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Past, present and future landscapes: Understanding alternative futures for climate change adaptation of coastal settlements and communities

Final Report

Philip Morley, Jamie Trammell, Ian Reeve, Judith McNeill,
David Brunckhorst and Scott Bassett

PAST, PRESENT AND FUTURE LANDSCAPES

Understanding Alternative Futures for Climate Change Adaptation of Coastal Settlements and Communities

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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Abbreviations

CA	*Cellular Automation*
CCD	*Census Collector District*
CBD	*Central Business District*
DEM	*Digital Elevation Model*
GCM	*General Circulation Model*
GIS	*Geographic Information System*
IPCC	*Intergovernmental Panel on Climate Change*
LGA	*Local Government Area*
LULC	*Land Use/Land Cover*
PCA	*Principal Components Analysis*
RFB	*Rural Fire Brigade*
SES	*State Emergency Service*
SLR	*Sea-Level Rise*

1. ABSTRACT

Though shaped by past elements, history demonstrates that future landscapes will be very different from those of the present. This is particularly so in coastal areas of rapid urban growth. The effects of climate change in the future will therefore be impacting on these quite different landscapes, not on those we see today.

To gauge the severity of these impacts we must understand the future settlement patterns likely to emerge. This project examines the past and present drivers of landscape change in the Northern Rivers region of north-eastern New South Wales, and then models several scenarios for the future, based on land use planning decisions that might be taken. For example, the two extremes are a scenario of 'deregulated' growth, and one which takes a high degree of precaution, a 'high climate adapted' scenario. The effects of these 'alternative futures' can be visualised, and the area of land, and number of people affected by climate change impacts, quantified. The approach enables important elements of the landscape to be integrated. Also, by enabling alternative futures to be visualised, the method may also be used to engage the community to have a say in their preferred pathway.

2. EXECUTIVE SUMMARY

Climate change poses unprecedented challenges to coastal local governments. Already managing high population growth rates, demographic changes within the population and pressures on infrastructure and services, climate change adds the threat of a range of uncertain and increasingly severe weather impacts.

Recognising the potential impact of climate change and natural hazards most councils now have implemented some predictive and precautionary revisions to planning schemes. However the roles and responsibilities of local government are not particularly clear, and the extent of planning for climate change adaptation varies considerably across the sector. Specifically, to incorporate planning for climate change and the long time frames involved, many local governments need to consider new planning instruments.

To gauge the impact of climate change in the decades ahead, we need to know the pattern of urban settlement decades ahead. This is not yet known, but we can model and test a number of alternative settlement scenarios – a set of 'alternative future landscapes'. By doing so, we can move away from trying to make accurate predictions about a single most likely future, and instead, investigate what a desirable future might be, or what a 'worst case' might look like. Tapping community preferences, it may then be possible to try to figure out how to make a chosen 'future' feasible.

Using the Northern Rivers region of New South Wales as a study area, this project demonstrates a novel approach to modelling alternative futures by linking the possible futures to various strategic land use planning options. Then the consequent vulnerabilities to climate change impacts may be assessed. The details of the scenarios modelled however, are not designed arbitrarily. To model a future landscape at a regional scale, it is vitally important to understand how past and current pressures are driving change. This past-present-future landscape approach allows a more integrated analysis of parameters that might change.

Maps which visualise how the future might look are produced for six land use planning options: a 'deregulated' scenario which has only minimal constraints on land use; a scenario that models land use constraints embodied in the Far North Coast Regional Plan; a scenario which increases the population density of urban settlement; an 'energy development' scenario which combines the Regional Plan constraints with those which would arise if coal seam gas was intensively exploited in the region; and two 'climate adapted' scenarios which place constraints on land use availability (additional to those in the Regional Plan) to protect areas vulnerable to either (i) 'High' climate change impacts or (ii) 'Low' climate impacts. Three population trajectories, measured as built-up area (in hectares) required by a growing population, are modelled for the scenarios – low (1% growth), medium (1.5% growth) and high (2% growth).

