**4th**	1	50	100	75	50
	4.88	52.9	62.5	39.84	46.75	**Top100**	**5th**	1	25	50	100	100
LeeSalee	1	95	50	90	80	**Top5**	**1st**	1	100	50	100	100
	1	95	52.5	90	75	**Top10**	**2nd**	1	100	50	100	50
	1	85	57.5	92.5	68.75	**Top20**	**3rd**	1	100	50	75	75
	1	74	56.5	82.5	64.02	**Top50**	**4th**	1	75	50	100	75
	1	70.25	62	77.03	58.58	**Top100**	**5th**	1	100	50	75	100
Pop	35	20.4	10.6	55	60.2	**Top5**	**1st**	50	25	25	25	100
	27.9	25.4	15.7	57.5	57.6	**Top10**	**2nd**	25	50	25	25	100
	32.95	36.6	23.2	56.4	60.1	**Top20**	**3rd**	50	1	1	75	75
	30.98	35.3	18.24	60.1	55.14	**Top50**	**4th**	25	1	1	50	25
	29.25	38.07	20.96	51.73	52.17	**Top100**	**5th**	25	25	1	100	1
Edges	90	90	90	45	35.6	**Top5**	**1st**	100	75	100	50	100
	70.1	80	72.5	65	40.5	**Top10**	**2nd**	100	75	100	50	1
	57.55	65.15	48.75	66.3	41.55	**Top20**	**3rd**	75	100	100	50	1
	49.66	54.22	44	63.1	46.2	**Top50**	**4th**	100	100	75	50	75
	49.69	46.26	40.75	57.64	48.18	**Top100**	**5th**	75	100	75	25	1
Clusters	65.2	75	70	35.4	50.4	**Top5**	**1st**	100	100	75	50	75
	77.6	72.5	72.5	35.3	45.3	**Top10**	**2nd**	100	75	75	50	75
	78.8	76.25	73.75	31.5	45.2	**Top20**	**3rd**	50	75	100	1	1
	77.08	79	75.5	34.32	47.7	**Top50**	**4th**	1	25	25	1	100
	72.86	76.77	73.5	31.84	44.51	**Top100**	**5th**	75	100	75	75	1
% Urban	100	100	100	10.6	60	**Top5**	**1st**	100	100	100	1	100
	100	100	100	13	50.2	**Top10**	**2nd**	100	100	100	1	75
	95	93.75	100	9.45	50.2	**Top20**	**3rd**	100	100	100	1	50
	91.5	92.5	95.5	15.02	52.18	**Top50**	**4th**	100	100	100	25	25
	86	87.25	94	17.71	50.94	**Top100**	**5th**	100	100	100	25	50

Phase 2 - Fine Calibration

After analysing the output files (the control metrics in "control_stats.log" file) of coarse calibration phase, the model was executed in calibration mode once again. In this fine calibration phase of the model, narrowed ranges of coefficient values were used. In this context, input and output directories for fine calibration phase were created under the related folders of SLEUTH directory, first. Then, the input images with small data frame (872x710 cells) and lower resolution (100x100 m cell size) were copied into the input directory. Next, the scenario file of coarse calibration phase (scenario.istanbul_coarseS) was copied as "scenario.istanbul_fineS" and opened in "Nano" text editor of Cygwin for modification. Then, the pathnames and coefficient values of the scenario file were modified for fine calibration phase. In this context, the START and STOP values of growth coefficients were set to 1 and 41 for Diffusion, 55 and 95 for Breed, 50 and 90 for Spread, 40 and 80 for Slope Resistance and Road Gravity coefficients with a STEP value of 8.

After saving changes in the scenario file, the model was executed in calibration mode with this new scenario file (scenario.istanbul_fineS) and run for 17 hours and 48 minutes. Once the model was terminated, "control_stats.log" file was opened in Excel and (in addition to provided 13 metrics of control) two more metrics (Combined and OSM) were calculated for each run. Then, the values of Combined, OSM, Pop, Edges, Clusters, LeeSalee and % Urban metrics were sorted in descending order and the averages of top 5, 10, 20, 50 and 100 coefficient values were calculated for each metric (Table 3.9). Next, analysing these averages with the top 5 values of each coefficient, the ranges of coefficient values were narrowed down for the final calibration phase. As a result, the value ranges were narrowed down to 1-21, 75-95, 50-70, 40-50 and 60-80 for Diffusion, Breed, Spread, Slope and Road-Gravity coefficients, respectively. Thus, for a range of 20, STEP values were set as 4 for final calibration phase.

Table 3.9: Analysis of Growth Metrics for Fine Calibration

	Diff	Brd	Sprd	Slp	RG	#_run: 7776		Diff	Brd	Sprd	Slp	RG
OSM	1	80.6	58	40	64	**Top5**	**1st**	1	95	58	40	64
	1	78.2	58	40.8	67.2	**Top10**	**2nd**	1	63	58	40	40
	1	80.2	59.2	41.6	61.2	**Top20**	**3rd**	1	87	58	40	64
	1	77.56	62.16	44.16	62.4	**Top50**	**4th**	1	71	58	40	80
	1	74.84	64.48	48.16	61.6	**Top100**	**5th**	1	87	58	40	72
Combined	1	85.4	61.2	46.4	62.4	**Top5**	**1st**	1	95	58	40	64
	1	83.8	62.8	48	63.2	**Top10**	**2nd**	1	63	58	40	40
	1	83	64.8	51.2	64.4	**Top20**	**3rd**	1	95	58	48	80
	1	79.16	66.96	54.4	60.96	**Top50**	**4th**	1	87	58	40	64
	1	78.52	67.6	56.96	60.24	**Top100**	**5th**	1	87	74	64	64
LeeSalee	1	93.4	54.8	80	57.6	**Top5**	**1st**	1	95	50	80	40
	1	92.6	53.2	79.2	60	**Top10**	**2nd**	1	95	58	80	48
	1	91.4	53.2	78	60.4	**Top20**	**3rd**	1	87	50	80	56
	1	85.72	53.36	76.64	60.32	**Top50**	**4th**	1	95	58	80	80
	1	82.68	53.92	75.04	59.6	**Top100**	**5th**	1	95	58	80	64
Pop	1	80.6	90	40	62.4	**Top5**	**1st**	1	79	90	40	56
	1	74.2	90	40	60.8	**Top10**	**2nd**	1	95	90	40	72
	1	75	90	40	63.6	**Top20**	**3rd**	1	79	90	40	72
	1	72.6	83.76	40.48	59.68	**Top50**	**4th**	1	55	90	40	72
	1	74.04	80.32	41.84	60.08	**Top100**	**5th**	1	95	90	40	40
Edges	41	95	88.4	41.6	62.4	**Top5**	**1st**	41	95	90	40	48
	41	93.4	86.8	40.8	62.4	**Top10**	**2nd**	41	95	90	40	72
	41	91.4	87.6	40.8	61.2	**Top20**	**3rd**	41	95	90	40	64
	40.04	89.72	87.28	42.56	62.08	**Top50**	**4th**	41	95	90	48	48
	39.4	88.92	86.64	44.64	60	**Top100**	**5th**	41	95	82	40	80
Clusters	41	93.4	85.2	41.6	64	**Top5**	**1st**	41	95	82	40	64
	37	92.6	80.4	41.6	56.8	**Top10**	**2nd**	41	95	74	48	72
	38.2	91	80.8	42.8	56.4	**Top20**	**3rd**	41	87	90	40	72
	38.76	89.24	81.04	44	59.52	**Top50**	**4th**	41	95	90	40	64
	38.76	87.96	82.08	44.32	60.08	**Top100**	**5th**	41	95	90	40	48
% Urban	41	93.4	90	40	64	**Top5**	**1st**	41	95	90	40	48
	41	91	90	40	60	**Top10**	**2nd**	41	95	90	40	72
	38.2	89.4	89.6	40.4	60	**Top20**	**3rd**	41	95	90	40	56
	26.92	85.4	89.36	40.48	60.96	**Top50**	**4th**	41	87	90	40	80
	24.84	82.92	89.36	41.12	60.72	**Top100**	**5th**	41	95	90	40	64

Phase 3 - Final Calibration

After analysing the output files (the control metrics in “control_stats.log” file) of fine calibration phase, the model was executed in calibration mode again. In this final calibration phase of the model, narrowed ranges of coefficient values were used. In this context, input and output directories for final calibration phase were created under the related folders of SLEUTH directory, first. Then, the input images with original resolution (50x50 m cell size) and small data frame (1744x1419 cells) were copied into the input directory. Next, the scenario file of fine calibration phase (scenario.istanbul_fineS) was copied and renamed as “scenario.istanbul_finalS”. Later, it was opened in “Nano” text editor of Cygwin and pathnames, input image flags and coefficient values were modified for final calibration phase. In this context, the START and STOP values of growth coefficients were set to 1 and 21 for Diffusion, 75 and 95 for Breed, 50 and 70 for Spread, 40 and 60 for Slope Resistance, 60 and 80 for Road Gravity coefficients with a STEP value of 4.

After saving changes in the scenario file, the model was executed in calibration mode with this new scenario file (scenario.istanbul_finalS) and run for 85 hours and 51 minutes. Once the model was terminated, “control_stats.log” file was opened in Excel and (in addition to provided 13 metrics of control) two more metrics (Combined and OSM) were calculated for each run. Then, the values of Combined, OSM, Pop, Edges, Clusters, LeeSalee and % Urban metrics were sorted in descending order and the averages of top 5, 10, 20, 50 and 100 coefficient values were calculated for each metric (Table 3.10). Next, analysing these averages with the top 5 values of each coefficient, final values of 3, 86, 60, 50 and 70 were derived for Diffusion, Breed, Spread, Slope and Road-Gravity coefficients, respectively.

Table 3.10: Analysis of Growth Metrics for Final Calibration

	Diff	Brd	Sprd	Slp	RG	#_run: 7776		Diff	Brd	Sprd	Slp	RG
OSM	1	91.8	62	47.2	68	**Top5**	**1st**	1	91	62	44	60
	1.4	85	62.8	48	70	**Top10**	**2nd**	1	91	62	48	60
	2.6	85	62.6	51.8	68.6	**Top20**	**3rd**	1	91	62	44	76
	4.44	86.92	59.6	49.44	69.6	**Top50**	**4th**	1	91	62	48	76
	6.48	86.8	59.68	48.16	70.12	**Top100**	**5th**	1	95	62	52	68
Combined	1	85.4	58	50.4	68.8	**Top5**	**1st**	1	83	58	44	64
	1	87.4	58.8	52.4	72.4	**Top10**	**2nd**	1	87	62	56	76
	1	88.6	57	52.2	71.6	**Top20**	**3rd**	1	87	58	56	60
	1.4	86.28	55.6	50.96	70	**Top50**	**4th**	1	87	54	52	72
	1.4	85.76	54.8	50.72	69.56	**Top100**	**5th**	1	83	58	44	72
LeeSalee	1	87	70	59.2	71.2	**Top5**	**1st**	1	95	70	56	72
	1	85.8	70	57.6	70.4	**Top10**	**2nd**	1	87	70	60	80
	1	86.6	70	58	69	**Top20**	**3rd**	1	83	70	60	60
	1	86.28	70	57.52	70.56	**Top50**	**4th**	1	91	70	60	72
	1	86.12	69.68	55.6	69.76	**Top100**	**5th**	1	79	70	60	72
Pop	2.6	87.8	62.8	50.4	68.8	**Top5**	**1st**	1	87	62	40	64
	3	89	62.4	50.4	67.6	**Top10**	**2nd**	1	91	66	56	76
	4.6	87	60.4	48.6	68	**Top20**	**3rd**	1	95	66	56	68
	6.44	84.76	58.72	48.64	70.48	**Top50**	**4th**	1	75	62	40	64
	7.28	84.68	58.04	49.28	70.12	**Top100**	**5th**	9	91	58	60	72
Edges	5	86.2	50	57.6	68.8	**Top5**	**1st**	1	87	50	60	76
	3.8	87.4	50	57.2	68.4	**Top10**	**2nd**	5	91	50	48	68
	3.6	86.8	50.2	55	69	**Top20**	**3rd**	9	79	50	60	76
	3.08	84.84	50.32	53.36	69.6	**Top50**	**4th**	5	95	50	60	64
	3.36	84.52	50.32	54.52	70.24	**Top100**	**5th**	5	79	50	60	60
Clusters	1	87	54	49.6	64.8	**Top5**	**1st**	1	83	50	44	60
	1	86.6	54.4	48.8	68	**Top10**	**2nd**	1	87	58	56	60
	1	84.8	53.8	48.4	69.6	**Top20**	**3rd**	1	79	62	52	60
	1.16	85.8	52.8	50.4	68.96	**Top50**	**4th**	1	91	50	52	76
	1.36	85.12	52.64	51.28	70.08	**Top100**	**5th**	1	95	50	44	68
% Urban	1	91.8	55.6	52.8	70.4	**Top5**	**1st**	1	95	54	48	64
	2.2	85.8	54.4	49.6	68.8	**Top10**	**2nd**	1	83	58	60	76
	2.4	86.4	55.2	51.6	71	**Top20**	**3rd**	1	95	58	60	64
	4.44	84.68	53.76	50.64	69.92	**Top50**	**4th**	1	91	54	48	76
	5.32	84.4	53.44	50.2	69.12	**Top100**	**5th**	1	95	54	48	72

Phase 4 - Last Calibration (Derive Forecasting Values)

After deriving the final values of growth coefficients in final calibration phase, the model was executed in calibration mode one last time to "produce a more robust forecasting coefficient set" (US Geological Survey & Department of Geography, 2005). In this last phase of the calibration process, derived final values of the coefficients were used.

In this context, input and output directories of the last calibration (forecasting) phase were created under the related folders of SLEUTH directory and the input images with original resolution (50x50 m cell size) and frame size (3368x1736 cells) were copied into the input directory. Next, the scenario file of final calibration phase (scenario.istanbul_finalS) was copied and renamed as "scenario.istanbul_forecastL". Then, it was opened in "Nano" text editor of Cygwin and pathnames, input image flags and coefficient values were modified for the last phase. In this phase, values of 3, 86, 60, 50 and 70 were used for Diffusion, Breed, Spread, Slope and Road Gravity coefficients, respectively.

Following the modification of scenario file (scenario.istanbul_forecastL), the model was executed in calibration mode and run for 42 minutes. After termination of the model, "avg.log" file was opened in "Nano" text editor of Cygwin and final values of Diffusion, Bread, Spread, Slope and Road Gravity coefficients for stop date (2017) were determined as; 4.00, 100.00, 80.03, 9.50 and 74.05, respectively. Then, these floating values were rounded to integers and final values of; 4, 100, 80, 10 and 74 were reached for Diffusion, Bread, Spread, Slope and Road Gravity coefficients, respectively. Later, these values of the coefficients are used to initialize the prediction runs of the model.

3.3.2.3.3 Prediction

After determining the best fitting values of growth coefficients for Istanbul City-Region case (through brute-force calibration process), the model was executed in prediction mode (with determined coefficient values) to simulate future urban growth. In order to explore the full scope of urban growth alternatives in future and increase the accuracy of prediction, five scenario alternatives were tested in prediction process of the model. In this context, the model was executed in prediction mode for five times with different sets of input images. Since the values of growth coefficients were determined through calibration process and reflect the pattern of urban growth in Istanbul City-Region, they were not changed for scenario alternatives.

For foreseeing/understanding the full extent of urban growth possibilities in the future, three main scenarios (conservative, moderate and aggressive) of limited, managed and unlimited growth were tested. In addition to these three main scenarios two aggressive scenario alternatives were also tested for comparison purposes.

Although the main purpose of this research was to determine the impacts of Mega Projects on the resilience of Istanbul City-Region, only the 3rd Bosporus Bridge and Northern Marmara Motorway Project was included in the main scenarios of the model since it was the only project that had been realised before completion of this research.

On the other hand, for determining the possible impacts of other Mega Projects on the urbanization process of Istanbul City-Region, two aggressive scenario alternatives were prepared with 3rd Airport and New Istanbul Projects. Since the 3rd Airport Project was planned to be completed in 2018, start date of this prediction run was set to 2018. On the other hand, covering nearly 7600 hectares of area and containing the 3rd Airport and Canal Istanbul Projects within itself, New Istanbul Project was assumed to be completed in 2030. Therefore, start date of this prediction run was set to 2030.

As in calibration phase, the input and output directories of each scenario alternative were prepared first. Then, the input images with original frame size (3368x1736 cells) and resolution (50x50m cell size) were copied into the input directories of scenario alternatives. Although same slope image was used for all the scenario alternatives, different combinations of urban, exclusion, transportation and hill-shade images were used for each one. After placing/moving the specific sets of images into input directories, the "scenario files" were modified for the prediction runs of scenario alternatives. In this context, determined best fitting values of growth coefficients (4, 100, 80, 10 and 74 for Diffusion, Breed, Spread, Slope-Resistance and Road Gravity coefficients, respectively) were set into the prediction flags in scenario files. Also, the stop dates of the predictions were set to 2050 and pathnames and input image flags were modified for each prediction run. Then, the model was executed in prediction mode with different sets of input images for each scenario alternative.

Scenario 1: Limited Urban Growth

As it was mentioned above there are three main scenarios of limited, managed and unlimited urban growth for conservative, moderate (business as usual) and aggressive development trends. In this conservative scenario alternative of limited urban growth, it was assumed that all of the conservation areas of Istanbul City-Region were protected or excluded from urban growth to some level.

In this context, the exclusion image of conservative scenario alternative was used in this prediction run. As it was mentioned before, the exclusion images include the areas of; Water Bodies, (1st, 2nd and 3rd Degree) Natural Conservation Sites, Nature Parks, Nature Reserve Areas, Wildlife Improvement Areas, (Strict, Short Distance and Medium Distance) Preservation Areas of Drinking Water Basins, Agricultural Lands (1st, 2nd and 3rd Degree Agricultural Soils), Forest Areas and Military Zones with varying cell values[29].

[29] Pixel values represent the exclusion levels (%) of these areas and a value of 100 describes total exclusion (100%) whereas the value of 0 means no exclusion.

For conservative scenario alternatives, exclusion levels (cell values) of water bodies, 1st degree natural conservation sites, nature parks, nature reserve areas, wildlife improvement areas, strict areas of drinking water basins, agricultural lands and forest areas were set to 100. In other words, they were totally excluded from the urban growth processes. Values of military zones were set to 90, since they could include military settlements. In terms of the regulations that regard natural conservation sites, the values of 2nd and 3rd degree natural conservation sites were set to 80 and 60, respectively. Also, in terms of Drinking Water Basins Regulation of Istanbul, short and medium distance preservation areas of drinking water basins were given the values of 80 and 60, respectively. Exclusion levels of all these areas are listed in Table 3.7 (p.162 above).

In addition to the exclusion image of conservative scenario alternatives, urban images of 1987, 2000, 2006 and 2017 were used with the transportation images of 1987, 2000 and 2017 for this prediction run.

After placing the images into the input directory and modifying the scenario file for prediction run, the model was executed in prediction mode and run for 20 minutes. Following the termination of model, output files and images of the prediction run were saved into the output directory. As a result, images of estimated (predicted) urban growth were produced for each single year between 2018 and 2050. In addition, a single image of cumulative urban growth was provided for further analyses. Also, an animated urban growth image was produced for demonstration/presentation purposes.

Scenario 2: Managed Urban Growth

In this business as usual scenario alternative of managed urban growth moderate protection of conservative areas was acknowledged as the current trend of urbanization in Istanbul City-Region. In this context, the exclusion image of moderate scenario alternatives was used for this prediction run.

In exclusion image of moderate scenario alternatives, cell values (exclusion levels) of only water bodies were set to 100. Since day-trip activities could take place in nature parks, nature reserve areas and wildlife improvement areas, their values were set to 90. On the other hand, exclusion levels of the remaining areas were mainly determined by analysing the trends of urban growth in these areas. As a result, values of strict, short distance and medium distance preservation areas of drinking water basins were set to 90, 70 and 50, respectively. In addition, the values of 1st, 2nd and 3rd degree natural conservation sites were set to 80, 50 and 30, respectively. Also a cell value of 80 was given to the military zones whereas the values of agricultural lands and forest areas were set to 70 and 60, respectively. Exclusion levels of all the conservation areas are listed in Table 3.7 (p.162 above). In addition to the exclusion image of moderate scenario alternatives, urban images of 1987, 2000, 2006 and 2017 were used with the transportation images of 1987, 2000 and 2017 for this prediction run.

After moving all images into the input directory and modifying the scenario file for prediction run, the model was executed in prediction mode and run for 25 minutes. Following the termination of the model, output files and images of the prediction run were saved into the output directory.

Scenario 3: Unlimited Urban Growth

In this aggressive scenario alternative of unlimited urban growth, it was assumed that none of the conservation areas were protected from the urbanization process except for the water bodies. Therefore, only the water bodies (since they are not habitable) were excluded in aggressive scenario alternatives. In this context, cell values of water bodies were set to 100 whereas values of the remaining areas were set to 0. In addition to the exclusion image of aggressive scenario alternatives, urban images of 1987, 2000, 2006 and 2017 were used with the transportation images of 1987, 2000 and 2017 for this prediction run.

After moving all images into the input directory and modifying the scenario file for prediction run, the model was executed in prediction mode and run for 45 minutes. Following the termination of the model, output files and images of the prediction run were saved into the output directory.

Scenario 4: Unlimited Urban Growth including 3rd Airport Project

In this scenario alternative of unlimited urban growth, it was assumed that the 3rd Airport Project would be completed in 2018 without any protection of conservation areas. In this context, only the water bodies were excluded from the urbanization process.

Assuming that the 3rd Airport Project would be realized in 2018, an extra urban image was prepared for 2018 with the project. In this context, expropriation area of "3rd Airport Project" (Final Environmental Impact Assessment Report of 3rd Airport Project, 2013) was digitised and attached to the urban areas of 2017. Therefore, in addition to the exclusion image of aggressive scenario alternatives and transportation images of 1987, 2000 and 2017, urban images of 1987, 2000, 2006 and 2018 were used. Since, the 3rd Airport Project was assumed to be completed in 2018, starting date of the prediction was set to 2018 in scenario file.

After moving all images into the input directory and modifying the scenario file for prediction run, the model was executed in prediction mode and run for 33 minutes. Following the termination of the model, output files and images of the prediction run were saved into the output directory.

Scenario 5: Unlimited Urban Growth including New Istanbul Project

In this scenario alternative of unlimited urban growth, it was assumed that the New Istanbul Project (including the 3rd Airport and Canal Istanbul Projects) would be launched and realized in 2030 without any protection of conservation areas. In this context, only the water bodies were excluded from the urbanization process.

Assuming that the New Istanbul Project would be realized in 2030, an extra urban image was prepared for 2030 with the project. In this context, expropriation area of "New Istanbul Project"[30], including the areas of 3rd Airport and Canal Istanbul Projects, was digitised and attached to the predicted urban areas of 2030. For this reason, predicted image of 2030 was acquired from the results of the unconstrained urban growth scenario alternative (see Figure 18). Therefore, in addition to the exclusion image of aggressive scenario alternatives and transportation images of 1987, 2000 and 2017, urban images of 1987, 2000, 2017 and 2030 were used in this scenario alternative. Since the New Istanbul Project was assumed to be realized in 2030, starting date of the prediction was set to 2030 in scenario file. Therefore, the urban growth was predicted for 20 years between 2030 and 2050 in this scenario alternative.

After moving all images into the input directory and modifying the scenario file for prediction run, the model was executed in prediction mode and run for 23 minutes. Following the termination of the model, output files and images of the prediction run were saved into the output directory.

3.3.3 Step 3: Synthesizing the Assessment Findings

Findings of the assessment process are synthesized in this final stage of the framework. In this context, the prediction results were examined for each scenario alternative and a conceptual model of the focal system was developed for synthesizing and summarizing the findings of the assessment process.

3.3.3.1 Step 3.1: Findings of the Assessment Process

As it was mentioned before; with termination of the model, output files and images (of each prediction run) were saved into the output directories of related prediction run. Output images of the prediction run contain; images of estimated (predicted) urban growth for each single year (between start and stop dates), an animated image

[30] Retrieved from the appendix of 2014/6028 numbered Decree of the Council of Ministers.

of urban growth (between start and stop dates) and an image of cumulative urban growth in GIF (Graphics Interchange Format) file format.

Image of cumulative urban growth provides the information of predicted urban macroform for 2050. In this image, pixel values represent the possibility of urbanization in 2050. In this context, a pixel value of 100 means that the pixel would be 100% urban in 2050. Therefore, these images of cumulative urban growth were used for examination of the prediction results. Since single GIF images do not provide georeferencing information, world files of GIF images (GFW) should be produced in order to get them back into ArcGIS. In this context, previously produced (by exporting the raster images in GIF format from ArcGIS) world file of GIF images (GFW) were copied into the same directory with cumulative urban growth image (GIF) and renamed as (associated to) the cumulative urban growth image. Thus, GIF image of cumulative urban growth was placed in real-world coordinate system when opened in ArcGIS.

After being opened in ArcGIS, the output images were reclassified and pixel values higher than 90 were classified as urban while the values lower than 90 were classified as non-urban. In other words, the cells with at least 90% of possibility to be urbanized in 2050 were set to be urban. In this context, pixel values higher than 90 were set to 255 whereas values lower than 90 were set to 0.

Then, vector data of conservation areas were opened in ArcGIS and superposed with reclassified images of 2050. Finally, urban growth in the conservation areas of Istanbul City-Region were analysed. To that end, urbanized areas in conservation areas were extracted by Extraction Tool of the ArcToolbox and compared with the current situation in 2017. Results of this examination stage are explained in the Results and Discussion chapter below.

3.3.3.2 Step 3.2: Developing a Conceptual Model of the System

Following the examination of assessment findings, a conceptual model of the social-ecological system is developed for synthesizing and summarizing the findings and presented in the Results and Discussion chapter below.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Results of Urban Growth Simulations for Istanbul City-Region

Setting the values of Diffusion, Breed, Spread, Slope-Resistance and Road-Gravity coefficients as 4, 100, 80, 10 and 74, respectively, and using the exclusion images of conservative, moderate and aggressive scenario alternatives, five different scenario alternatives were tested in prediction stage of SLEUTH Urban Growth Model. As a result of these coefficient values, that were determined at the end of a brute-force calibration process, an organic (edge) type of urban growth was observed in all five of the scenario alternatives.

After each prediction run, log files and output images were saved under the output directory of related scenario alternative. Among other images, an image of cumulative urban growth was also produced for the prediction year of 2050. Providing information about the probability of urbanization for each cell, these images were used in the examination of prediction results. In these images of cumulative urban growth, the values of each cell represents the possibility of that cell to become urban in 2050 by percentages. For example, a value of 90 means that the possibility of that cell to become urban in 2050 is 90%. Therefore, the cells with a value of 90 or higher regarded as urban for this study. To that end, cumulative urban growth images of 2050 were brought back to ArcGIS and superposed with the boundaries of conservation areas. Then, the changes within the boundaries of each conservation area were analysed. As a result, the amount of urban growth in each conservation area was determined and listed in the tables below. Results of the scenario alternatives are also elaborated in details below.

4.1.1 Prediction Results of Limited Urban Growth Scenario

As it was mentioned before, urban areas were covering nearly 98 513 ha of the surface area of Istanbul City-Region in 2017. With the scenario alternative of Limited Urban Growth, it was estimated that the urban areas would increase by 11.41% (11 241 ha) and cover nearly 109 754 ha of the City-Region's surface in 2050 (see Figure 4.1). Assuming strict protection of the conservation areas, the exclusion image of conservative scenario alternatives (with the highest levels of exclusion) was used in this Limited Urban Growth scenario alternative. As a result, the conservation areas of Istanbul City-Region were mostly protected and only 6.5% of total urban growth (731 ha) took place within the boundaries of conservation areas (see Figure 4.2). This urban growth in conservation areas mainly took place within the boundaries of; Forest Areas (315 ha), Agricultural Lands (176 ha), 3rd Degree Natural Conservation Sites (152 ha) and Medium Distance Preservation Areas of Drinking Water Basins (68 ha). Remaining conservation areas were mostly excluded from the urban growth in this scenario alternative (see Table 4.1). In spite of the fact that the most of the urban growth in conservation areas took place within the boundaries of; Forest Areas, Agricultural Lands, 3rd Degree Natural Conservation Sites and Medium Distance Preservation Areas of Drinking Water Basins, the amount of urban growth in these areas was negligible compared to the total surface areas of each conservation area (see Figure 4.3, Figure 4.4, Figure 4.7, and Figure 4.13).

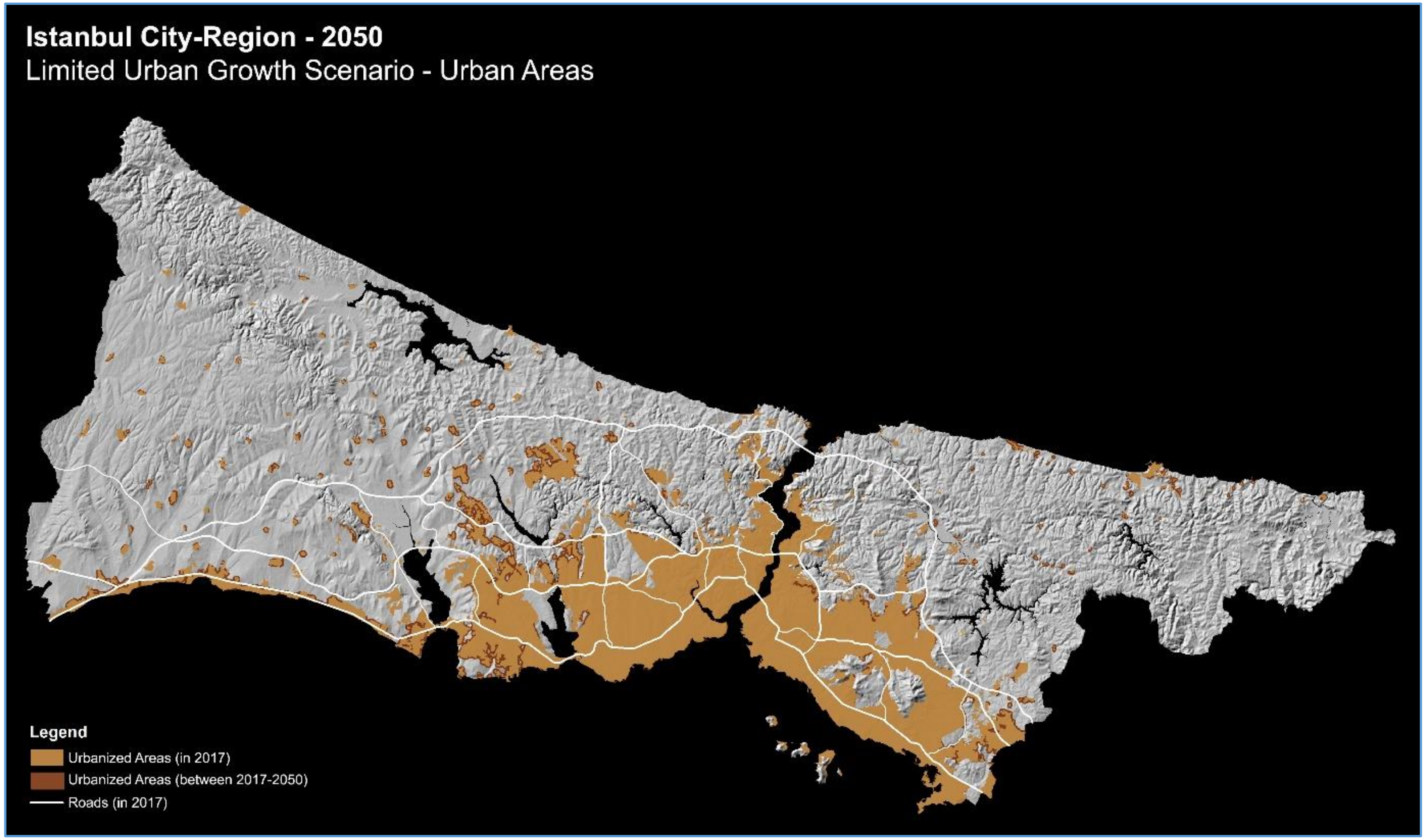

Figure 4.1: Urban Areas of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

On the other hand, the amount of urban growth within the boundaries of 1st Degree Natural Conservation Sites (13 ha), 2nd Degree Natural Conservation Sites (1 ha), Nature Parks (1 ha), Nature Reserve Areas (1 ha) and Strict Preservation Areas of Drinking Water Basins (4 ha) were also negligible compared to the amount of total urban growth between 2017 and 2050 (see Table 4.1 with Figure 4.5, Figure 4.6, Figure 4.8, Figure 4.9, and Figure 4.11). Additionally, Wildlife Improvement Areas, Short Distance Preservation Areas of Drinking Water Basins and Military Zones were totally excluded from the urban growth in this scenario alternative (see Figure 4.10, Figure 4.12, and Figure 4.15).

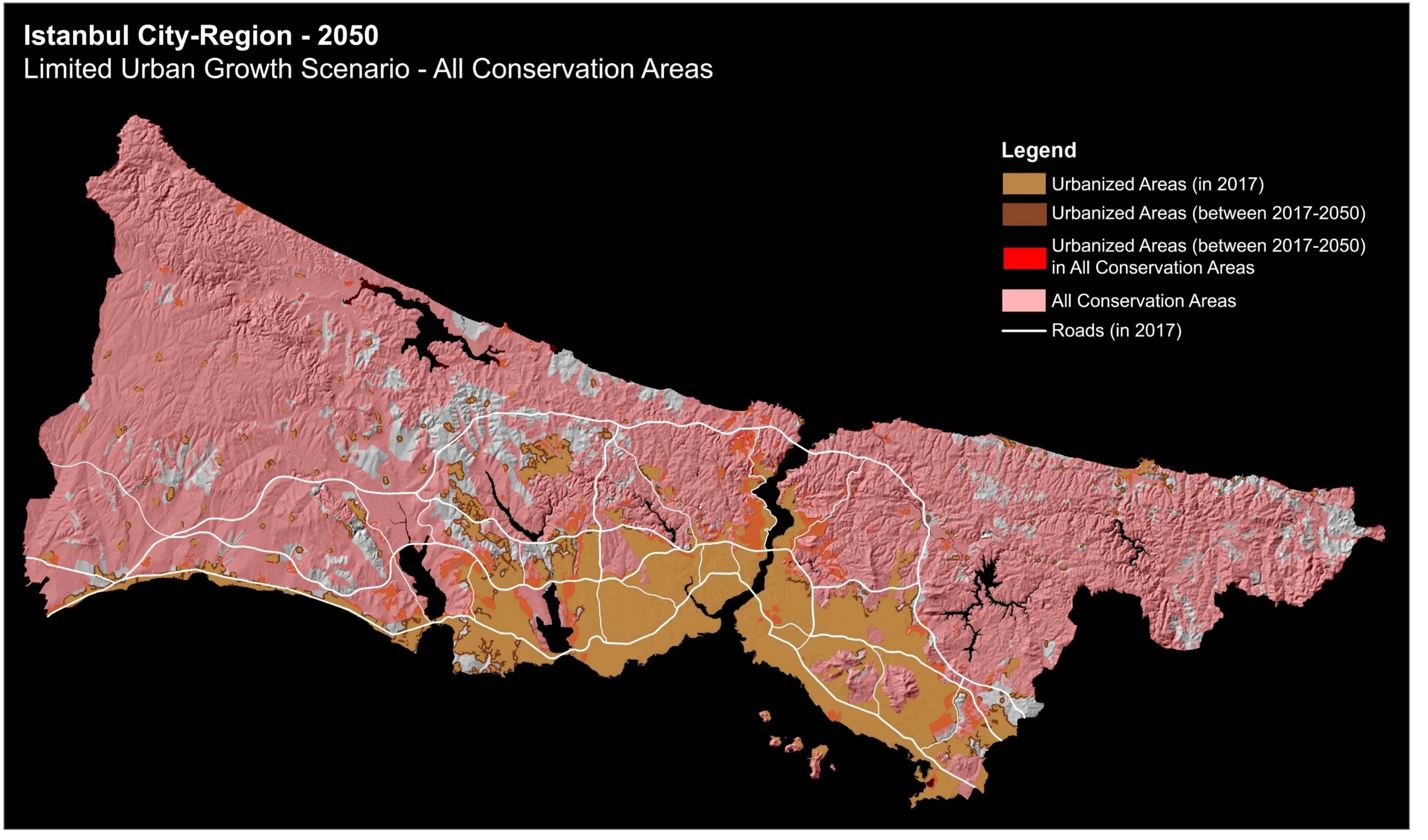

Figure 4.2: All Conservation Areas of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

Table 4.1: Results of Limited Urban Growth Scenario

LIMITED URBAN GROWTH SCENARIO	**Total Urban Areas**	**Agricultural Lands**	**Forest Areas**	**1st Degree Natural Conservation Sites**	**2nd Degree Natural Conservation Sites**	**3rd Degree Natural Conservation Sites**	**Nature Parks**	**Nature Reserve Areas**	**Wildlife Improvement Areas**	**Strict Preservation Areas of Drinking Water Basins**	**Short Distance Preservation Areas of Drinking Water Basins**	**Medium Distance Preservation Areas of Drinking Water Basins**	**Military Zones**	**TOTAL**
exclusion levels (0-100)		**100**	**100**	**80**	**60**	**100**	**100**	**10**	**100**	**100**	**80**	**60**	**90**	
total area (ha)		173 891	237 481	27 520	4 594	9 113	5 017	44	37 144	11 131	18 656	21 121	8 482	**554 194**
total urban areas in 2017 (ha)	98 513	8 681	0	1 015	664	3 579	69	1	274	77	540	912	290	**16 102**
total urban areas (90-100%) in 2050 (ha)	109 754	8 857	315	1 028	665	3 731	70	2	274	81	540	980	290	**16 833**
urban areas in 2017 (%)		4.99%	0.00%	3.69%	14.45%	39.27%	1.38%	2.27%	0.74%	0.69%	2.89%	4.32%	3.42%	**2.91%**
total urban areas (90-100%) in 2050 (%)		5.09%	0.13%	3.74%	14.48%	40.94%	1.40%	4.55%	0.74%	0.73%	2.89%	4.64%	3.42%	**3.04%**
urbanization between 2017-2050 (ha)	11 241	176	315	13	1	152	1	1	0	4	0	68	0	**731**
urbanization between 2017-2050 (%)	11.41%	2.03%	-	1.28%	0.15%	4.25%	1.45%	100.00%	0.00%	5.19%	0.00%	7.46%	0.00%	**4.54%**
ratio of urbanization between 2017-2050 to total conservation area (%)		**0.10%**	**0.13%**	**0.05%**	**0.02%**	**1.67%**	**0.02%**	**2.27%**	**0.00%**	**0.04%**	**0.00%**	**0.32%**	**0.00%**	**0.13%**

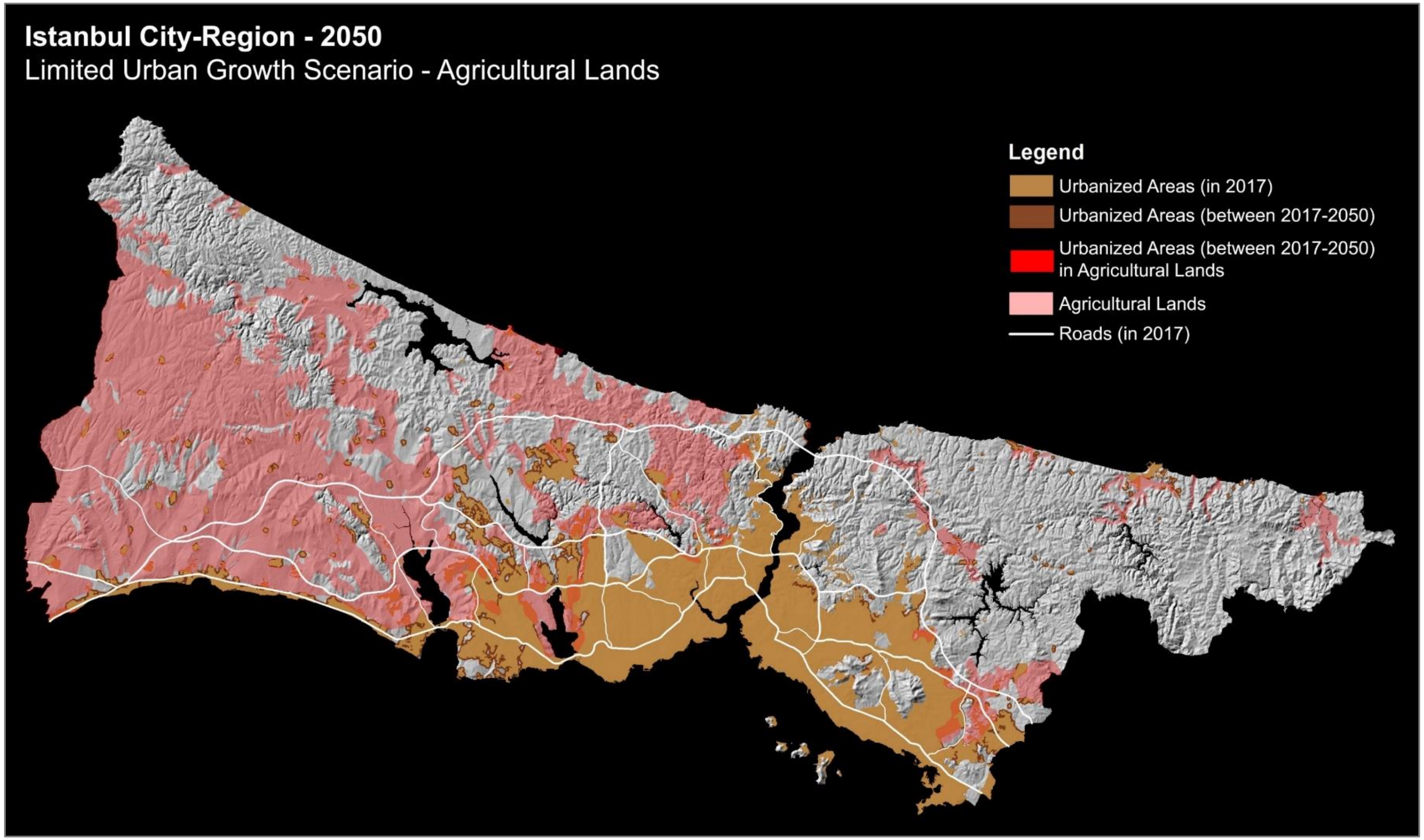

Figure 4.3: Agricultural Lands of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

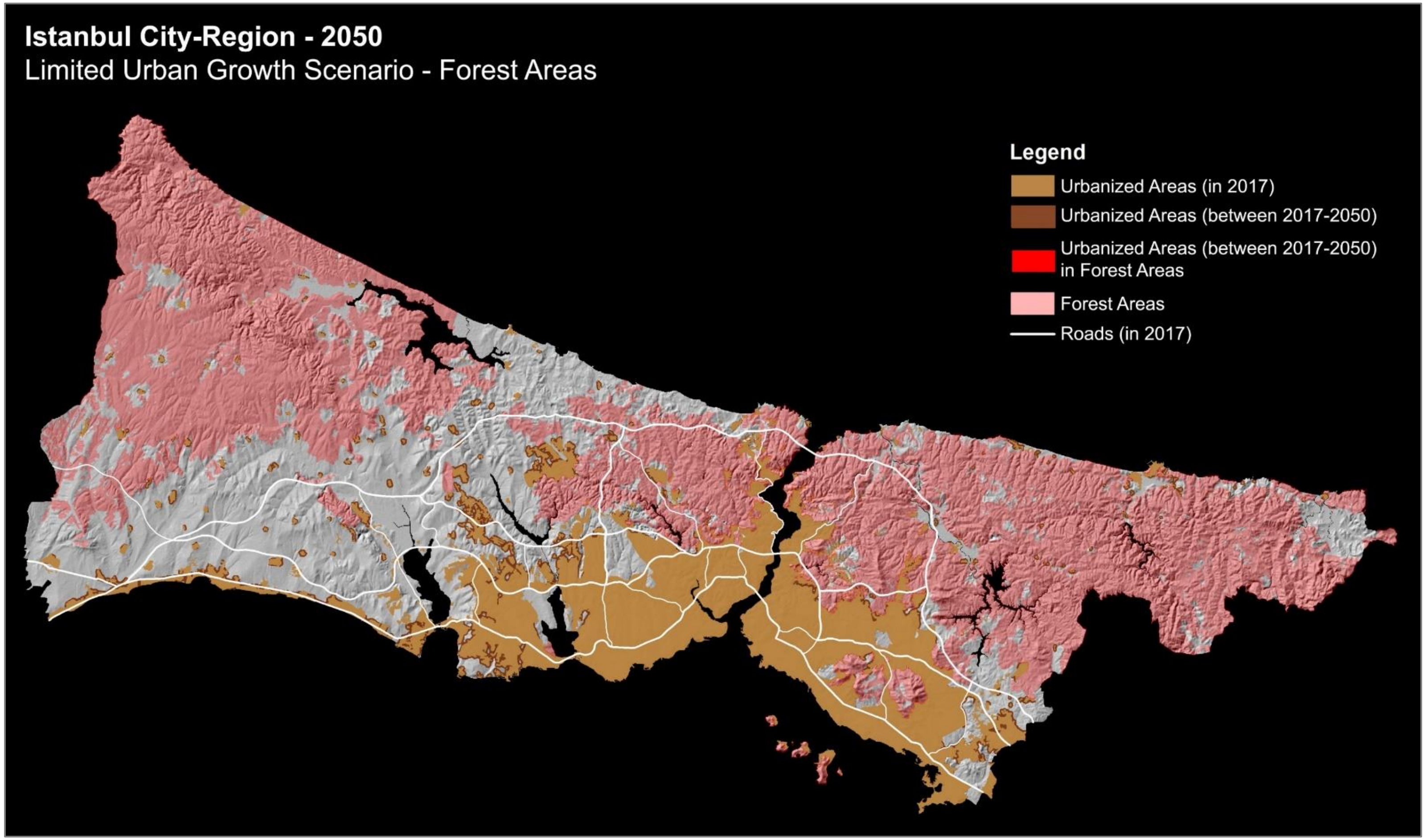

Figure 4.4: Forest Areas of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

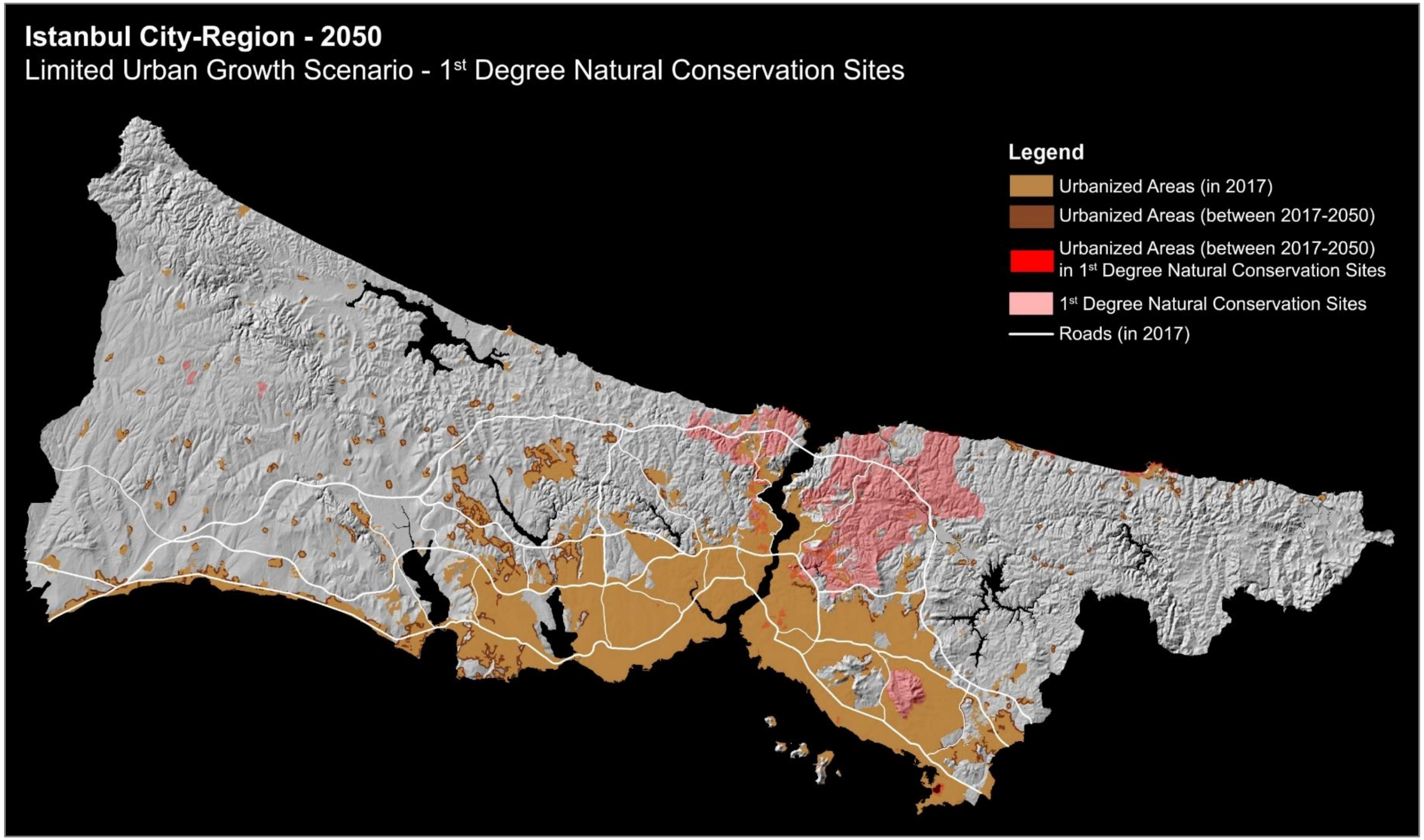

Figure 4.5: 1st Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

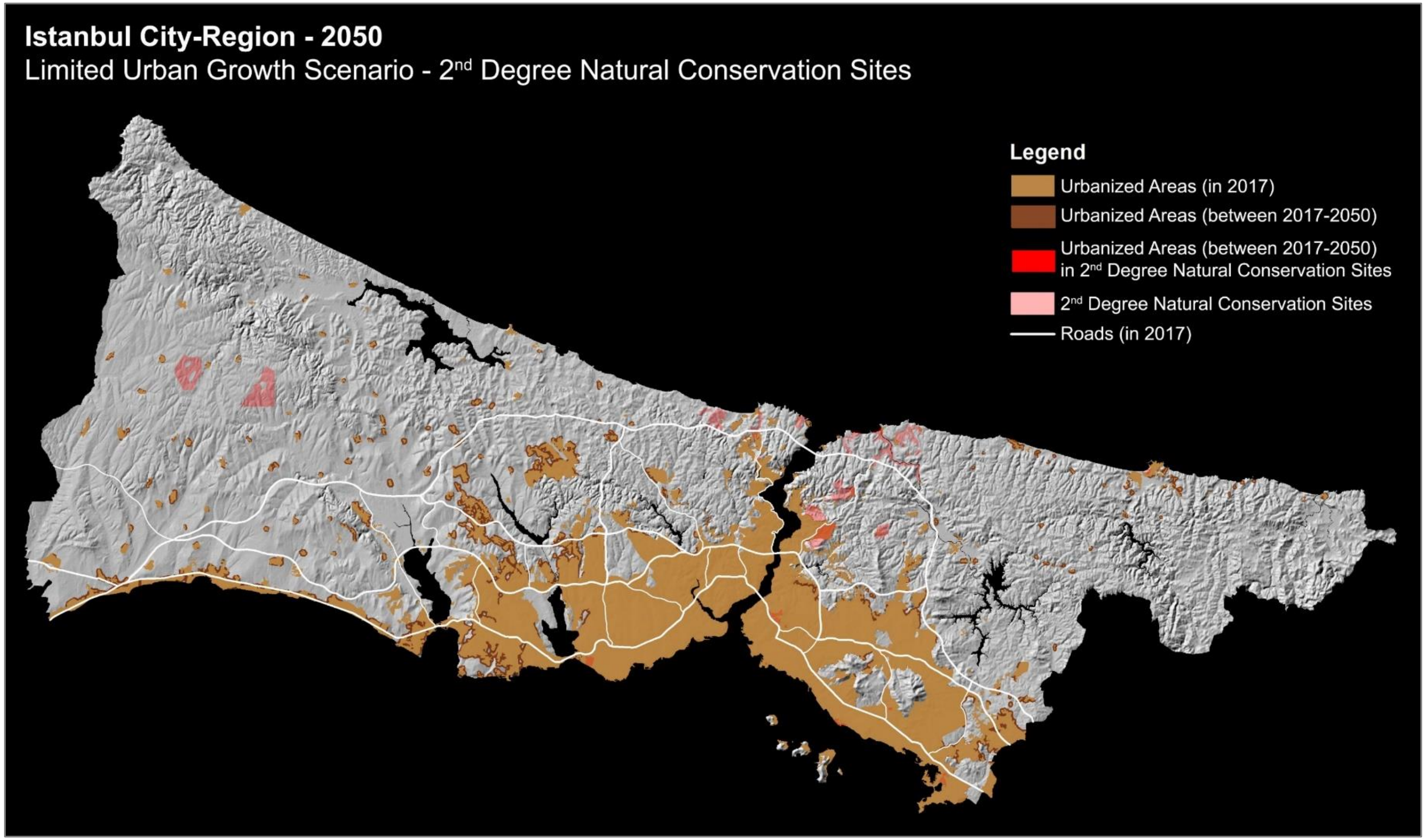

Figure 4.6: 2nd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

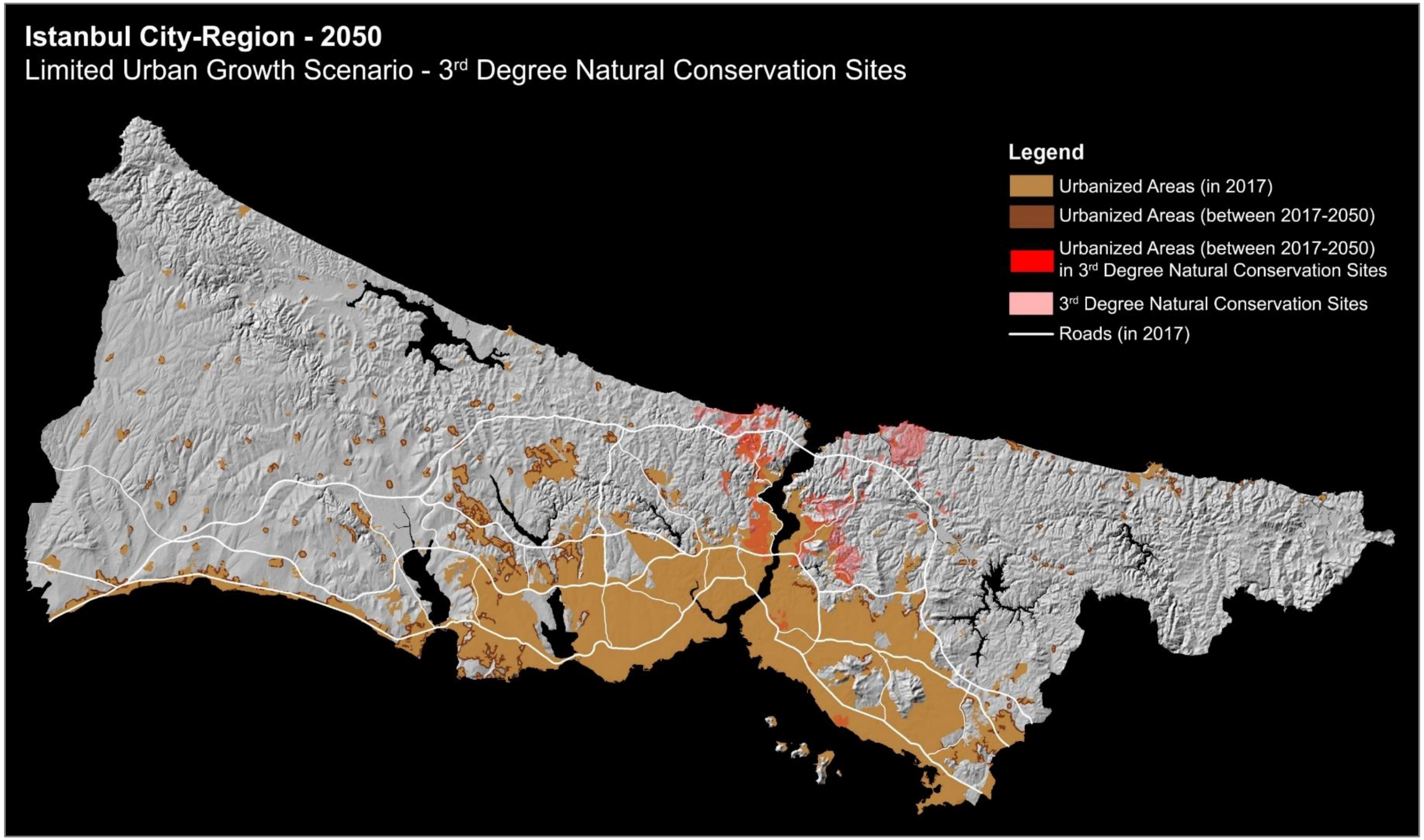

Figure 4.7: 3rd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

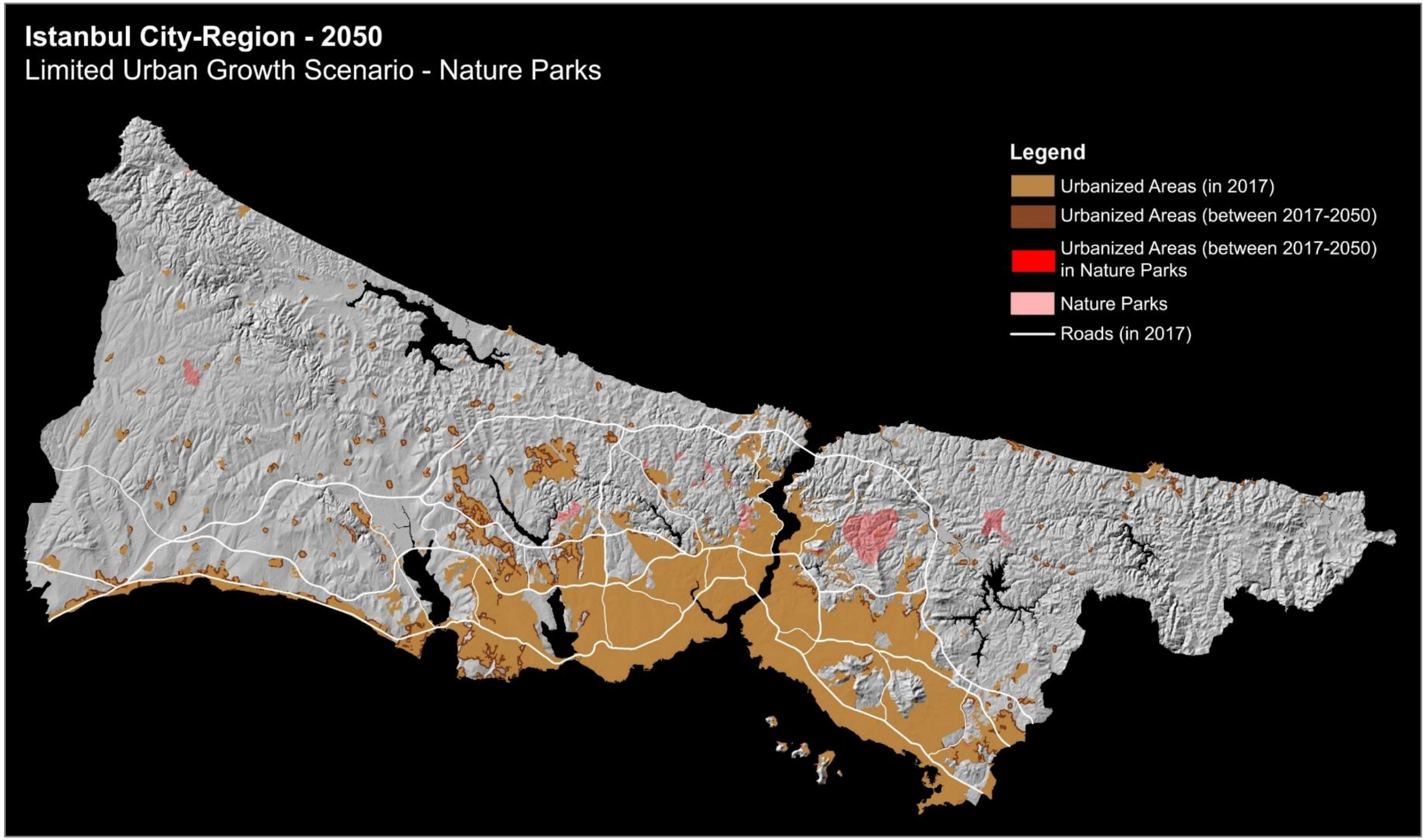

Figure 4.8: Nature Parks of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

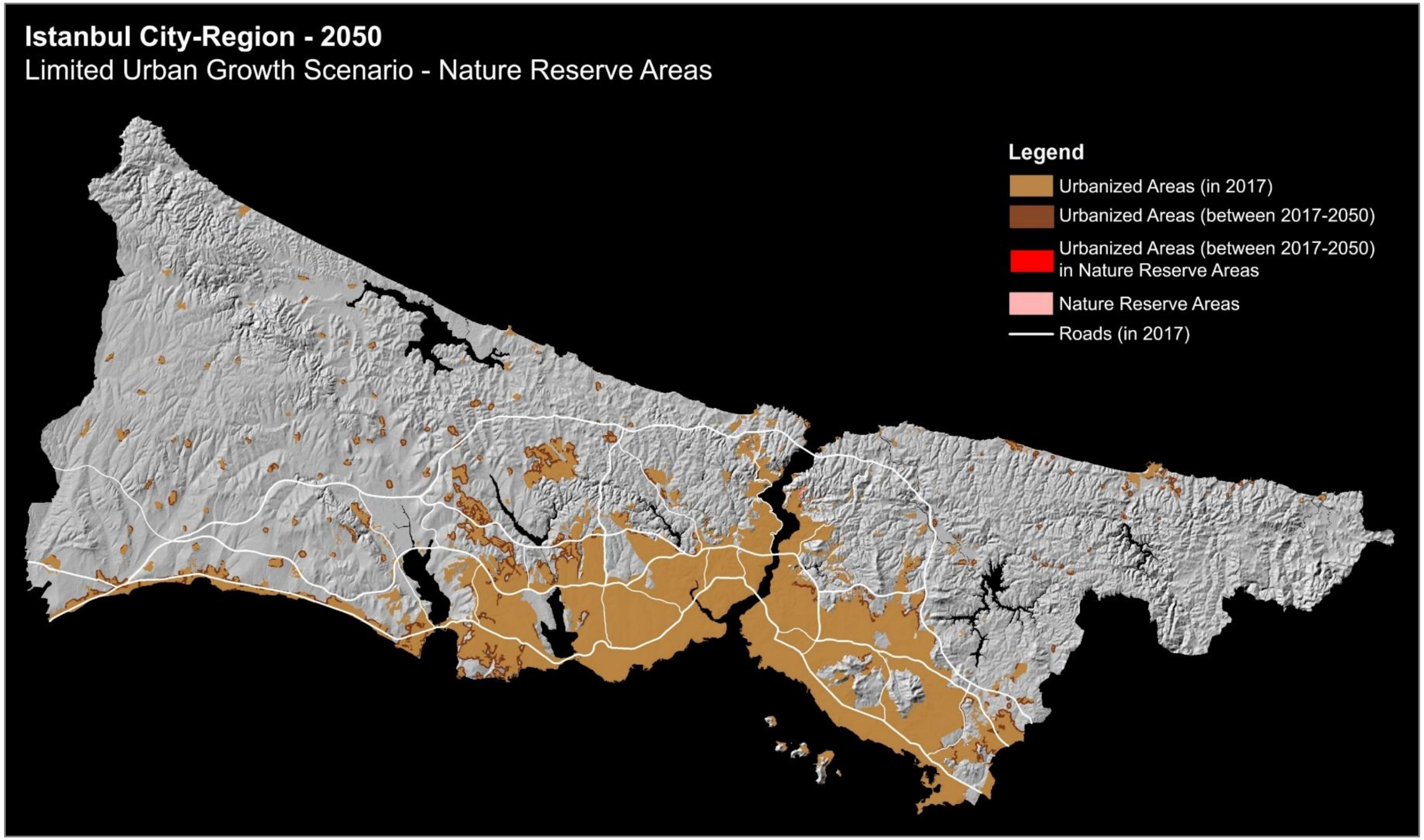

Figure 4.9: Nature Reserve Areas of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

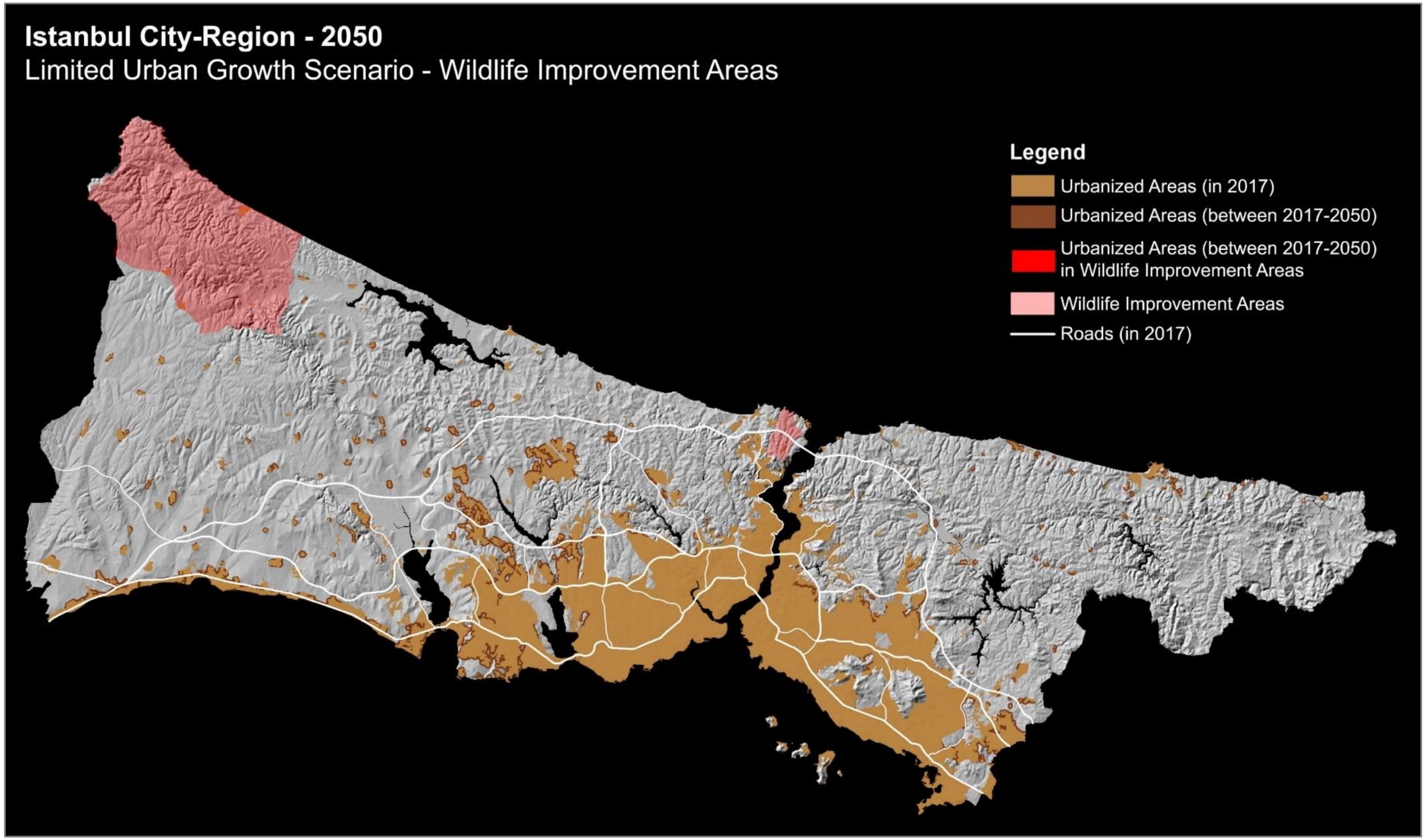

Figure 4.10: Wildlife Improvement Areas of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

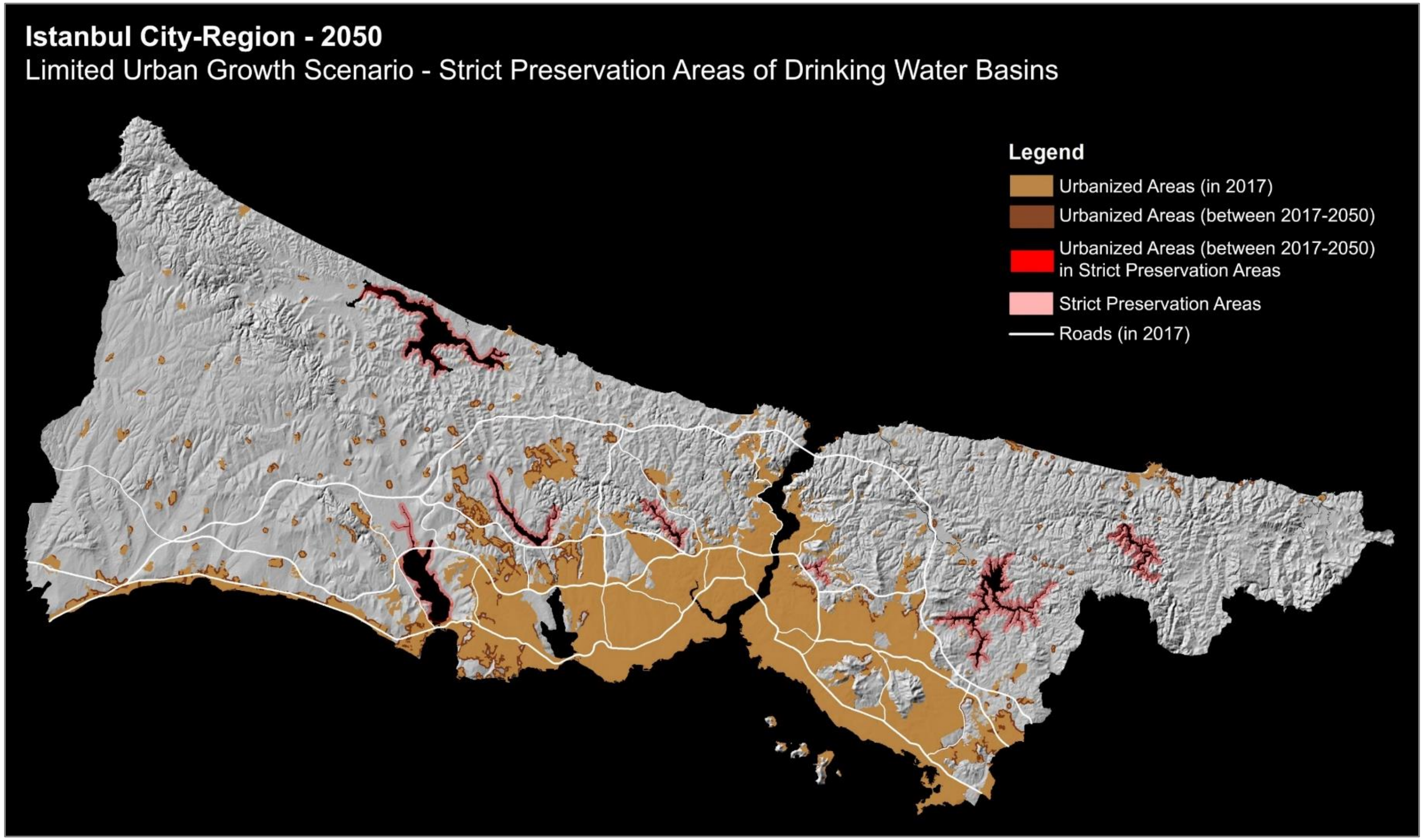

Figure 4.11: Strict Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

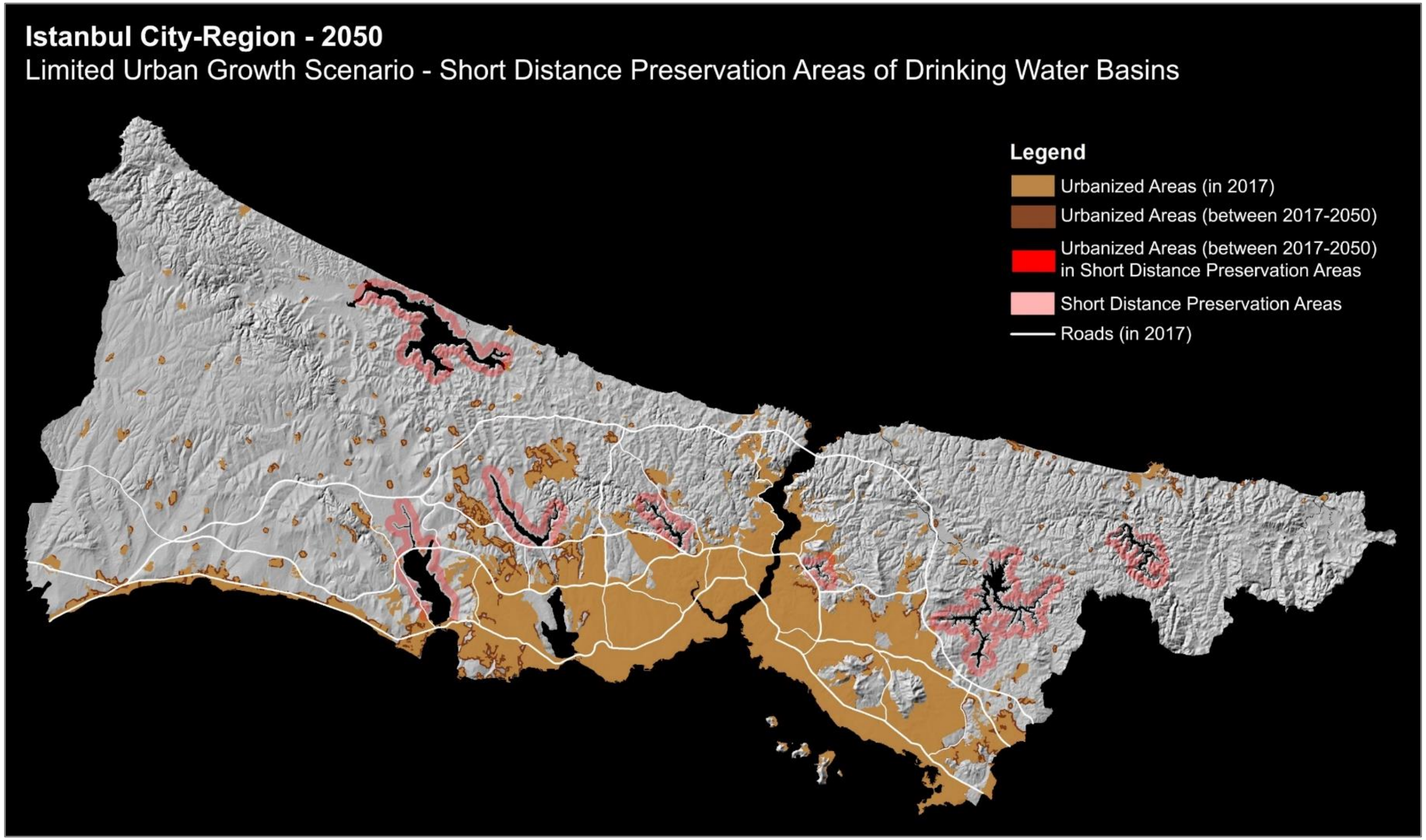

Figure 4.12: Short Distance Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

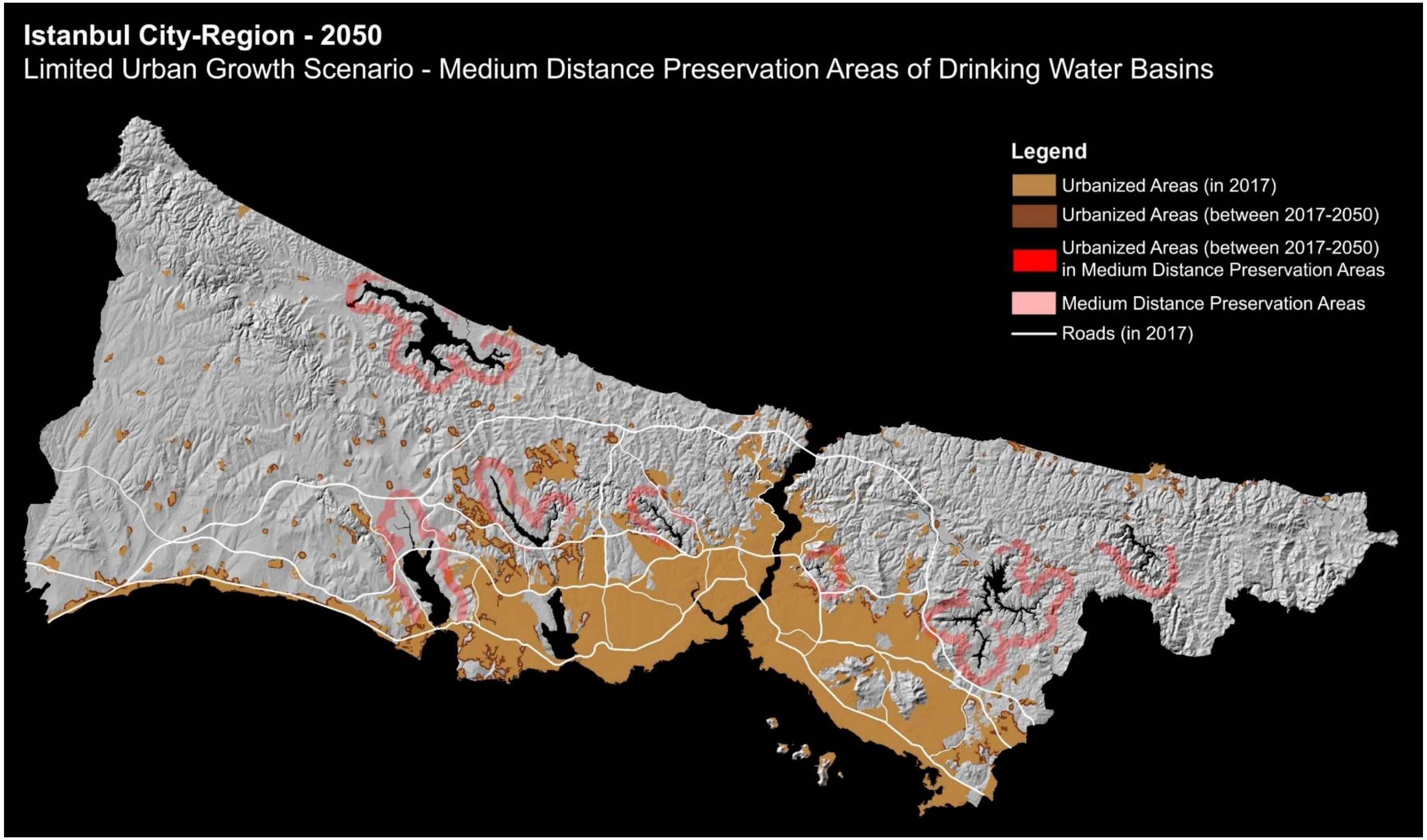

Figure 4.13: Medium Distance Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

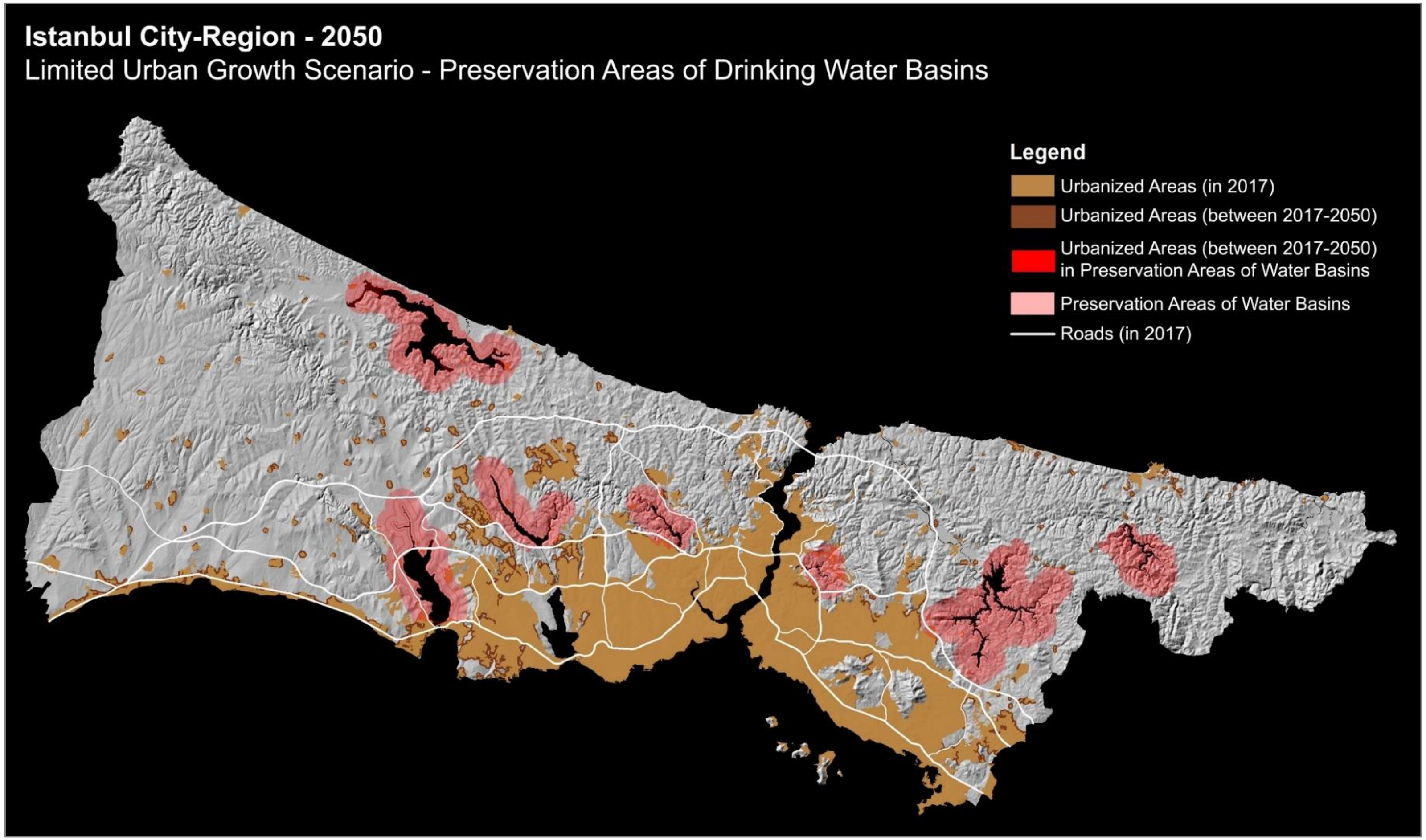

Figure 4.14: Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

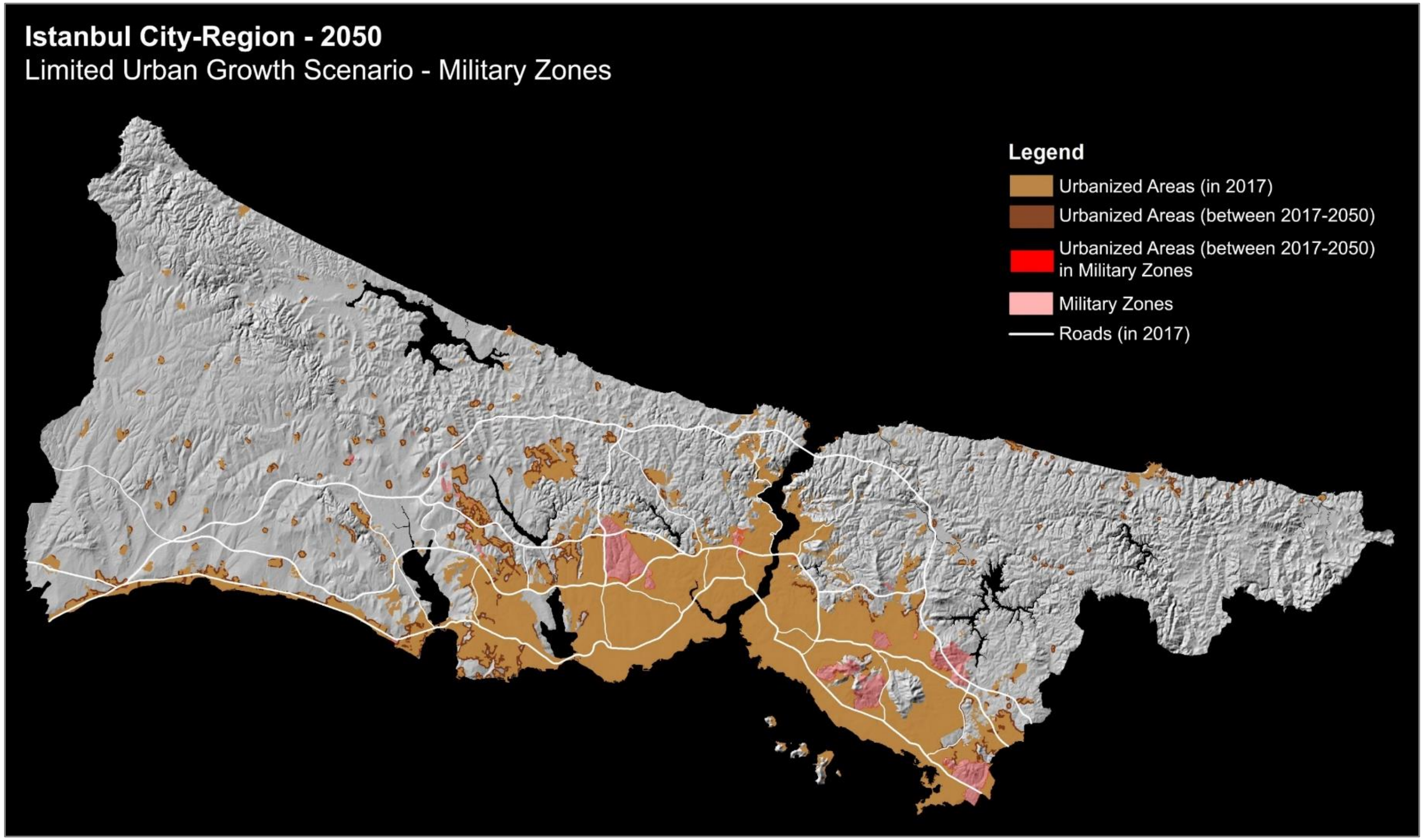

Figure 4.15: Military Zones of Istanbul City-Region in 2050 – Limited Urban Growth Scenario

4.1.2 Prediction Results of Managed Urban Growth Scenario

Assuming moderate protection of the conservation areas, the exclusion image of moderate scenario alternatives was used in this business as usual scenario alternative of Managed Urban Growth. With this scenario alternative, it was estimated that the urban areas would increase by 38.89 % (38 307 ha) and cover nearly 136 820 ha of the City Region's surface area in 2050 (see Figure 4.16). As a result of moderate protection of the conservation areas, nearly 47% (17 929 ha) of total urban growth took place within the boundaries of conservation areas (see Figure 4.17). Similar to the Limited Urban Growth scenario, the urban growth in conservation areas mainly took place within the boundaries of Agricultural Lands (6716 ha), Forest Areas (5928 ha), 3rd Degree Natural Conservation Sites (1961 ha) and Medium Distance Preservation Areas of Drinking Water Basins (1275 ha) (see Table 4.2 with Figure 4.18, Figure 4.19, Figure 4.22, and Figure 4.28). In addition, 711 ha (2.58%) of 1st Degree Natural Conservation Sites, 552 ha (6.51%) of Military Zones, 416 ha (2.23%) of Short Distance Preservation Areas of Drinking Water Basins and 349 ha (7.60%) of 2nd Degree Natural Conservation Sites were also urbanized between 2017 and 2050 in this scenario alternative of Managed Urban Growth (see Table 4.2 with Figure 4.20, Figure 4.21, Figure 4.27, and Figure 4.30).

With 90 % exclusion from urban growth; Nature Parks, Nature Reserve Areas and Wildlife Improvement Areas were mostly protected in this scenario alternative (see Figure 4.23, Figure 4.24, and Figure 4.25). As a result; only 2, 7 and 1 hectares of Nature Parks, Nature Reserve Areas and Wildlife Improvement Areas were urbanized in 2050, respectively (see Table 4.2). Since there is only one Nature Reserve Area of Istanbul City-Region with 44 ha of surface area, with 7 ha of urban growth in this area nearly 28% of Nature Reserve Areas were urbanized in 2050 (Figure 4.24). On the other hand, similar to the results of Limited Urban Growth scenario alternative, only 1.42% of Nature Parks and 0.74% of Wildlife Improvement Areas were urbanized in 2050, respectively.

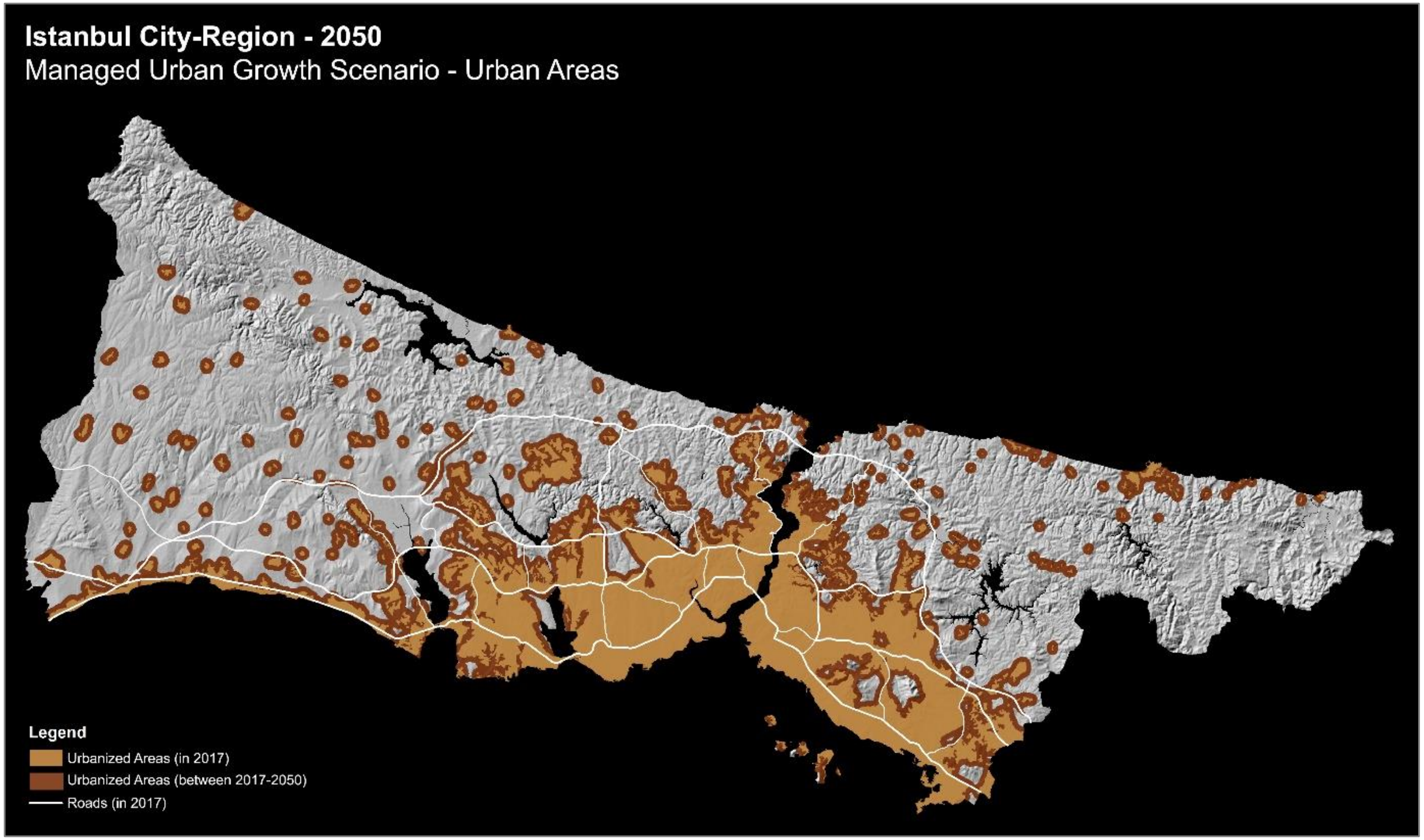

Figure 4.16: Urban Areas of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

Nearly 71% (12 644 ha) of the total urban growth in conservation areas took place within the boundaries of Agricultural Lands (6716 ha) and Forest Areas (5928 ha) hence 8.85% (15 397 ha) and 2.50% (5928 ha) of these areas became urbanized in 2050, respectively (see Figure 4.18 and Figure 4.19). On the other hand, with 1961 ha of urban growth in 33 years, nearly 61% (5540 ha) of the total surface area of 3rd Degree Natural Conservation Sites were urbanized in 2050 (Figure 4.22). This is because nearly 40% (3579 ha) of these areas were already urbanized in 2017.

In terms of the rate of urban growth between 2017 and 2050, Nature Reserve Areas took place on the top with 700% however the amount of total urban growth in these areas was only 7 ha in this scenario alternative. On the other hand, although the rate of urban growth in Forest Areas could not be calculated as a result of the fact that there were not any urban areas within the boundaries of Forest Areas in 2017, the highest rate of growth was occurred in these areas with 5928 ha of urban growth. Rates of urban growth within the boundaries of Military Zones and Medium Distance Preservation Areas of Drinking Water Basins follow the rate of Forest Areas with the values of 190.34% and 139.80%, respectively (see Table 4.2 with Figure 4.28 and Figure 4.30). Furthermore, the rates of urban growth in Agricultural Lands, 1st Degree Natural Conservation Sites, Short Distance Preservation Areas of Drinking Water Basins, 3rd Degree and 2nd Degree Natural Conservation Sites follow these rates with the values of 77.36%, 77.05%, 77.04%, 54.79% and 52.56%, respectively (see Table 4.2).