In addition to the scenarios of physical impacts, the study considers how social vulnerability to climate change impacts might be assessed. Disadvantaged groups may find it more difficult to identify the risks they face, may have less capacity to manage those risks and in some cases, the impacts of climate change can exacerbate the causes of disadvantage. However future climate change impacts will be felt by future landscape residents, and the socio-economic characteristics of an area change over time. The question is: can an analysis of past and current trends lend any insights to future social vulnerability? We find that we can take important lessons from an analysis of current census-based demographic patterns. There are clear guides both in the drivers of vulnerability, and in the spatial patterns of vulnerability, that can suggest planning and social policies to reduce the risks in the future to the socially disadvantaged.

The central conclusion from the scenario analysis is that the Far North Coast Regional Plan is well equipped to handle the climate change impacts assessed in the study. It is important, therefore, that local governments are well supported and do not give in to pressures to weaken controls in the Plan. Moreover, the Plan must 'hold its ground' well beyond 2030.

If the controls on the Regional Plan are weakened, then a future closer to the 'deregulated' future scenario – the one that has the most severe vulnerabilities to the climate impacts modelled – is likely. Not surprisingly, the future with the greatest protection from impact is the 'high climate adapted futures'. Scenarios with impacts in between these two extremes actually had relatively minimal impacts, even though they modelled varying land use planning options. Each scenario did however have a baseline that kept the protections embodied in the Regional Plan.

Accessing good quality data was the most serious difficulty for this study. A national review of data available is urgently required. The review must ensure that consistent data can be provided at scales appropriate to an investigation such as this. An understanding of smaller scale locality-specific factors that might compound (or alleviate) impacts identified at the larger scale is also critical. Such finer scale assessments are therefore an important complement to regional landscape scale studies such as this one.

3. INTRODUCTION

3.1 *Objectives of the Research*

The only sure thing is change. Australia faces considerable climate change impacts and our current choices must be carefully considered to avoid maladaptation (Palutikof 2010; Barnett & O'Neill 2010). History teaches us that the choices we made in the past, guide the decisions we make in the present. In turn these choices will influence our future decisions and our exposure to risk and hazards.

Future climate change events will impact on human settlements that are derived from, but different to, the landscape patterns of today. A serious difficulty in many climate change vulnerability and adaptation studies of settlement areas is that the predicted future climate change impacts are being assessed on the *current* landscape, land-uses and settlement patterns, rather than on these features as they will look in the future. Globally, methodologies and studies for climate change adaptation that address (likely) future human settlements are sparse. We refer to this problem as 'one of temporal inconsistency' in climate change impact studies.

Studies of climate change impacts also need to consider and understand the possible flow-on effects of current planning decisions. For example, shifting future settlement patterns to avoid climate change impacts might reduce available high productivity agricultural land or disrupt other ecosystem services or biodiversity adaptation requirements (Brunckhorst *et al.* 2009; Bardsley & Sweeney 2010).

Doubtless, the most pervasive force of landscape change along many parts of the Australian coastline is increasing urbanisation and development of new settlements. Methods for testing alternative landscape pattern designs that will accommodate future urban settlements and also ameliorate climate change impacts, are needed. By developing scenarios of future landscapes, and evaluating future impacts of climate change on those future landscapes, the critical issues may emerge.

Accordingly, the objectives of this project are to:

- Develop spatial analysis and visualisation tools to examine future trends of settlement and social patterns.
- Provide a clear quantitative understanding of current settlement trends and their future trajectories (the future landscape pattern they will produce and their climate change vulnerability at that time in the future).
- Design and test several alternative landscape futures as adaptive strategies reducing vulnerability of settlements and communities to predicted climate change events
- By application to a case study area, demonstrate application and transferability of the techniques used to other contexts and landscapes, and demonstrate the integration and synthesis capabilities of these techniques.
- Develop and demonstrate one solution to the temporal inconsistency in climate change vulnerability studies.
- To provide an integrated approach to better guide current planning and policy decisions for adaptation that will provide future resilience.

To meet these outcomes, the project has built on methods of mapping past and current land use trends to visualise the future trajectory of settlement patterns. The spatial patterns of likely future settlements and landscape elements are analysed to quantify areas of land use potentially affected by climate change. Alternative landscape futures scenarios are then designed and analysed to provide a quantifiable understanding of adaptation towards more resilient landscape futures that will minimise future climate event impacts. The application of the proposed techniques will provide powerful visualisation for a range of long term planning outcomes relevant to governance and policy settings. These policy settings will be required very soon in order to achieve more resilient, adaptable settlements and communities under future climate change conditions.

3.2 *Conceptual Framework*

Throughout the world, landscapes have been modified over time to meet the needs of humans. Although change is normal for all systems, this reshaping of landscapes and regions to meet our urban, agricultural and industrial needs has changed the structure and function of ecosystems at local and regional scales (Norton & Ulanowicz 1992; Power 1996; Essex & Brown 1997; Turner *et al.* 2001). Landscapes are often defined by the function of their interacting ecological processes and patterns (Forman & Godron 1986; Hansen & DiCastri 1992, Forman 1995; Turner *et al.* 2001). However, landscapes are also a human construct because they include people and communities, economies, and political institutions interacting with elements of biodiversity and ecological systems (Brunckhorst 2002). As an important influence on human perceptions, landscapes provide a useful framework for guiding our expectations (and actions) towards shaping how we wish our environment to appear now and in the future (Cantrill & Senechah 2001; Lindley & McEvoy 2002; Field *et al.* 2003; Stewart *et al.* 2004; Dortmans 2005).

Remote imagery and spatial analysis technologies can provide relevant information on the distribution patterns of human communities, ecological systems and processes as well as the understanding of the products of social-ecological systems interactions (e.g., Mouat *et al.* 1993; O'Neill *et al.* 1999; Jones *et al.* 2001; Kepner & Edmonds 2002; Turner 2003). Such spatial data and analysis systems provide an improved policy and planning capacity for regional landscapes. They expand knowledge of externalities and of progressively limited options so that more sustainable outcomes can be enabled (Brunckhorst *et al.* 2008; Field *et al.* 2003; Batabyal & Nijkamp 2004).

With multi-scale spatial analysis tools, a regional landscape approach provides for the study of spatial patterns and processes of complex interacting social and ecological elements (Slocombe 1983; Forman 1995; Brunckhorst 2000). It also allows for the influence of these elements on the sustainability of regional development and land use to be examined (Brand & de Bruijn 1999; Irwin & Geoghegan 2001; Batabyal & Nijkamp 2004). Analysis of the past trends of the changes of landscape elements and their interactions over time, allows for the modelling of future trends and for the future land use characteristics to be visualized with acceptable precision (Yang & Lo 2003; Cohen & Goward 2004; Syphard *et al.* 2005).

Within this framework, this project presents applied research to a case-study region. The approach facilitates design or redesign of landscape elements towards a future that is adaptive to pressures of climate change, population migration and urban growth. This ‘Alternative Landscape Futures’ approach allows for explicit examination of the interactions of changing elements, specific to a spatial social-ecological context. This provides the capacity to visualize and analyse the future effect of present day decisions of modifications to landscape processes, and hence to adjust decisions and plan for the long-term. These methods seek, not to generate a ‘panacea’ as a single solution, but to provide, through visualization, a clearer understanding of a climate adapted future.

The methodology has been considerably adapted from Steinitz *et al.* (2003); Shearer *et al.* (2006) and Hulse *et al.* (2000). Regional context and project framing marks the beginning of an iterative methodology to understand interacting settlement and land-use changes and issues that will inevitably arise in the future as represented in Figures 3.1 and 3.2.