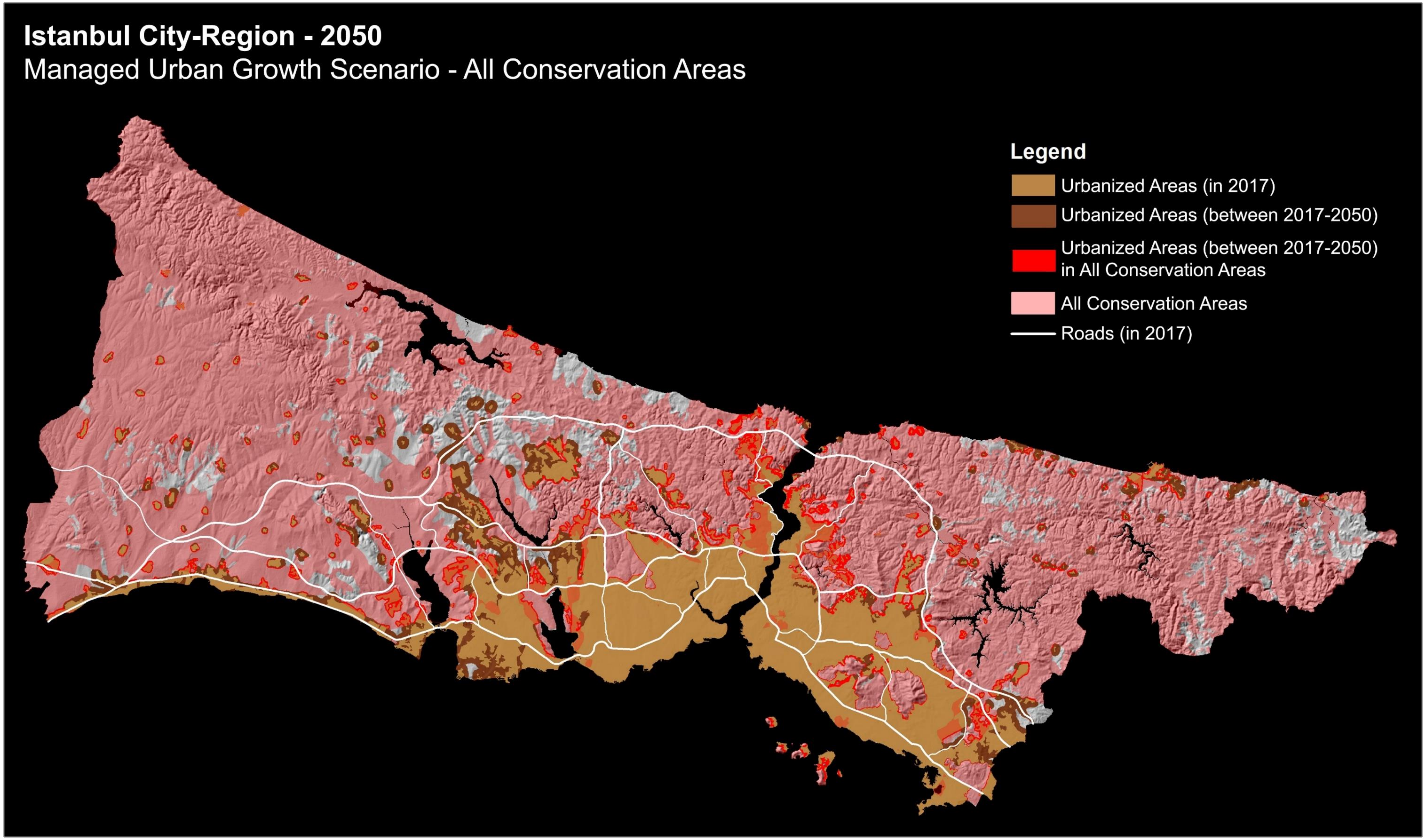

Figure 4.17: All Conservation Areas of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

Table 4.2: Results of Managed Urban Growth Scenario

MANAGED URBAN GROWTH SCENARIO	Total Urban Areas	Agricultural Lands	Forest Areas	1st Degree Natural Conservation Sites	2nd Degree Natural Conservation Sites	3rd Degree Natural Conservation Sites	Nature Parks	Nature Reserve Areas	Wildlife Improvement Areas	Strict Preservation Areas of Drinking Water Basins	Short Distance Preservation Areas of Drinking Water Basins	Medium Distance Preservation Areas of Drinking Water Basins	Military Zones	TOTAL
exclusion levels (0-100)		**70**	**60**	**80**	**50**	**30**	**90**	**90**	**90**	**90**	**70**	**50**	**80**	
total area (ha)		173 891	237 481	27 520	4 594	9 113	5 017	44	37 144	11 131	18 656	21 121	8 482	**554 194**
total urban areas in 2017 (ha)	98 513	8 681	0	1 015	664	3 579	69	1	274	77	540	912	290	**16 102**
total urban areas (90-100%) in 2050 (ha)	136 820	15 397	5 928	1 726	1 013	5 540	71	8	275	88	956	2 187	842	**34 031**
urban areas in 2017 (%)		4.99%	0.00%	3.69%	14.45%	39.27%	1.38%	2.27%	0.74%	0.69%	2.89%	4.32%	3.42%	**2.91%**
total urban areas (90-100%) in 2050 (%)		8.85%	2.50%	6.27%	22.05%	60.79%	1.42%	18.18%	0.74%	0.79%	5.12%	10.35%	9.93%	**6.14%**
urbanization between 2017-2050 (ha)	38 307	6 716	5 928	711	349	1 961	2	7	1	11	416	1 275	552	**17 929**
urbanization between 2017-2050 (%)	38.89%	77.36%	-	70.05%	52.56%	54.79%	2.90%	700.00%	0.36%	14.29%	77.04%	139.80%	190.34 %	**111.35%**
ratio of urbanization between 2017-2050 to total conservation area (%)		**3.86%**	**2.50%**	**2.58%**	**7.60%**	**21.52%**	**0.04%**	**15.91%**	**0.00%**	**0.10%**	**2.23%**	**6.04%**	**6.51%**	**3.24%**

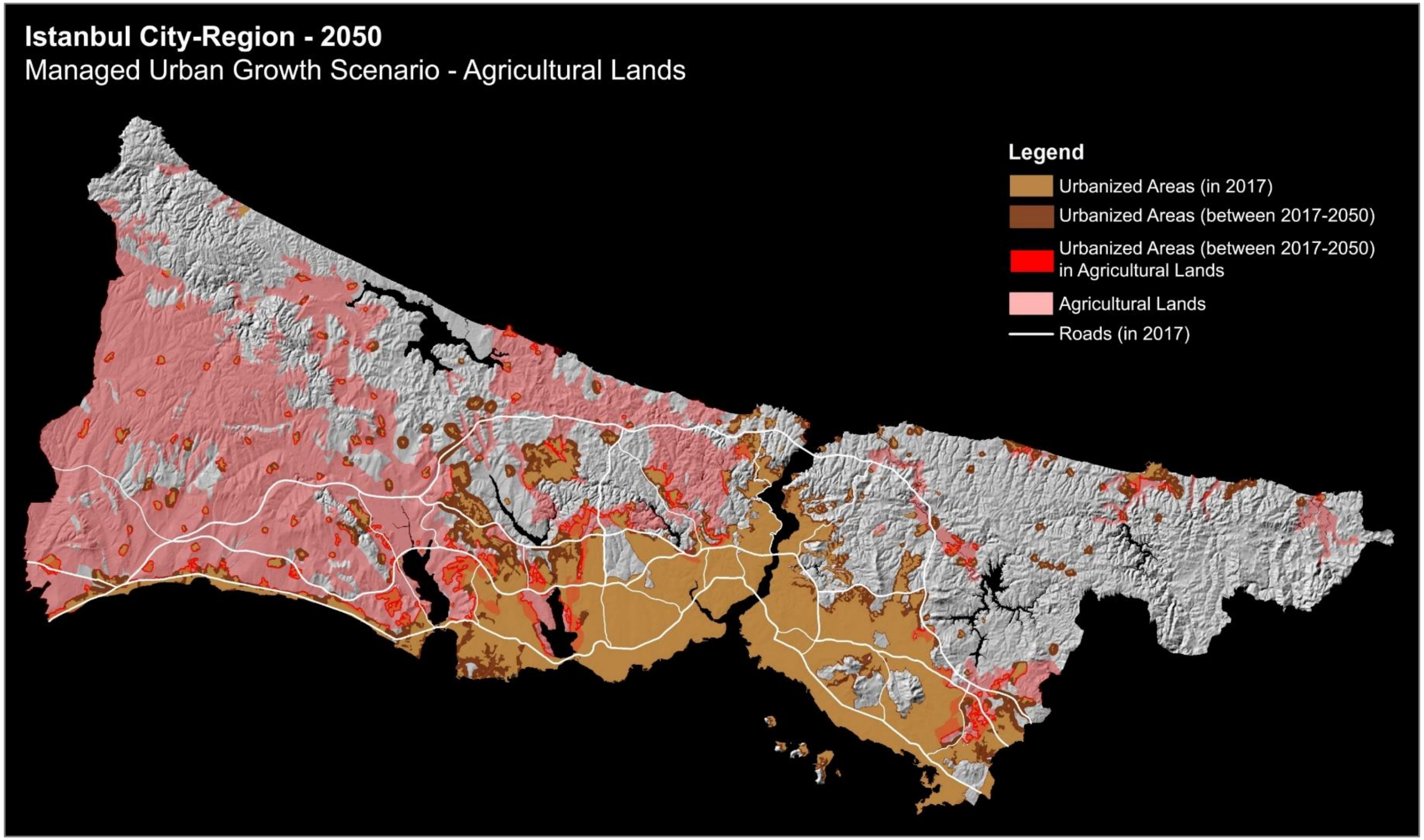

Figure 4.18: Agricultural Lands of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

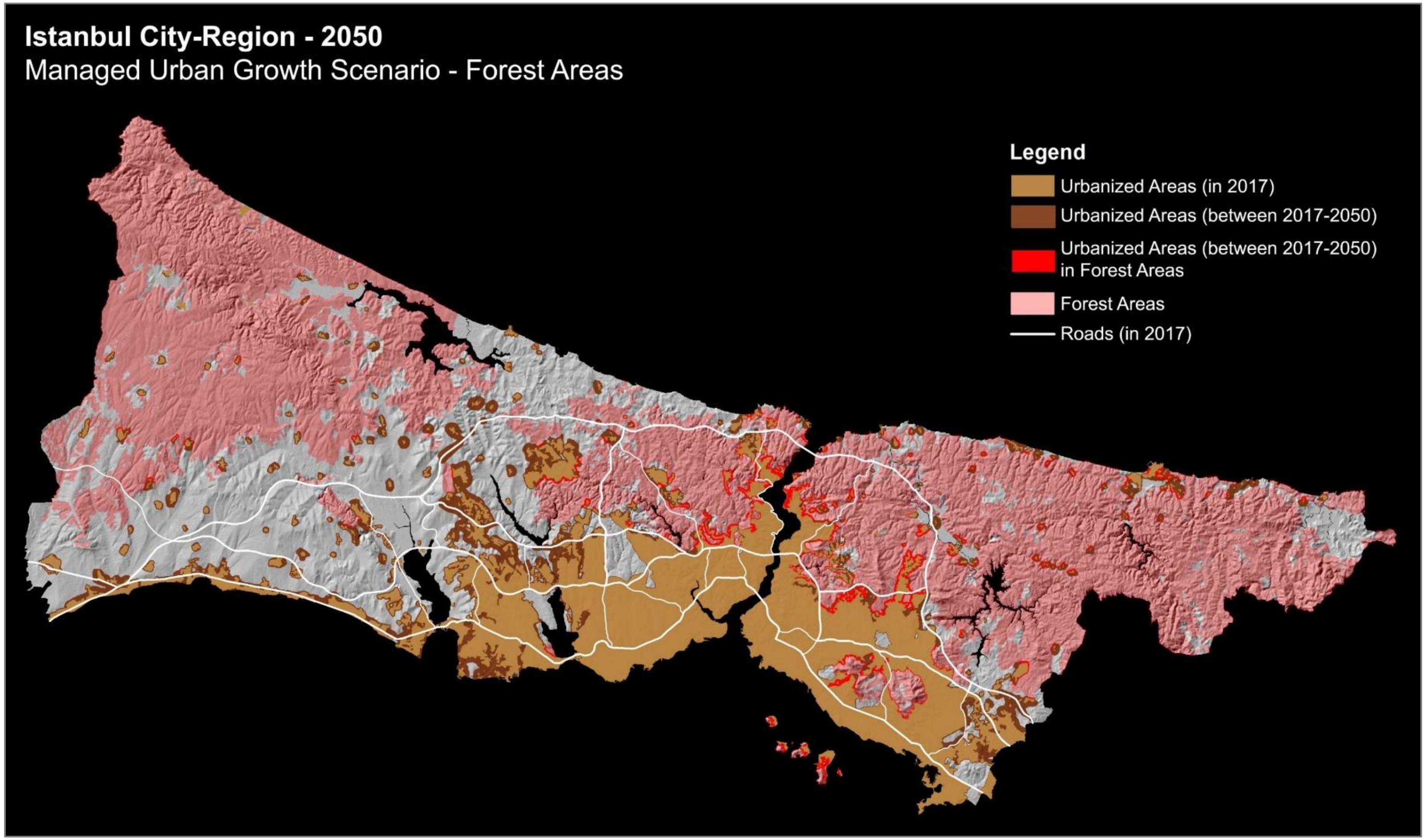

Figure 4.19: Forest Areas of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

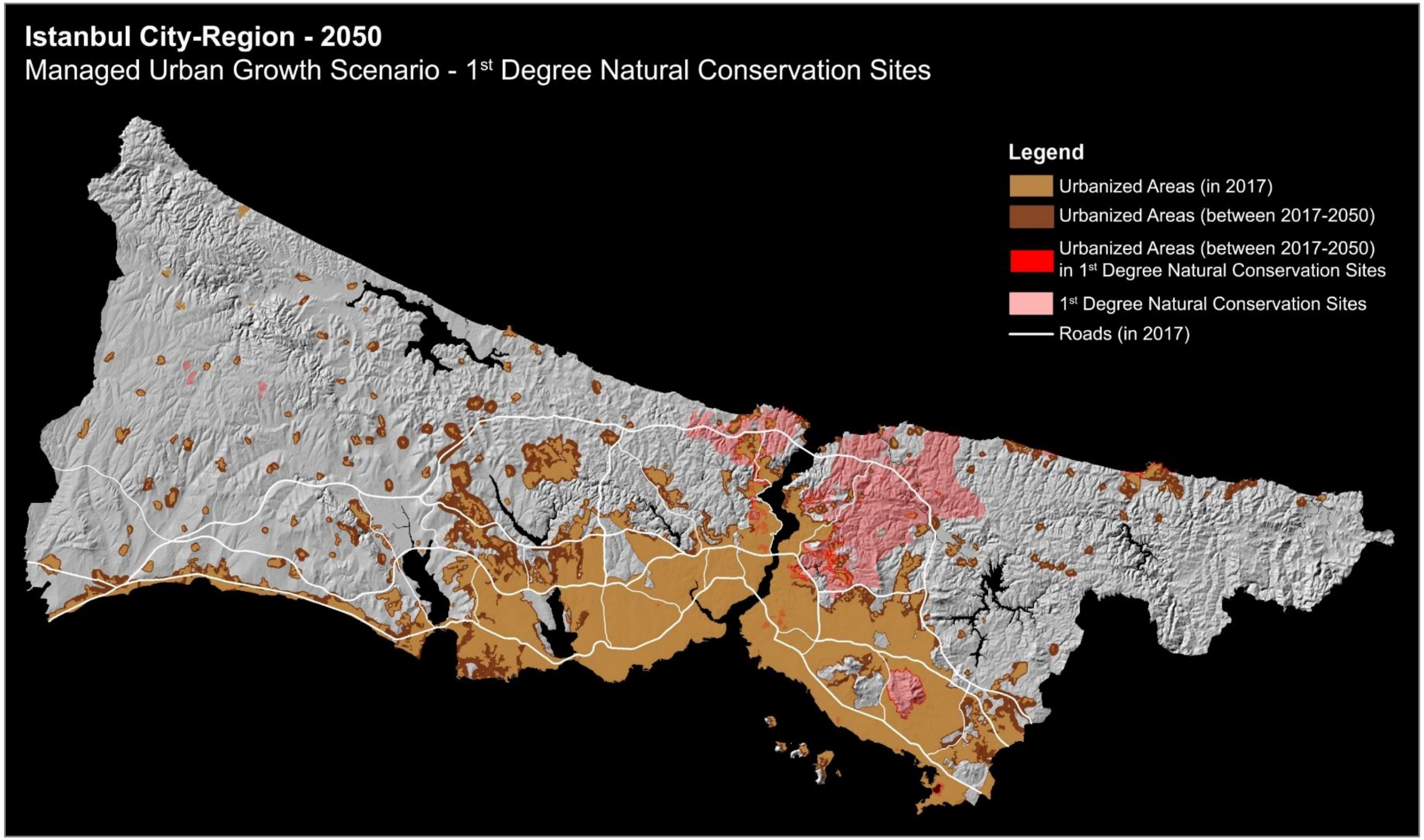

Figure 4.20: 1st Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

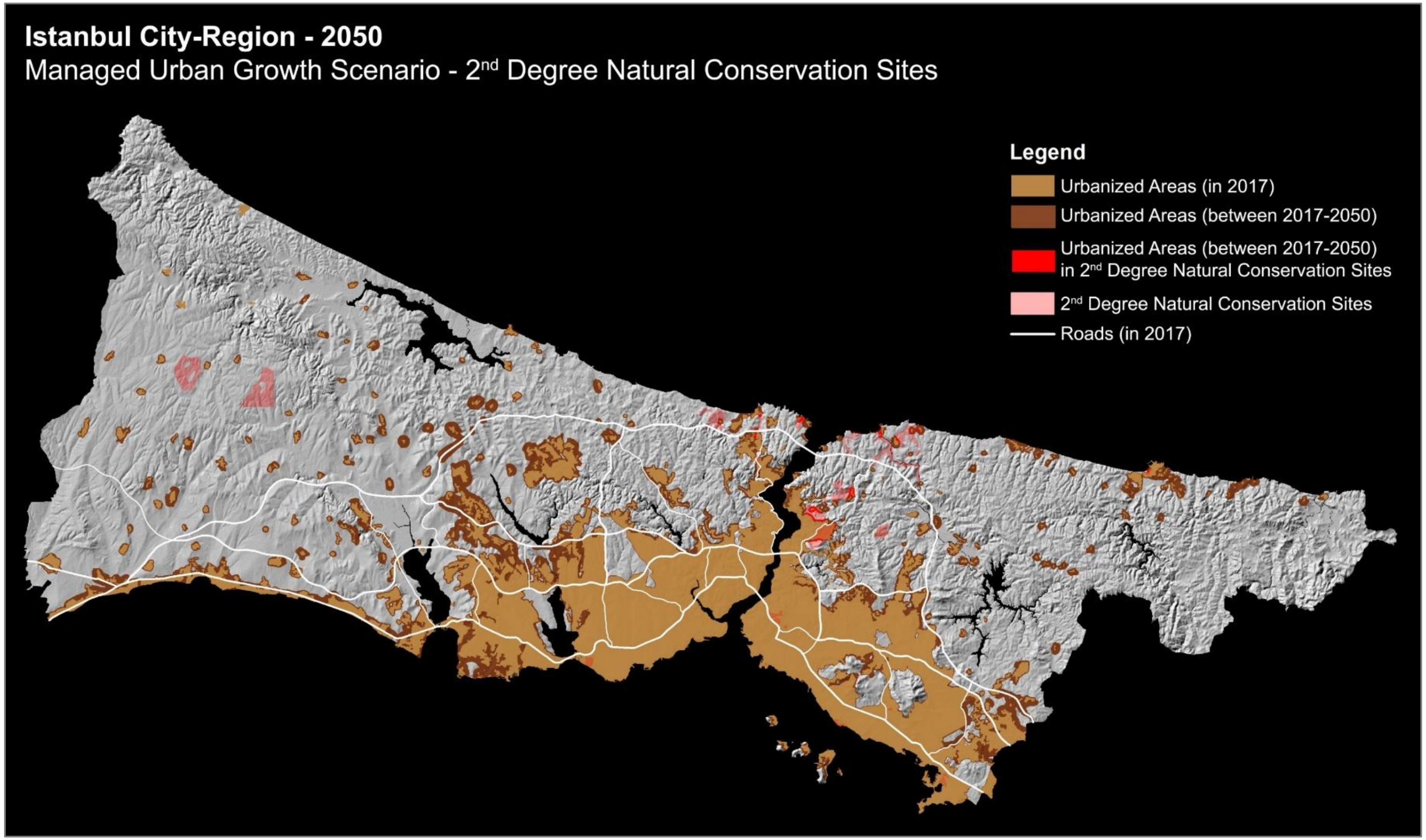

Figure 4.21: 2nd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

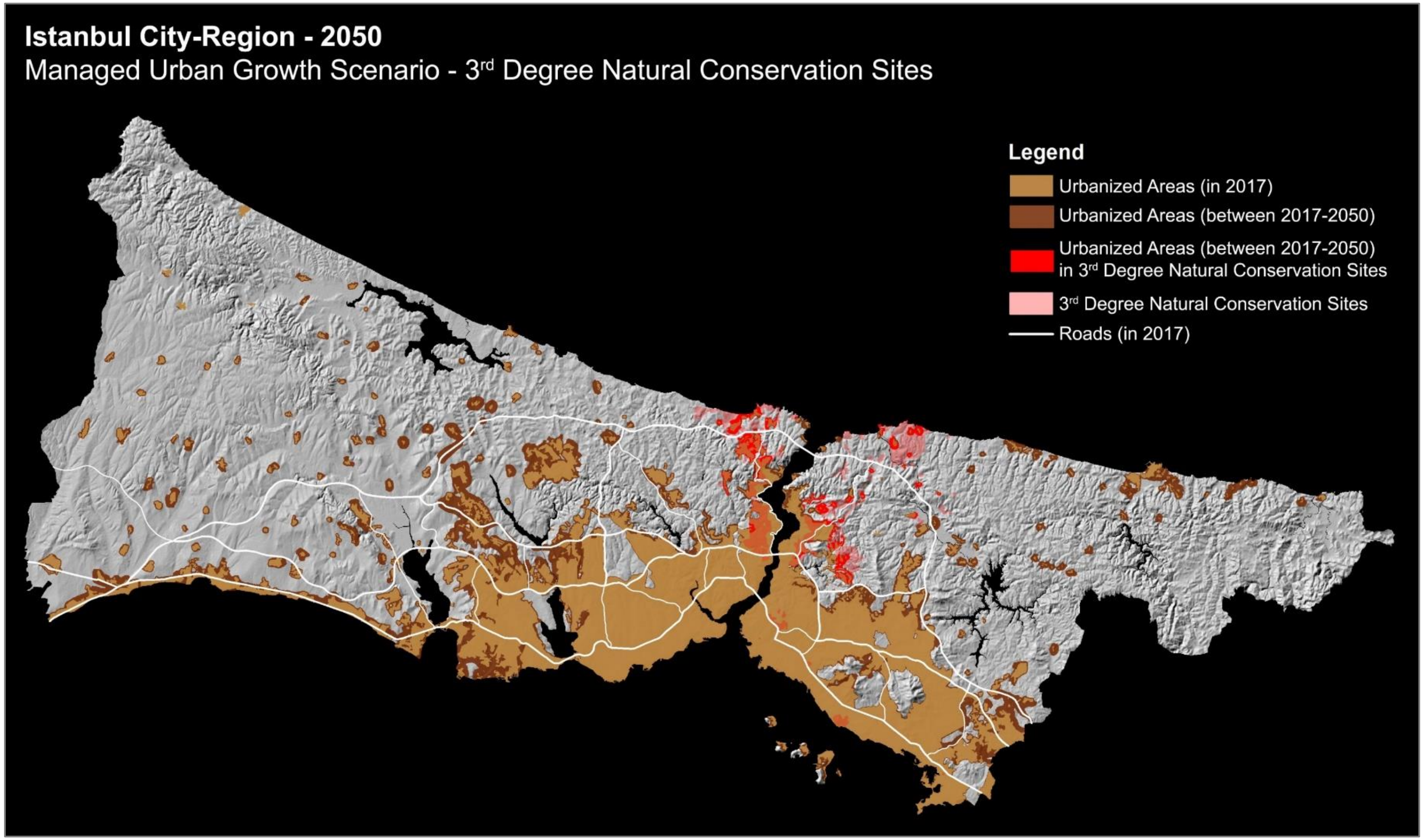

Figure 4.22: 3rd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

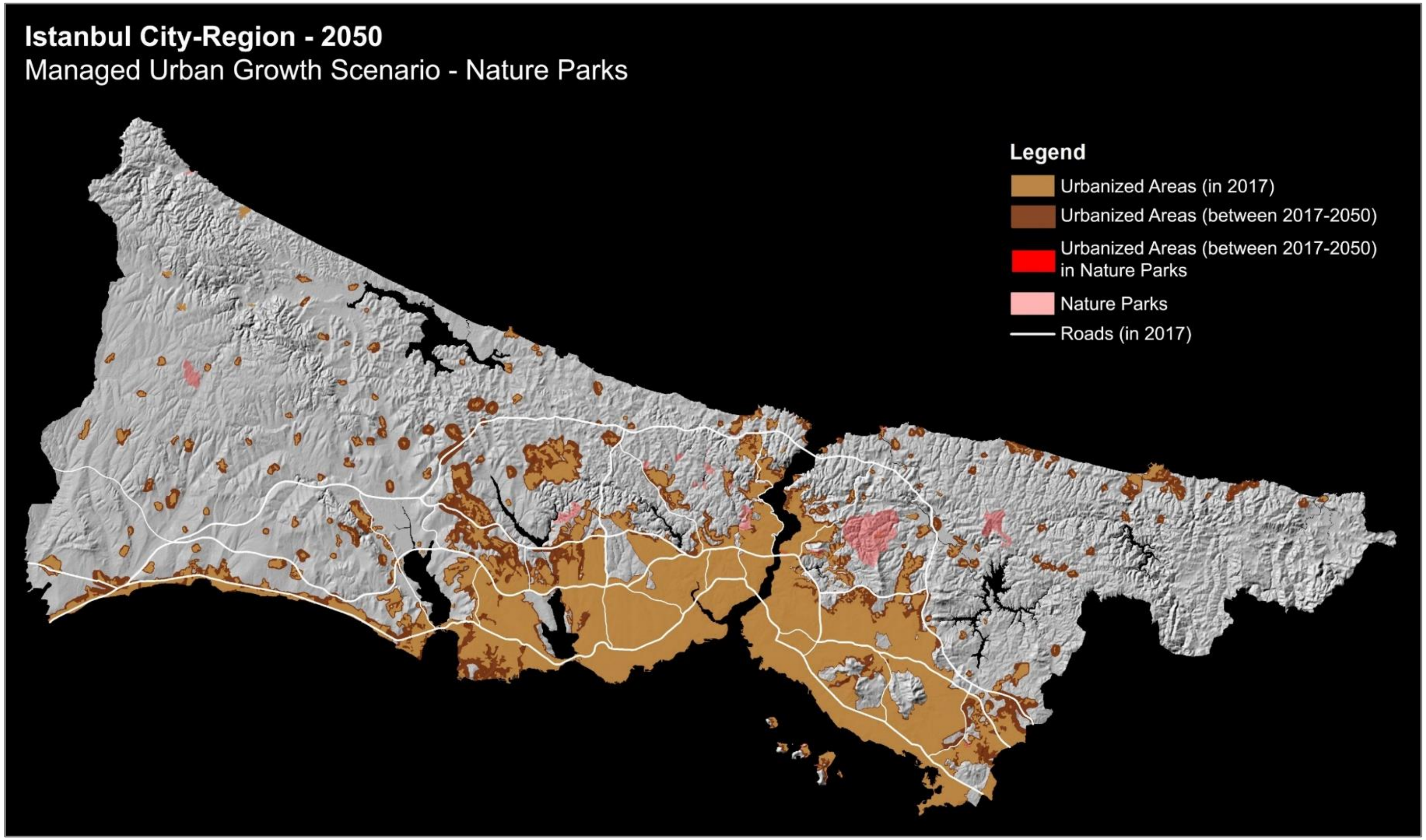

Figure 4.23: Nature Parks of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

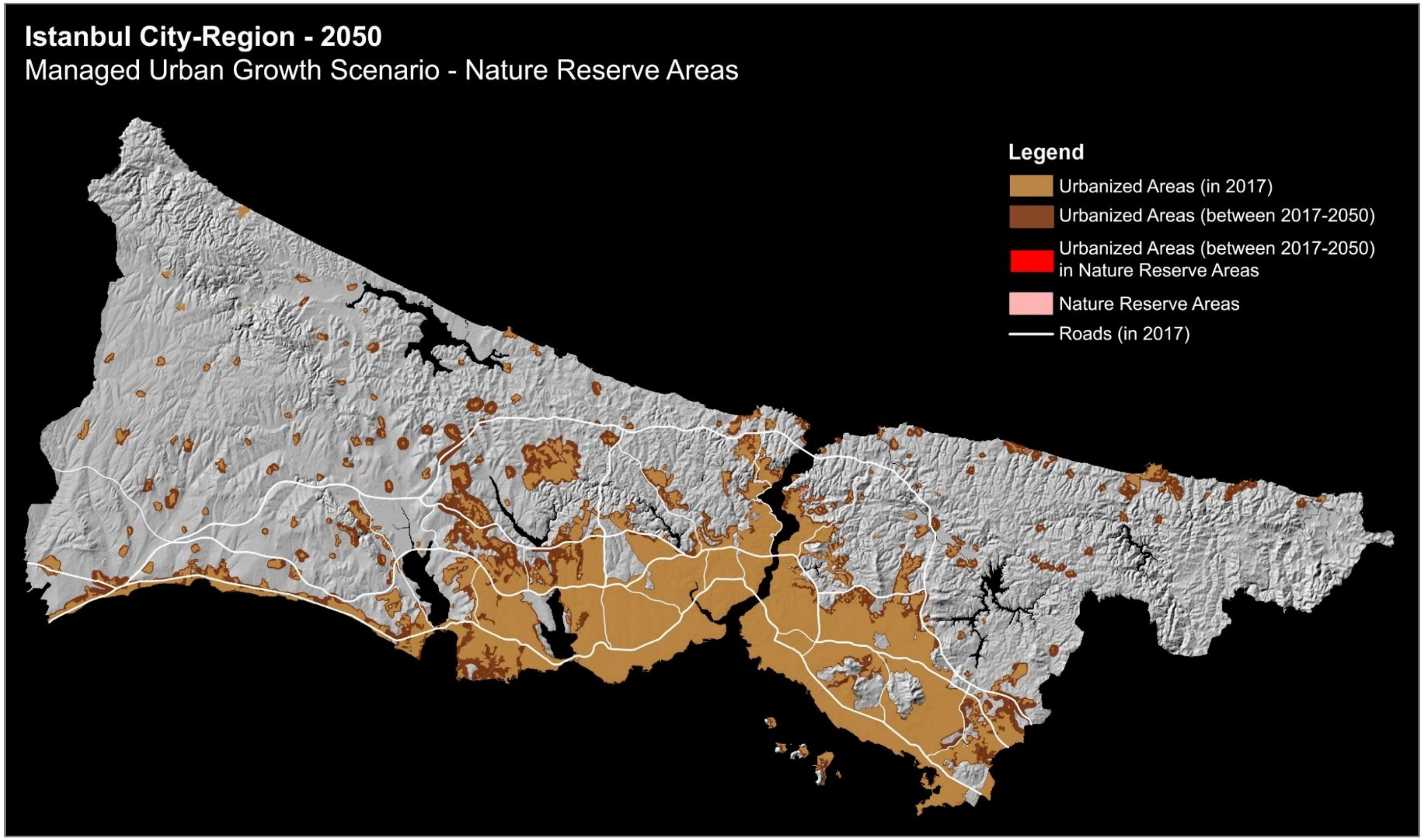

Figure 4.24: Nature Reserve Areas of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

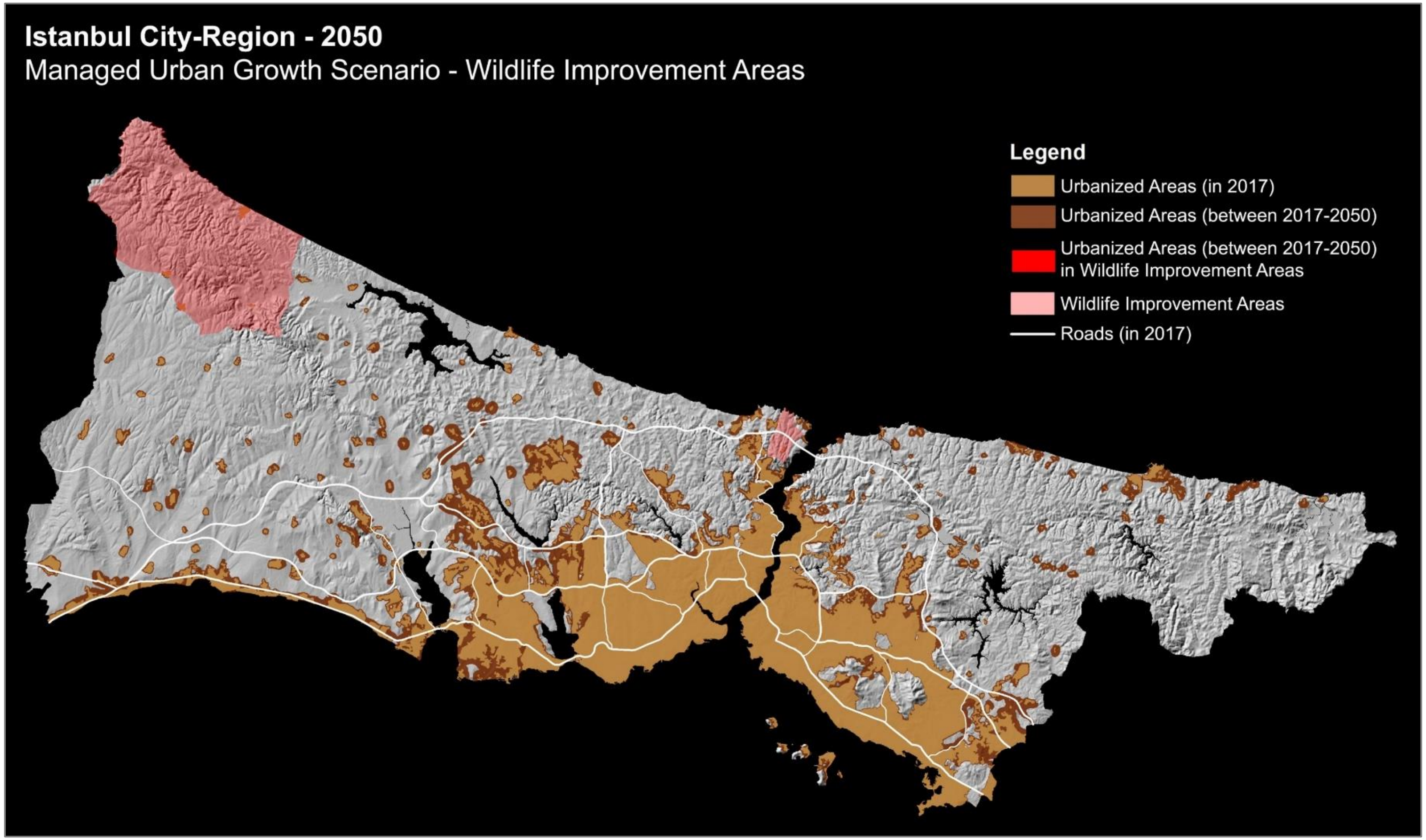

Figure 4.25: Wildlife Improvement Areas of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

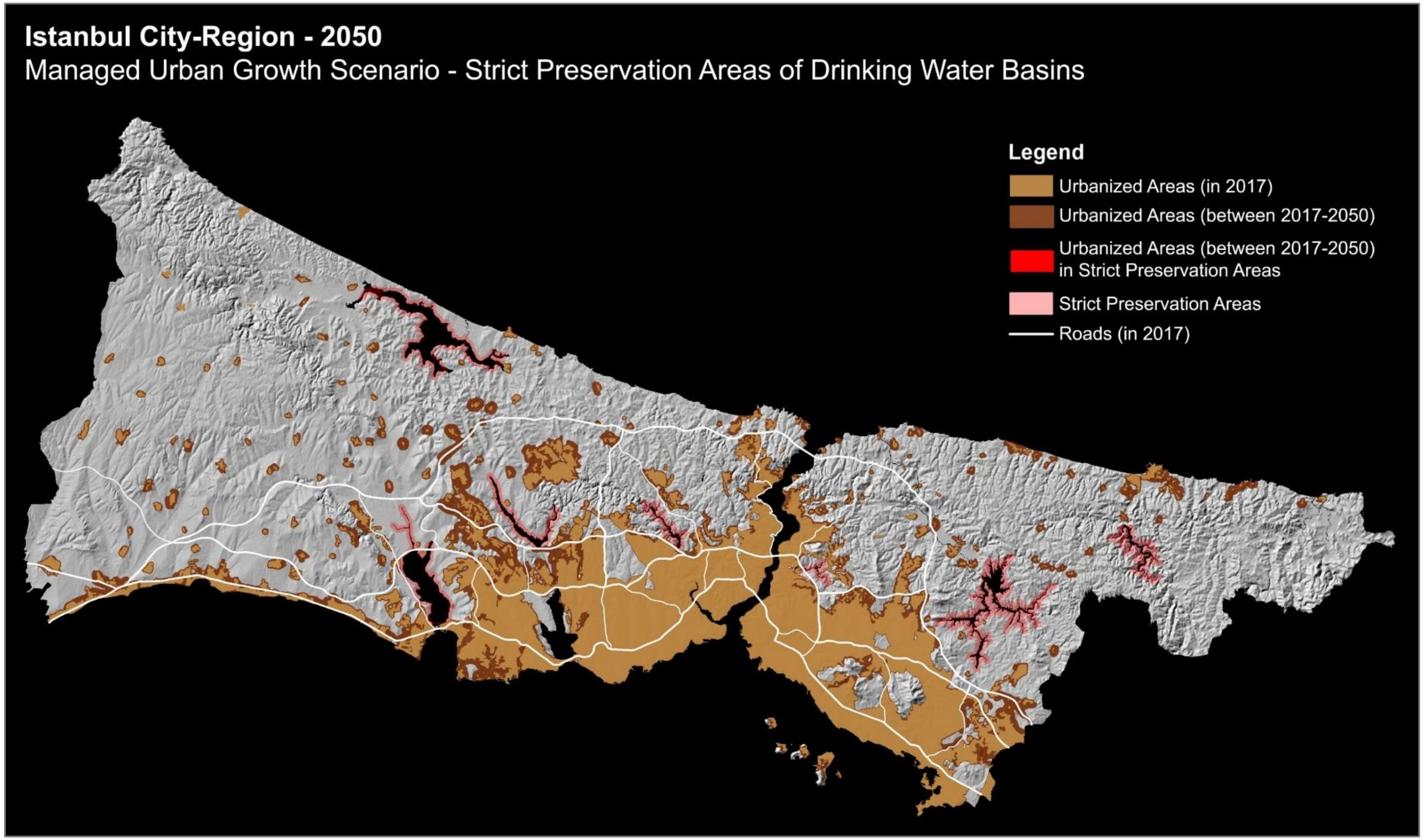

Figure 4.26: Strict Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

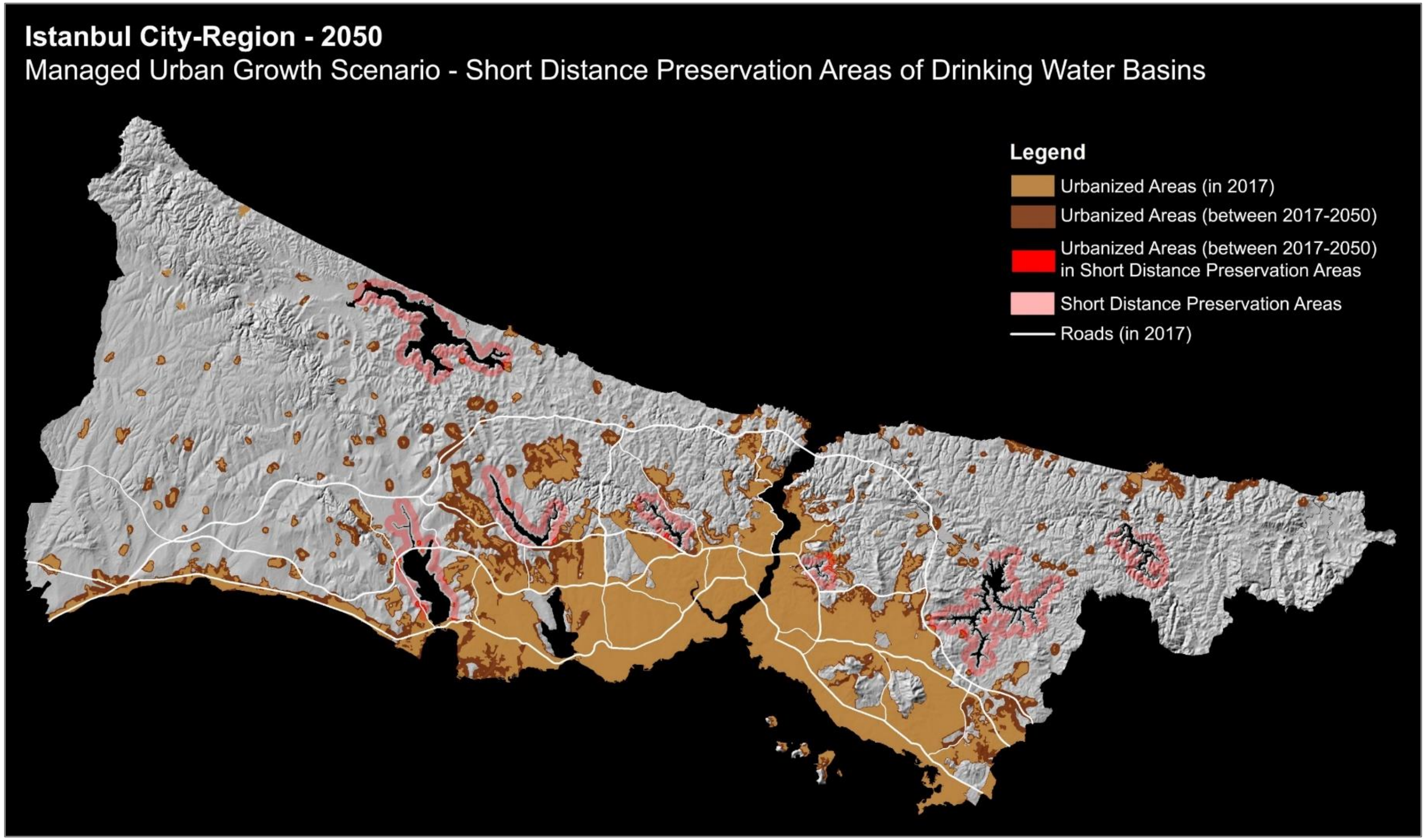

Figure 4.27: Short Distance Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

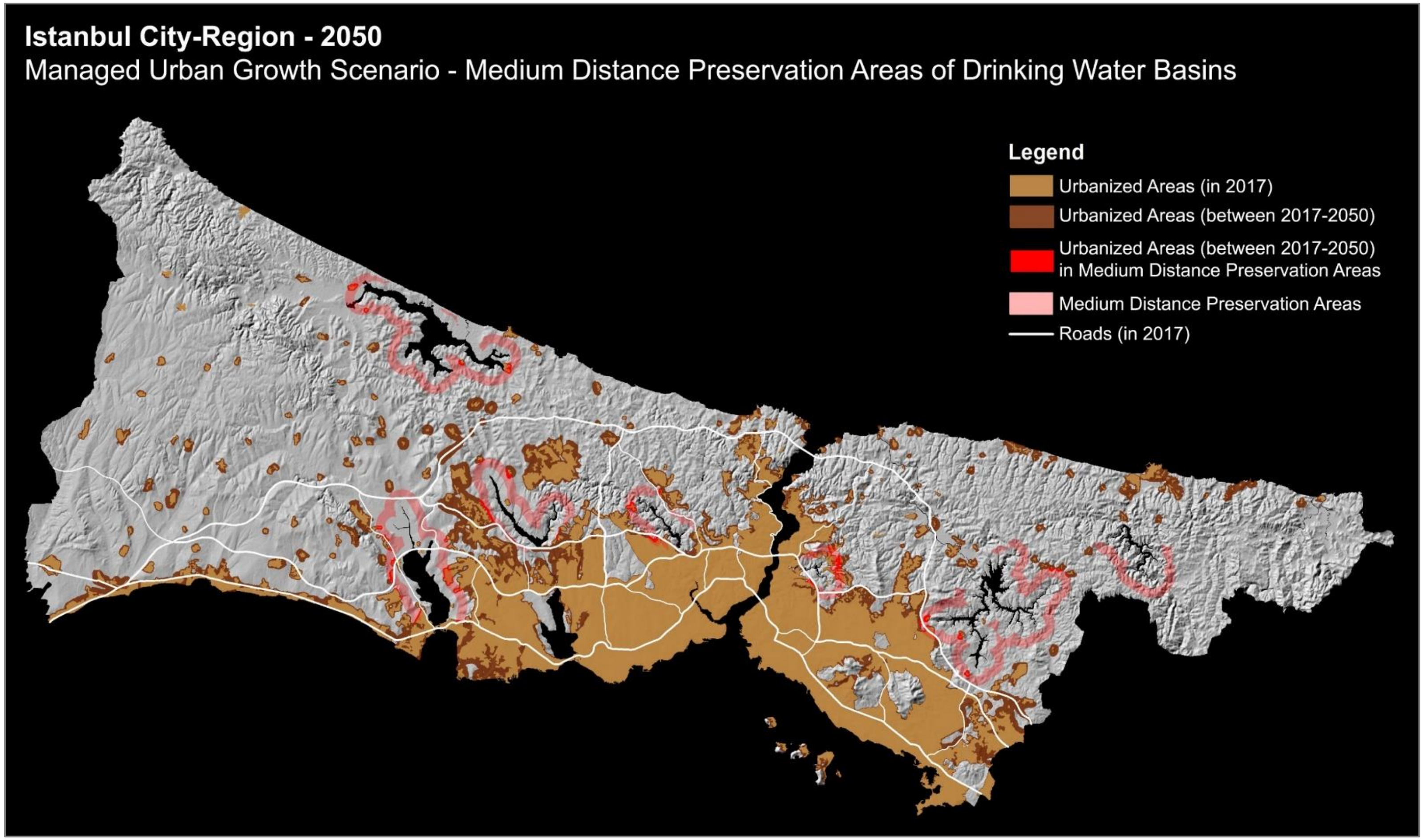

Figure 4.28: Medium Distance Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