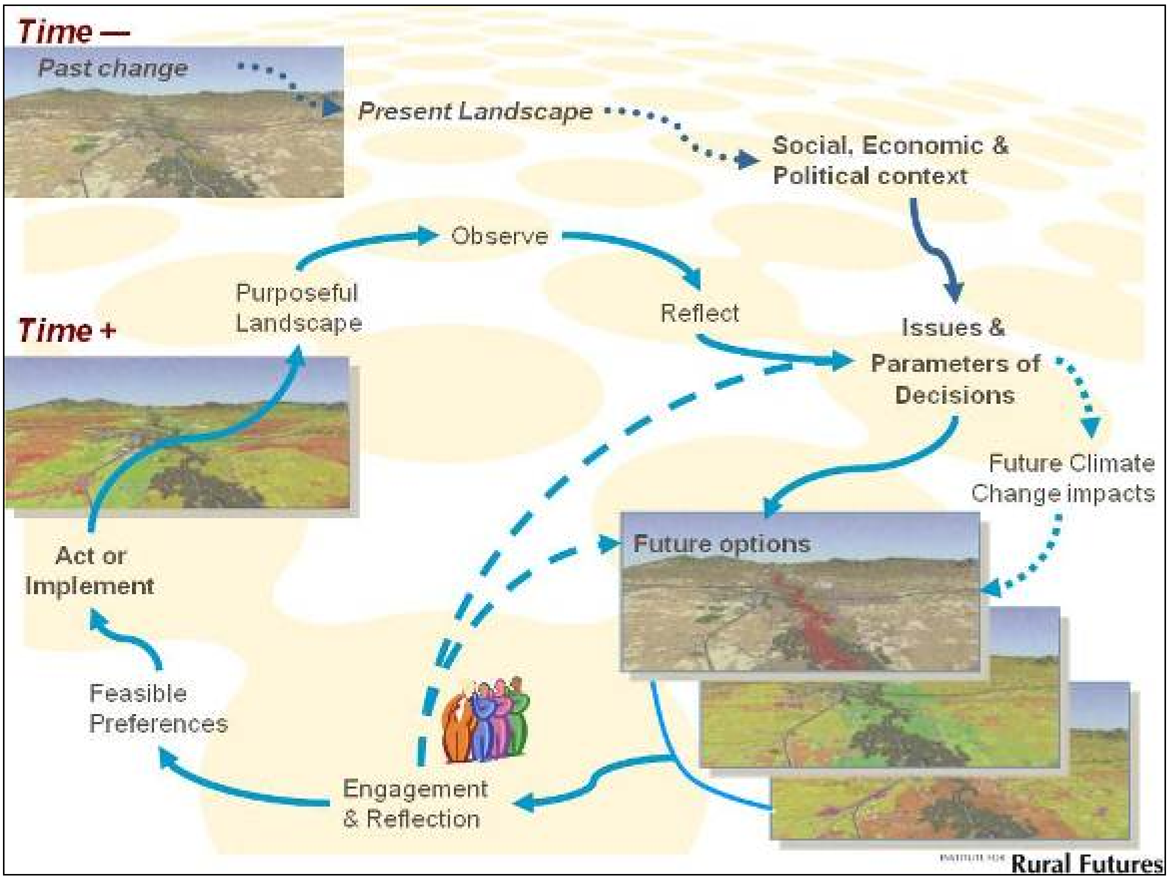


FIGURE 3.1 UNDERSTANDING THE DYNAMICS OF FUTURE CHANGE OF LANDSCAPE PATTERNS TOGETHER WITH CLIMATE CHANGE (BRUNCKHORST 2000,2005).

The framework identifies several different questions. The procedural path initially starts from the top (see Figure 3.2) passing down through the series of questions required of each theory driven model. A model is derived from an examination of the past changes and trends to contribute to understanding of what kind of landscape recent population changes and settlement patterns are taking us towards. This model is used as a 'first pass' which specifies the context, content and scope and also defines specific questions relevant to the study area.

Proceeding through the framework with the current trajectory model provides the capacity to recognise and describe purposeful landscape changes within the study area. Alternative landscape future designs are devised to reflect plausible changes and iteratively pass through the procedural framework to be assessed. With this method a number of future options are developed that distil the most plausible, practical, sustainable and climate resilient alternatives and allow for a variety of future situations.

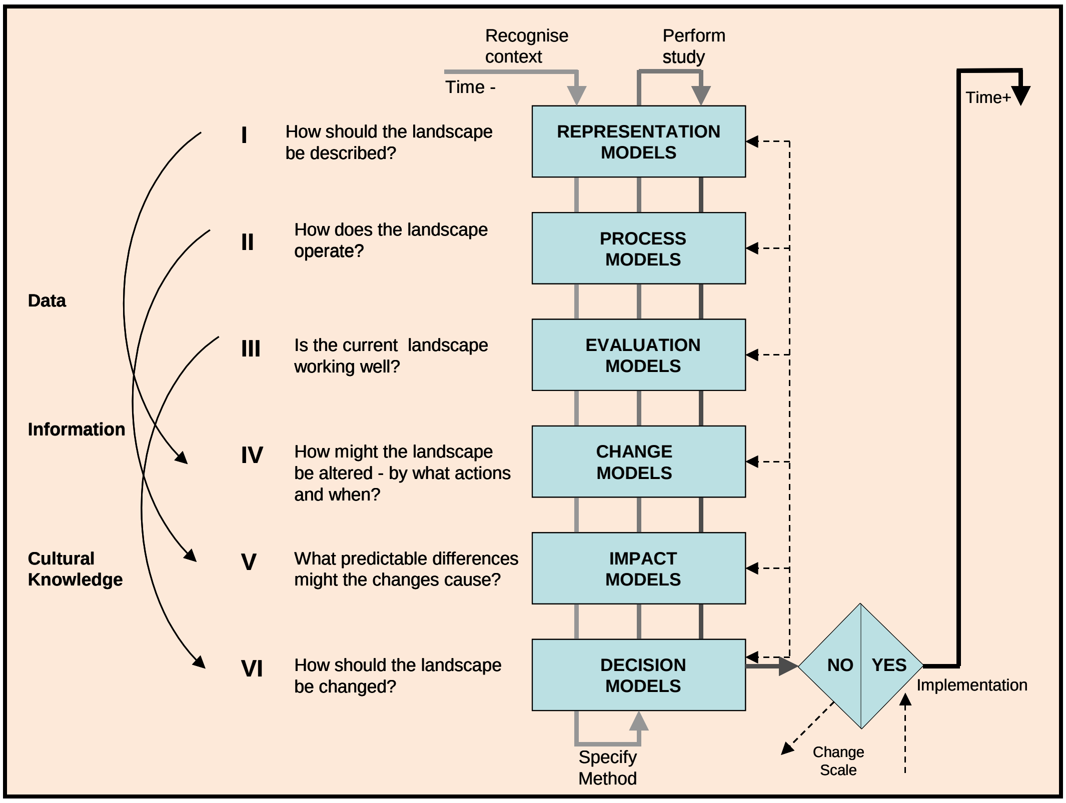


FIGURE 3.2 FLOWCHART FRAMEWORK FOR ALTERNATIVE LANDSCAPE FUTURES (STEINITZ *ET AL.* 2003)

3.3 *Study Area: The Northern Rivers Region of New South Wales*

The Northern Rivers region of New South Wales (Figure 3.3) is a distinct social-ecological spatial context defined by sub-tropical ecosystems, agricultural systems, coastal flood plains, communities of interest and sea-side lifestyles (NRRSa 2003, Brunckhorst *et al.* 2008). Located in the north east of New South Wales, the region is characterised by major river valleys and covers an area of approximately 67,400 sq hectares ranging from south of Evans Head to the Queensland border in the north. With a population of approximately 240,000 in 2010 it is renowned for its surf beaches, scenic coastline, fertile and lush farm land, as well its natural environment.

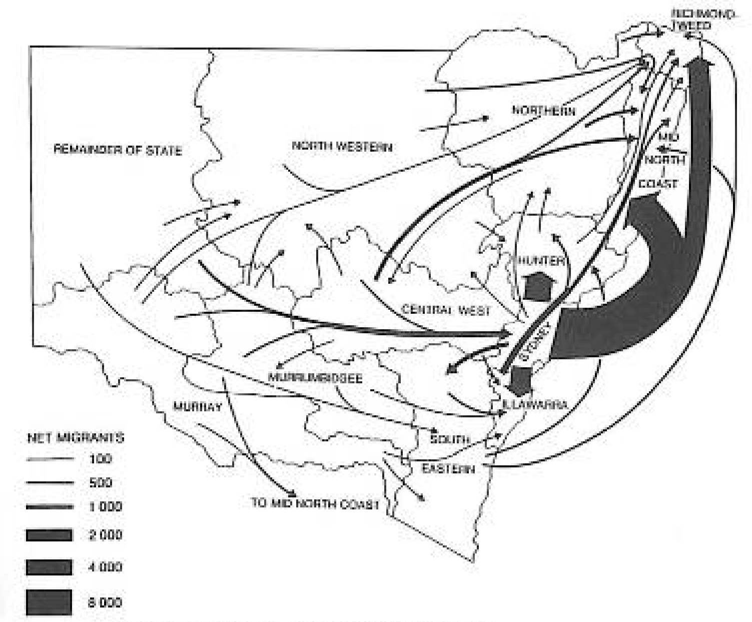
Geography, latitudinal location and climatic conditions also define the region as an ecotone, having the southern-most limit for a range of tropical flora and fauna as well as the northern-most limit for a variety of temperate organisms (RACAC 1996). Accordingly, the region has the second highest level of biodiversity in Australia, supporting a number of locally, regionally and internationally significant species and including a number of World Heritage listed areas (RACAC 1996).