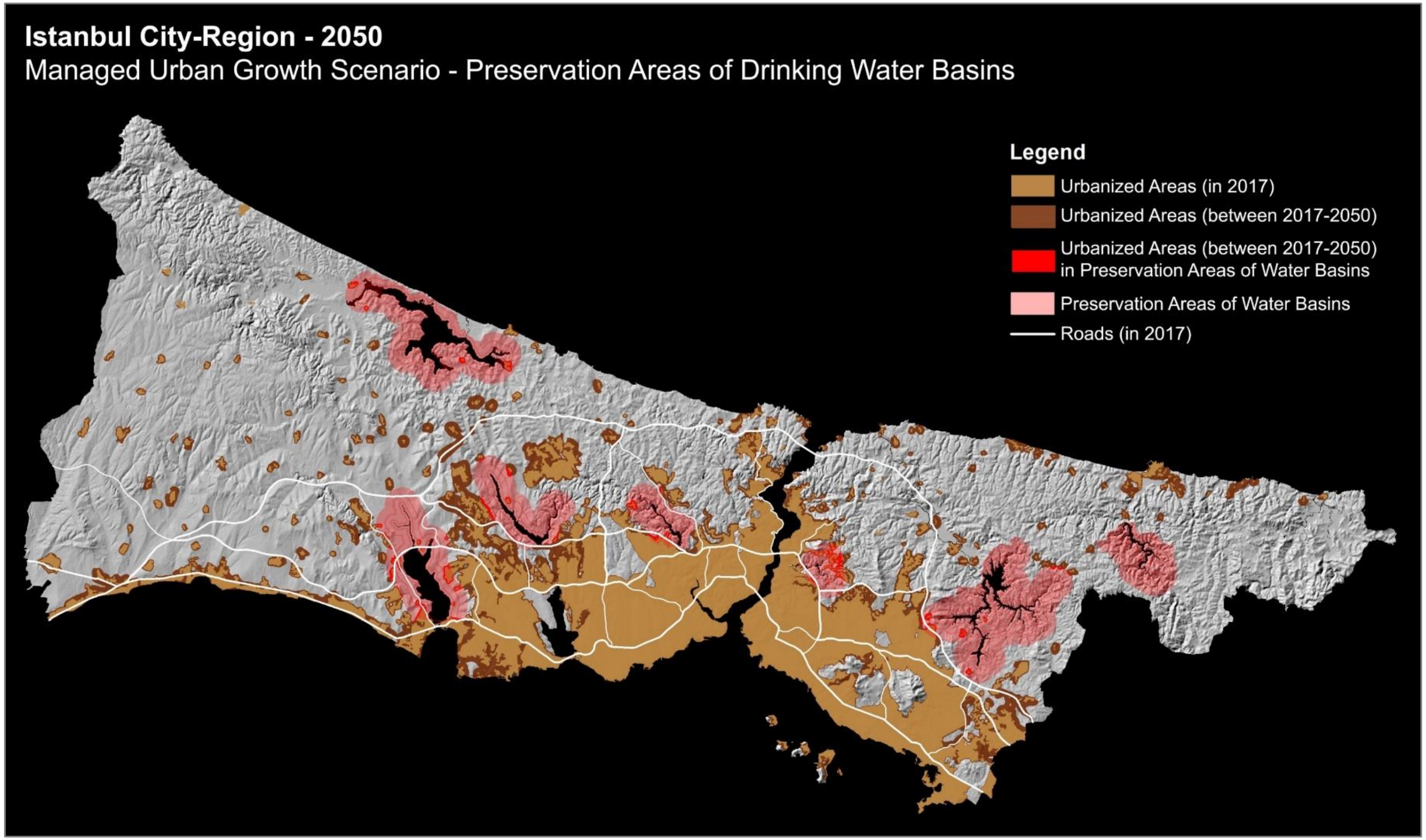

Figure 4.29: Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

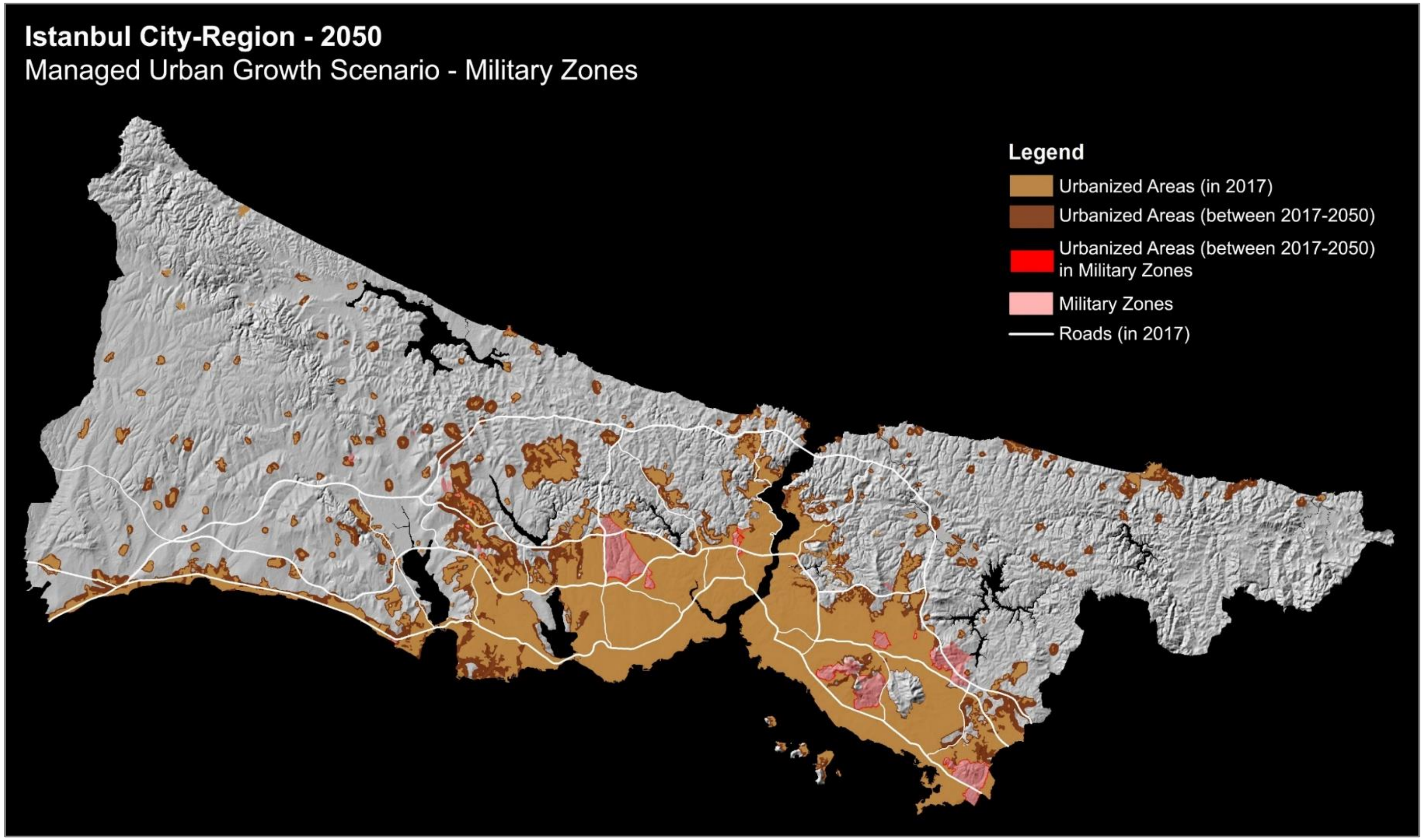

Figure 4.30: Military Zones of Istanbul City-Region in 2050 – Managed Urban Growth Scenario

4.1.3 Prediction Results of Unlimited Urban Growth Scenario

Assuming that none of the conservation areas would be protected in this scenario alternative of Unlimited Urban Growth, the exclusion image of aggressive scenario alternatives (without any exclusion except for the water bodies) was used. With this scenario alternative, it was estimated that the urban areas would increase by 87.25% (85 948 ha) and cover nearly 184 461 ha of the City Region's surface area in 2050 (see Figure 4.31).

Without any protection of the conservation areas, nearly 95% (81 231 ha) of total urban growth took place within the boundaries of conservation areas (see Table 4.3 and Figure 4.32 below). More than half of the urban growth in conservation areas mainly took place within the boundaries of Agricultural Lands (31 154 ha) and Forest Areas (23 859 ha). As a result, nearly 23% and 10% of these areas became urbanized in 2050, respectively (see Figure 4.33 and Figure 4.34). In addition, 6975 ha (25.35%) of 1st Degree Natural Conservation Sites, 4698 ha (55.39%) of Military Zones, 4459 ha (21.11%) of Medium Distance Preservation Areas of Drinking Water Basins, 3252 ha (35.69%) of 3rd Degree Natural Conservation Sites, 2608 ha (13.98%) of Short Distance Preservation Areas of Drinking Water Basins, 1405 ha (3.78%) of Wildlife Improvement Areas, 1115 ha (24.27%) of 2nd Degree Natural Conservation Sites, 850 ha (16.94%) of Nature Parks, 813 ha (7.30%) of Strict Preservation Areas of Drinking Water Basins and 43 ha (97.73%) of Nature Reserve Areas were also urbanized between 2017 and 2050 in this scenario alternative of Unlimited Urban Growth (see Table 4.3 with Figure 4.33 - Figure 4.45).

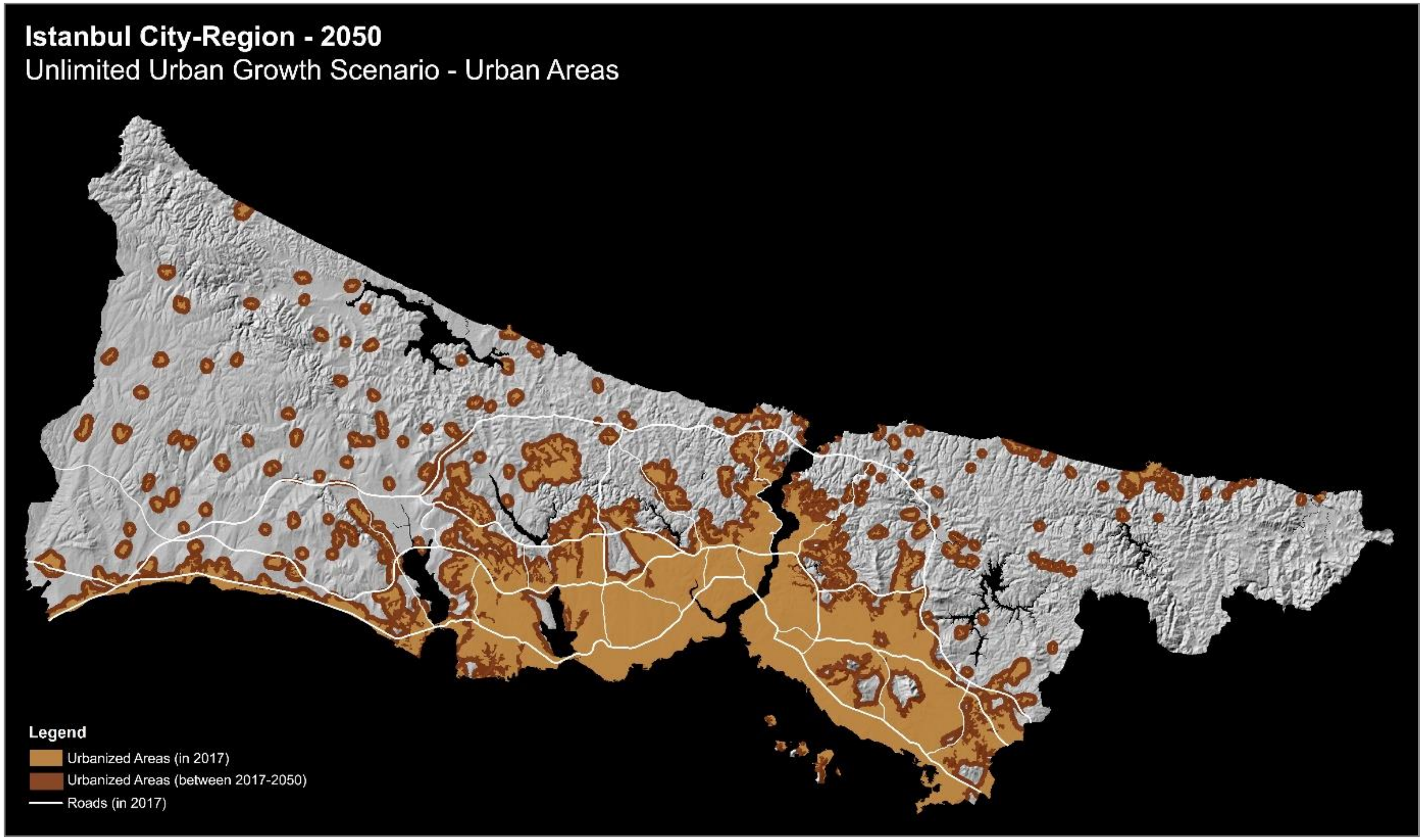

Figure 4.31: Urban Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

Covering 44 ha area in total, Nature Reserve Areas of Istanbul City-Region became totally urbanized in 2050 with this scenario alternative (see Figure 4.39). Also, with 3252 ha of urban growth between 2017 and 2050, nearly 75% (6831 ha) of the total surface area of 3rd Degree Natural Conservation Sites became urbanized in 2050 (see Figure 4.37). In fact, nearly 40% (3579 ha) of the total surface area of 3rd Degree Natural Conservation Sites was already urbanized in 2017 (see Table 4.3). On the other hand, although only 3.42% of the Military Zones were urbanized in 2017, nearly 59% of their total surface area became urbanized in 2050 with an urban growth of 4698 ha in 33 years (see Figure 4.45).

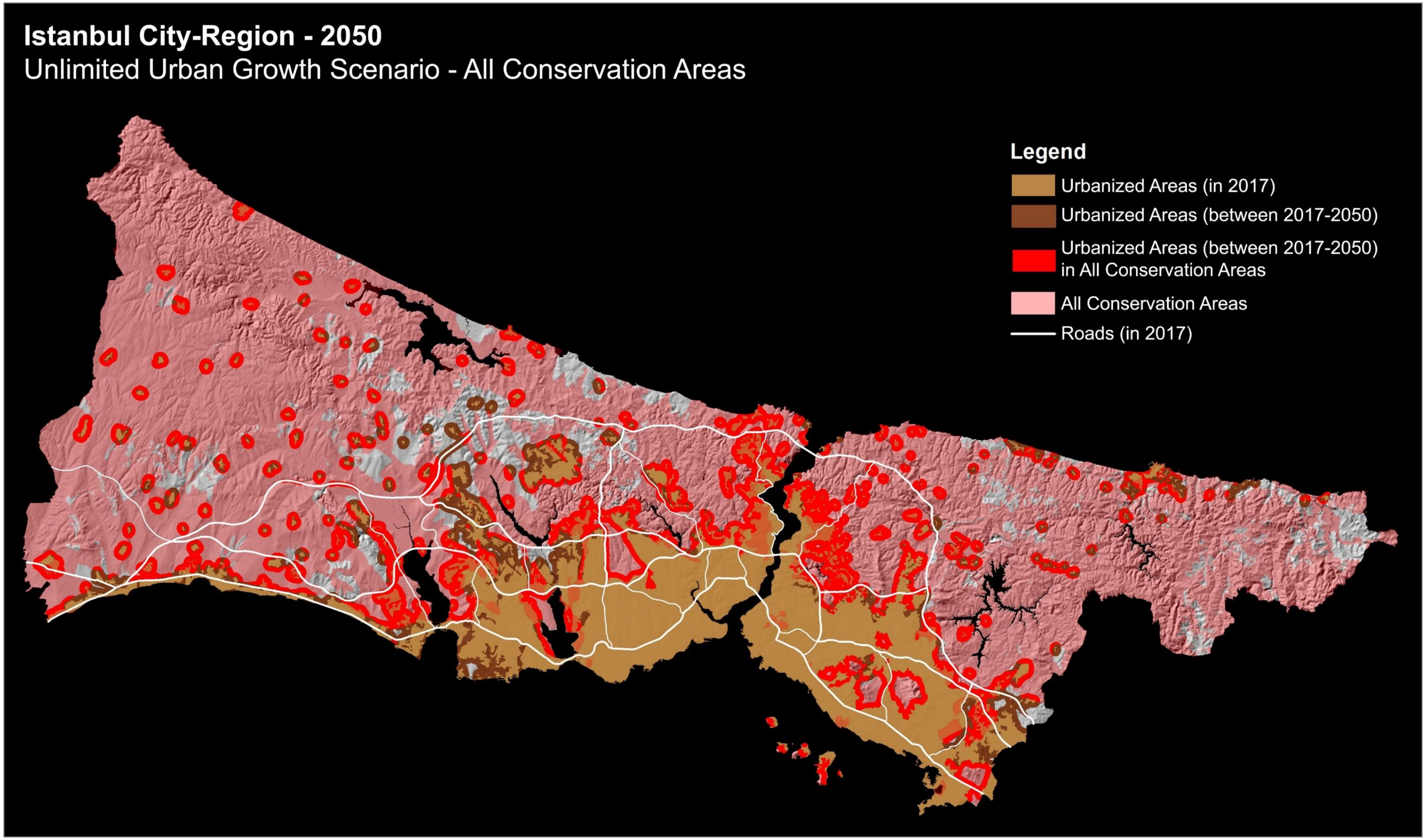

Figure 4.32: All Conservation Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

Table 4.3: Results of Unlimited Urban Growth Scenario

UNLIMITED URBAN GROWTH SCENARIO	**Total Urban Areas**	**Agricultural Lands**	**Forest Areas**	**1st Degree Natural Conservation Sites**	**2nd Degree Natural Conservation Sites**	**3rd Degree Natural Conservation Sites**	**Nature Parks**	**Nature Reserve Areas**	**Wildlife Improvement Areas**	**Strict Preservation Areas of Drinking Water Basins**	**Short Distance Preservation Areas of Drinking Water Basins**	**Medium Distance Preservation Areas of Drinking Water Basins**	**Military Zones**	**TOTAL**
exclusion level (0-100)		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
total area (ha)		173 891	237 481	27 520	4 594	9 113	5 017	44	37 144	11 131	18 656	21 121	8 482	**554 194**
total urban areas in 2017 (ha)	98 513	8 681	0	1 015	664	3 579	69	1	274	77	540	912	290	**16 102**
total urban areas (90-100%) in 2050 (ha)	184 461	39 835	23 859	7 990	1 779	6 831	919	44	1 679	890	3 148	5 371	4 988	**97 333**
urban areas in 2017 (%)		4.99%	0.00%	3.69%	14.45%	39.27%	1.38%	2.27%	0.74%	0.69%	2.89%	4.32%	3.42%	**2.91%**
total urban areas (90-100%) in 2050 (%)		22.91%	10.05%	29.03%	38.72%	74.96%	18.32%	100.00%	4.52%	8.00%	16.87%	25.43%	58.81%	**17.56%**
urbanization between 2017-2050 (ha)	85 948	31 154	23 859	6 975	1 115	3 252	850	43	1 405	813	2 608	4 459	4 698	**81 231**
urbanization between 2017-2050 (%)	87.25%	358.88%	-	687.19%	167.92%	90.86%	1231.88%	4300.00%	512.77%	1055.84%	482.96%	488.93%	1620.00%	**504.48%**
ratio of urbanization between 2017-2050 to total conservation area (%)		**17.92%**	**10.05%**	**25.35%**	**24.27%**	**35.69%**	**16.94%**	**97.73%**	**3.78%**	**7.30%**	**13.98%**	**21.11%**	**55.39%**	**14.66%**

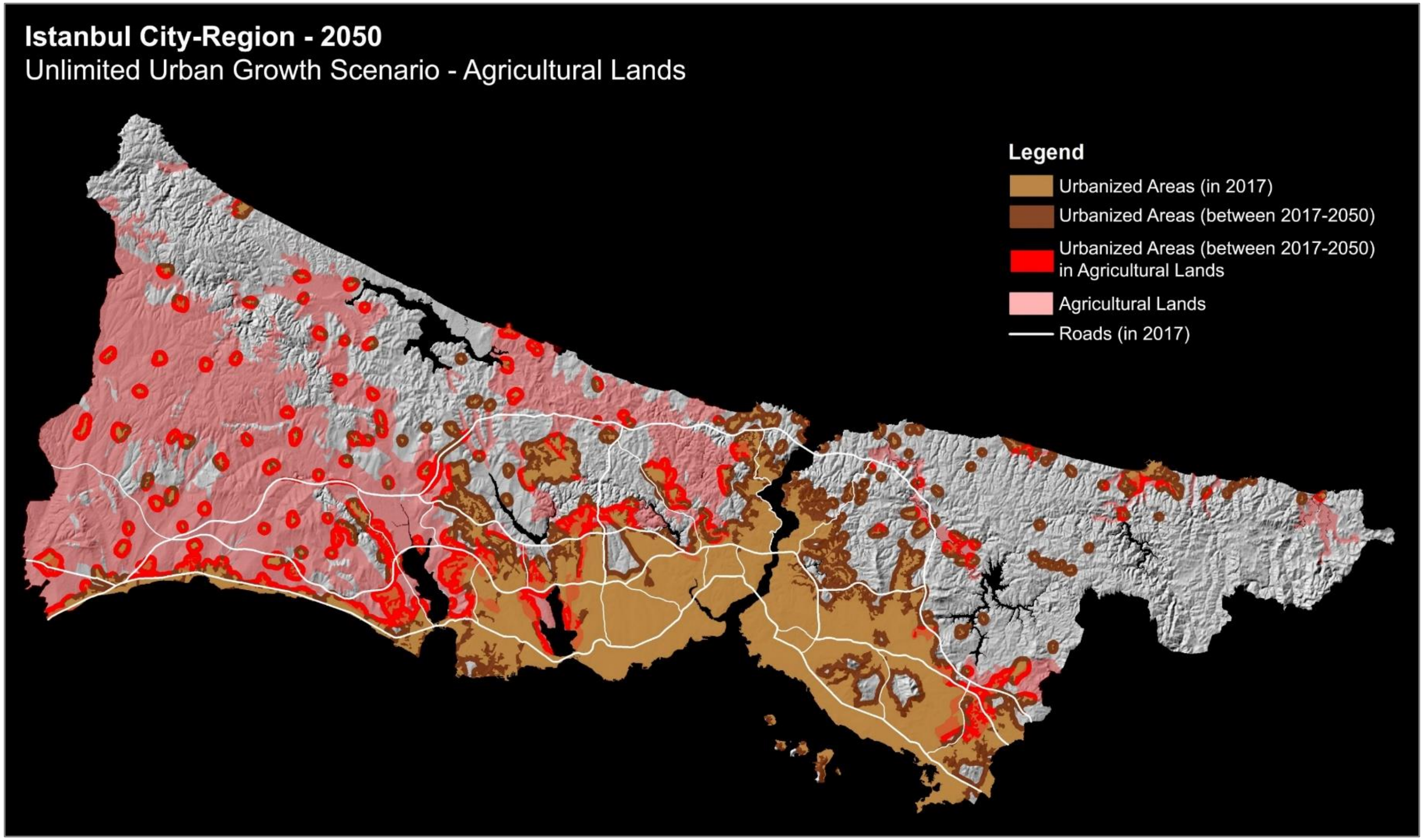

Figure 4.33: Agricultural Lands of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

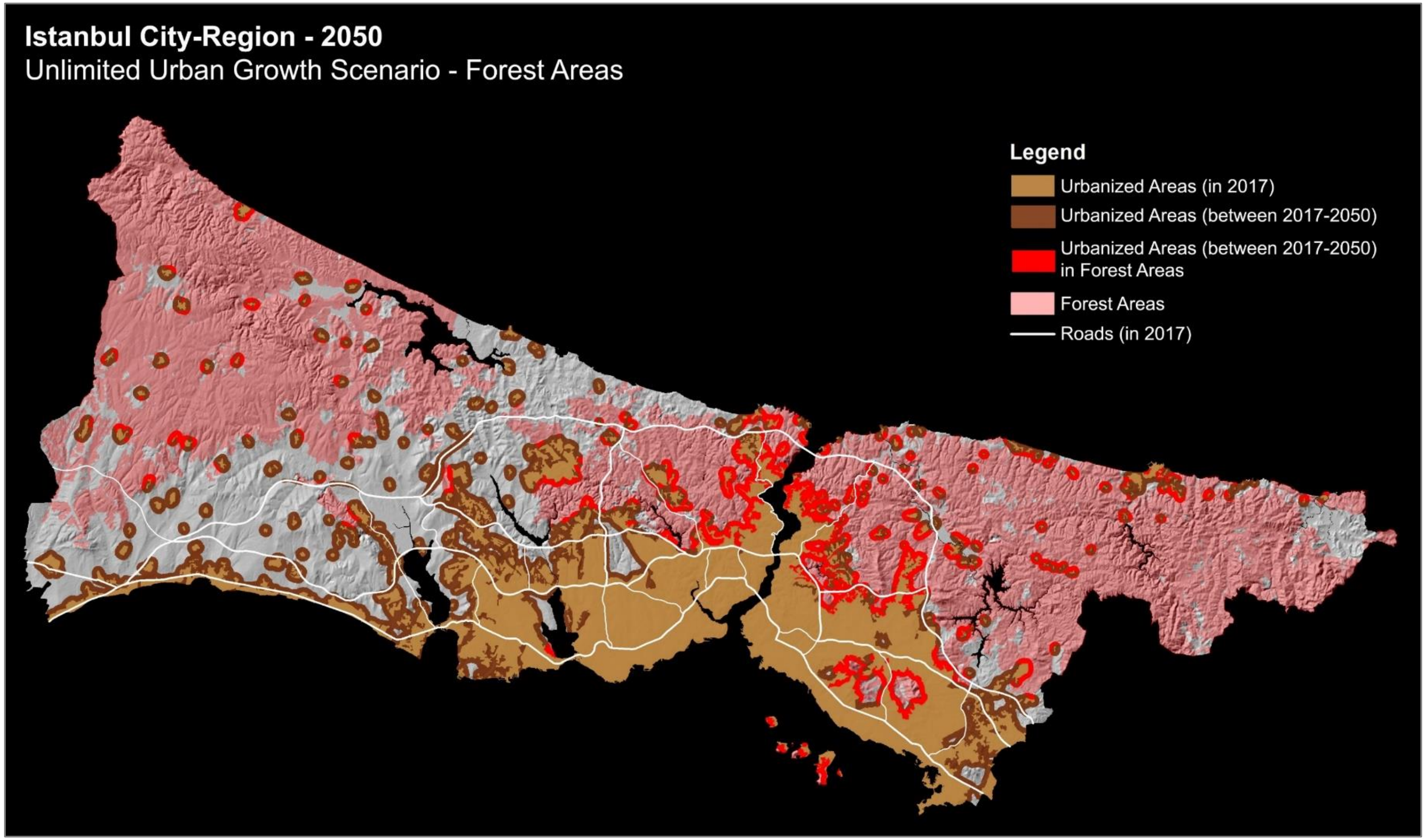

Figure 4.34: Forest Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

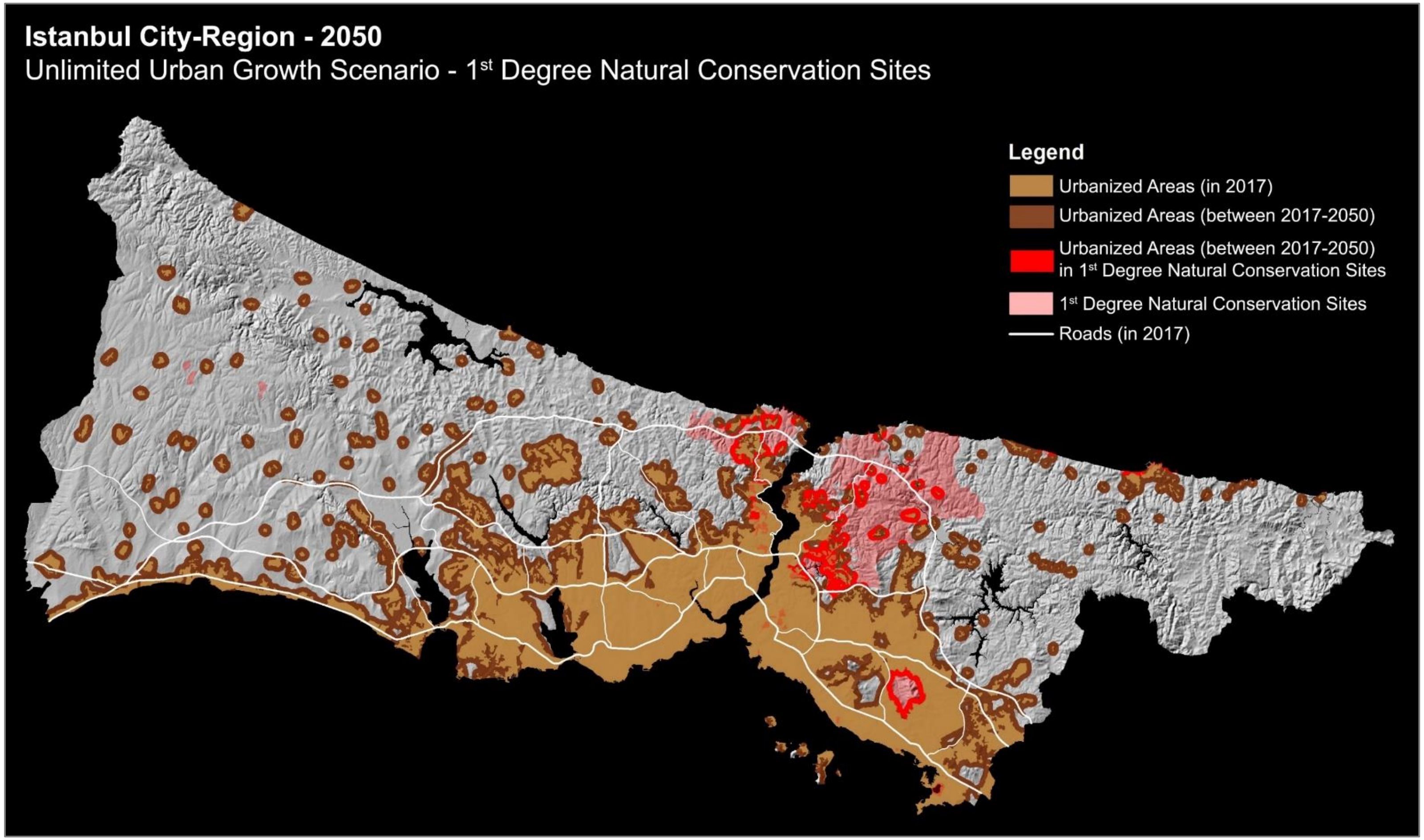

Figure 4.35: 1st Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

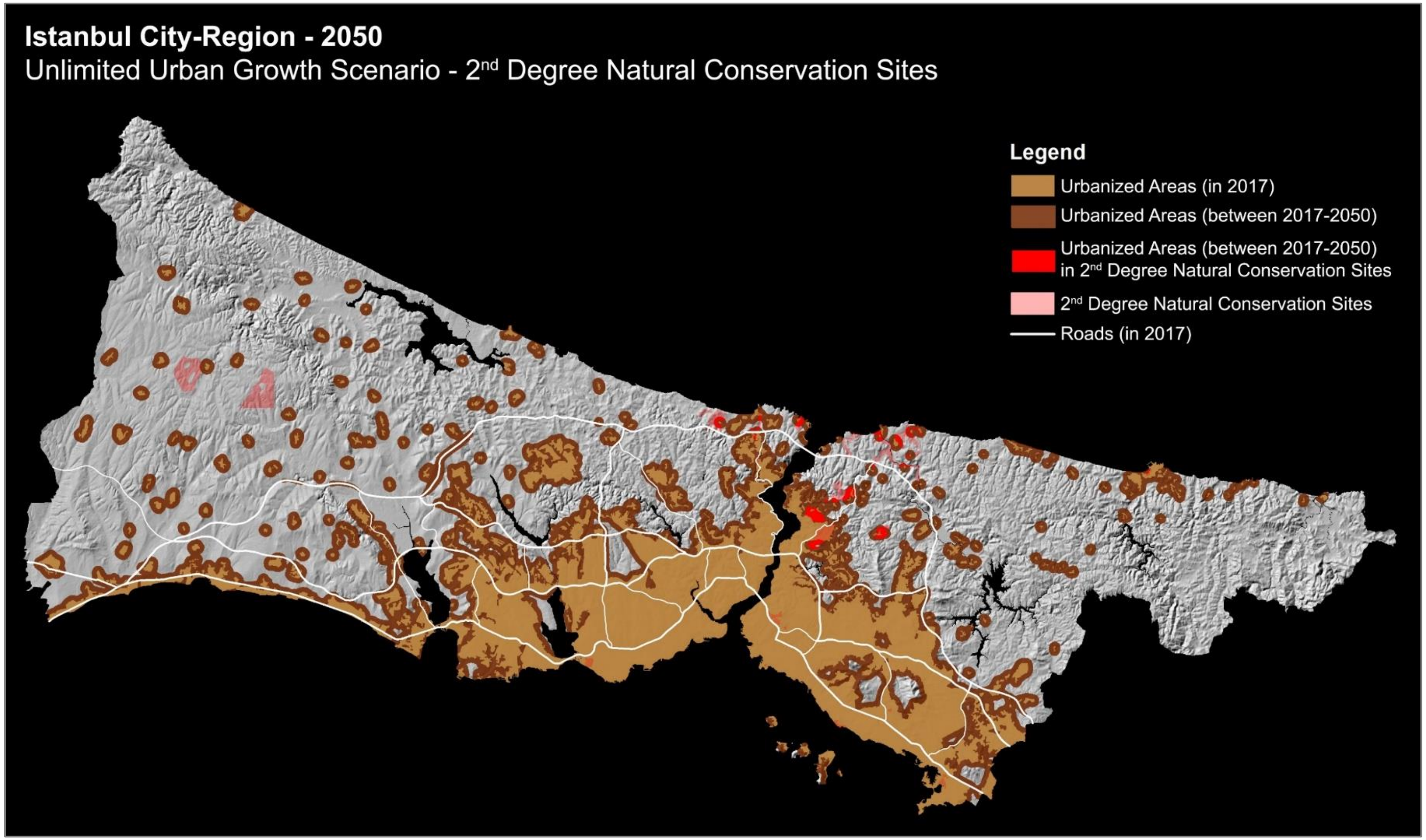

Figure 4.36: 2nd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

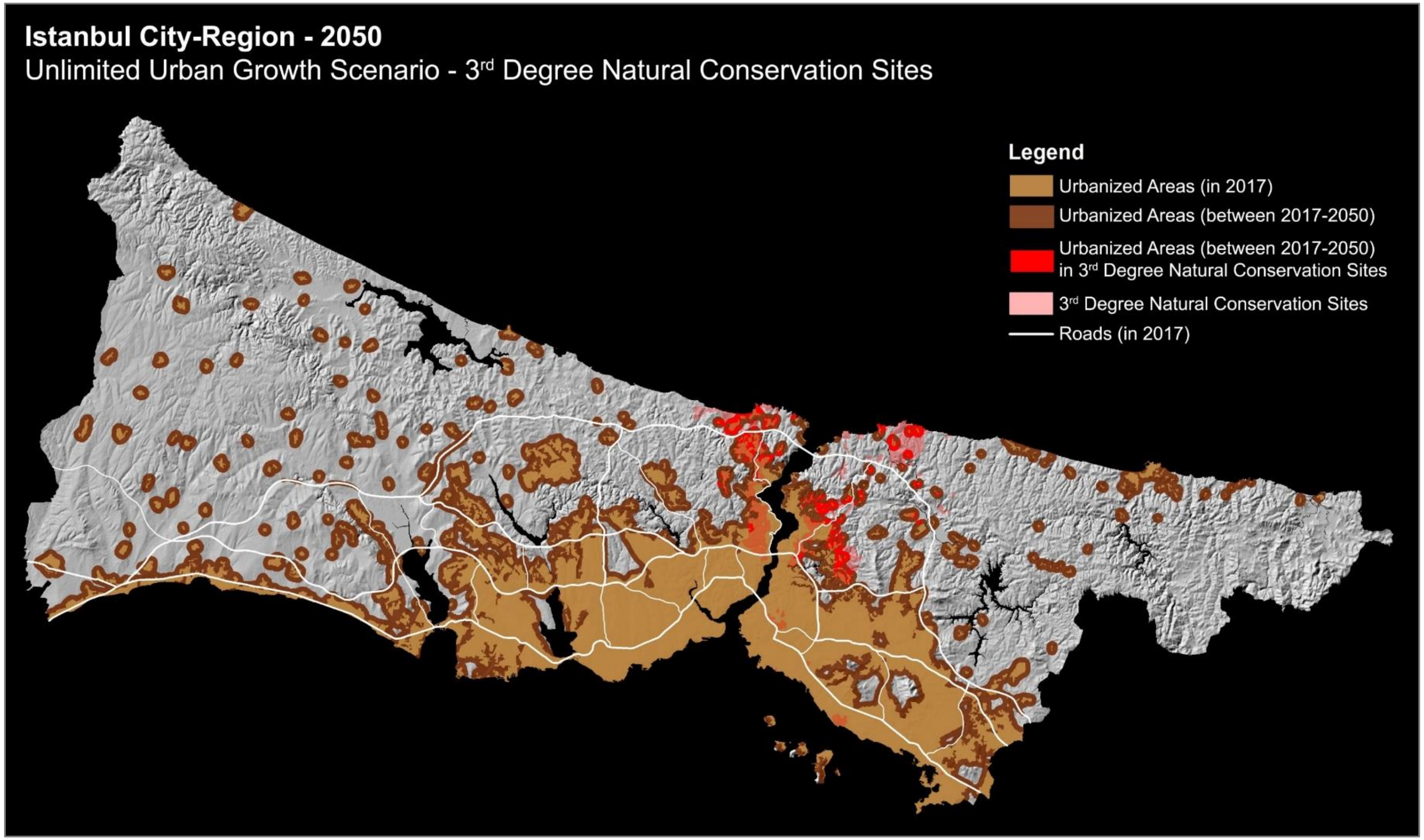

Figure 4.37: 3rd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

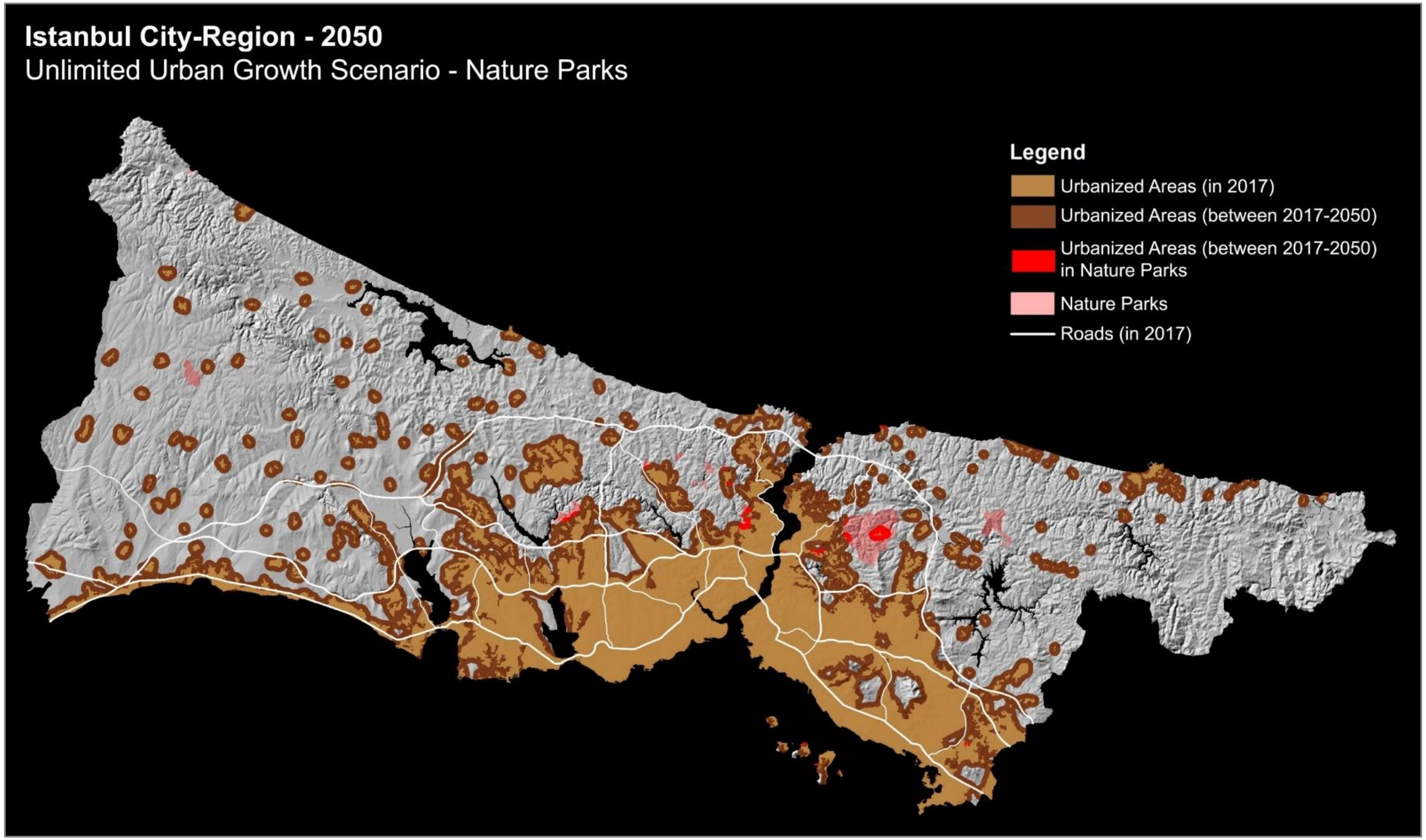

Figure 4.38: Nature Parks of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

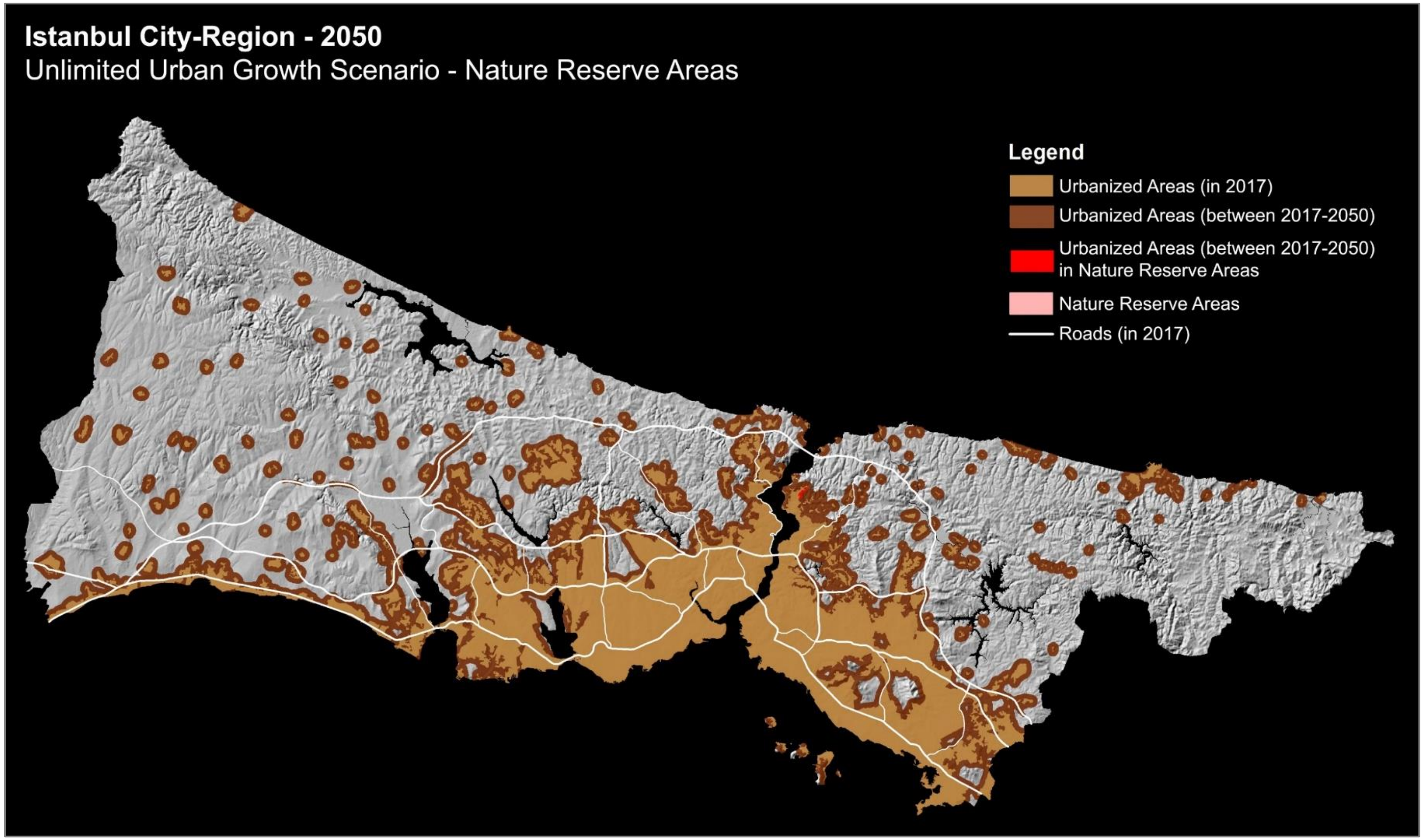

Figure 4.39: Nature Reserve Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

Figure 4.40: Wildlife Improvement Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