Settlement patterns within the region are historically linked to early transport routes and land use practices for economic development. The economic base of the region developed through agricultural and forestry industries. The regional landscape is dominated by agriculture land uses (20%), forestry (50%) and environmental conservation (30%) (NRRS 2005). Dairy farming was a predominant agricultural land use within the region, but this has declined over the last 30 years (DOTARS 2003) and although previously renowned for its sugar cane industry, this is also now giving way to growth in macadamia nuts, banana, avocados and beef (DPI 2000). This historical background and the reliance on agriculture throughout much of the region has given most areas a predominantly rural outlook.

Aside from agricultural holdings, the region contains numerous cities, towns, villages and smaller communities (NRRS 2003b) incorporated into the five local government areas of Byron, Ballina, Lismore, Richmond Valley and Tweed. Many of these communities have a strong sense of identity based around their historical, environmental and lifestyle attributes. A number, such as Nimbin and Byron Bay have international reputations for the lifestyle that many residents enjoy, while others are well known as coastal holiday destinations for different groups.

FIGURE 3.3: STUDY AREA WITHIN NORTHERN RIVERS REGION OF NSW (DERIVED FROM GEOSCIENCE AUSTRALIA (NATMAP))

From the end of World War II to 1976, the Northern Rivers population rose from 75,000 to 92,000 persons (NRACC 2004). However, intrastate migration saw a dramatic rise in population growth along the north coast (Walmsley & Sorensen 1988). This shift in population mostly originated from Sydney and inland Northern and Western New South Wales as shown in Figure 3.4. The main reasons for this change, surmised by Walmsley and Sorensen (1992), were improved lifestyle such as better climate, less pollution, access to beaches and other leisure time pursuits. In more recent years, whilst the reasons for moving have remained the same; it is noted by the Australian Bureau of Statistics (ABS) that four out of five people moving to high growth coastal areas are aged under 50 (ABS 2004). With this strong growth, the region nearly tripled its population from 1976 to 2010. The Northern Rivers region is one of the ten fastest growing areas in Australia (NIEIR 1998) and is considered one of the major 'sea change' regions of Australia (Burnley & Murphy 2004).



Migration within New South Wales, 1976–81

FIGURE 3.4: MIGRATION WITHIN NSW (WALMSLEY & SORENSEN 1992, P57)

3.3.1 *Far North Coast Regional Strategy*

With the growth in popularity of the region, particularly along the sea-board portion, the Northern Rivers Regional Strategy (NRRS) was formed to attempt to reconcile the range of both long standing and arising issues within the region (NRRS 2000).

Underpinned by the concept of ecologically sustainable development, the NRRS aimed to manage the development of the region so that it can maintain the lifestyle aspirations of its residents for which the region is recognised, as well as provide some protection of the natural environment. The Strategy developed the following principles (NRRS 2003a):

- Integration of planning within the region to promote co-operation and regional identity;
- Development of human settlements and activities to ensure sustainability within communities;
- Sustainable economic development and employment growth;
- Improvement of the region's distinctive quality of life for all people;

- Protection, maintenance and strengthening of regional biodiversity and ecosystems;
- Protection of the region's natural resource base and ensuring the efficiency of its use;
- Improvement of communications, accessibility and transport
- Accommodation of the diversity of views and values within the region and reduction of the conflict between them.