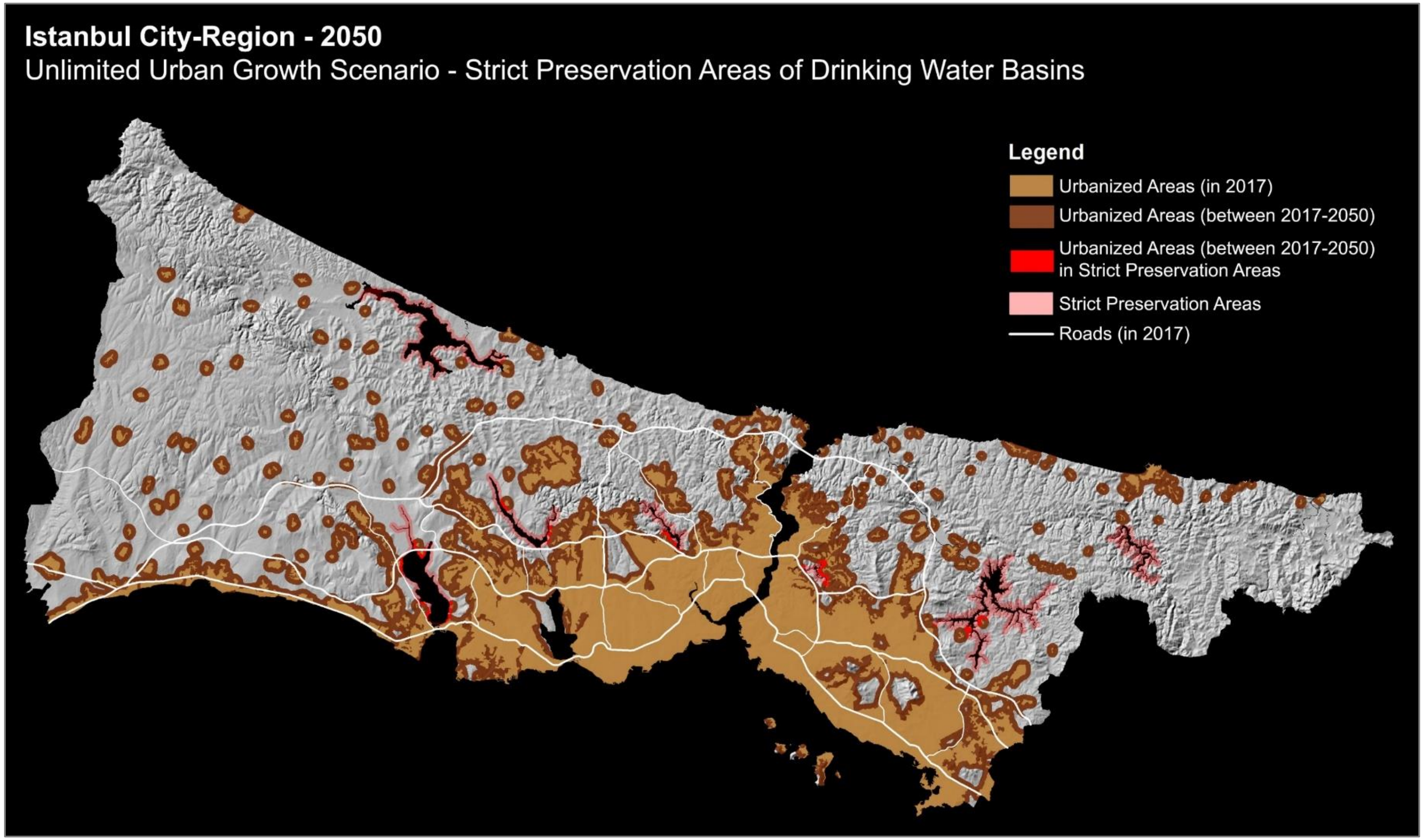

Figure 4.41: Strict Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

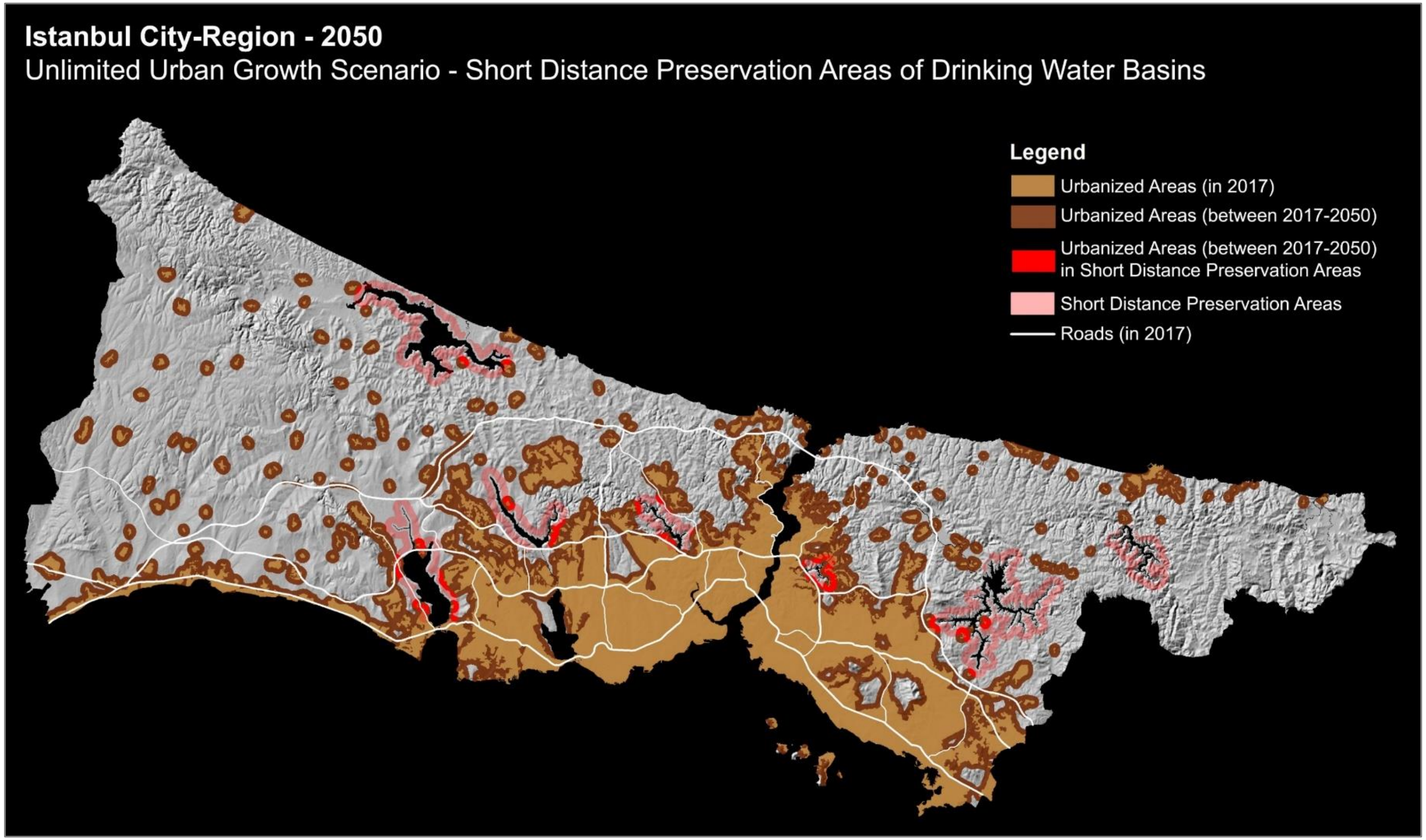

Figure 4.42: Short Distance Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

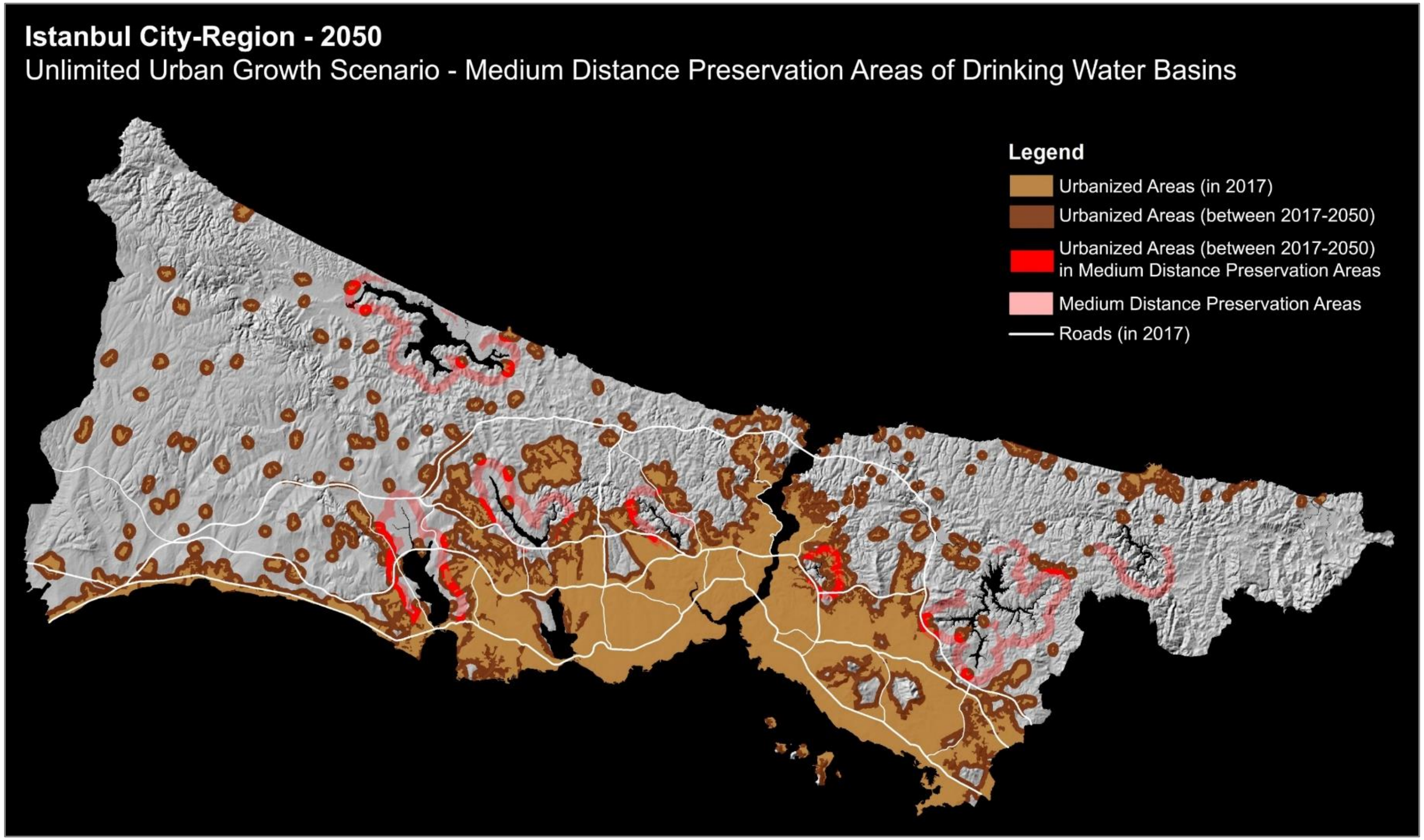

Figure 4.43: Medium Distance Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

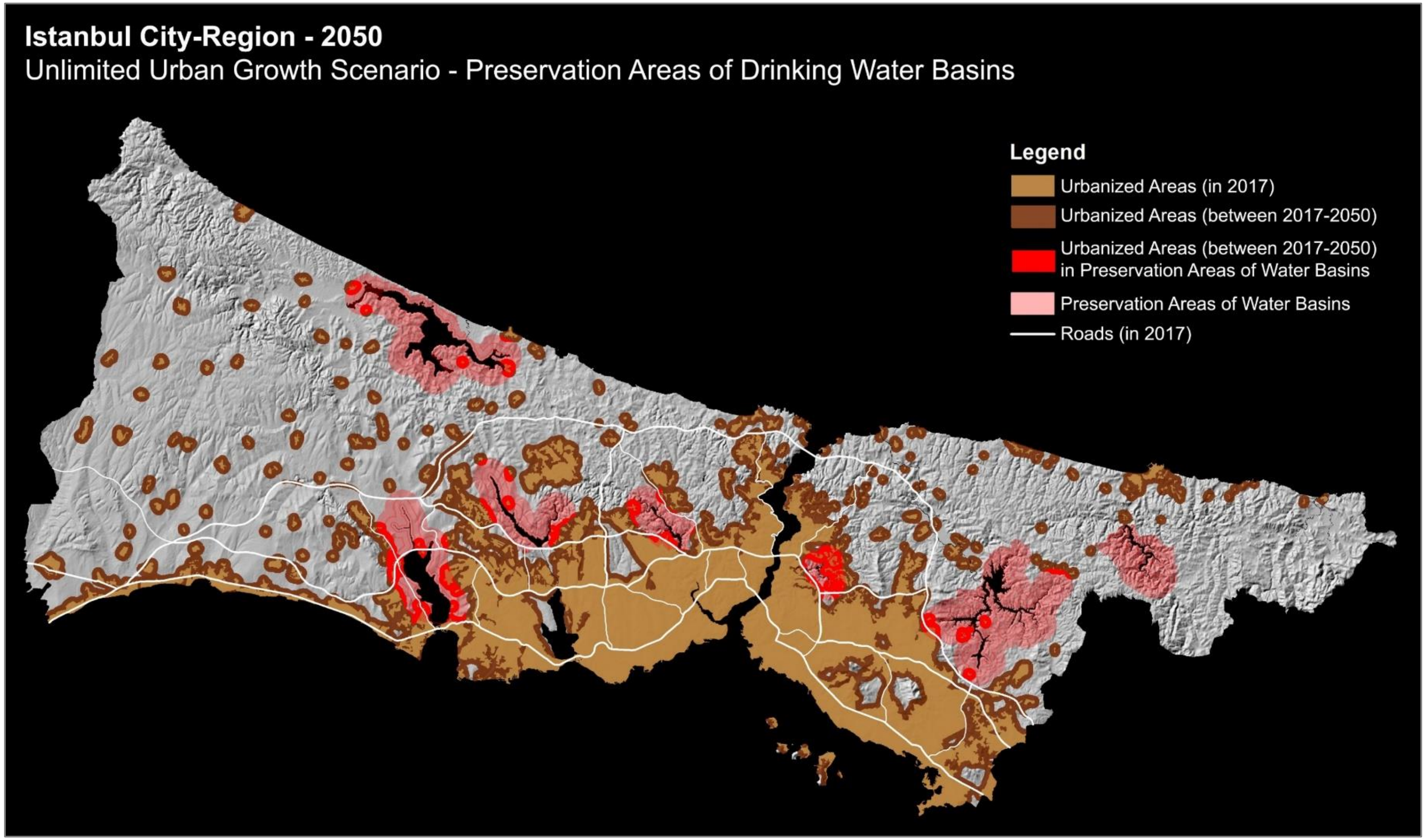

Figure 4.44: Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

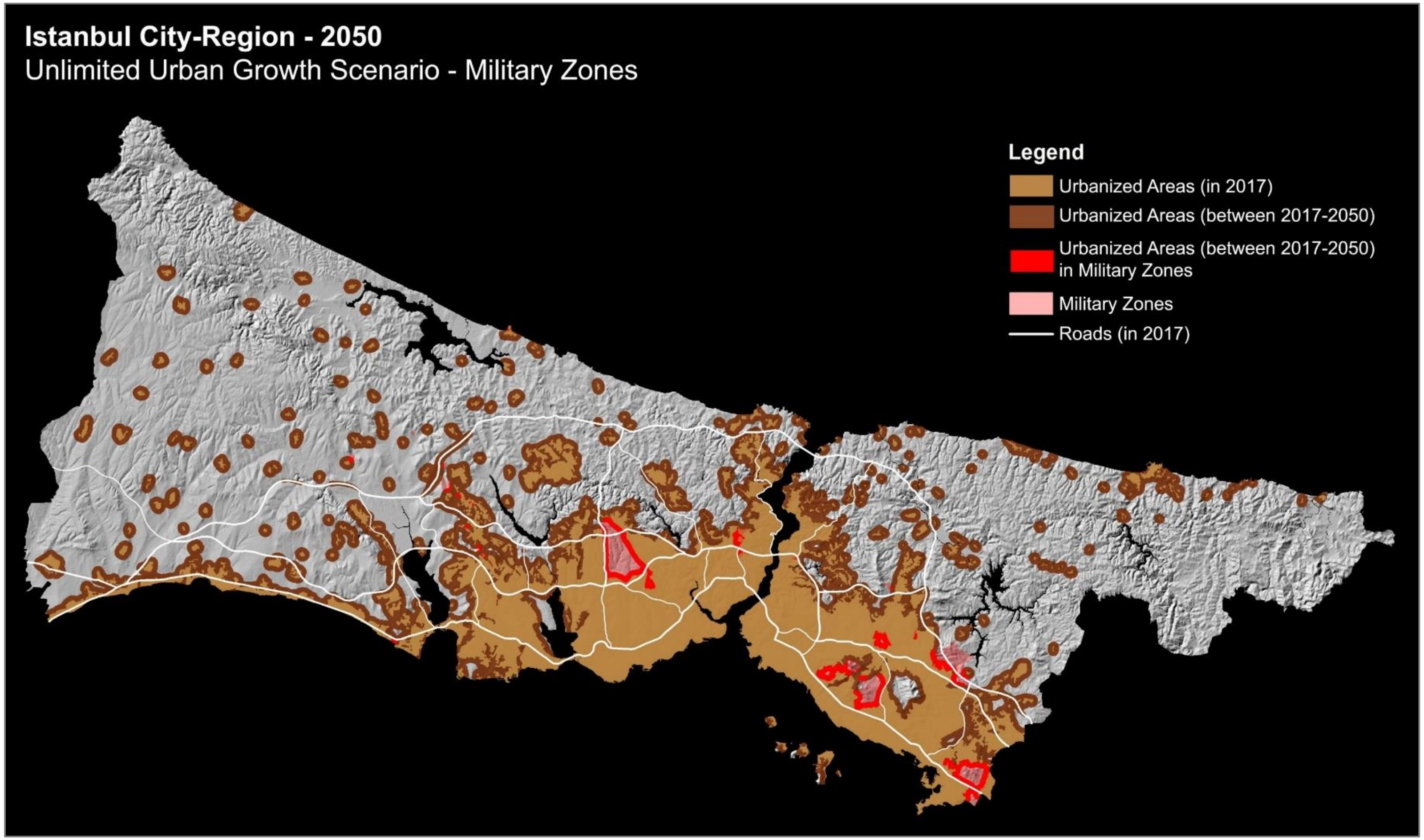

Figure 4.45: Military Zones of Istanbul City-Region in 2050 – Unlimited Urban Growth Scenario

4.1.4 Prediction Results of Unlimited Urban Growth with 3rd Airport Project Scenario

Assuming that none of the conservation areas would be protected, the exclusion image of aggressive scenario alternatives was used in this scenario alternative of Unlimited Urban Growth including the 3rd Airport Project. Different from the first three scenario alternatives, prediction process started from 2018 in this scenario alternative. Urban image of 2018 was produced by adding the expropriation area of 3rd Airport Project to the urban areas of 2017. As a result, the total surface area of the urban areas was covered nearly 106 103 ha of Istanbul City-Region in 2018 (see Table 4.4.). Nearly 92% (6955 ha) of the expropriation area of the 3rd Airport Project takes place within the boundaries of Agricultural Lands (5624 ha) and Forest Areas (1331 ha). Therefore, 8.23% of Agricultural Lands and 0.56% of Forest Areas became urbanized just in 2018. With this scenario alternative, it was estimated that the urban areas would increase by 93.69% (92 297 ha) from 2017 to 2050 and cover nearly 190 810 ha of the City Region's surface area in 2050 (see Figure 4.46).

Without any protection of the conservation areas, nearly 94% (86 219 ha) of total urban growth took place within the boundaries of conservation areas (see Figure 4.47). The urban growth in conservation areas mainly took place within the boundaries of Agricultural Lands (36 791 ha) and Forest Areas (24 130 ha). As a result, nearly 26.15% and 10.16% of these areas became urbanized in 2050, respectively (see Figure 4.48 and Figure 4.49).

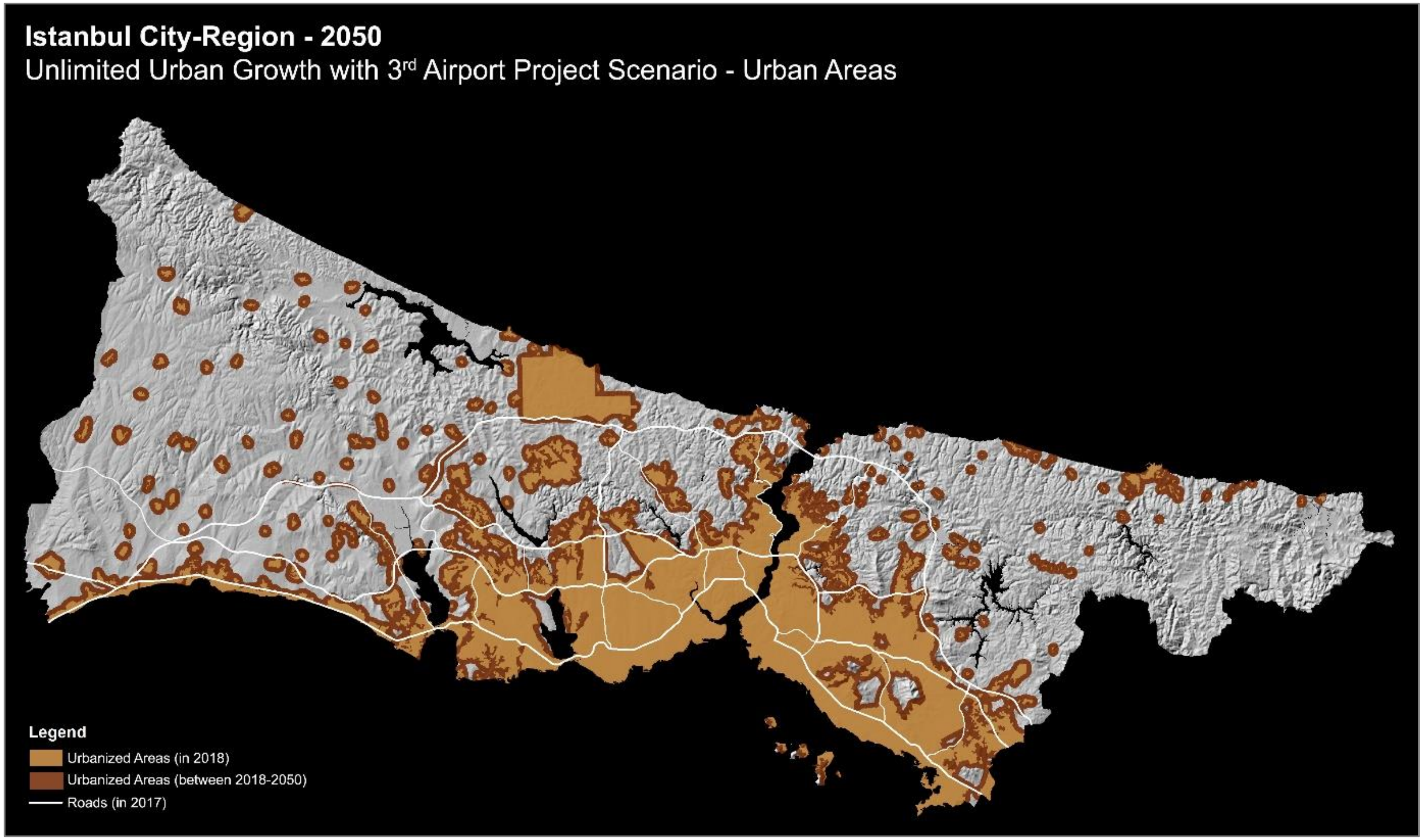

Figure 4.46: Urban Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

In addition, 6701 ha (24.35%) of 1^{st} Degree Natural Conservation Sites, 4546 ha (53.60%) of Military Zones, 4348 ha (20.59%) of Medium Distance Preservation Areas of Drinking Water Basins, 3167 ha (34.75%) of 3^{rd} Degree Natural Conservation Sites, 2497 ha (13.38%) of Short Distance Preservation Areas of Drinking Water Basins, 1325 ha (3.57%) of Wildlife Improvement Areas, 1085 ha (23.62%) of 2^{nd} Degree Natural Conservation Sites, 808 ha (16.11%) of Nature Parks, 778 ha (6.99%) of Strict Preservation Areas of Drinking Water Basins and 43 ha (97.73%) of Nature Reserve Areas were also urbanized between 2017 and 2050 in this scenario alternative of Unlimited Urban Growth with 3^{rd} Airport Project (see Table 4.4 with Figure 4.50 - Figure 4.60).

Similar to the previous scenario alternative, with 43 ha of urban growth in 33 years Nature Reserve Areas of Istanbul City-Region became totally urbanized in 2050 with this scenario alternative (see Figure 4.54). Also, with 3167 ha of urban growth between 2017 and 2050, nearly 74% (6746 ha) of the total surface area of 3^{rd} Degree Natural Conservation Sites became urbanized in 2050 (see Figure 4.52). In fact, nearly 40% (3579 ha) of the total surface area of 3^{rd} Degree Natural Conservation Sites was already urbanized in 2017 (see Table 4.4). On the other hand, although only 3.42% of the Military Zones were urbanized in 2017, nearly 57% of their total surface area became urbanized in 2050 with an urban growth of 4546 ha in 33 years (see Figure 4.60).

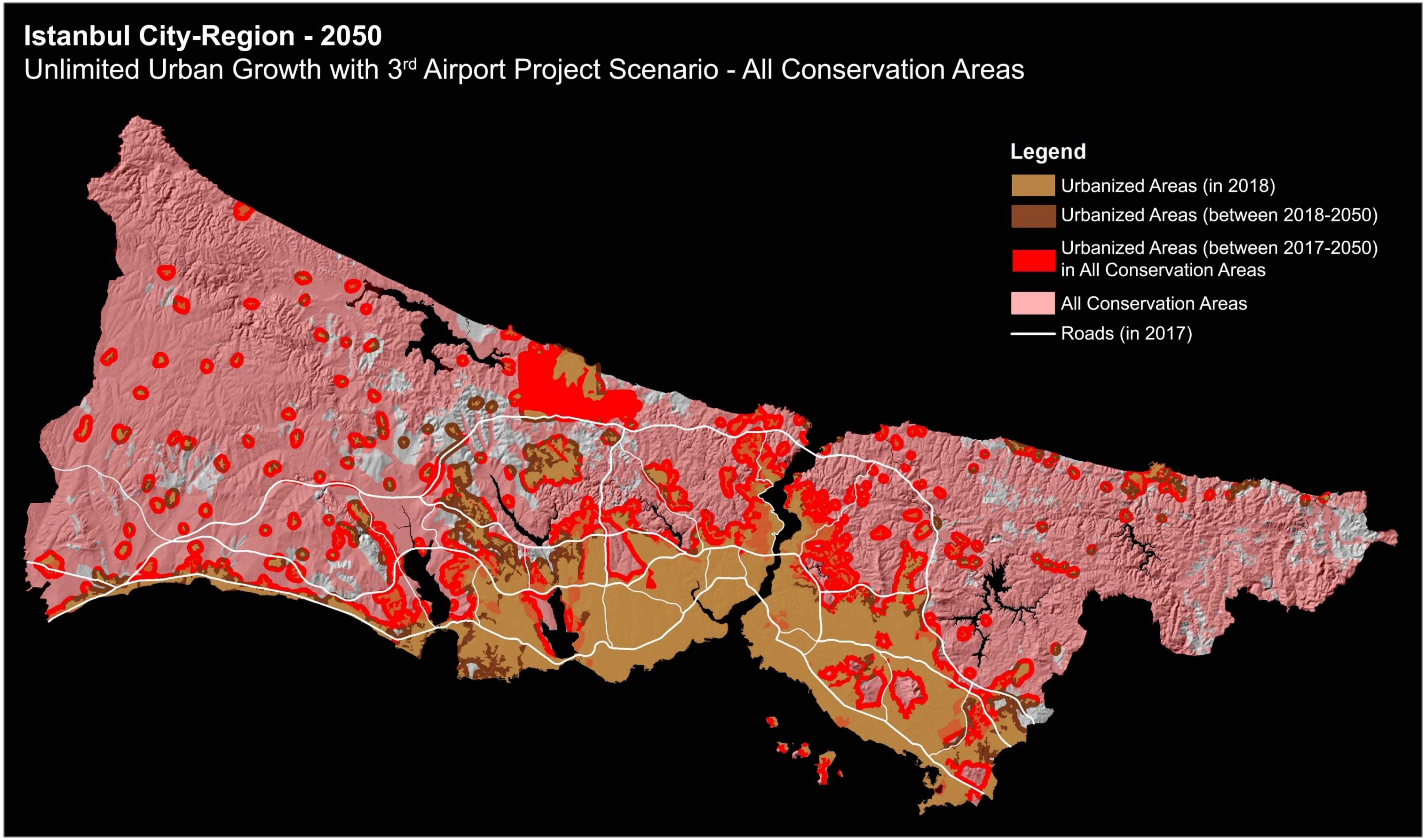

Figure 4.47: All Conservation Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

Table 4.4: Results of Unlimited Urban Growth with the 3rd Airport Project Scenario

UNLIMITED URBAN GROWTH WITH 3rd AIRPORT PROJECT	**Total Urban Areas**	**Agricultural Lands**	**Forest Areas**	**1st Degree Natural Conservation Sites**	**2nd Degree Natural Conservation Sites**	**3rd Degree Natural Conservation Sites**	**Nature Parks**	**Nature Reserve Areas**	**Wildlife Improvement Areas**	**Strict Preservation Areas of Drinking Water Basins**	**Short Distance Preservation Areas of Drinking Water Basins**	**Medium Distance Preservation Areas of Drinking Water Basins**	**Military Zones**	**TOTAL**
exclusion level (0-100)		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
total area (ha)		173.891	237.481	27.520	4.594	9.113	5.017	44	37.144	11.131	18.656	21.121	8.482	**554.194**
total urban areas in 2017 (without 3rd Airport Project) (ha)	98.513	8.681	0	1.015	664	3.579	69	1	274	77	540	912	290	**16.102**
total urban areas in 2018 (with 3rd Airport Project) (ha)	106.103	14.305	1.331	1.015	664	3.579	69	1	274	77	540	912	290	**23.057**
total urban areas (90-100%) in 2050 (ha)	190.810	45.472	24.130	7.716	1.749	6.746	877	44	1.599	855	3.037	5.260	4.836	**102.321**
urban areas in 2018 (with 3rd Airport Project) (%)		8,23%	0,56%	3,69%	14,45%	39,27%	1,38%	2,27%	0,74%	0,69%	2,89%	4,32%	3,42%	**4,16%**
total urban areas (90-100%) in 2050 (%)		26,15%	10,16%	28,04%	38,07%	74,03%	17,48%	100,00%	4,30%	7,68%	16,28%	24,90%	57,01%	**18,46%**
urbanization between 2017-2050 (ha)	92.297	36.791	24.130	6.701	1.085	3.167	808	43	1.325	778	2.497	4.348	4.546	**86.219**
urbanization between 2017-2050 (%)	93,69%	257,19%	1812,92%	660,20%	163,40%	88,49%	1171,01%	4300,00%	483,58%	1010,39%	462,41%	476,75%	1567,59%	**535,46%**
urbanization between 2018-2050 (ha)	84.707	31.167	22.799	6.701	1.085	3.167	808	43	1.325	778	2.497	4.348	4.546	**79.264**
urbanization between 2018-2050 (%)	79,83%	217,87%	1712,92%	660,20%	163,40%	88,49%	1171,01%	4300,00%	483,58%	1010,39%	462,41%	476,75%	1567,59%	**343,77%**
ratio of urbanization between 2017-2050 to total conservation area (%)		**17,92%**	**9,60%**	**24,35%**	**23,62%**	**34,75%**	**16,11%**	**97,73%**	**3,57%**	**6,99%**	**13,38%**	**20,59%**	**53,60%**	**14,30%**

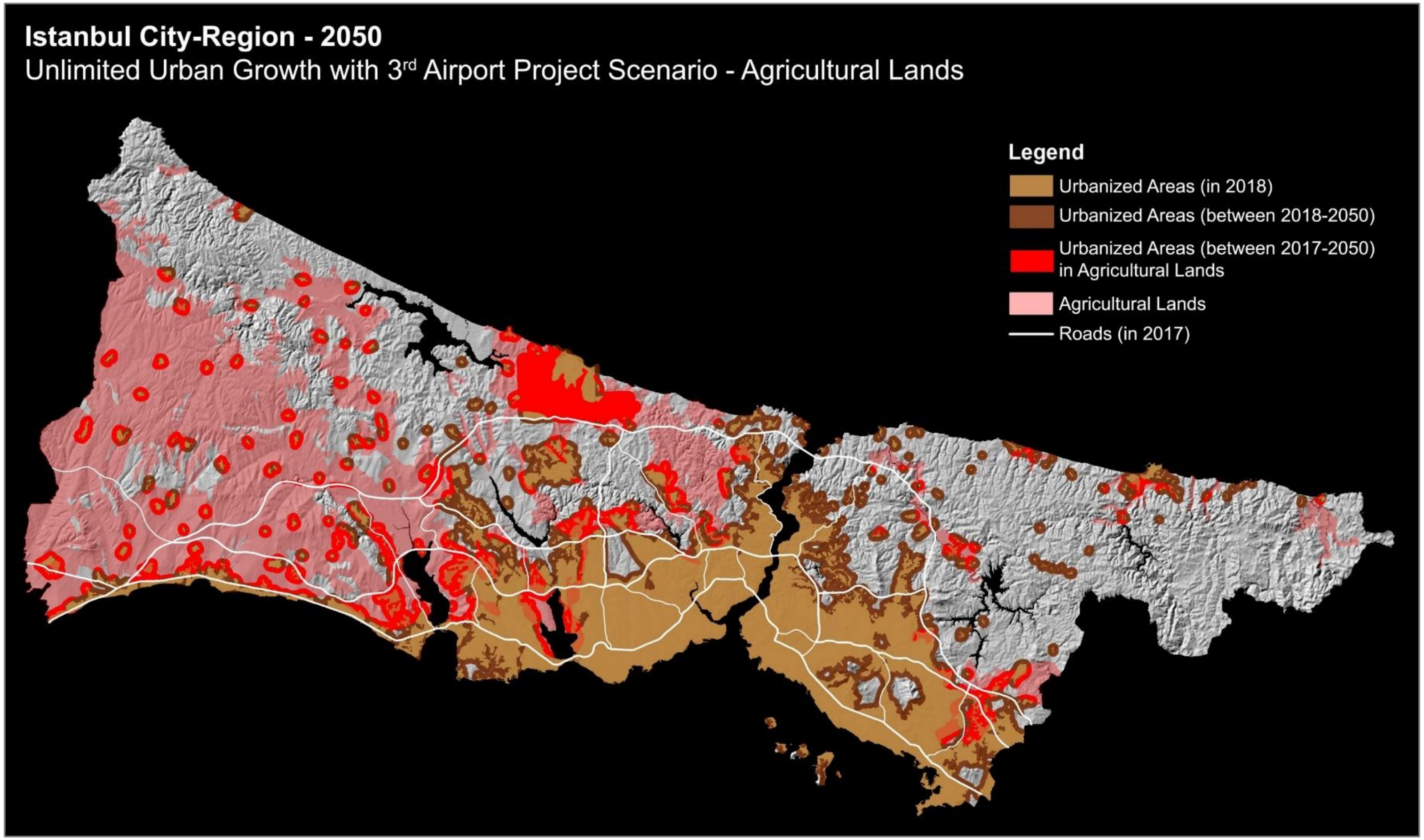

Figure 4.48: Agricultural Lands of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

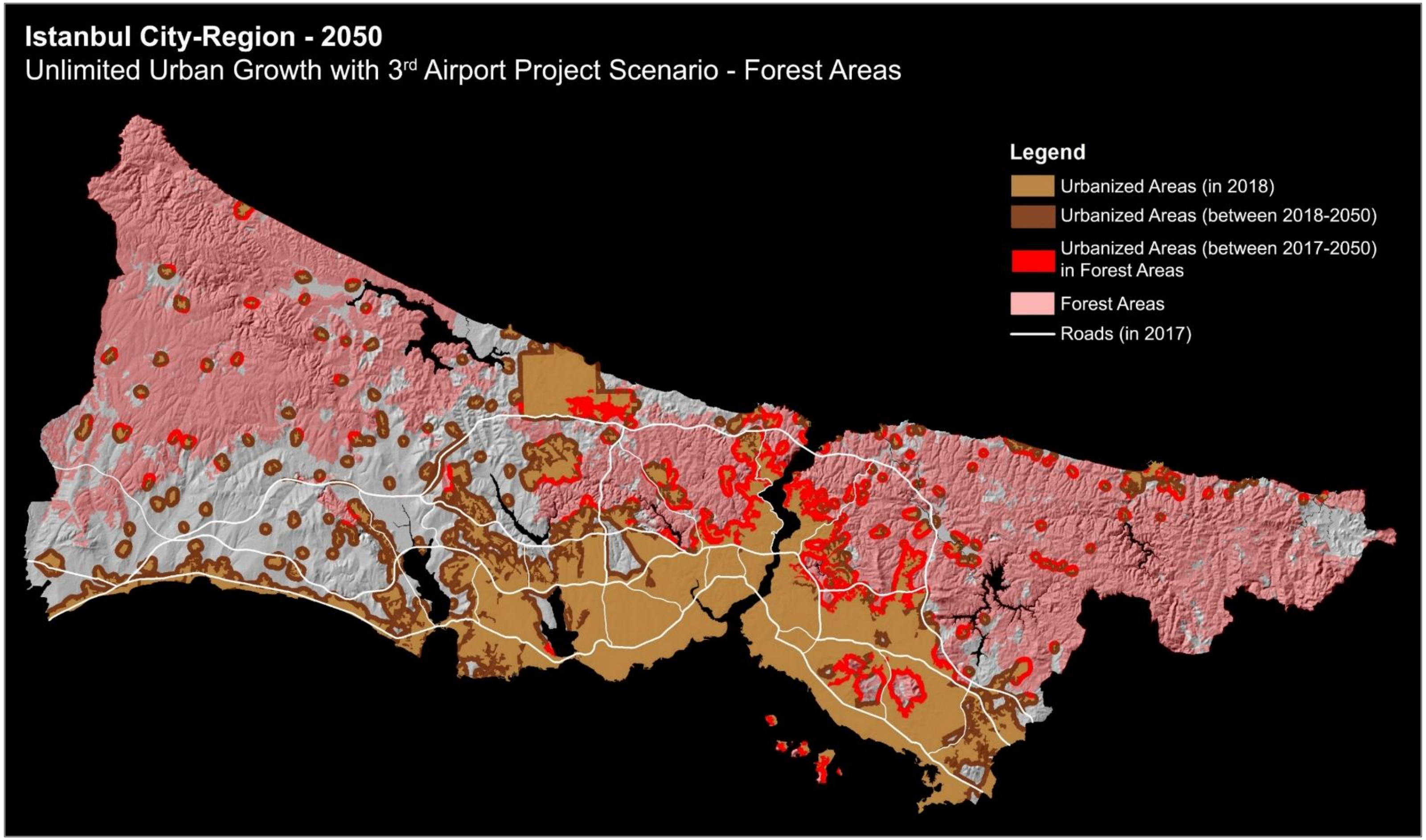

Figure 4.49: Forest Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

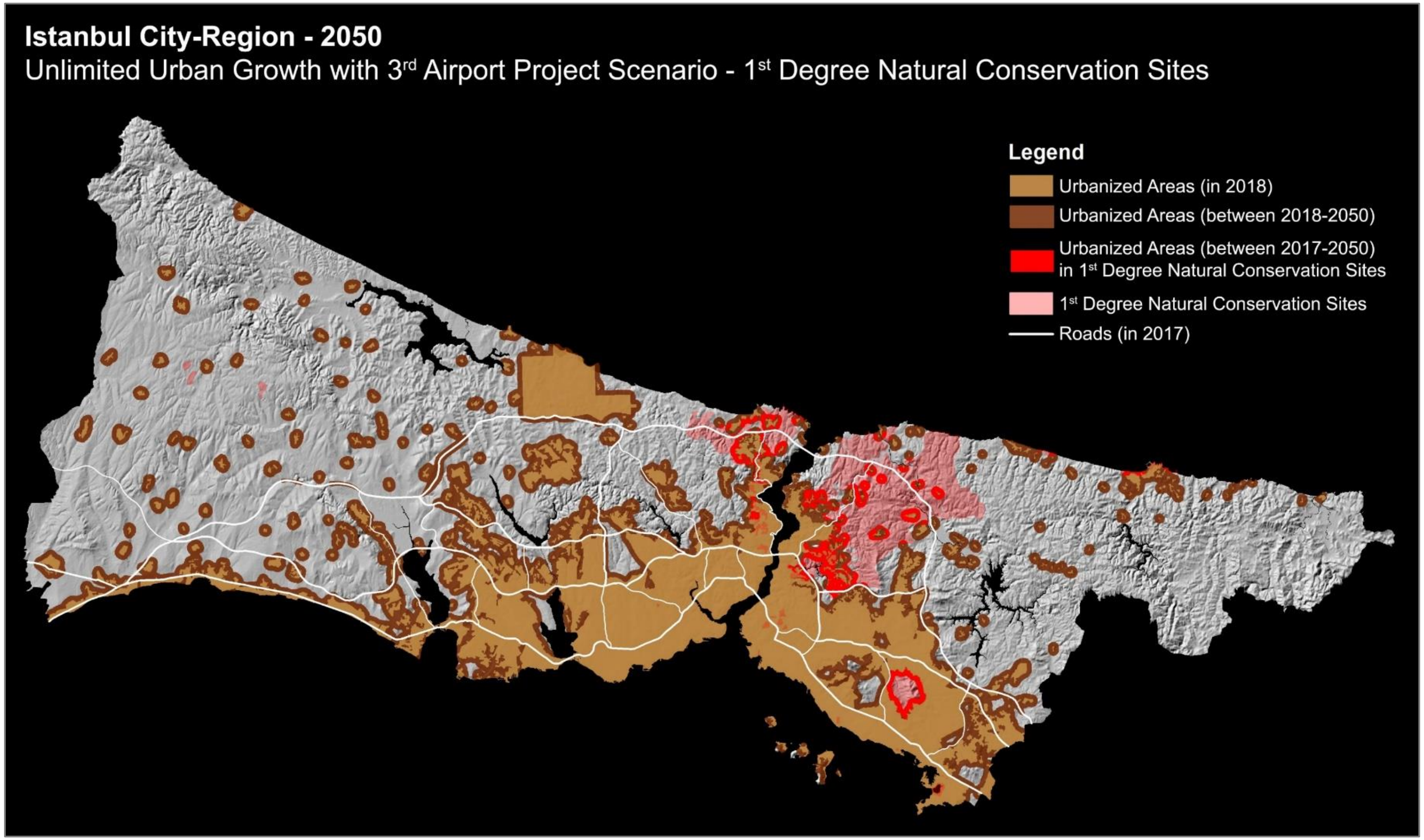

Figure 4.50: 1st Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

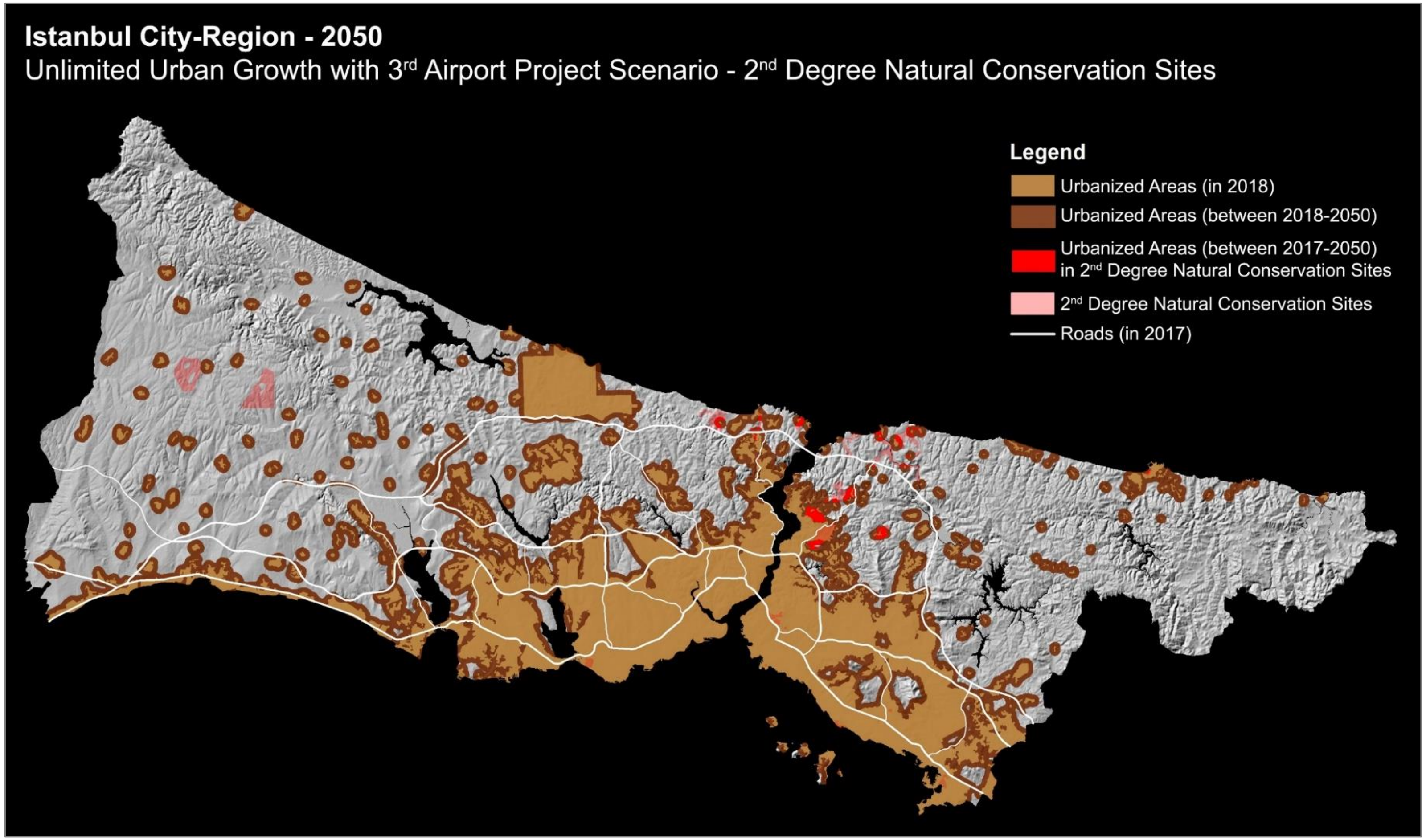

Figure 4.51: 2nd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

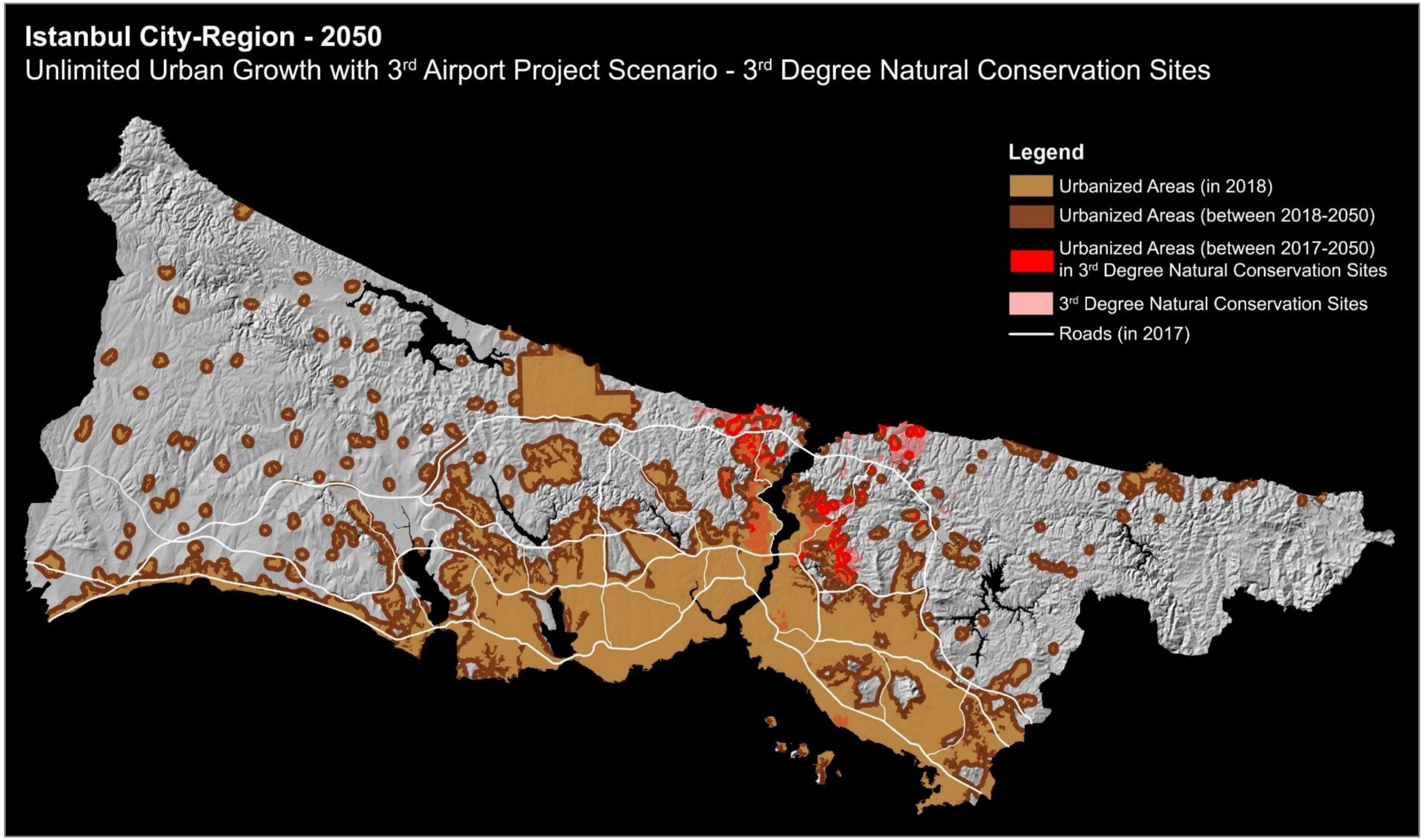

Figure 4.52: 3rd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

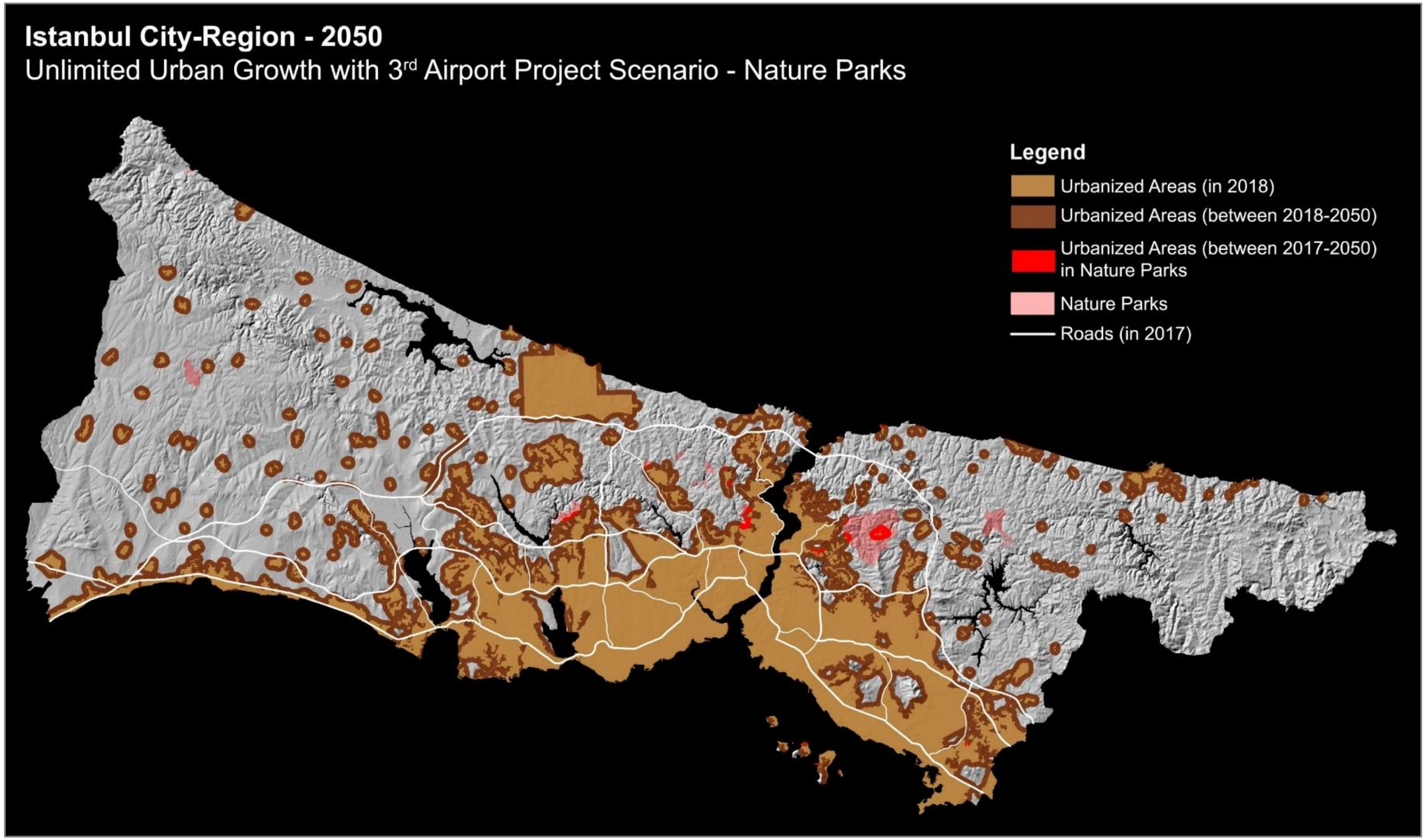

Figure 4.53: Nature Parks of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

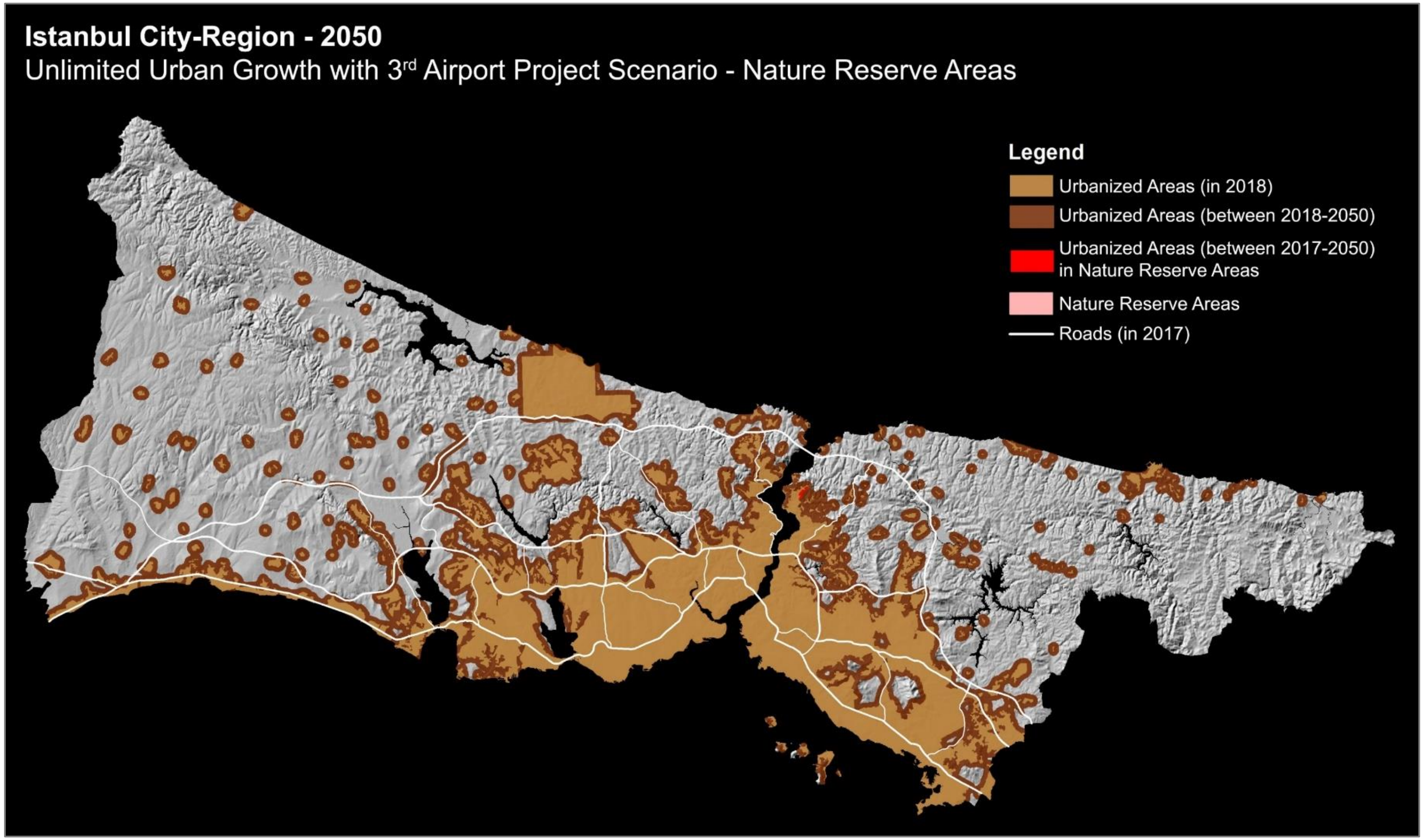

Figure 4.54: Nature Reserve Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

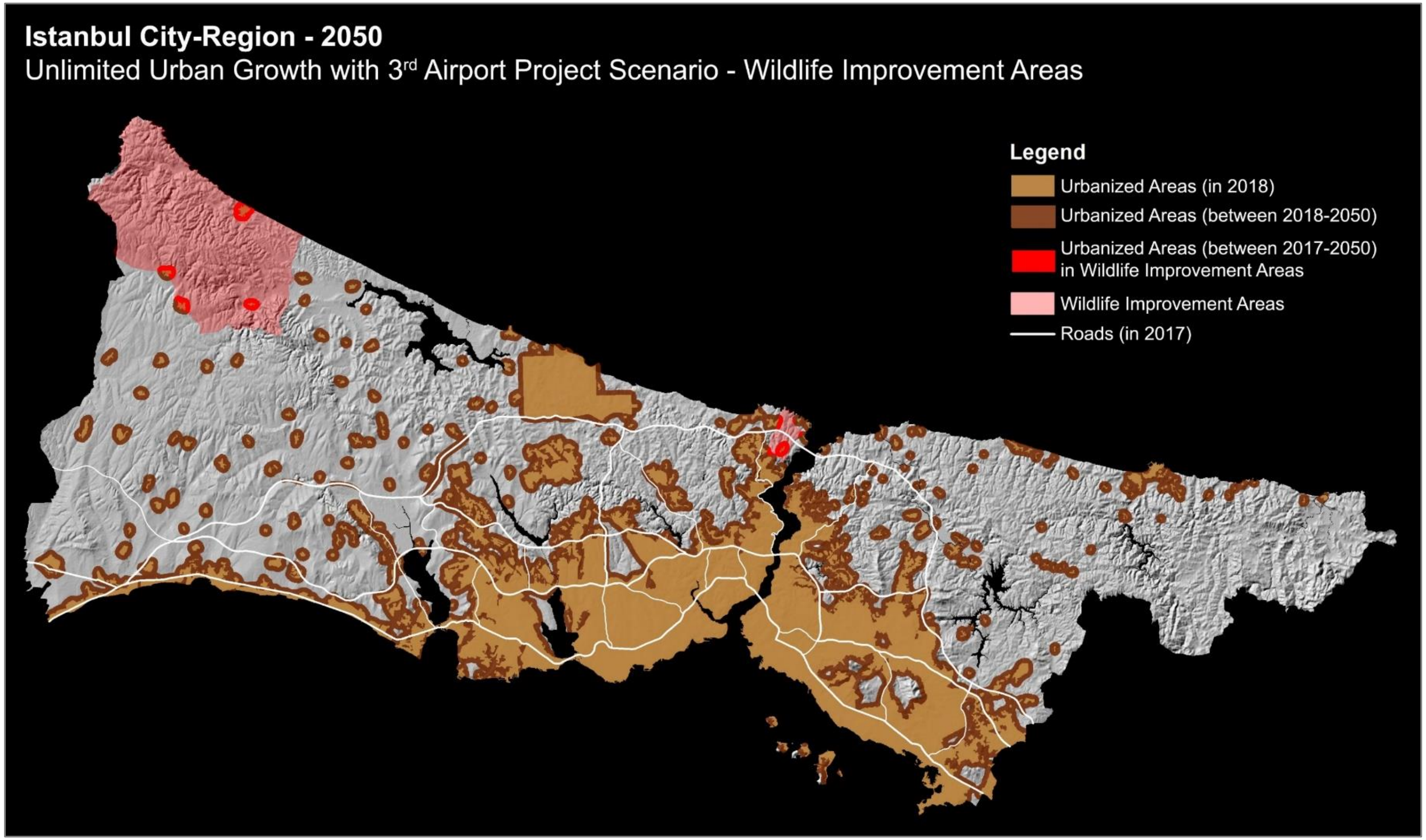

Figure 4.55: Wildlife Improvement Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

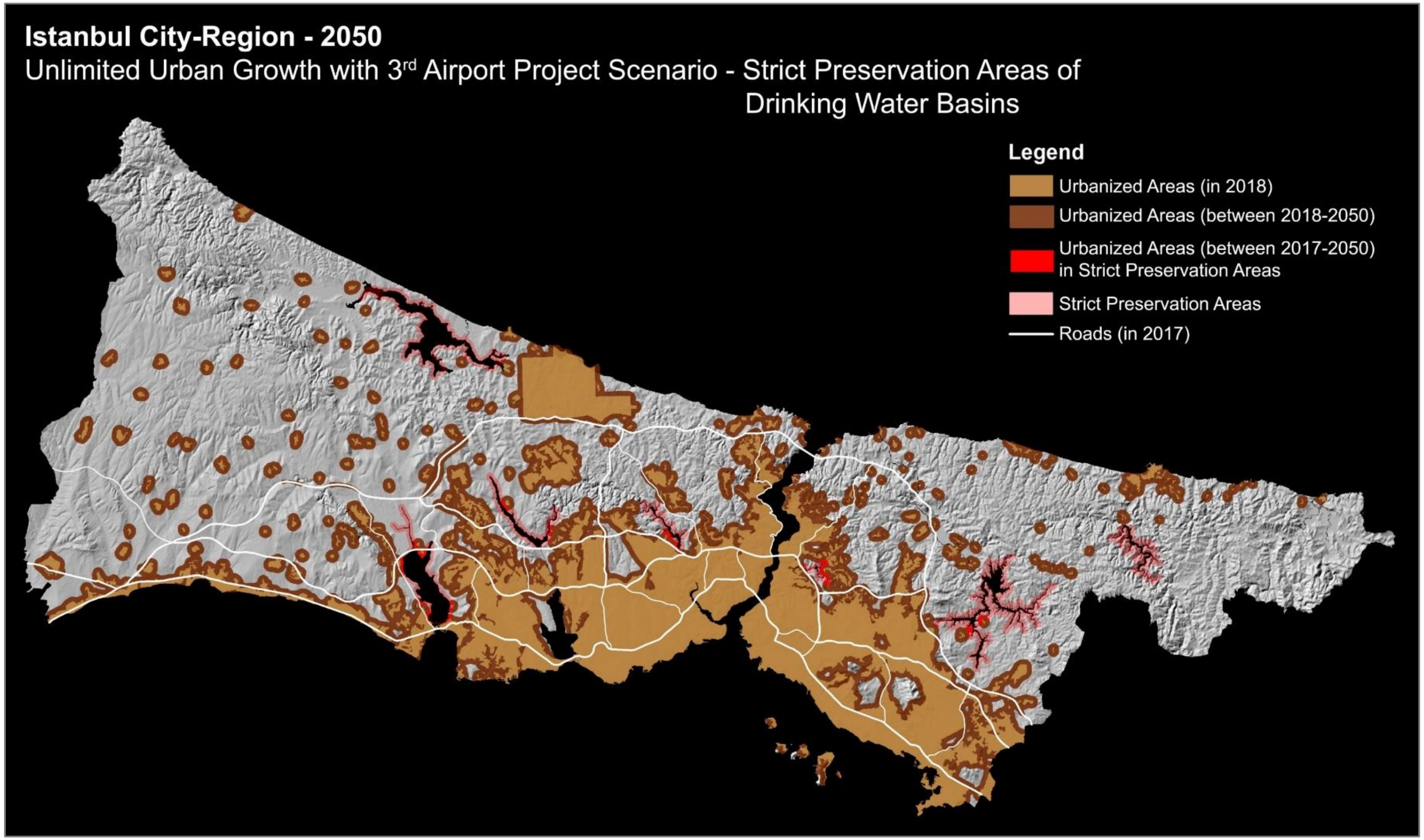

Figure 4.56: Strict Preservation Areas of Drinking Water Basins in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

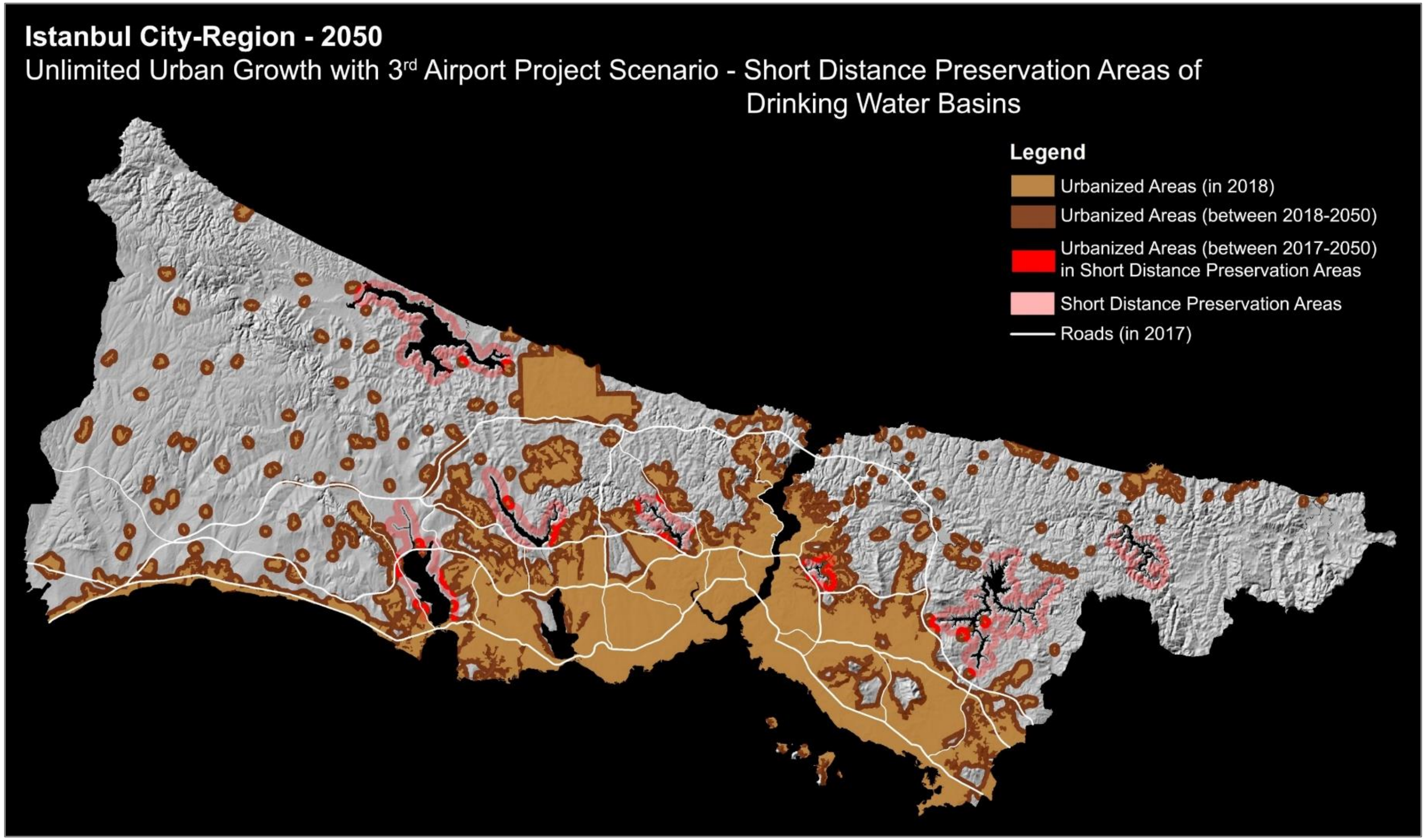

Figure 4.57: Short Distance Preservation Areas of Drinking Water Basins in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

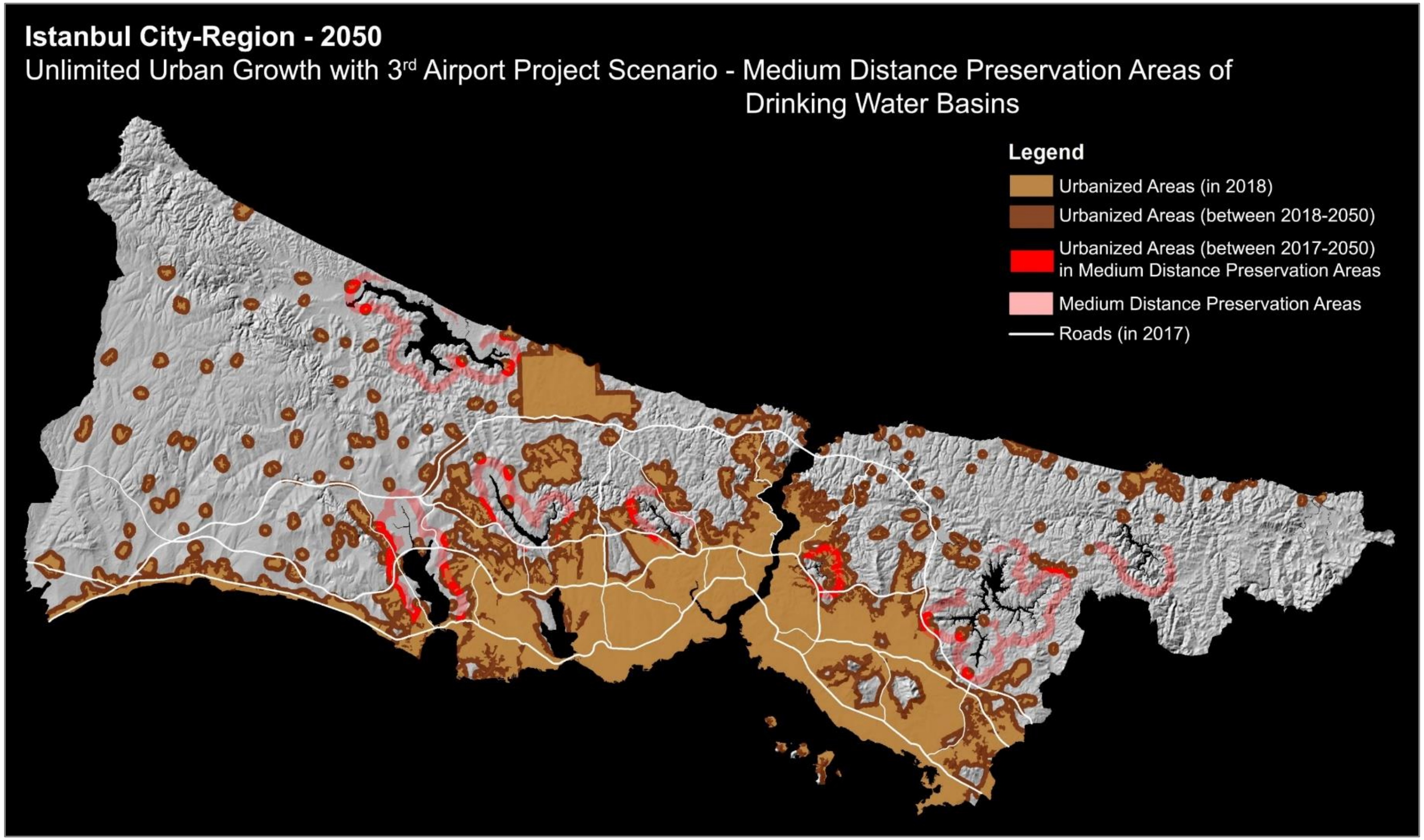

Figure 4.58: Medium Distance Preservation Areas of Drinking Water Basins in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

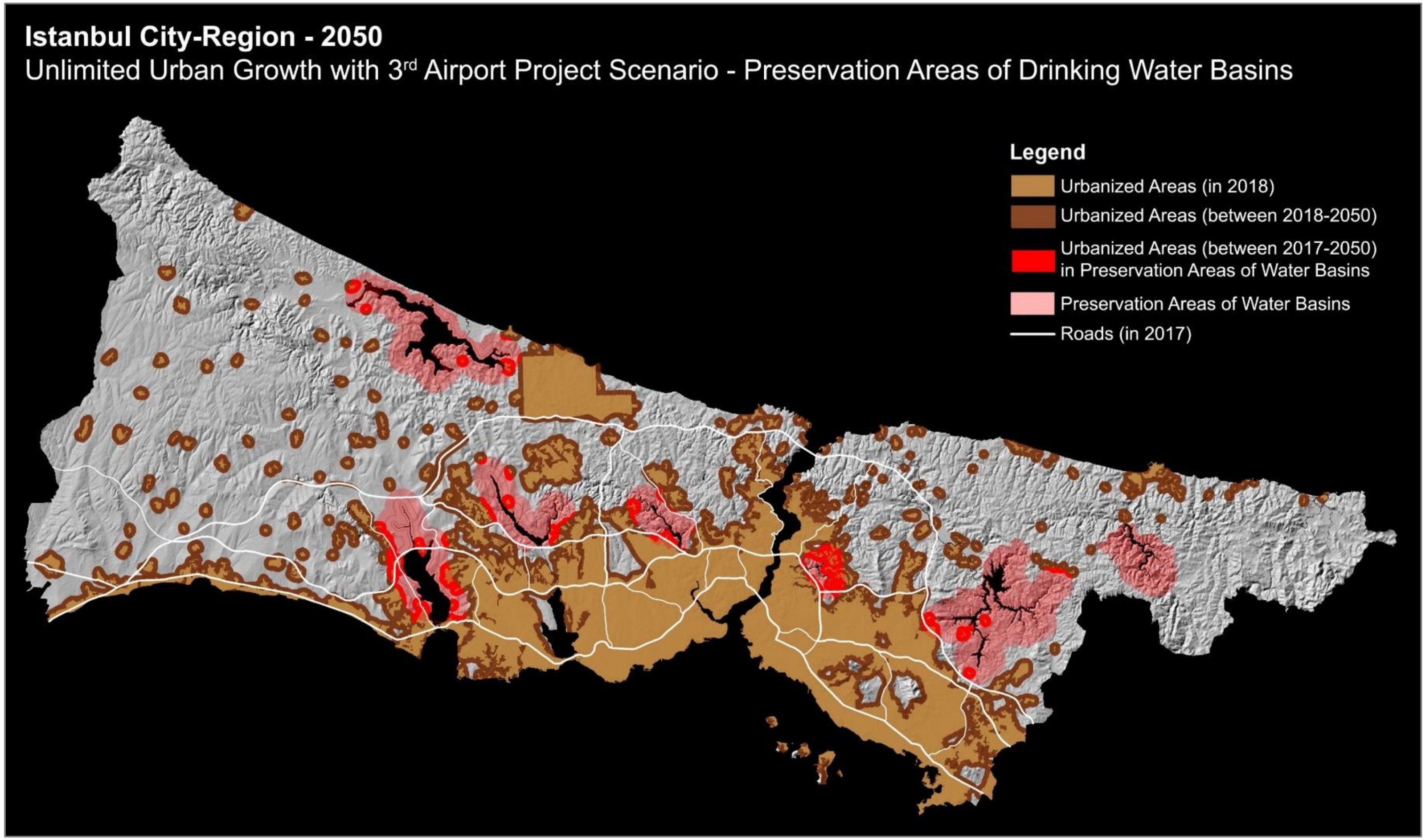

Figure 4.59: Preservation Areas of Drinking Water Basins of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

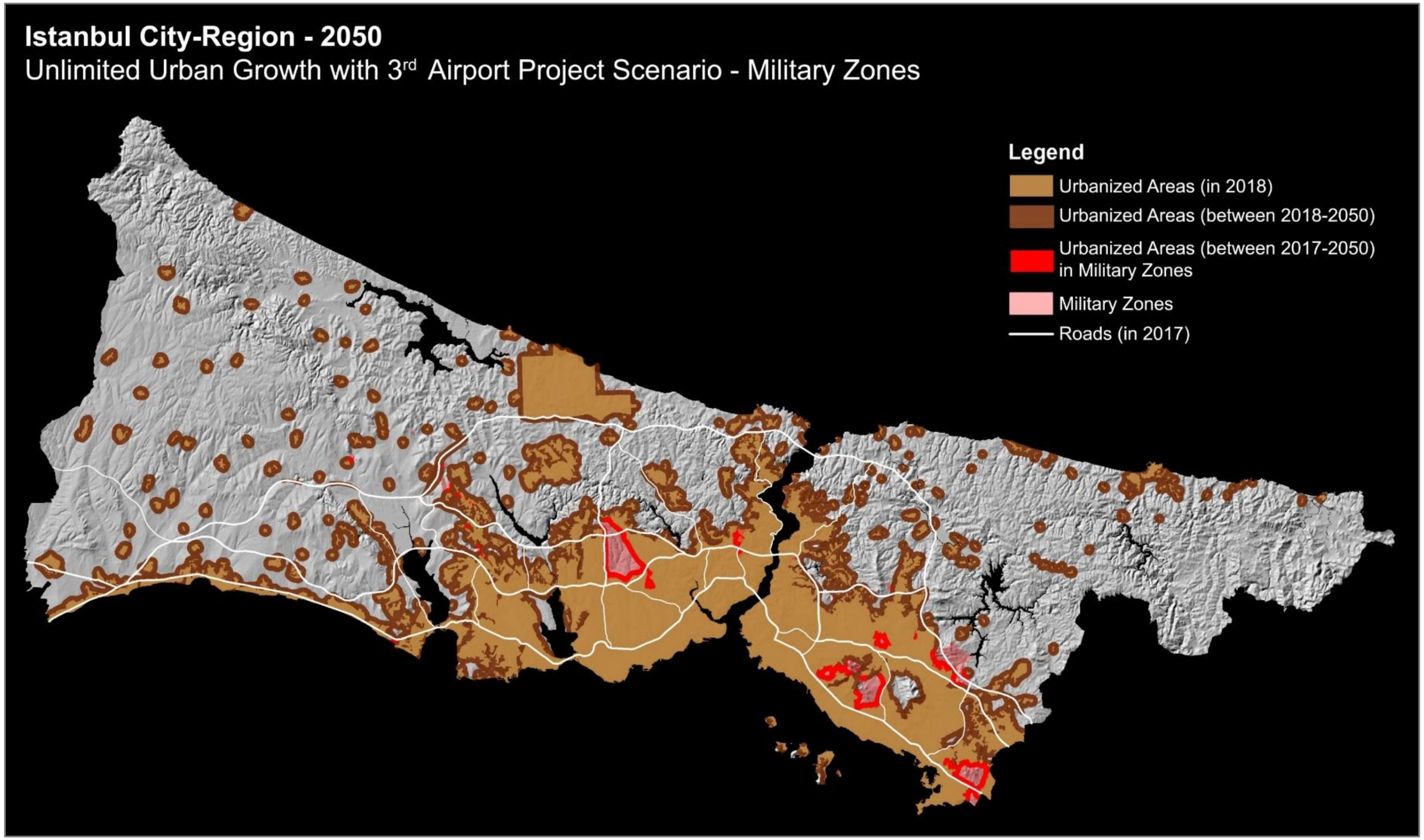

Figure 4.60: Military Zones of Istanbul City-Region in 2050 – Unlimited Urban Growth with the 3rd Airport Project Scenario

4.1.5 Prediction Results of Unlimited Urban Growth with New Istanbul Project Scenario

Assuming that none of the conservation areas would be protected, the exclusion image of aggressive scenario alternatives was used in this scenario alternative of Unlimited Urban Growth with the New Istanbul Project. Different from the former scenarios, prediction process started from 2030 in this scenario alternative. Urban image of 2030 was produced by adding the expropriation area of New Istanbul Project (covering the boundaries of 3rd Airport and Canal Istanbul Projects) to the predicted urban areas of 2030 (from the results of Unlimited Urban Growth scenario). In terms of the results of Unlimited Urban Growth scenario alternative, urban areas covered nearly 125 180 ha of the total surface area of Istanbul City-Region in 2030. With the inclusion of New Istanbul Project, the total surface area of urban areas covered nearly 152 704 ha in 2030 (see Figure 4.61).

Nearly 75% (24 987 ha) of the expropriation area of the New Istanbul Project takes place within the boundaries of conservation areas. Therefore, with inclusion of the expropriation area of New Istanbul Project, 16.68% of Agricultural Lands, 3.30% of Forest Areas, 9.38% of Strict Preservation Areas of Drinking Water Basins, 17.47% of Short Distance Preservation Areas of Drinking Water Basins, 21.87 % of Medium Distance Preservation Areas of Drinking Water Basins and 47.68% of Military Zones became urbanized in 2030 (see Table 4.5).

With this scenario alternative, it was estimated that the urban areas would increase by 93.99% (92 595 ha) from 2017 to 2050 and cover nearly 191 108 ha of the City Region's surface area in 2050 (see Figure 4.61). Without any protection of the conservation areas, nearly 88% (81 172 ha) of total urban growth took place within the boundaries of conservation areas (see Figure 4.62). This urban growth in conservation areas mainly took place within the boundaries of Agricultural Lands (34 485 ha) and Forest Areas (19 688 ha). As a result, nearly 24.8% and 8.3% of these areas became urbanized in 2050, respectively (see Figure 4.63 and Figure 4.64).

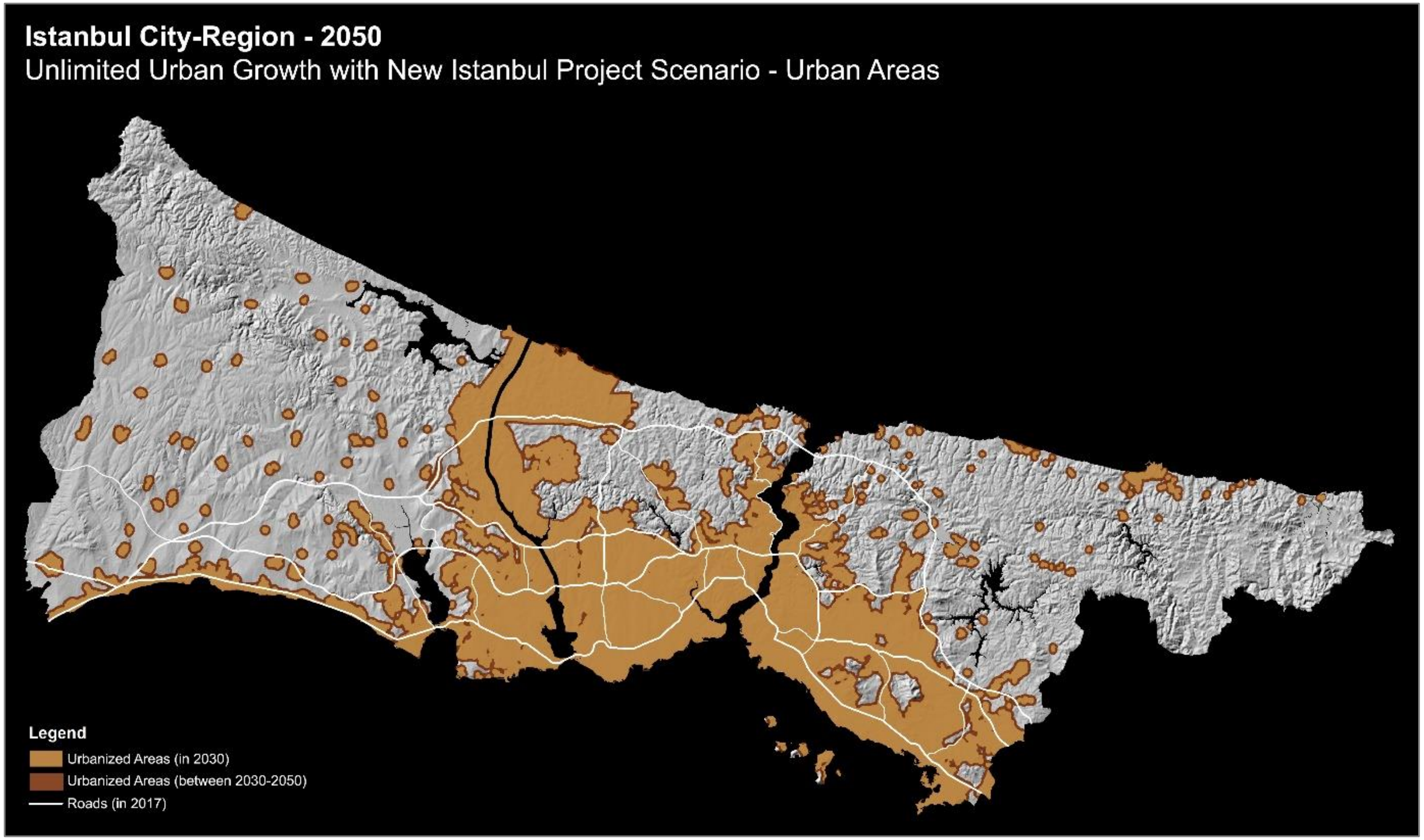

Figure 4.61: Urban Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

In addition, 5855 ha (27.72%) of Medium Distance Preservation Areas of Drinking Water Basins, 5372 ha (63.33%) of Military Zones, 5176 ha (18.81%) of 1st Degree Natural Conservation Sites, 3913 ha (20.97%) of Short Distance Preservation Areas of Drinking Water Basins, 2710 ha (29.74%) of 3rd Degree Natural Conservation Sites, 1427 ha (12.82%) of Strict Preservation Areas of Drinking Water Basins, 958 ha (2.58%) of Wildlife Improvement Areas, 874 ha (19.02%) of 2nd Degree Natural Conservation Sites, 671 ha (13.37%) of Nature Parks and 43 ha (97.73%) of Nature Reserve Areas were also urbanized between 2017 and 2050 in this scenario alternative of Unlimited Urban Growth with New Istanbul Project (see Table 4.5 with Figure 4.65- Figure 4.75).

Similar to the previous scenario alternatives of unlimited urban growth, with 43 ha of urban growth in 33 years Nature Reserve Areas of Istanbul City-Region became totally urbanized in 2050 with this scenario alternative (see Figure 4.69). Also, with 2710 ha of urban growth between 2017 and 2050, nearly 69% (6289 ha) of the total surface area of 3rd Degree Natural Conservation Sites became urbanized in 2050 (see Figure 4.67). In fact, nearly 40% (3579 ha) of the total surface area of 3rd Degree Natural Conservation Sites was already urbanized in 2017 (see Table 4.5). On the other hand, although only 3.42% of the Military Zones were urbanized in 2017, nearly 63% of their total surface area became urbanized in 2050 with an urban growth of 5372 ha in 33 years (see Figure 4.75). The highest amount of urban growth in Military Zones occurred in this scenario alternative as a result of the inclusion of Esenler Military Zone within the expropriation area of New Istanbul Project.

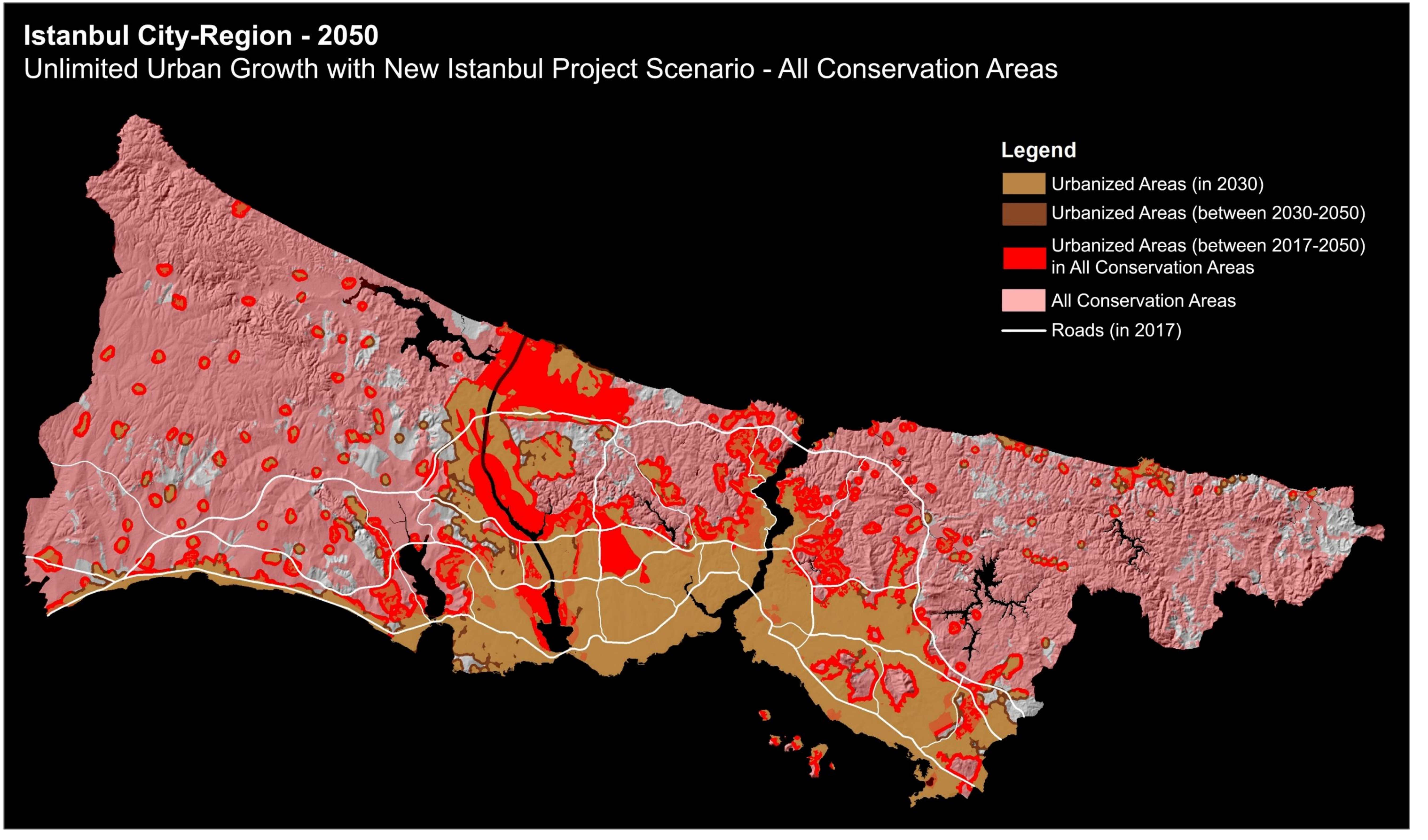

Figure 4.62: All Conservation Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

Table 4.5: Results of Unlimited Urban Growth with the New Istanbul Project Scenario

UNLIMITED URBAN GROWTH WITH NEW ISTANBUL PROJECT	**Total Urban Areas**	**Agricultural Lands**	**Forest Areas**	**1st Degree Natural Conservation Sites**	**2nd Degree Natural Conservation Sites**	**3rd Degree Natural Conservation Sites**	**Nature Parks**	**Nature Reserve Areas**	**Wildlife Improvement Areas**	**Strict Preservation Areas of Drinking Water Basins**	**Short Distance Preservation Areas of Drinking Water Basins**	**Medium Distance Preservation Areas of Drinking Water Basins**	**Military Zones**	**TOTAL**
exclusion level (0-100)		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
total area (ha)		173.891	237.481	27.520	4.594	9.113	5.017	44	37.144	11.131	18.656	21.121	8.482	**554.194**
total urban areas in 2017 (ha)	98.513	8.681	0	1.015	664	3.579	69	1	274	77	540	912	290	**16.102**
total urban areas in 2030 (without New Istanbul Project) (ha)	125.180	16.600	5.919	2.698	960	4.936	260	34	563	249	1.151	2.089	1.754	**37.213**
expropriation area of New Istanbul Project	33.174	14.334	1.973	0	0	0	0	0	0	936	2.261	2.744	2.739	**24.987**
total urban areas in 2030 (with New Istanbul Project) (ha)	152.704	28.997	7.839	2.698	960	4.936	260	34	563	1.044	3.259	4.620	4.044	**59.254**
total urban areas (90-100%) in 2050 (ha)	191.108	43.166	19.688	6.191	1.538	6.289	740	44	1.232	1.504	4.453	6.767	5.662	**97.274**
urban areas in 2017 (%)		4,99%	0,00%	3,69%	14,45%	39,27%	1,38%	2,27%	0,74%	0,69%	2,89%	4,32%	3,42%	**2,91%**
urban areas in 2030 (with New Istanbul Project) (%)		16,68%	3,30%	9,80%	20,90%	54,16%	5,18%	77,27%	1,52%	9,38%	17,47%	21,87%	47,68%	**10,69%**
total urban areas (90-100%) in 2050 (%)		24,82%	8,29%	22,50%	33,48%	69,01%	14,75%	100,00%	3,32%	13,51%	23,87%	32,04%	66,75%	**17,55%**
urbanization between 2017-2030 (ha)	54.191	20.316	7.839	1.683	296	1.357	191	33	289	967	2.719	3.708	3.754	**43.152**
urbanization between 2017-2030 (%)	55,01%	234,03%	-	165,81%	44,58%	37,92%	276,81%	3300,00 %	105,47%	1255,84%	503,52%	406,58%	1294,48%	**267,99%**
urbanization between 2030-2050 (ha)	38.404	14.169	11.849	3.493	578	1.353	480	10	669	460	1.194	2.147	1.618	**38.020**
urbanization between 2030-2050 (%)	25,15%	48,86%	151,15%	129,47%	60,21%	27,41%	184,62%	29,41%	118,83%	44,06%	36,64%	46,47%	40,01%	**64,16%**
urbanization between 2017-2050 (ha)	92.595	34.485	19.688	5.176	874	2.710	671	43	958	1.427	3.913	5.855	5.372	**81.172**
urbanization between 2017-2050 (%)	93,99%	397,25%	-	509,95%	131,63%	75,72%	972,46%	4300,00 %	349,64%	1853,25%	724,63%	642,00%	1852,41%	**504,11%**
ratio of urbanization between 2017-2050 to total conservation area (%)		**19,83%**	**8,29%**	**18,81%**	**19,02%**	**29,74%**	**13,37%**	**97,73%**	**2,58%**	**12,82%**	**20,97%**	**27,72%**	**63,33%**	**14,65%**