The NRRS aimed to increase the prosperity, employment, quality of life, cultural diversity and the environmental quality of the region. The strategy recognised fragmented planning as one of the biggest problems of the region and aimed to reduce the sprawl of new development, reduce the conflict between and within communities, and minimise the loss of farming potential.

The New South Wales Department of Planning consolidated and built upon the work of the NRRS in the development of the Far North Coast Regional Plan (DIPNR 2007). The overriding strategic planning document for the region, its purpose is to "is to manage the Region's expected high growth rate in a sustainable manner." It aims to protect the significant environmental, cultural, social and economic assets of the region as well as ensure there is sufficient infrastructure and space for new development.

Recognising that the region has experienced numerous severe floods, and that specific areas such as parts of Byron Bay and Ballina have suffered from coastal erosion, the plan seeks to ensure that future urban development is not located in areas of high risk from natural hazards. This is conducted through council local environment plans. The regional plan and its imposed restrictions to new development are discussed in more detail in chapter 7 in regard to scenario design.

4. LAND USE/LAND COVER CHANGE

Changes in land cover, often driven by both natural and anthropogenic factors (Lambin *et al.* 2001; Veldkamp & Lambin 2001), are evident worldwide (Vitousek 1994; Vitousek *et al.* 1997. This has created a changing mosaic of natural and human landscapes (Hesperger 2006; Forman 1995; Cadenasso *et al.* 2006. Land cover change not only impacts *local* ecosystem services and processes (Lambin *et al.* 2003; Nelson *et al.* 2009; Vitousek *et al.* 1997; Chapin *et al.* 2000; Fleishman *et al.* 2011), but also impacts the *global* hydrologic (Stoholgren *et al.* 1998; Eckhardt & Ulbrich 2003) and climate cycles (Nicholson 2000; Bonan 2008; Feddema *et al.* 2005). For these and other reasons, great effort has been put into modeling and forecasting LULC change around the world (Turner *et al.* 1996; Turner *et al.* 2007; Valor & Casselles 1996; Bürgi *et al.* 2004; Lepers *et al.* 2005; Ramankutty & Foley 1998; Sobrino & Raissouni 2000) and to a lesser extent in Australia (Pickup *et al.* 1993; Pickup *et al.* 1998; Fensham *et al.* 2005; Pitman *et al.* 2004).

Although many of the natural causes (e.g. fire) of land cover change are outside the control of the human population, anthropogenic influences can be seen on most landscapes. The two largest anthropogenic influences on the modern landscape are in the development of agriculture and urban areas. Both of these influence the pattern of land cover, but can also be controlled by policies and preference. Agriculture can be retired or expanded (Napton *et al.* 2010, Feng *et al.* 2006), while residents in urban areas can choose to live at higher or lower densities (Lenth *et al.* 2006, Colding 2007). To aid in our assessment of potential anthropogenic land cover change, researchers have developed a number of techniques to forecast how our choice of policies influences future land cover patterns.

Techniques vary in their complexity and data requirements, and many rely on computer simulations. The use of satellite imagery for regional LULC identification can provide a relative indication of urbanisation and vegetation change. Although various forms of satellite imagery from a variety of sensors exist, a relatively small subset of the available satellite imagery/sensors provides the necessary information for assessments of LULC change. Within the context of this study and over a 30-year time span, the Landsat satellites in operation at the time of image acquisition highlighted LULC characteristics of interest. Subsequently, image acquisition followed roughly a five-year interval, with Landsat satellite images acquired for the years 1980, 1985, 1990, 1995, 2000, 2004 and 2010. Whenever possible, images acquired reflected time periods where the possibility of vegetation discrimination was at its highest. However, cloud cover and Landsat image corruption limited the availability of usable satellite images for specific areas within the study area. When images meeting cloud cover and corruption requirements could not be acquired for the desired time period, secondary images for a less favourable time period were acquired.