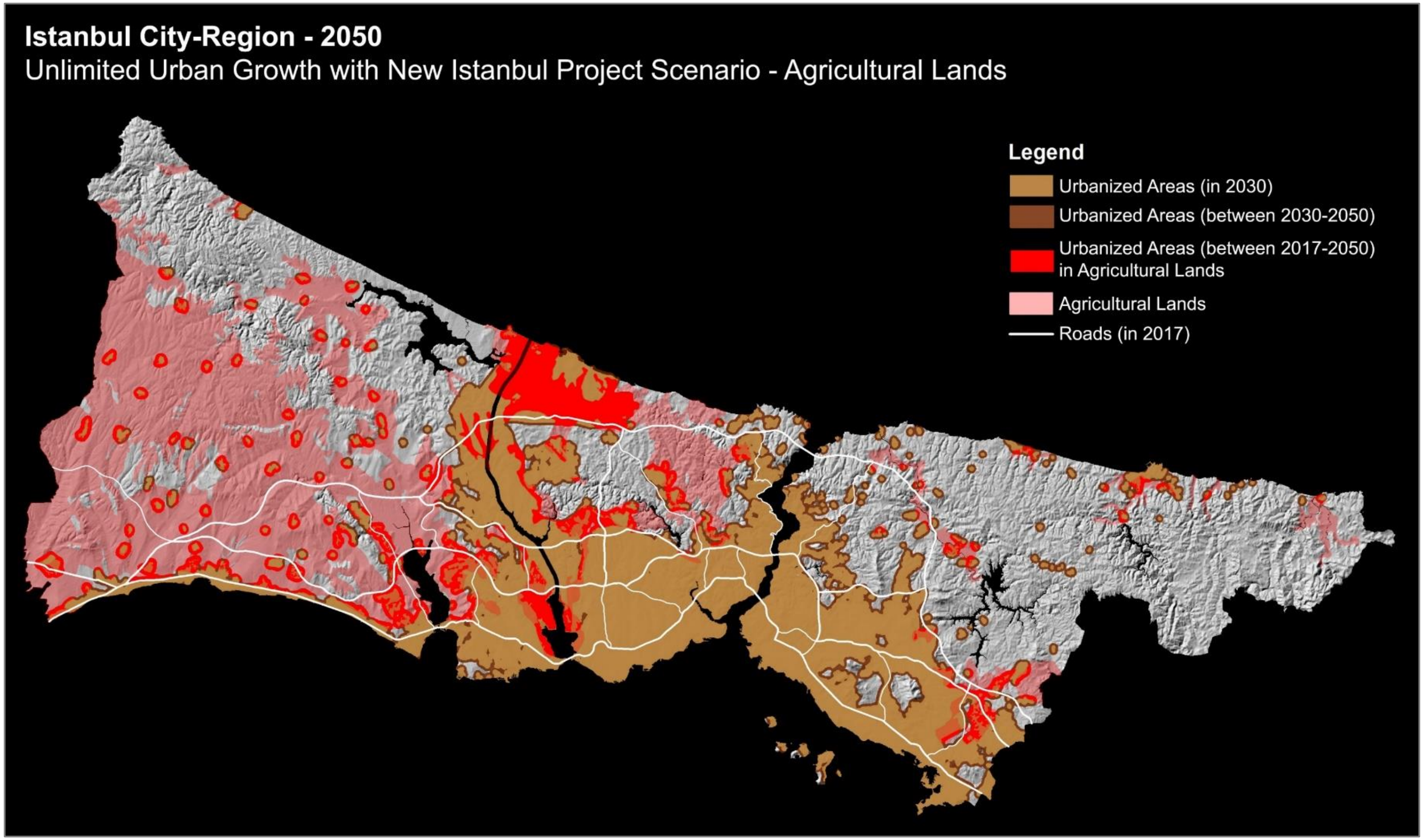

Figure 4.63: Agricultural Lands of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

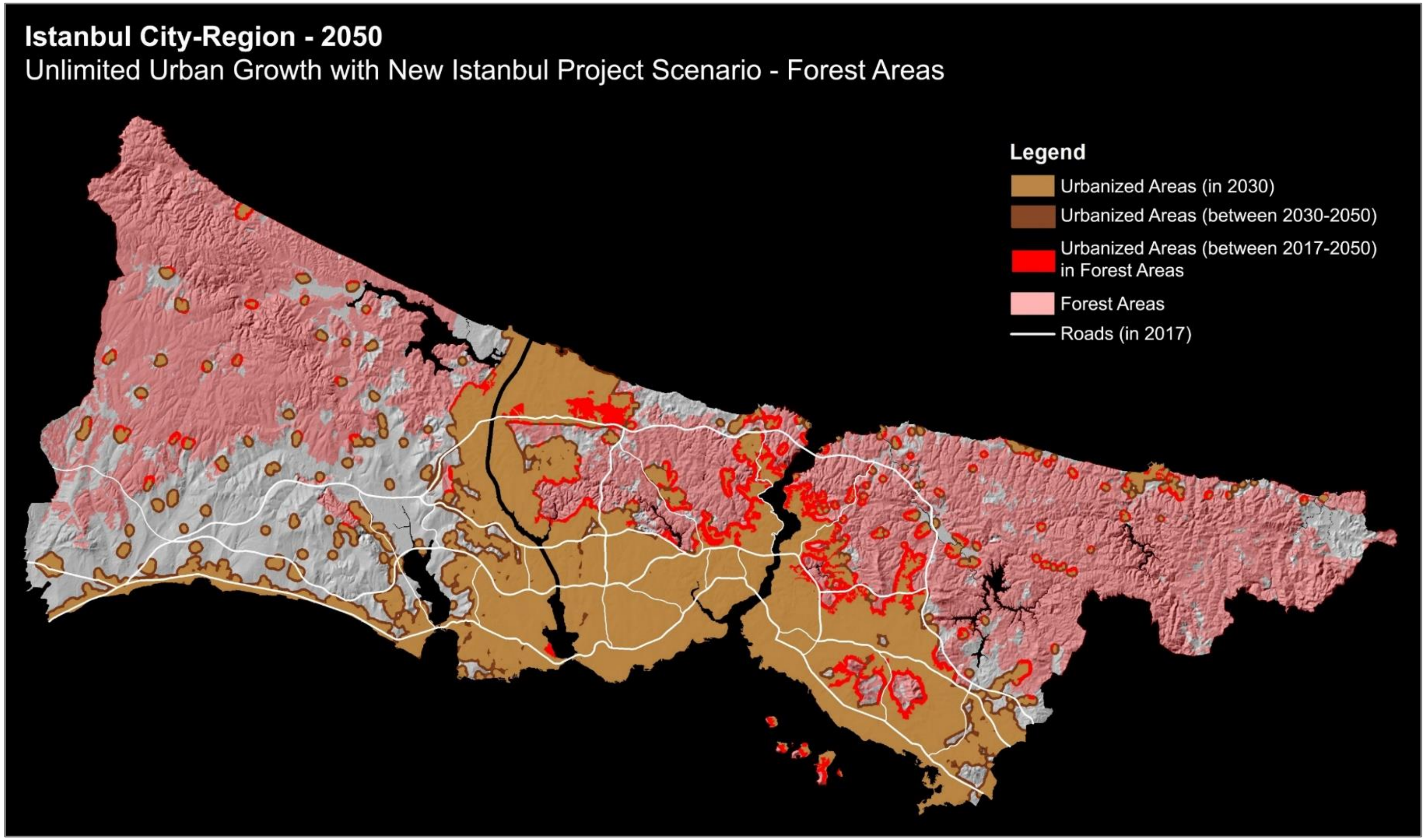

Figure 4.64: Forest Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

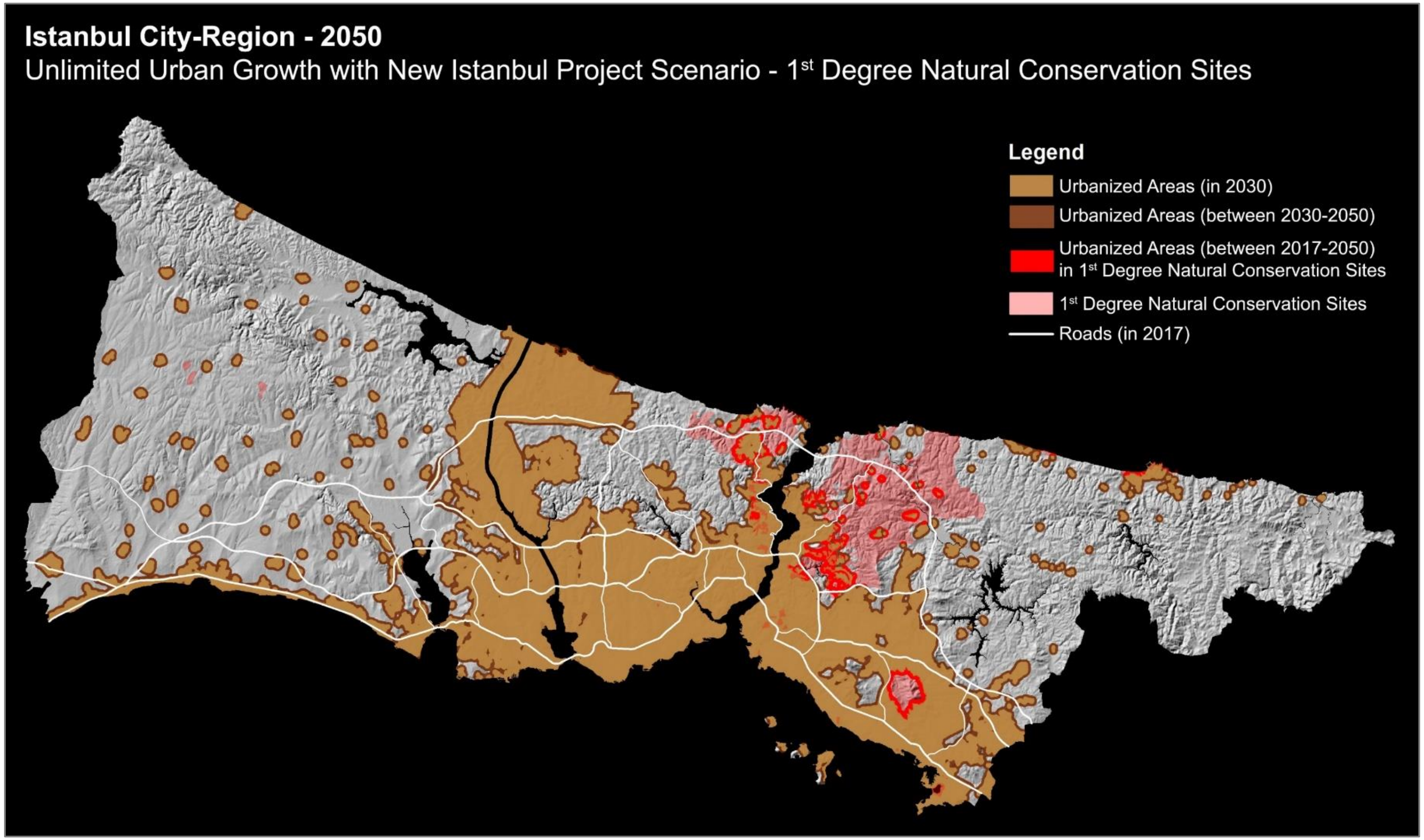

Figure 4.65: 1st Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

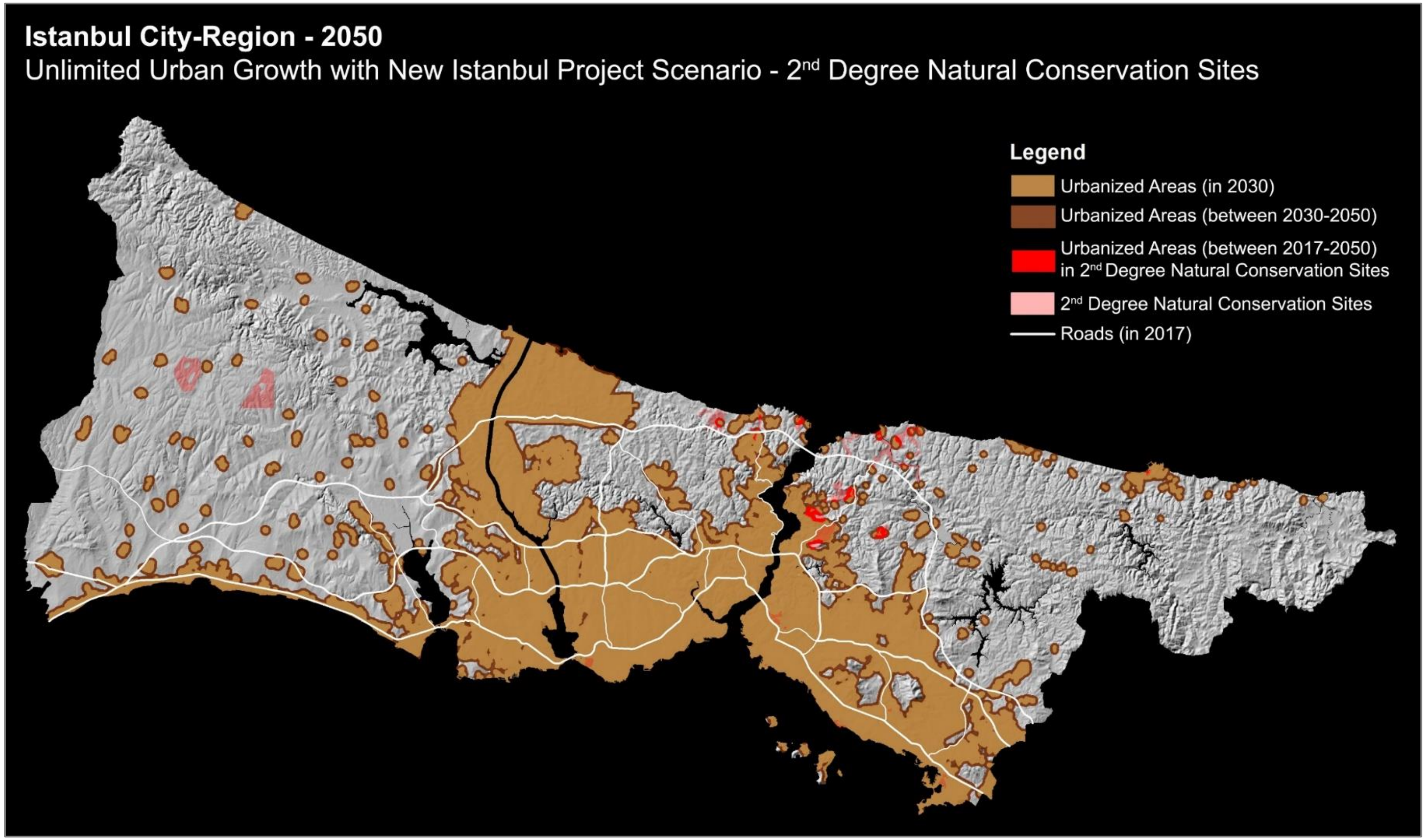

Figure 4.66: 2nd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

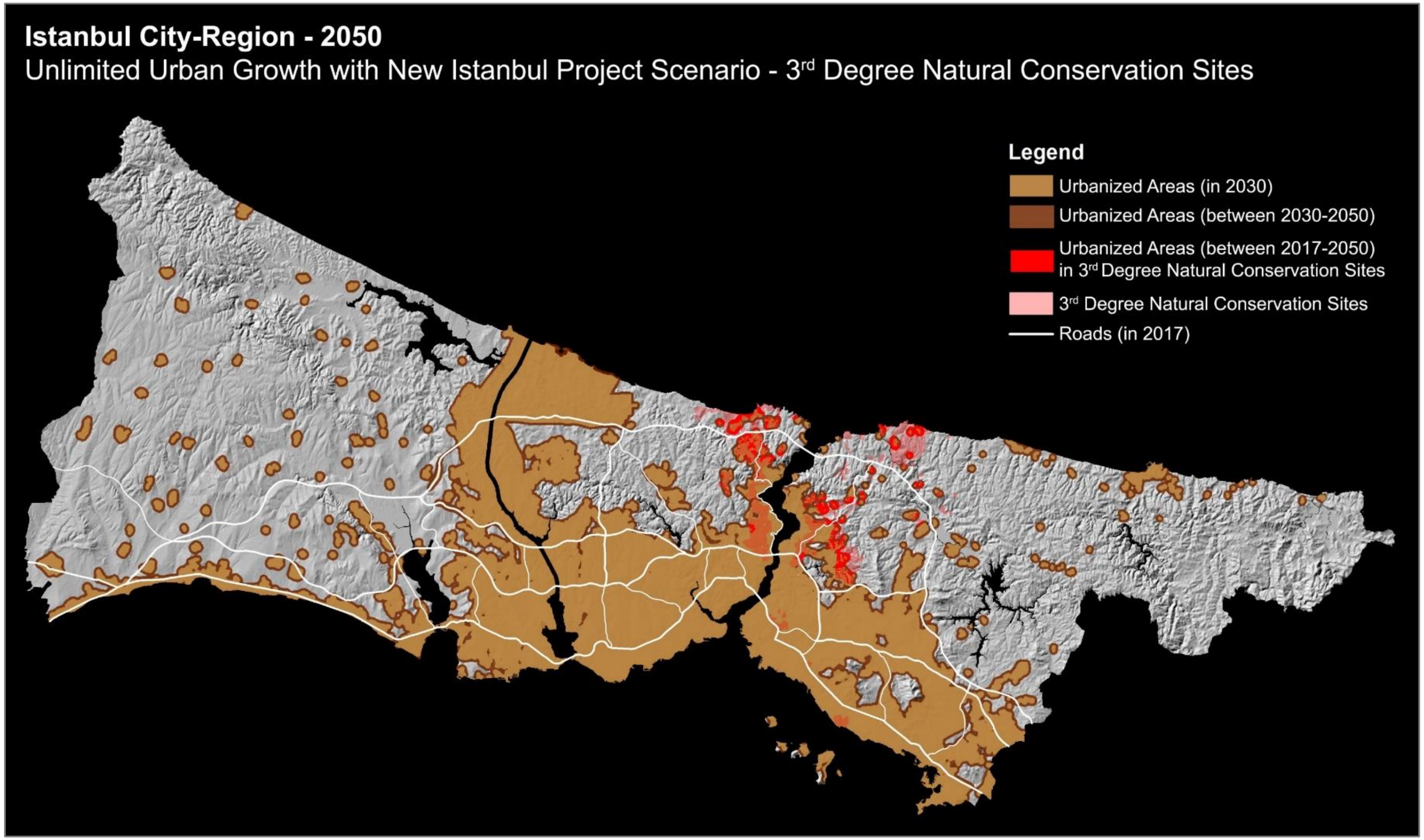

Figure 4.67: 3rd Degree Natural Conservation Sites of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

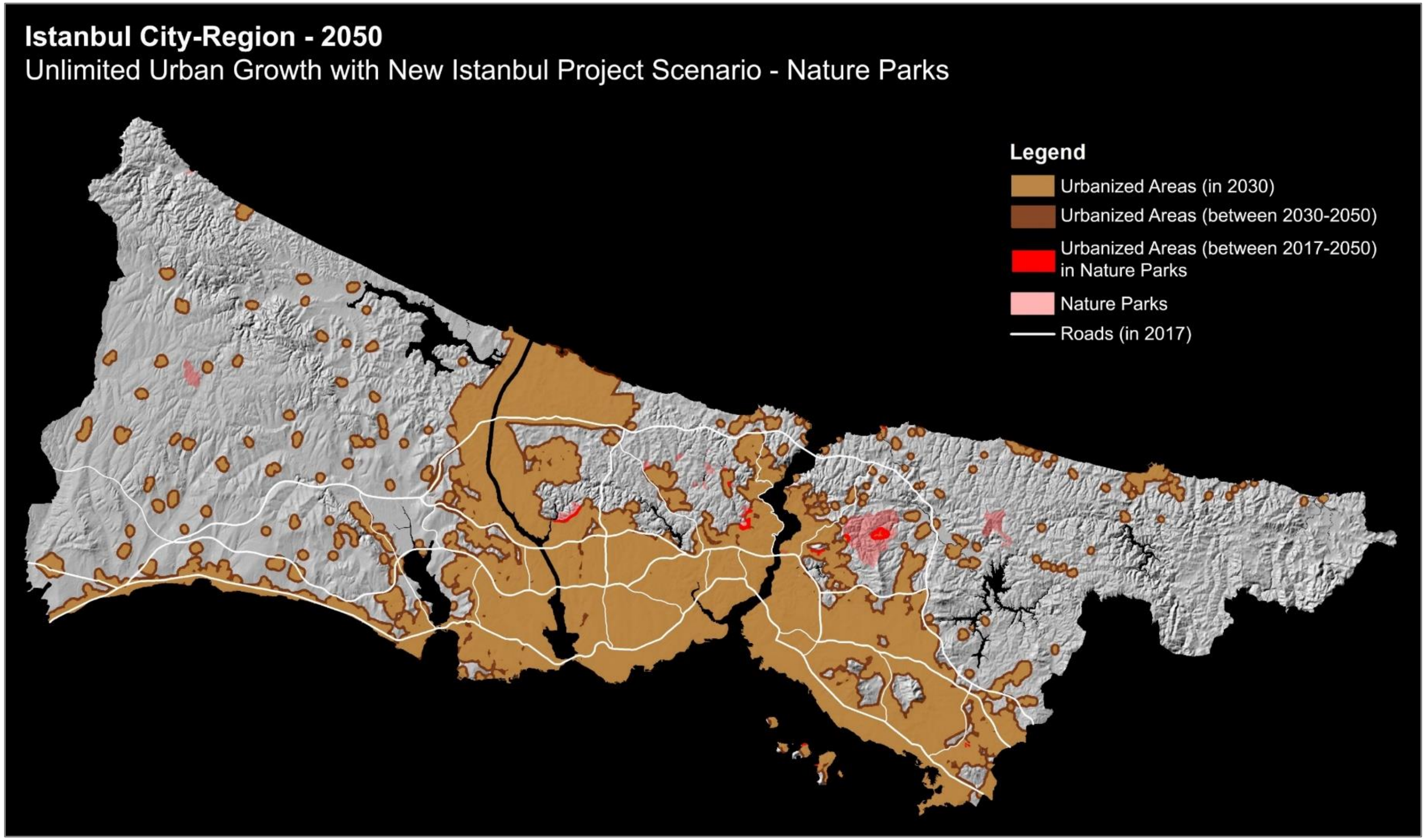

Figure 4.68: Nature Parks of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

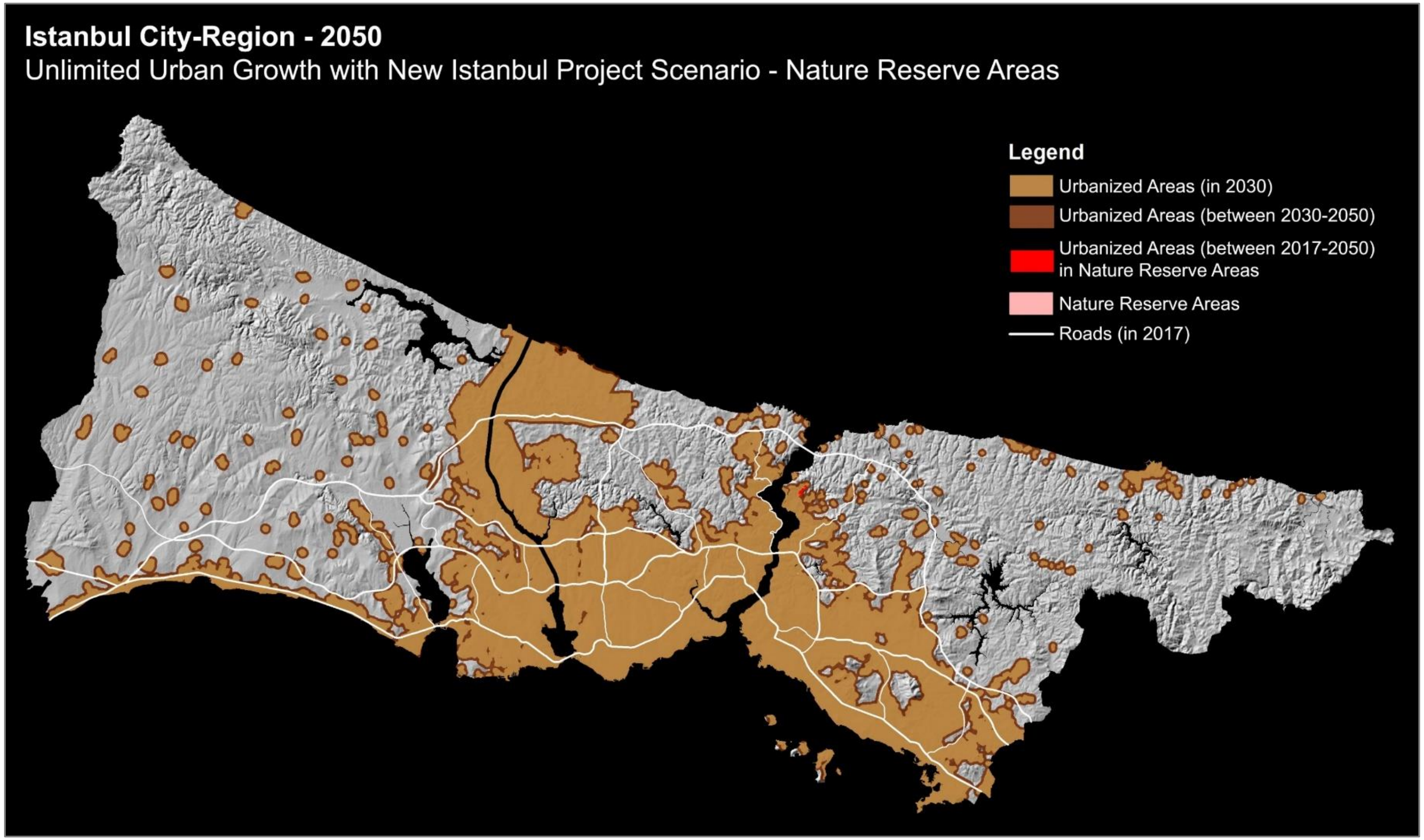

Figure 4.69: Nature Reserve Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

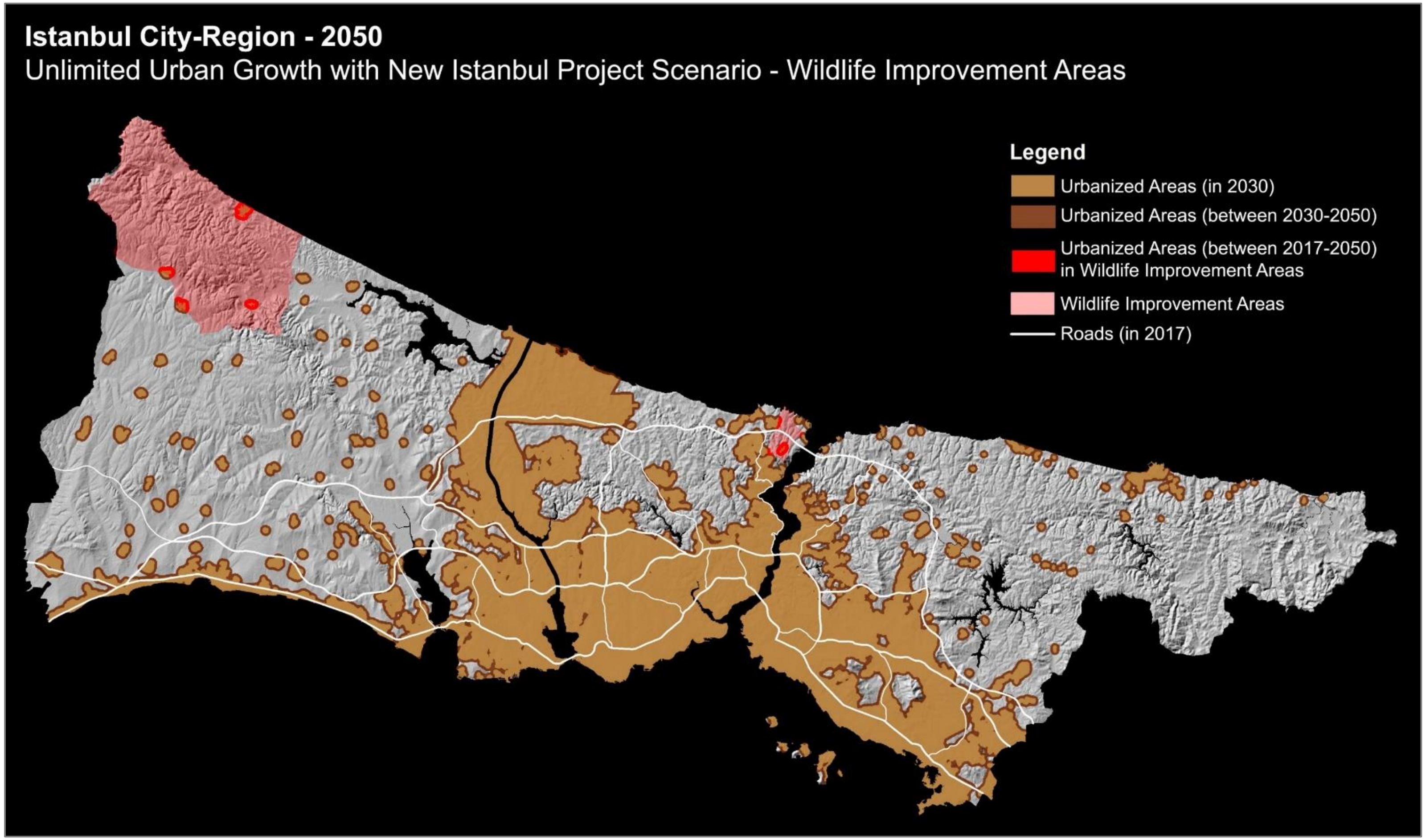

Figure 4.70: Wildlife Improvement Areas of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

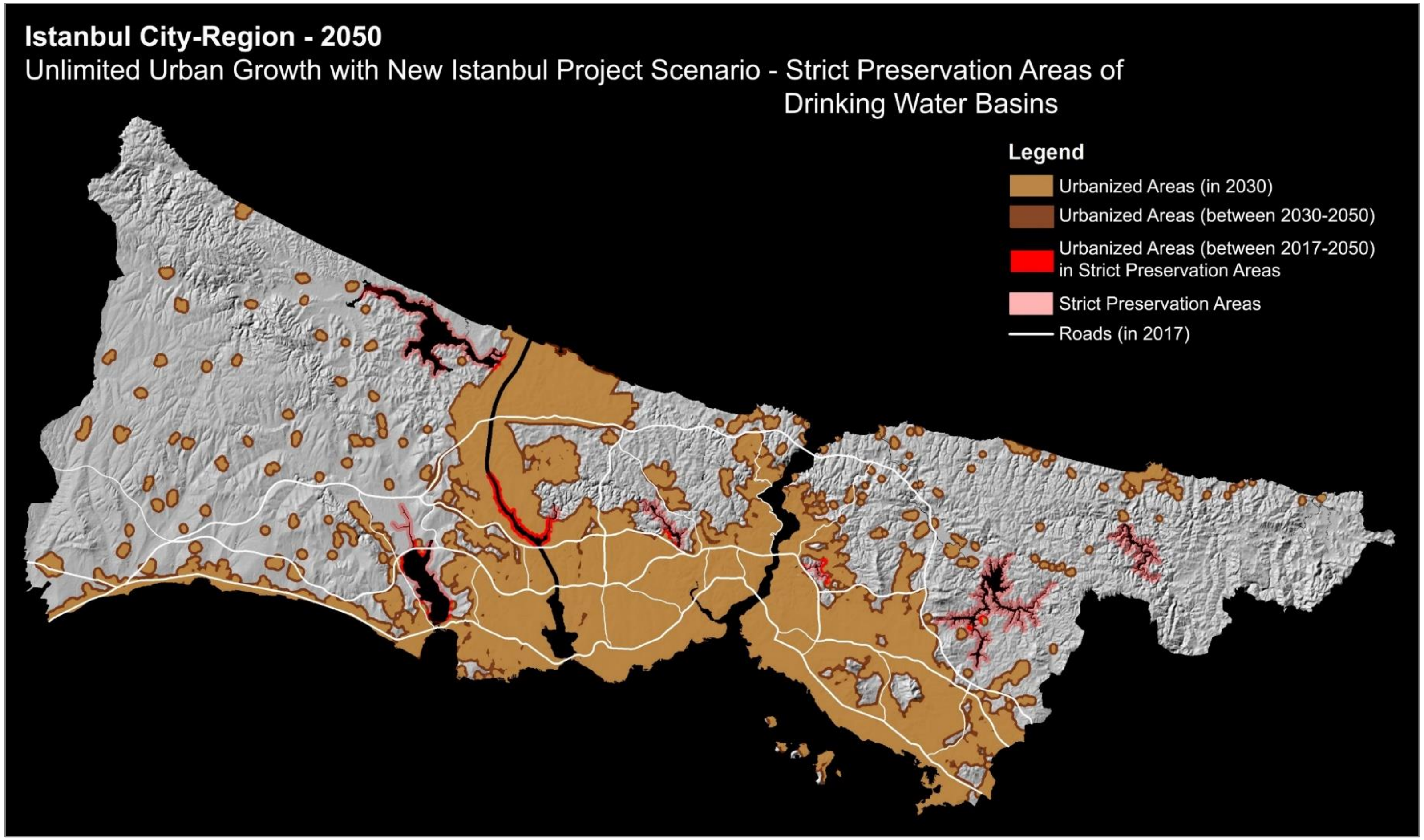

Figure 4.71: Strict Preservation Areas of Drinking Water Basin in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

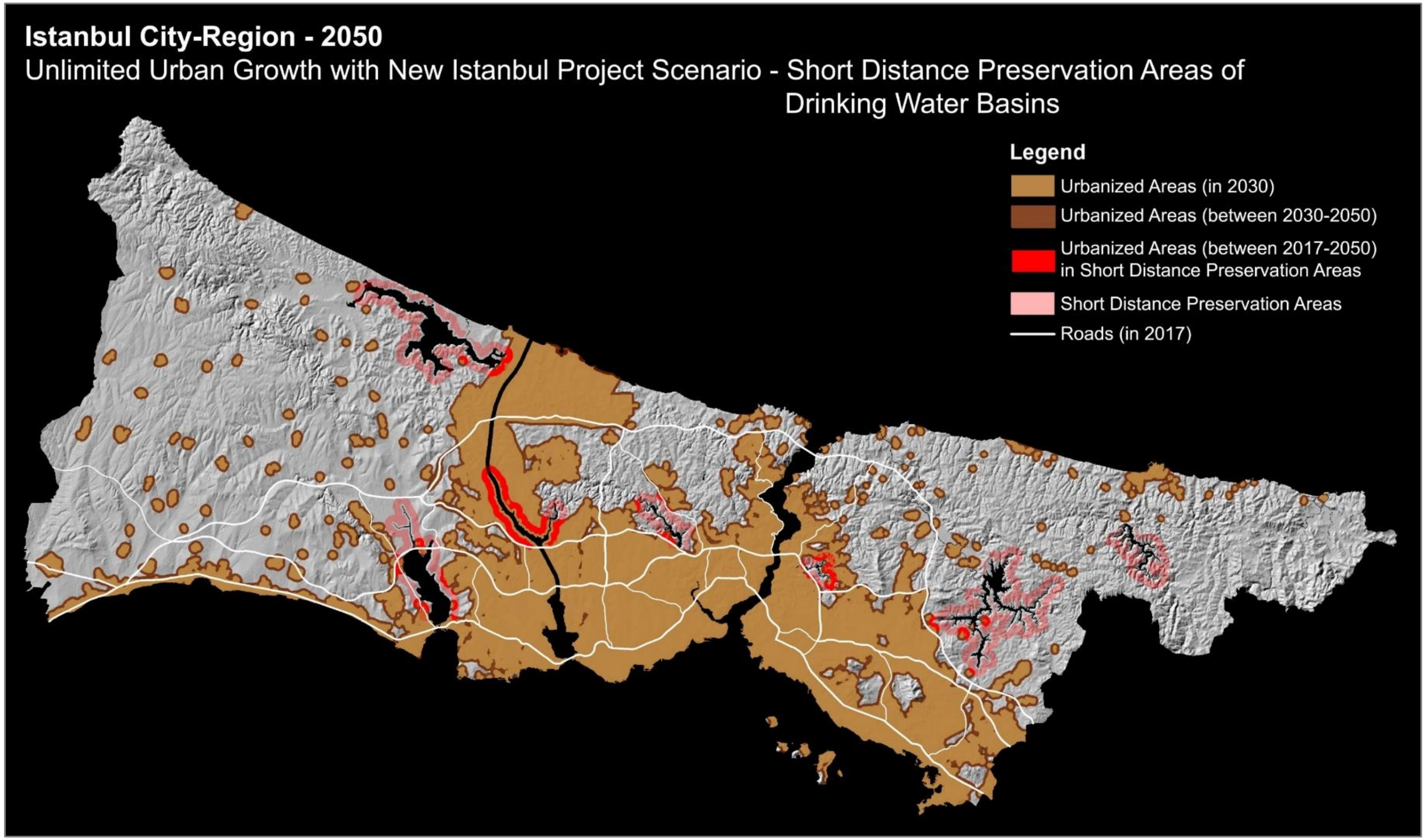

Figure 4.72: Short Distance Preservation Areas of Drinking Water Basin in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

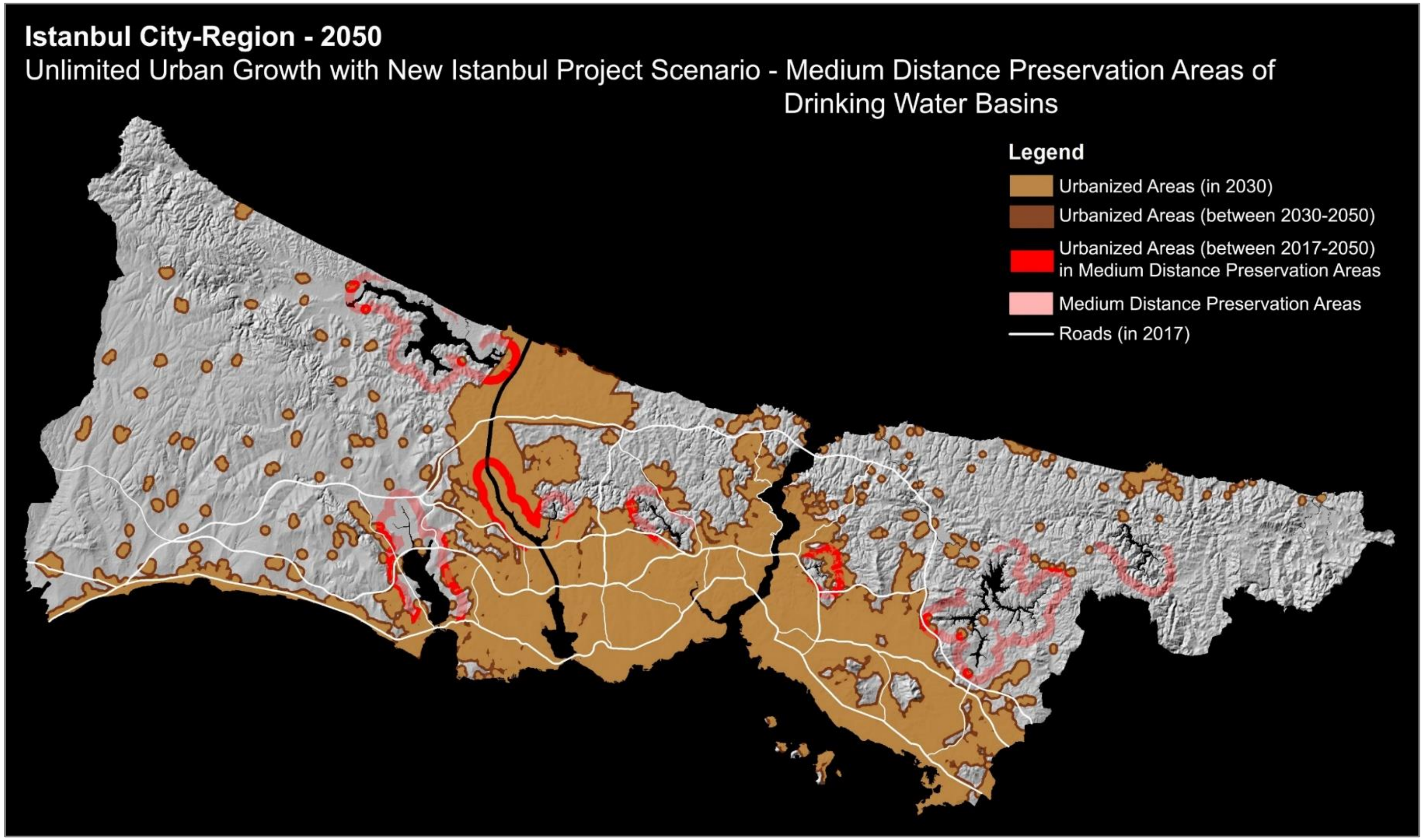

Figure 4.73: Medium Distance Preservation Areas of Drinking Water Basin in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

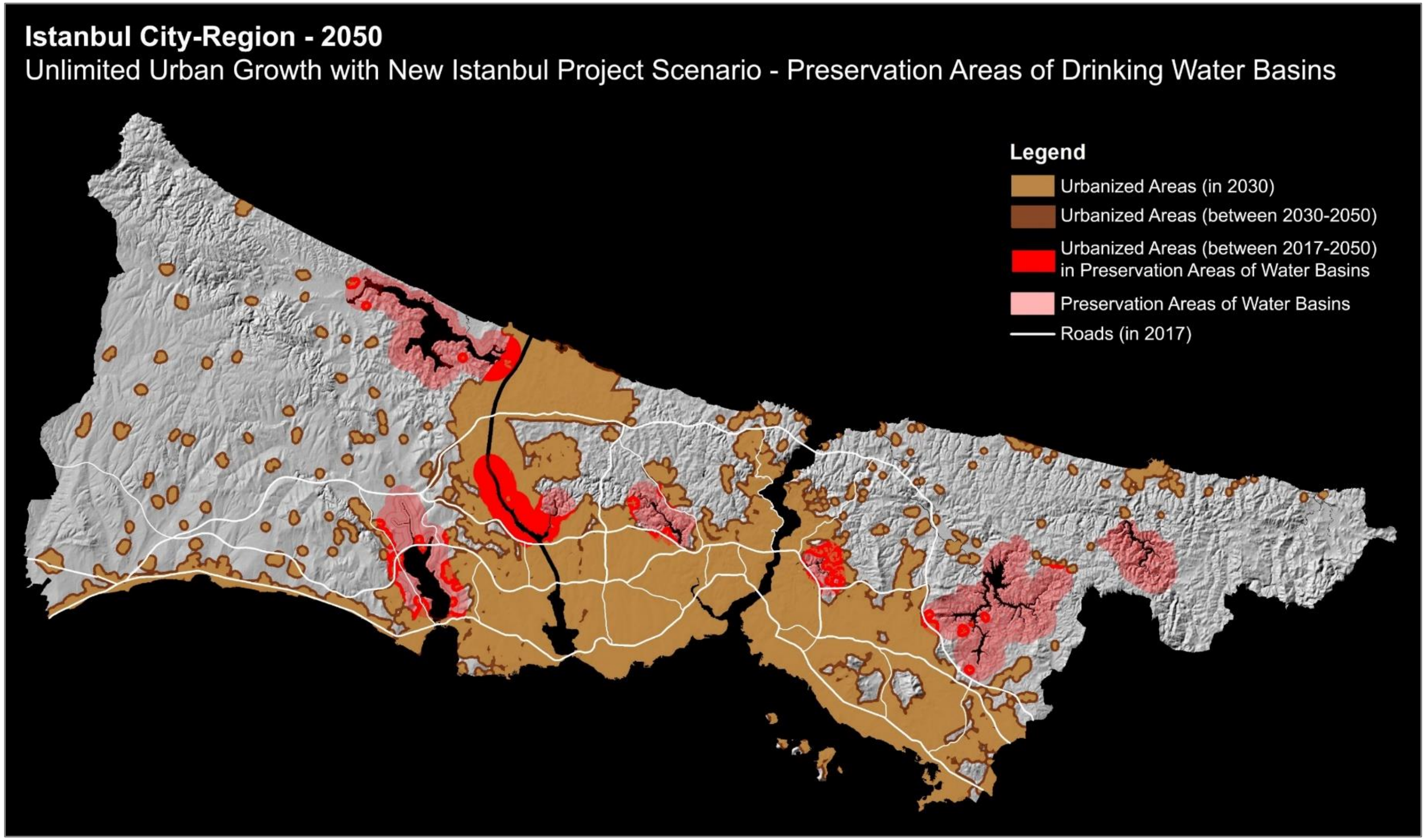

Figure 4.74: Preservation Areas of Drinking Water Basin in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

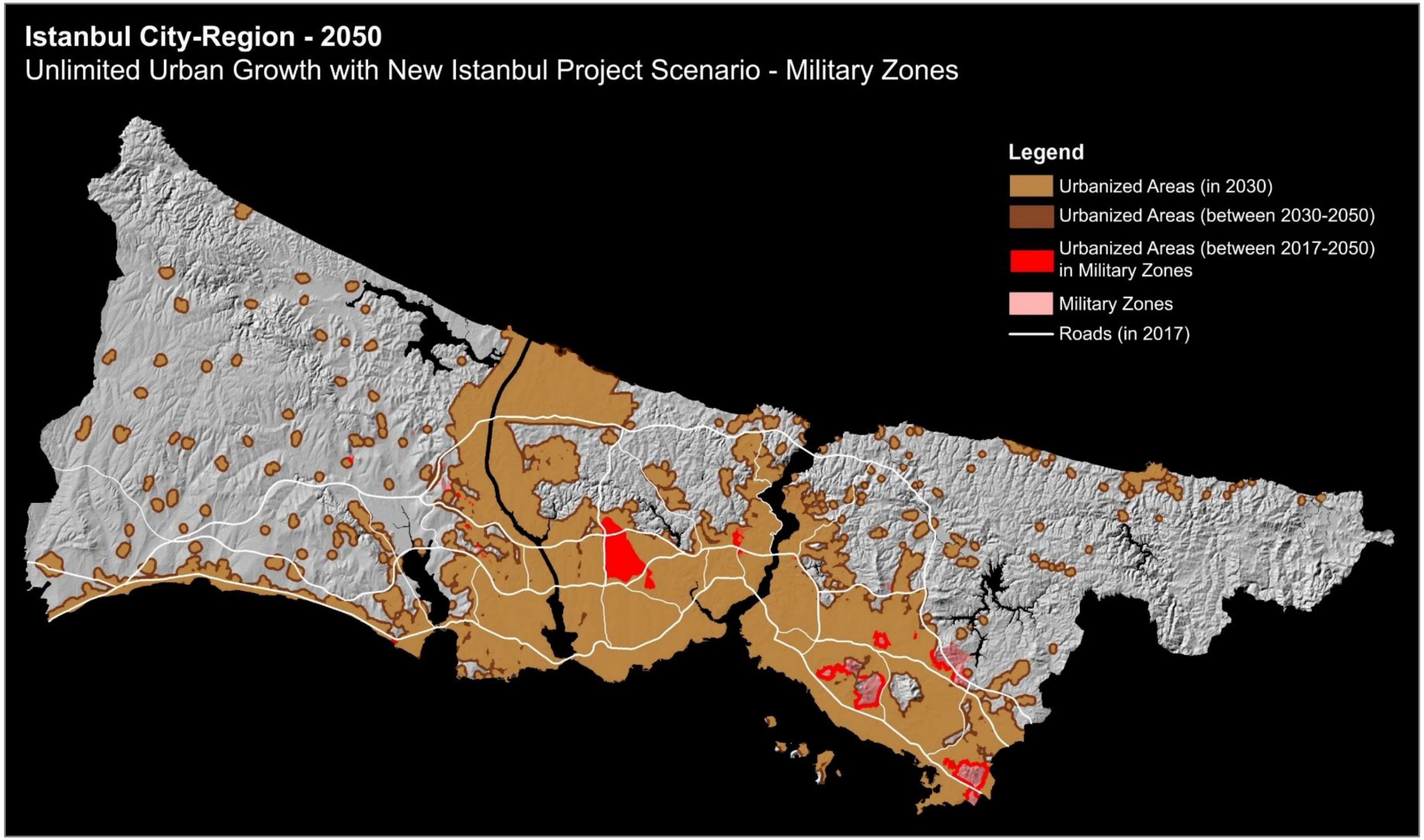

Figure 4.75: Military Zones of Istanbul City-Region in 2050 – Unlimited Urban Growth with the New Istanbul Project Scenario

4.2 Discussion

As a result of the application of resilience assessment framework for Istanbul City-Region, degradation and loss of the life support systems determined as the main issue of assessment. Providing various goods and services for the system; water resources, forest areas and natural conservation areas are the key components of the social-ecological system. In spite of their importance for the resilience and sustainability of the system, these components are being degraded and destroyed for the sake of development. In Istanbul City-Region case, these important components of the system are being degraded and destroyed as a result of urban growth and population increase.

Table 4.6: Total Urban Areas and Population in 2050

	Limited Urban Growth Scenario	**Managed Urban Growth Scenario**	**Unlimited Urban Growth Scenario**	**Unlimited Urban Growth with 3rd Airport Project Scenario**	**Unlimited Urban Growth with New Istanbul Project Scenario**
Total urban areas in 2050	109 754 ha	136 820 ha	184 461 ha	190 810 ha	191 108 ha
Total population in 2050	16 744 070	20 873 259	28 141 370	29 109 974	29 155 437

Prediction results of the urban growth simulations support this claim. Except for the Limited Urban Growth Scenario, a large amount of urban growth was observed in all scenario alternatives. Urban areas were covering nearly 98 513 ha of the Istanbul City-Region's surface area in 2017. With the scenario alternatives of Unlimited Urban Growth, surface areas of urban areas nearly duplicate in 33 years. Since total population of Istanbul City-Region was 15 029 231 in 2017, the population density was calculated as 152.56 people per hectares. Assuming that the population density would be constant for the prediction period, total population of Istanbul City-Region was calculated for each scenario alternative (Table 4.6). As a result, it was estimated that the total population of Istanbul City-Region in 2050 would exceed 28 million with Unlimited Urban Growth scenarios. However, considering the carrying capacities of life support systems, 2023 population of Istanbul City-Region was determined as 16 million with 1/100.000 scaled Environment Plan of Istanbul. In other words, with Environment Plan it was indicated that Istanbul City-Region would not carry a population higher than 16 million people. With increasing population, the demand on scarce resources would also increase. On the other hand, increasing population and expanding urban areas consume and pollute already scarce resources. Prediction results support this claim.

Prediction results also reveal that an important amount of natural resources of Istanbul-City Region would be lost in 2050 (Table 4.7). As a result of the Limited Urban Growth scenario, only 731 ha of natural resource areas would be lost. However, this conservative scenario alternative is the least possible one. With business as usual scenario alternative of Managed Urban Growth, 17 377 ha of natural resource areas would be lost. As a result of Managed Urban Growth scenario 6716 ha of Agricultural Lands and 5928 ha of Forest Areas would be lost in 2050.

With the scenario alternatives of Unlimited Urban Growth, total amount of area loss exceeds 75 thousand hectares. As a result of Unlimited Urban Growth scenario, nearly 15% of natural resource areas would be lost. With Unlimited Urban Growth scenario nearly 31 154 ha of Agricultural Lands, 23 859 ha of Forest Areas, 13 640 ha of Natural Conservation Areas and 7 880 ha of Water Basin Preservation Areas would be lost.

As a result of Unlimited Urban Growth with 3rd Airport Project scenario, nearly 16% of natural resource areas would be lost. With this scenario alternative nearly 36 791 ha of Agricultural Lands, 24 130 ha of Forest Areas, 13 129 ha of Natural Conservation Areas and 7 623 ha of Water Basin Preservation Areas would be lost. With the construction of 3rd Airport on the catchment areas of Pirinççi, Terkos and Alibey Dams, amounts of water catchment would decrease while the pollution increases (Gürbüz, 2014). Also, 3rd Airport is being constructed on an important bird area that is located on one of the bird migration routes of Turkey and provides shelter for more than 200 bird species (Arslangündoğdu, 2014). Construction of the airport on a bird migration route not only not only destroys an important habitat but also cause aviation accidents.

Table 4.7: Total Area Losses between 2017 and 2050

		Agricultural Lands	**Forest Areas**	**Natural Conservation Areas***	**Preservation Areas of Drinking Water Basins****	**TOTAL**
total surface areas in 2017 without urban areas		165 210 ha	237 481 ha	77 830 ha	49 379 ha	529 900 ha
total area loss between 2017 and 2050	**Limited Urban Growth Scenario**	176 ha (0.11%)	315 ha (0.13%)	168 ha (0.22%)	72 ha (0.15%)	731 ha (0.14%)
	Managed Urban Growth Scenario	6716 ha (4.07%)	5928 ha (2.50%)	3031 ha (3.89%)	1702 ha (3.45%)	17 377 ha (3.28%)
	Unlimited Urban Growth Scenario	31 154 ha (18.86%)	23 859 ha (10.05%)	13 640 ha (17.53%)	7880 ha (15.96%)	76 533 ha (14.44%)
	Unlimited Urban Growth with 3rd Airport Project Scenario	36 791 ha (22.27%)	24 130 ha (10.16%)	13 129 ha (16.87%)	7 623 ha (15.44%)	81 673 ha (15.41%)
	Unlimited Urban Growth with New Istanbul Project Scenario	34 485 ha (20.87%)	19 688 (8.29%)	10 432 ha (13.40%)	11 195 ha (22.67%)	75 800 ha (14.30%)

* Including 1st, 2nd and 3rd Degree Natural Conservation Sites, Nature Parks, Nature Reserve Areas, and Wildlife Improvement Areas.
** Including Strict, Short Distance, and Medium Distance Preservation Areas of Drinking Water Basins.

As a result of Unlimited Urban Growth with New Istanbul Project scenario, nearly 15% of natural resource areas would be lost. With this scenario alternative nearly 34 485 ha of Agricultural Lands, 19 688 ha of Forest Areas, 10 432 ha of Natural Conservation Areas and 11 195 ha of Water Basin Preservation Areas would be lost. With construction of a Canal between Küçükçekmece Lake and Black Sea, Küçükçekmece Lake and Sazlıdere Dam would be destroyed. Hence, one of the scarce drinking water resources of Istanbul City-Region, Sazlıdere Dam, would be lost for the sake of a transportation project (Tolunay, 2014). Also, even though Küçükçekmece Lake could not provide drinking water anymore, it continues to provide various ecosystem services for Istanbul City-Region. This important ecosystem would also be lost for the sake of Canal Istanbul Project. Construction of a Canal near groundwater reserves would also cause to salinization on groundwater (Gürbüz, 2014).

In addition, with Canal Istanbul Project the balance of sea systems would be destroyed. Opening a second connection between Marmara Sea and Black Sea would change the dynamics of sea ecosystems. Balance between the upper and lower layers of Istanbul's straits system would be destroyed by the Canal Project. Also, polluted water flow from Black Sea would increase and the pollution level of Marmara Sea would increase rapidly (Özsoy & Saydam, 2014).

CHAPTER V

CONCLUSION

As a result of the combination of coefficient values that were determined for Istanbul City Region through brute-force calibration process, an Organic (Edge) Type of Urban Growth pattern was observed in all of the scenario alternatives. Although a New Spreading Centres (Diffusive) type of an urban growth pattern was also expected to be observed with a value of '100' for the Breed coefficient, an Organic type of urban growth pattern dominated all of the scenario alternatives for Istanbul City-Region.

As it was elaborated in the Literature Review chapter, a single growth cycle of the model is composed of four successive growth types. These growth types of; Spontaneous, New Spreading Centres (Diffusive), Organic (Edge) and Road-Influenced Urban Growth follow each other, in each growth cycle. Different sets of the growth coefficients control the urban growth in these successive growth types or phases. The first phase of Spontaneous Urban Growth depends mainly on the Diffusion coefficient. Therefore, with a value of '4' for the Diffusion coefficient, there should have been limited urban growth in this phase of the growth cycles. On the other hand, the second phase of New Spreading Centres urban growth mainly depends on the Breed coefficient and the amount of urban growth in the previous phase of Spontaneous Urban Growth. Thus, even with the highest value of '100' for the Breed coefficient, the New Spreading Centres type of urban growth should have been limited by the amount of urban growth in the previous step of the cycle. On the contrary, the third phase of Organic (Edge) urban growth does not rely on the amount of urban growth in the previous phases of growth. Therefore, depending mainly on the value of Spread coefficient, Organic (Edge) Urban Growth should have been the dominant type of urban growth in Istanbul City-Region with a value of ‘80’ for the Spread coefficient.

As it was mentioned before, the amount and type of urban growth in the predictions are determined by the values of growth coefficients and the images of exclusion. In addition to the values of growth coefficients, the exclusion levels of conservation areas determine the amount and direction of urban growth in scenario alternatives. Thus, using the exclusion images of conservative, moderate and aggressive scenario alternatives with different combinations of input images, five scenario alternatives were tested in this study.

As expected, the lowest amount of urban growth was observed in the conservative scenario alternative of Limited Urban Growth with an increase of 11 241 ha (11.41%) between 2017 and 2050. On the other hand, with aggressive scenario alternative of Unlimited Urban Growth, the total surface area of urban areas reached 184 461 ha in 2050 with an increase of 85 948 ha (87.25%) since 2017. Thus, without any protection of the conservation areas in Unlimited Urban Growth scenario alternative, nearly eight fold of the urban growth in Limited Urban Growth scenario alternative was reached.

Although the highest amount of urban growth took place in the scenario alternative of Unlimited Urban Growth with New Istanbul Project with 92 595 ha, the growth in conservation areas was only 87.7% (81 172 ha) of this amount. Whereas, with 86 219 ha of urban growth in conservation areas between 2017 and 2050, the highest amount of growth within the boundaries of conservation areas took place in the scenario alternative of Unlimited Urban Growth with 3rd Airport Project. On the other hand, in terms of the ratio of growth in conservation areas to growth in total, the highest rate was observed in the scenario alternative of Unlimited Urban Growth with 94.5%. In brief, even though the highest amount of urban growth took place in the scenario alternative of Unlimited Urban Growth with New Istanbul Project, the amount of growth within the boundaries of conservation areas in this scenario alternative was the lowest among other aggressive (unlimited growth) scenario alternatives. A possible explanation for this might be that the projects of urban development not only increase the amount of urban growth but also change the direction of growth. This situation underlines the role projects on attracting urban growth and emphasizes the importance of holistic planning practices.

Without any protection for the conservation areas, more than 87% of the total urban growth in all three scenario alternatives of Unlimited Urban Growth took place within the boundaries of conservation areas. More than 80 000 ha of conservation areas became urbanised in these aggressive scenario alternatives. Conversely, only 6.5% of total urban growth in scenario alternative of Limited Urban Growth took place within the boundaries of conservation areas and only 731 ha of conservation areas became urbanised between 2017 and 2050. On the other hand, with 17 929 ha of growth, nearly 47% of total urban growth took place within the boundaries of conservation areas in the scenario alternative of Managed Urban Growth.

In all five of the scenario alternatives, the highest amounts of urban growth within the boundaries of conservation areas took place in Agricultural Lands and Forest Areas. In both Limited and Managed Urban Growth scenario alternatives; 3rd Degree Natural Conservation Sites, Medium Distance Preservation Areas of Water Basins and 1st Degree Natural Conservation Sites followed these areas, respectively.

Despite the fact that Agricultural Lands and Forest Areas were totally (100%) excluded from urban growth in the scenario alternative of Limited Urban Growth, nearly 67% (491 ha) of the urban growth in conservation areas took place within the boundaries of these areas in this scenario alternative. The urban growth in these totally excluded areas could be a result of the urbanization pressure induced by the values of growth coefficients that were determined through the calibration process.

As a result of the strict protection of all conservation areas in this scenario alternative, the pressure of urban growth should have been directed to the edges of existing urban areas and resulted in illegal housing in the strictly protected areas. Therefore, having the largest borders with urban areas, Agricultural Lands and Forest Areas could have been exposed to urban growth despite their exclusion from the urban growth. These findings suggest that it is not possible to protect conservation areas without managing the amount and direction of future urban growth. Hence, in order to protect the conservation areas from urban growth, policies and strategies for controlling the amount and direction of urban expansion should also be developed.

In spite of the inclusion of nearly 7590 and 27 524 hectares of additional urban areas with the projects of 3rd Airport and New Istanbul, respectively, the amount of total urban growth in the scenario alternatives of Unlimited Urban Growth did not differentiate as much as it was expected. Total amount of urban growth between 2017 and 2050 was predicted to be 85 948 ha in the scenario alternative of Unlimited Urban Growth without inclusion of any urban development projects. On the other hand, with inclusion of the expropriation area of 3rd Airport Project as an urban area in 2018, total amount of urban growth predicted to be 92 297 ha in the scenario alternative of Unlimited Urban Growth with 3rd Airport Project. Despite the addition of 7590 ha area to urban areas in 2018, the total amount of urban growth in this scenario alternative exceeded the amount of growth in Unlimited Urban Growth scenario by only 6349 ha. Furthermore, with inclusion of the expropriation area of New Istanbul Project (33 174 ha) as urban area, the total amount of urban areas reached 152 704 ha in 2030. Nonetheless, in spite of the addition of 27 524 ha area to urban areas in 2030, the total amount of urban growth in this scenario alternative exceeded the amounts of growth in the scenario alternatives of Unlimited Urban Growth and Unlimited Urban Growth with 3rd Airport Project by only 6647 and 298 hectares, respectively.

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Appendix A

Key Questions and Guiding Principles for the Resilience Assessment Framework Presented in the Version 1.0 of A Practitioners Workbook by Resilience Alliance (Resilience Alliance, 2007a)

Step 1.1 – Describing the Present

- What are the main issues that need to be addressed?
- For each issue, what is a reasonable geographic boundary for your system?
- Given the central issue or challenge, what is an appropriate time span over which to examine this system?

The Natural Resources

- What are the main natural resource uses in the focal system (those that are important and need to be included in the assessment)? Consider also the perspectives of others not present (including future generations)—are there uses they would have added to the list?
- Are there critical non-marketed ecosystem goods and services (i.e., the benefits that society derives from ecosystems) that are derived from the region?

The People

- Who are the key stakeholder groups in the region (particularly with respect to policy, management and use of natural resources)? Consider including future generations in your analysis. How might their values and goals for managing natural resources be considered?

- Are there major conflicts between stakeholders, particularly with regard to the central issue you have identified above? Are there important points of agreement?
- What is the economic status of each group? Are people generally wealthy or poor? To what extent are their options constrained by lack of financial resources?
- Can you identify individuals or organizations that have key leadership roles with respect to the issue of interest to your group?
- Is learning and innovation a strong or weak feature of the community? What are the sources of learning and innovation?

Governance

- What are the property rights in your focal system? Are there mainly public lands (waters), private lands (waters), common property lands (waters) or a mixture of all three? What are the access rights on these lands (water bodies)? Do the different kinds of tenure conflict with or complement each other?
- What organizations control or manage the critical resources in your focal system? What are the relationships between these organizations (pecking order, etc.)?
- Are there other, informal institutions that are important with respect to resource use?
- Where does the real power lie? Who has the power to influence your issue?
- Are there key policies, laws or regulations governing resource use that enhance or constrain flexibility to manage resources and issues that arise?
- What information were you missing for the analysis above? Devise a plan for obtaining the information. Are there key individuals/groups who should participate in the assessment?

Step 1.2 – Multiple Scales

- What are the higher and lower level policy structures or groups (both governmental and non-governmental)? What are the organizations, above and below your focal scale, that deal with cultural issues or social values and what are the major interactions they have with your focal system?
- Why are these appropriate critical scales? In other words, what are the major influences on or interactions they have with your focal scale?

Step 1.3 – Historical Timeline

- How would you characterize the system before the transition? How would you characterize the system after the transition?
- How often do 'triggering events' come from the coarser scale(s)? How often from the finer scale(s)? How often from the economic domain? The social? The ecological? In other words, what are the critical domains in your system, and is there a pattern of cross-scale interactions?

Step 1.4 – Disturbances

- Which of these disturbances appear most threatening to the valued attributes of your focal system? In other words, which might have the capacity to introduce a severe 'shock' to the system?
- Consider the disturbances identified above. Which of these are actively managed, or suppressed? Is there any reason to believe that there is too much suppression of any of the disturbances—in other words, that by overly protecting the system (be it ecological or human) you are making it less resilient and more vulnerable to unmanaged disturbances? Should any of these management strategies be reconsidered?

Step 2.3 – Scenarios

- What surprises (i.e. changes in focal configuration, or in external drivers) would lead to one or more of these future states?

- What indicators would you track to know which, if any, of the trajectories might be currently on-track?

Step 3.1 – Cycles of Change

- What phase is each of these [social, economic, and ecological domains] in? What does this mean for the overall phase of the system?
- How long have each of the domains been in their current phase? How long has the whole focal system been in its current phase?
- Does the system appear to be close to changing into another phase? If yes, what current dynamics or situations lead you to that conclusion?
- Using the information that you developed in the timeline activity, can you identify past adaptive cycles for your focal system? How long did each last? Did those cycles conform to the basic sequence of change in the adaptive cycle or did they appear to follow a different trajectory? If so, what trajectory?
- What crisis or disturbance (review the list of disturbances developed previously) appeared to trigger the move from the fore loop to the back loop? What structures or characteristics of the system made it vulnerable to that crisis or event? (In other words, why wasn't the crisis absorbed without triggering a back loop?) Was the next adaptive cycle very similar to, somewhat similar to, or very different from the previous one? If different, how was it different? If it is the same, what does that say about the back loop in terms of thresholds?

Innovation and Learning

- What were the sources of innovation and learning you identified? Are these retained through all phases of the adaptive cycle? Are different strategies required to promote them in different stages of the adaptive cycle? Should you consider promoting more innovation and learning—for example, retaining the innovators even when things appear to be going smoothly?

Front Loop

- How much flexibility—in the social, economic, and ecological domains—have you retained in your system? Is there a reasonable balance between flexibility and efficiency? If not, how can balance be reintroduced?

Back Loop

- What plans are in place, if any, to retain critical capital during periods of change and reorganization? Is more needed?

Step 3.2 – Cross-scale Interactions

- What phases of the adaptive cycle are your finer scale sub-systems in? Are each of these sub-systems at the finer scale(s) in a similar phase of the adaptive cycle, or different phases? How does this pattern depend on domain (social, economic, and ecological)?
- Are the innovations and learning that come from back loops at the finer scales being captured at the focal scale? If not, what mechanisms can be put into place for capturing this innovation and learning, and incorporating needed flexibility at the focal scale?
- What phase of the adaptive cycle do the larger-scale systems (i.e. larger than your focal-scale system) appear to be in?
- What are the main larger-scale influences on your focal system? Does memory exist mostly in the ecological, economic and/or social domains?
- How many new adaptive cycles replicate older ones? What sources of memory might have been acting in the system then?
- Considering the phases of the adaptive cycle in which you find your focal system and the larger-scale systems, in what ways do the larger-scale systems (in both ecological and social components) constrain the focal system? How have inputs from larger-scale systems fostered change or resisted change in your focal system?

- As an initial assessment, would you say there is a good balance between flexibility and efficiency in your focal system? In other words, is your focal system likely to avoid moving into a late ‘conservation’ phase?
- What management strategies are needed, if any, to enhance memory from larger scales or reduce constraints?
- Is your focal system in a conservation phase? Are the finer scale sub-systems also in a conservation phase? If both the focal system and sub-systems are all in a conservation phase, then there is an increased risk of disturbance cascading across scales. Are conditions such that you may want to create large-scale change in your focal system?
- If the nested set of systems is aligned in the conservation phase, but large-scale change is to be avoided, what management strategies might help break this alignment? What costs or challenges might come from breaking this alignment? Can you put into place programs to minimize the costs, or make them tolerable?
- If the constraints from the larger-scale system are too stringent, are there individuals or organizations that you can approach to discuss how to weaken these constraints in order to build resilience and flexibility? Who are those individuals and organizations?

Stage 4 – Adaptability and Transformative Change

- Is transformation of the system desirable or necessary? What obstacles can you identify to transforming the system? How might you get around those obstacles?
- Identify individuals or organizations that have key leadership roles. Are there mechanisms in place to develop leaders and leadership skills?
- How would you characterize the levels of ‘trust’ among key stakeholders in the system?
- Do stakeholders at all levels of governance have a say in the management of the system? What mechanisms are in place for gathering and incorporating input from stakeholders into the management of the system?

- How would you describe the capacity of the community to respond to crisis or disturbance? What limits this capacity?
- Which forms of capital present in the system most need to be enhanced?
- What is the role of social networks in the system? Do they tend to be dynamic or restrictive i.e. are existing social networks perceived as beneficial to the system or do they impede opportunity for change and innovation?
- How is knowledge-sharing among stakeholders facilitated? Is the process of knowledge-sharing formalized or institutionalized in any manner?
- Consider the following list of examples for building capital and trust – are any of these practices occurring in the system?
  - strategic investments to secure ecosystem goods and services
  - incorporating ecological knowledge into institutional structures
  - creating social and ecological network
  - combining different forms of knowledge for learning
  - providing incentives for stakeholder participation
  - identifying and addressing knowledge gaps
  - developing expertise
- Is the system being managed for enhanced resilience to specific threats? If so, does this focus on a specific aspect of the system strengthen or challenge the system's overall general resilience?
- What institutions (formal and informal) are important in regards to resource use in the system? How flexible are these institutions? Is innovation, encouraged in these institutions? If not, how might this be changed?

Appendix B

Key Questions and Guiding Principles for the Resilience Assessment Framework Presented in the Version 1.1 of A Workbook for Scientists by Resilience Alliance (Resilience Alliance, 2007b)

Step 1.1 – Resilience of What?

- What are the big issues? Can they be considered collectively (preferable), or do they need to be dealt with separately?
- What are the "variables of concern"? What is it that the stakeholders (from all scales) are concerned about and wish to maintain?
- Identify, and approximately demarcate the boundaries of, the scales you need to consider.
- Considering the ecosystem goods and services that support the main resource uses and also the non-marketed ecosystem goods and services, relatively, how important are these biophysical variables? Which of them are most significant and need to be included in the assessment?
- From the perspective of the key groups of people in the region (i.e., with respect to policy, management, and use of natural resources), what conflicts, issues, and challenges do they face? And what conflicts, issues, opportunities, and challenges might future generations face?
- Which of these challenges, conflicts, opportunities, and issues most need to be included in the analysis?

Step 1.2 – Resilience to What?

- What are the system drivers and disturbances?

- What are the trends in the major resources (soils, water, biota), and the major resource uses?
- What important ecological and social changes are currently taking place? How have they changed over time - gradual ramp up, slow decline, rapid jump, collapse, oscillation?
- What are the characteristic disturbances, in both the social and ecological domains, at each relevant scale? Are there changes in the patterns of these disturbances – in frequencies or intensities? Are there novel kinds of disturbances emerging? Are there attempts by managers to control or modify these disturbance events?
- Develop a historical profile of the system. Identify the times/periods of major events that changed the system. It is useful to do this at each scale of analysis (the focal scale, below and above), and identify cross-scale connections – how events at one scale either caused or resulted from events at another scale.
- How has the system been modified to alter the flows of a) goods, and b) ecosystem services?
- Considering these modifications, re-visit the "big issues". Do they need to be changed?
- Using the insights gained from this historical profile, try to identify underlying controlling variables (often ones that have been changing slowly) that caused changes in the natural system, the people, and in the interventions that people made.

Step 1.3 – People and Governance

- Identify individuals or organisations who have key leadership roles.
- Where does the real power lie? Who has the power to influence the system, directly through changing policies, or indirectly through voting, lobbying, advertising, or funding those with direct power?
- At each scale of governance: What are the property rights? How much public land (or water) and private land is there, and are there common

property resources? Are property rights, and access rights, clear and agreed by all? How do the different kinds of tenure conflict with or complement each other, and is their juxtaposition a factor in this?

- Who controls resource use and regulations at each relevant scale? What are the relationships between the control agencies? How much overlap is there?
- What other formal bodies exist in regard to resource use (e.g., advisory)?
- What other informal institutions are important in regard to resource use (e.g., lobby groups, informal associations or groups)? How flexible or variable are they?
- How effective are social networks and what role are they playing (or could they play) in learning and changes in resource use and management?
- Are there key policies, laws or regulations governing resources use that enhance or constrain flexibility to manage resources and issues that arise?
- Are there cross-scale influences (such as interactions of national land tenure with traditional local tenure)?

Step 2.1 – Developing Conceptual Models

- What mental models of ecosystem dynamics exist, for different user groups, and how do they differ between user groups, and between users and researchers? How do they differ in regard to the responses of ecosystems to various kinds and levels of use?
- How do the mental models of social 'values' and benefits derived from ecosystem use differ? Are there clearly different attitudes to ecosystem use and the value of ecosystems to society?
- Does the system (at the focal scale of interest) appear to be in a particular phase of the adaptive cycle? If so, how long has it been in that phase, and does it appear to be approaching a phase change? Refer back to the historical profile and examine it for a likely pattern involving the current system state.
- Can you identify the main scales above and below the focal scale? Considering the issues you identified earlier, what are the most significant

cross-scale influences (effects) that have a bearing on the dynamics of the system at the focal scale?

- Using the mental models that stakeholders (including scientists) have of ecosystem dynamics, develop a conceptual and/or state-and-transition model of how the system behaves. Consider the following set of questions to guide model development:
- What does the system consist of? Based on what's been learned about the variables of concern, the controlling variables that determine their dynamics, and the drivers and disturbances, start describing the system in terms of a box-and-arrow diagram.
- For a state-and-transition model, What are the possible states (structures) the system can be in? What transitions between the states are possible? Can you identify possible future trajectories (development pathways) of the SES? For these trajectories, can you identify any different "end-states" the system could be headed for, and what the intermediate states might be? Where, along the various pathways, are there non-return points, that foreclose moving to other trajectories?
- Critical assumptions: In this conceptual model try to identify, make explicit, and keep track of the assumptions that underlie the dynamics. Which assumptions need to be tested, either in models or through management?

Step 2.2 – Alternate System Regimes

- Can you now develop a conceptual model of possible regime shifts, and of thresholds? Can you posit alternate basins of attraction, at various scales, in the ecological, economic and social domains?
- Which drivers are pushing the system towards thresholds, and which disturbances (shocks) are likely to cause the system to cross a threshold?
- What are the likely consequences for the system if these thresholds are crossed? Is it possible to restore the system to its original state once these thresholds have been crossed? Are there alternate regimes (basins of

attraction), either realized or potential, and can the system flip into an alternate undesirable regime?

- Is the system already in an undesirable basin? If so, is it possible (technically/economically/legally/socially, etc.) to navigate out of that basin?
- Likely pathways into the future (scenario analysis). Identify 2 or 3 possible pathways into the future, in terms of land use, livelihoods, population numbers and distribution, climate, economic conditions, etc., that bracket the range of possible futures.
- Considering the possible state changes suggested by the state and transition 'model', are there any likely transitions that indicate irreversible, or hysteretic, changes? What are the controlling variables in the system on which these thresholds might occur? Consider also possible future changes in flows of desired ecosystem goods and services and desired social conditions in identifying these controlling (slow) variables.
- What kinds of economic and social tipping points (e.g., in social attitudes that might lead to changes in regulations) are likely or possible in the transitions between states?
- Feedback changes: What feedbacks are evident in the pattern of system dynamics, in regard to the ways in which the amounts of these key slow system variables are regulated? Consider both negative and possible positive feedbacks. In particular, what feedbacks occur between the ecological and social domains?
- From conceptual to quantitative models: Try to determine where the thresholds are, and what determines their positions on the controlling variables (a quantitative model may be helpful in determining threshold positions but quantitative assessment of thresholds is technically challenging).

Step 2.3 – Likely Interactions Among Thresholds

- Considering each of the derived future pathways (scenarios) in turn, examine the effects of likely "shocks", including normal variation in environmental or social conditions, on the dynamics of the system in relation to each threshold, and assess the relative likelihoods that the thresholds will be crossed. Using the Fig 4 type of template, develop possible/likely sequences (cascades) of thresholds being crossed.

Step 2.4 – Cross-examination of Models with Attributes

- Response diversity. Are there key functional groups (ecological or social) that are represented by only one or two different species or members? Has response diversity changed? Increases in efficiency of production (eg, removal of apparent redundancy) can reduce response diversity and decrease resilience. Has this kind of efficiency been increasing? Is it a goal of management?
- Feedback changes. Thinking about feedbacks that control key 'slow' variables, what has changed, is changing, or is likely to change? Are feedbacks in the system getting weakened or delayed? Is the gap between an individual's or an organisation's actions, and their knowledge of the consequences of those actions, widening?
- What are the current directions and rates of change of important slow variables? What could alter this? Which variables influence it?
- Is the system becoming more inter-connected? How does this aspect relate to identified processes and feedbacks?
- Governance. How important are elements of the governance system (described in section 1.3.2) in influencing the capacity of the social domain to respond to and manage the resource base? And how important are they in the resilience of the governance system itself?
- Social capacity. This is a difficult aspect to get to grips with and the following questions are meant as guides to help identify where attributes of the social system are constraining (or facilitating) adaptability. Some may not be quantifiable but it may be possible to use a relative, or scale approach.

- How capable is the community of responding to a crisis or disturbance? How long does it take society to respond? Importantly, what limits (or facilitates) this capacity? What is the status of community organisation (e.g., local stewards)? What social networks are in operation and are they dynamic, or restrictive? Are any feedbacks changing in the social networks? Is there evidence of: self-organisation and action, communication infrastructure and networks, lobby groups?
- Are there mechanisms in place to develop leaders and leadership skills? What is happening to trust in the system – within social groups, and between social groups?
- Learning. How strong is learning in the system and how does it occur? Is it an ongoing process? What limits it? Are reservoirs of knowledge and information formalized or transient? Is experimentation being encouraged or dampened? What kinds of encouragement (e.g., subsidies) is in place in regard to either promoting novelty or inducing people to keep on with the same practices? Is innovation evident? What are the sources/evidence of new products, crop types, markets, institutions?
- What particular aspects of the social system are critical in determining social capacity in this system?
- Changes in capitals. Relatively, what kinds of capitals (natural, built, human, social, financial) are mostly acting as limiting factors in determining adaptability? Which aspects of these capitals are the most important?

Step 2.5 – Cycles of Change and Cross-Scale Interactions

- What phases of the adaptive cycle does the system, at each of the scales, appear to be in? What are the implications of this for the dynamics and likely future changes in the system at each scale?
- What are the major influences from the scales above, and are they constraining or facilitating changes at the focal scale?
- Are there particular aspects of the spatial pattern and/or inter-connections of the sub-divisions at any scale that are important in their dynamics and/or

the ways they are used? How do the kinds and levels of connectivity at scales below the focal scale influence its adaptability and capacity to respond?

Appendix C

Guiding Questions for the Resilience Assessment Framework Presented in the Revised Version 2.0 of Workbook for Practitioners by Resilience Alliance (Resilience Alliance, 2010)

Step 1.1 – Identifying the Main Issues

- To whom are the valued attributes important?
- What is an appropriate time span over which to examine this system?
- Is the main issue(s) already being actively managed? If so, how effective has this management been?
- What are the environmental and social impacts of the main issue(s) that was identified?

Step 1.2 – Resilience of What?

- What is the level of resource dependence in the focal system?
- Are the resources held under public, private, or common property, or a combination thereof?
- Are there additional rights or conflicts associated with the resource?
- Considering the main resource use(s) that is central to the main issue, what are the key ecological components of the natural resource that change relatively slowly over time?
- What are the key ecological components of the natural resource that change relatively fast over time?
- Who are the key stakeholders and what role(s) do they play in the system?
- What are the main ecosystem services that are most important to stakeholders and others?

Step 1.3 – Resilience to What?

- Have any of the disturbances altered the nature of system or caused it to change in a fundamental way?
- Which disturbances pose the greatest threat to the valued attributes of the system?
- Are there any changes in magnitude or frequency of disturbances in time? If so, what might be driving these changes?
- Are there any problematic management strategies?
- What is known (in summary) about the main disturbance regime(s) of the system?
- What are the main disturbance events?
- What are the social and ecological impacts of disturbances in the system?

Step 1.4 – Expanding the System

- What were the driving forces that contributed to or triggered major change?
- Are there any obvious patterns in the historical timeline?
- Are there any patterns of cross-scale interactions?
- What are the larger-scale external controls that interact in a significant way with the focal system?
- Are there smaller nested systems that affect any of the faster-changing components of the focal system?
- How do current institutional responses differ from those in the past?

Step 2.1 – A Conceptual Model of Change

- Which change-causing drivers or factors appear to play a major role in the functioning of the system?
- What types of natural and social capital should be maintained in the system to enable reorganization and renewal?

- Are there key system components that change relatively slowly or quickly and that should be added to the SES model?
- If the adaptive cycle exercise revealed any new insights into social and ecological impacts or institutional responses, add these to the model.

Step 2.2 – Multiple States

- How do the alternate states of the system map onto the adaptive cycle? Are they represented by different phases of the adaptive cycle or would they be more accurately described using separate adaptive cycles?
- Are there undesirable alternate states that are to be avoided? What are the main challenges associated with moving away from these undesirable states?
- Without oversimplifying, are there components of the SES that you might want to remove or set aside from the model?
- What are the key slow variables associated with thresholds that are (or would be) responsible for a shift between the alternate states that you identified previously? At what scale do these slow variables operate?

Step 2.3 – Thresholds and Interactions

- How might the focal system in its current state experience transition into each of the alternate states?
- What are the most critical thresholds and the most undesirable states of the system?
- Are any of the system disturbances likely to move the system closer to a threshold?
- How do any of the thresholds in social subsystem interacts with thresholds in the ecological subsystem (and vice versa)?
- Are there any thresholds that you may have overlooked because of the level of expertise of those conducting the assessment?
- What are the system disturbances identified earlier that might mode the system closer to a threshold?

Step 3.1 – Cross-scale Interactions

- In what ways do the larger-scale systems either foster change or constrain the focal system?
- Are the innovations and learning coming from smaller-scale subsystems being captured at the focal scale? If so, how? If not, what mechanisms can be put into place to take advantage of this innovation and learning?
- Are there any opportunities for leveraging cross-scale interactions to achieve desirable outcomes at the focal scale?
- Do any of the cross-scale interactions … involve the slowly changing variables …?

Step 3.2 – Interacting Thresholds and Cascading Change

- What evidence do you have for the thresholds that you have identified?
- How might you go about improving the level of certainty you have for each of the thresholds?
- Are there any potential slow variable thresholds that are vulnerable to disturbances?

Step 3.3 – General and Specified Resilience

- Which attributes pose the greatest threat to general resilience in focal system?
- In which parts of the system is there little or no diversity [or openness, tightness of feedbacks, system reserves, modularity, etc.], which might render the system vulnerable to a loss of function?
- Are there any trends that reflect declines in diversity [or openness, tightness of feedbacks, system reserves, modularity, etc.]?
- Are there potential slow-variable thresholds that you previously identified with respect to general system resilience?

Step 4.1 – Adaptive Governance and Institutions

- What key formal and informal institutions have a bearing on decision-making within the focal system? Do any of these enhance or constrain flexibility to address issues as they arise?
- At what levels are key decisions being made that affect the focal system and the main issue(s) of concern? Are these levels appropriate given the issue(s) of concern in the focal system?
- Is rule compliance and enforcement effective?
- Are conflict resolution mechanisms in place to deal with power inequalities and differences in values, interests and perspectives? Is there a general willingness to engage in in collaborative decision-making?
- Is decision making concentrated within a single group or institution, or is a diversity of institutions accepted by stakeholders?
- Is the current governance system geared toward responding to ecological changes at the appropriate scales? If not, how might it be improved?
- Is decision-making taking place at larger scales (external to the focal system) that significantly impact your focal system?
- Are there power dynamics in the social domain of your focal system that significantly influence how the system is structured and how it functions?
- What role does the governance of your focal system play in the potential for crossing or avoidance of slow-variable thresholds in your diagram?

Step 4.2 – Social Networks Among Stakeholders

- In the focal system, are there any highly central actors in the network? Are subgroups present? If so, how isolated are these subgroups?
- Are there key people or groups of people who are not connected to others? How might this affect the potential for solving resource conflicts, reaching consensus on management strategies, etc.?
- To what extent do highly central and potentially influential actors represent the views and interests of the other stakeholders? If centrality is a strong

feature of the network, is it a source of social cohesion or a potential barrier to achieving it?

- Are there any actors in the network that link otherwise separated groups and do they represent bridges or barriers to collaborative governance?
- Are there multiple groups of actors, or are all actors connected within one large group? What might be the implications of this characteristic of the network in terms of achieving social cohesiveness versus maintaining specialised knowledge and expertise?
- Are there isolated subgroups that might pose a barrier to social cohesion?
- To what extent does the network "hang together" instead of being divided into separate subgroups?

Step 5.3 – Time for Transformation?

- If the focal system is heading toward a threshold of potential concern, how is the general resilience of the system likely to be affected by a transformation in governance and management?
- In whose interests might a transformation be, and who might be negatively affected?

Appendix D

Guiding Questions for the Resilience Assessment Framework Presented by Walker and Salt (2012)

Step 1 – Describing the System

- What are the significant components and interactions in your system that need to be taken into account?
- What's the minimum, but sufficient, information we need to incorporate in our understanding—our models—to make robust decisions about planning and management?

Scales

- How would you frame the area that encompasses what's important to you?
- What resource sectors are present in your focal scale? For example, are they dryland farming, irrigated farming, biodiversity conservation, water flow regulation (weirs and dams), forestry, mining? From where do the people in these sectors get the inputs they need, and where are their markets?

People and Governance

- What are the "user groups" (sectors) and what are their "rights" or entitlements-especially their property and access rights?
- What rights do people have to access or control resources? Are property rights and access rights clear and agreed to by all, or are rights a contentious issue?
- How do the different kinds of tenure conflict with or complement each other, and is their juxtaposition a factor in this?

- Who are the "secondary" users-suppliers, repair shops, and so forth? How significant are they?
- Who controls resource use and regulations at each relevant scale?
- Are there problems in the relationships between the control agencies?
- Do the problems hinder or otherwise influence appropriate resource use?
- Are the objectives of the agencies compatible, or do they give rise to conflicts?
- How much overlap is there?
- How effective are social networks and what role are they playing (or could they play) in learning and management?

The Resilience of What?

- What is it about the system that you want to be resilient?
- What do people value in, and want out of, the system? And what are the big issues that concern them?
- What trade-offs are occurring among the valued system services?
- Are there examples of private property assets that are in fact functioning as common property, and are there any resilience issues involved?
- What are the shapes of the relationships between the pairs of ecosystem services-do any of them exhibit sharp changes or threshold-like effects? Does this call for a change in the way the ecosystem services are managed, and regulated?
- What are the big issues? What are people worried about?
- What do you want to make resilient? (Resilience of what?)

The Resilience to What?

- What is it that you want your system to be able to recover from? (Resilience to what?)

Drivers and Trends

- How did it [the system] get to be that way [unique]? What were, and what now are, the 'drivers' of system change?
- What are the current drivers at each scale? What trends are occurring at national and global scales?

Step 2 – Assessing Resilience

Specified Resilience

State-and-Transition Models

- At various scales and in different domains (biophysical, social, and economic), or even including more than one of each, can you describe the current state of the system and the possible alternate states it could be in?
- What are the possible states the system can be in?
- What transitions between these identified states are possible, and what are the necessary conditions for the transitions to occur?
- Can you identify possible trajectories for the system? For these trajectories, can you identify the different end states the system could be headed for and what the intermediate states might be?
- Along the various pathways, are there any no-return points, or thresholds? Could any of these transitions have threshold effects? Are any of them non-reversible?

General Resilience

- Based on your developing model (understanding) of the system, could any of the changes that have occurred or are occurring have significant effects on resilience, in general?

Diversity

- Have there been any changes in diversity that might relate to the valued goods and services identified earlier?

- Do any of the changes amount to persistent trends, and could any of these make the system more vulnerable to external shocks?
- In which parts of the system is there little or no diversity, and does this make the system vulnerable?
- Where in the system is there only one way of carrying out a vital function?

Openness

- What trends are occurring? Is there any evidence (social or ecological) that the system is becoming (or is) too closed?

Reserves

- Can you identify any reserves that have come into play in the past, and are any of them changing?
- What changes are occurring, and are any trends worth flagging as something of concern?

Tightness of Feedbacks

- Can you identify changes in any feedbacks (social, ecological, economic) that might be of concern? From your developing model of the system, can you identify critical feedbacks that act to keep the system in its current state—and are any of these changing, or weakening?

Modularity

- In what ways is the system modular? Are there any trends in this modularity? Is the system becoming more fully connected, or are there parts of it that are becoming more isolated, or too loosely connected? Do any of these warrant further investigation?
- What has conferred "coping capacity" to your system in times of trouble? What worked in the past? If there were past failures, could they be attributed to any of the features conferring general resilience?
- Is there anything that is worrisome now?

- In a time of trouble, how good are the cross-scale connections and connections within the focal scale? Are there missing connections, especially between the focal scale you're interested in and scales above and below? When disaster has struck, were state and federal officials and politicians responsive? Was there a constructive community response (how good are the networks within your focal scale)?
- Are there any trends in any of the attributes in the list above?

Step 3 – Managing Resilience

- What kinds of interventions are called for?
- What actions would be most appropriate, how could they be applied, and at what scales?
- In which parts/sectors/industries/enterprises should we be trying to enhance resilience because they are in states that we like, that are good for us, and that have good future prospects, and in which parts should we be reducing resilience in order to ease transformation into a different kind of system?

Transformation

- Ask yourself if your system is in a trap. If so, is transformation needed?

Adaptive Management

- How can interventions be implemented in an adaptive-management framework?

Adaptive Governance

- How well are current institutions matched to the time scales and the biophysical, social, and economic scales at which they are required to operate?
- To what extent is adaptation of governance at regional and local scales helped or hindered by governance at state, national, and international scales?

- How can new, adaptive institutions be incorporated into current institutional arrangements?
- Can institutions be designed to be robust across a range of circumstances? Should there be "rules for changing the rules" so that institutions can be activated or silenced according to circumstances?
- How can adaptive governance be introduced?

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Education

Institution (Date from - to)	Degrees
Middle East Technical University / City and Regional Planning (2009 - 2018)	PhD Degree
Middle East Technical University / Regional Planning (2006 - 2009)	Master of Science Degree
Middle East Technical University / City and Regional Planning (2001 - 2006)	Bachelor's Degree
Süleyman Demirel Anatolian High School, Ankara (1994 - 2001)	

Language skills

Language	Reading	Speaking	Writing
Turkish	Mother tongue	Mother tongue	Mother tongue
English	Excellent	Excellent	Excellent

Membership of professional bodies & Certification

- Urban and Regional Research Centre (Kentsel ve Bölgesel Araştırmalar Merkezi, KBAM) – Executive Committee Member since 2009
- Nature Association Member since 2006
- Chamber of City Planners Member since 2006
- ArcGIS 9.1 Education Program Certificate by Chamber of City Planners (in 2008)
- Project Cycle Management Education Program Certificate by GEKA (in 2017)

Other skills

- Guitar playing
- Free-hand drawing

Present position: City and Regional Planner

Years within the firm: 3.5 Years

Key qualifications

- Experience in planning projects (academic and practical)
- Experience in project management (especially Master Plan projects)
- Experience in academic research
- Experience in ecology and environmental issues
- Knowledge and experience in graphic design programs (PhotoShop, CorelDraw, etc.)
- Knowledge and experience in statistical techniques
- Good documentation abilities

Publications

- Gürçay, M., (2018). Impacts of Mega Projects on the Resilience of Istanbul City-Region. PhD Thesis, Middle East Technical University, Ankara.
- Gürçay, M., (2010). Sulak Alanların Yeniden Yapılan(dırıl)ması: Kazan(ıl)anlar – Kaybed(il)enler. 8 Kasım Dünya Şehircilik Günü 32. Kolokyumu "Kentsel Yeniden Yapılanma: Kazananlar Kaybedenler" Bildiriler Kitabı. Korza Yayıncılık, Ankara, Cilt 2, 709-725. (paper presented in November 2008)
- Gürçay, M., (2009). Human Interventions on Wetlands and Their Long Term Impacts on Human Well-Being; a Study of Kızılırmak Delta Case, Samsun, Turkey. M.Sc. Thesis, Middle East Technical University, Ankara.

Computer literacy

- ArcGIS
- PhotoShop
- NetCAD
- CorelDraw
- SPSS
- MS Office

Research Interests

- Resilience & Panarchy
- Environmental Modelling (Cellular Automata, SLEUTH)
- Natural Resources & Ecosystem Services
- Complex Systems Theory
- Ecology
- Climate Change & Sustainable Development
- Planning Theory

Professional and Academic Experience

Date from - to	Location	Company / Project / Reference	Position
11.2014 - Ongoing	Turkey/Aydın	Aydın Metropolitan Municipality	Contracted Officer
16-20.10.2017	Turkey/Aydın	Southern Aegean Development Agency (GEKA) / PCM Course	Participant
16-18.10.2014	Turkey/Ankara	Urban and Regional Research Centre (KBAM) / Çankaya University and METU CRP / 5th Symposium	Executive Committee Member
12.2013 – 01.2014	Turkey/Ankara	METU, Research and Implementation Center for Built Environment and Design (YTM-MATPUM) / Keskin County Urban Development Advisory Project	Supervisor
11.2007 – 01.2014	Turkey/Ankara	Middle East Technical University (METU) / Department of City and Regional Planning (CRP)	Research Assistant
28-30.11.2013	Turkey/Ankara	Urban and Regional Research Centre (KBAM) /Mersin University and METU CRP / 4th Symposium	Executive Committee Member
06-07.12.2012	Turkey/Ankara	Urban and Regional Research Centre (KBAM) / Gazi University and METU CRP / 3rd Symposium	Executive Committee Member

11-15.07.2012	Turkey/Ankara	METU CRP & Association of European Schools of Planning (AESOP) / 26th Annual Congress of AESOP in Ankara, Turkey	Organizing Committee Member
06.2011 – 11.2012	Turkey/Ankara-Antalya	METU, YTM-MATPUM / “Antalya, Milas-Bodrum and Adnan Menderes Airports Master Plans” Project	Planner and Management Team Member
08-10.12.2011	Turkey/Ankara	Urban and Regional Research Centre (KBAM) / METU CRP / 2nd Symposium	Executive Committee Member
02.2011 – 05.2011	Belgium/Leuven	Katholieke Universiteit Leuven / European Module in Spatial Development Planning (EMSDP)	PhD Candidate
12.2009 – 02.2011	Turkey/Ankara	METU, CRP / “Sustainable Land Use Policies for Resilient Cities” International Project	Researcher
12.2009 – 02.2011	Turkey/Ankara-Dalaman	METU, YTM-MATPUM / “Atatürk, Esenboğa and Dalaman Airports Master Plans Revision” Project	Planner and Management Team Member
20-21.09.2010	Turkey/Ankara	Urban and Regional Research Centre (KBAM) / METU CRP / 1st Search Conference	Executive Committee Member
07-21.09.2005	Germany/Hamburg	Hamburg Technical University – Harburg / Erasmus Intensive Program	Student

08.2005 – 09.2005	Turkey/Şanlıurfa	METU, CRP / Şanlıurfa Municipality Inventory Work	Intern
13-17.06.2005	Turkey/Ankara	Gazi University, Department of City and Regional Planning / “Missing Natural and Cultural Values: Atatürk Model Farm” International Summer School	Student