The spatial extent of the Northern Rivers study region required multiple images for all sensors in any given time period. Given multiple images comprising all time periods, and to expedite the image classification process, images were 'mosaiced'. The mosaic process used the overlap areas to standardise spectral values among the images (Homer *et al*. 1997). The earlier years, 1980 and 1985, required four Landsat satellite images from MSS sensors be acquired and mosaiced. The other four time periods required two images from TM sensors. Table 4.1 highlights the dates, sensor, path, and row for each time period.

TABLE 4.1. LANDSAT SATELLITE IMAGES USED TO DEVELOP THE LAND COVER CHANGE ANALYSIS

Date	Sensor	Path	Row
Aug. 1980	MSS II	94-95	80-81
Feb. 1985	MSS V	94-95	80-81
Aug. 1990	TM V	89	80-81
Apr. 1995	TM V	89	80-81
June 2000	ETM VII	89	80-81
Nov 2004	TM V	89	80-81
July. 2010	TM V	89	80-81

4.1 *Classification of Landsat satellite images*

A possible disadvantage of using mosaiced images is an increase in spectral variability, which may result in increased misclassification rates. The advantage is the need to conduct the image classification process only once per time period. Although the study area has a broad spatial extent, the overall LULC heterogeneity remains fairly constant. Thus, we consider that the advantages override the potential disadvantages in this case.

For all time periods the classification process generated unsupervised spectral clusters using the Imagine™ Isodata algorithm. Prior to clustering, urban areas in the region were masked from the image to reduced spectral variability. An iterative process provided an optimal number of spectral clusters to use in the LULC classification process. Beyond the spectral clusters, a number of other ancillary datasets provided additional information prior to the LULC classification. The ancillary datasets represent GIS layers describing the physical properties or context of many LULC types of interest. The intent of incorporating ancillary datasets into the classification process is to reduce the potential for misclassification of specific cover types. When ancillary datasets are used in combination, the descriptive power and subsequent level of detail of the physical landscape often increases. Table 4.2 lists the ancillary datasets used in the classification process and their role or interval.

TABLE 4.2. ANCILLARY DATASETS USED IN THE LULC CLASSIFICATION.

Elevation	Elevation divisions at roughly 90 meter intervals
Slope	Slope divisions smaller at lower slopes and greater at higher slope values
Aspect	Followed the eight dominant directions
Distance from Ocean	Used to identify beaches and the inland extent of coastal vegetation
Sugar cane locations	Used to identify and limit potential sugar cane field locations
Orchard locations	Used to identify and limit potential orchard locations

With the spectral clusters and ancillary datasets generated, cover type rule-sets were developed. Training sites were identified and visited, providing the foundation for land use and LULC classification with each site’s cover type overlaid on spectral cluster and ancillary datasets. Rule-set were then generated to reflect the per-pixel distribution of spectral cluster values within each training site and ancillary dataset.

Eight dominant land cover types could be readily identified with what was believed to be little misclassification error (Table 4.3). The eight types readily identified through the above procedure are: forest, coastal complex, beach, water, sugar cane, pasture/crops, orchard, and urban. Higher discrimination among cover types could not be obtained through all time periods even though attempts to do so were made. Urban areas include a combination of dwellings (of various types), infrastructure, utilities, roads, schools, light industry and commercial areas.

TABLE 4.3. DESCRIPTIONS OF MAPPED COVER TYPES

Cover type	Description
Forest	Sclerophyll forests containing mostly species of *Eucalyptus* trees with various levels of density ranging from rainforests to dry and open forests.
Coastal complex	Vegetation communities found only within 15 km of the coast ranging from shrubs to mangroves.
Pasture/crop	Natural and exotic pasture land including mostly annual vegetation, primarily grassland communities. Isolated crops including corn, tea tree, or other plants which are cultivated mainly for human consumption.
Orchard	Orchards dominated by plantations of macadamia and avocado trees.
Sugar Cane	Fields where sugar cane production is the dominant activity. With a crop rotation system in place and sugar cane harvesting occurring every two years, the crops grown may be sugar cane or a legume.
Water	Locations dominated by either fresh or salt water.
Beach	Sandy beaches located within 150 meters of the Pacific Ocean.
Urban / Built-up Area	Manmade features dominated by commercial or industrial buildings; the cover type includes urban residential, semi-urban residential or rural residential houses readily identified on satellite imagery.

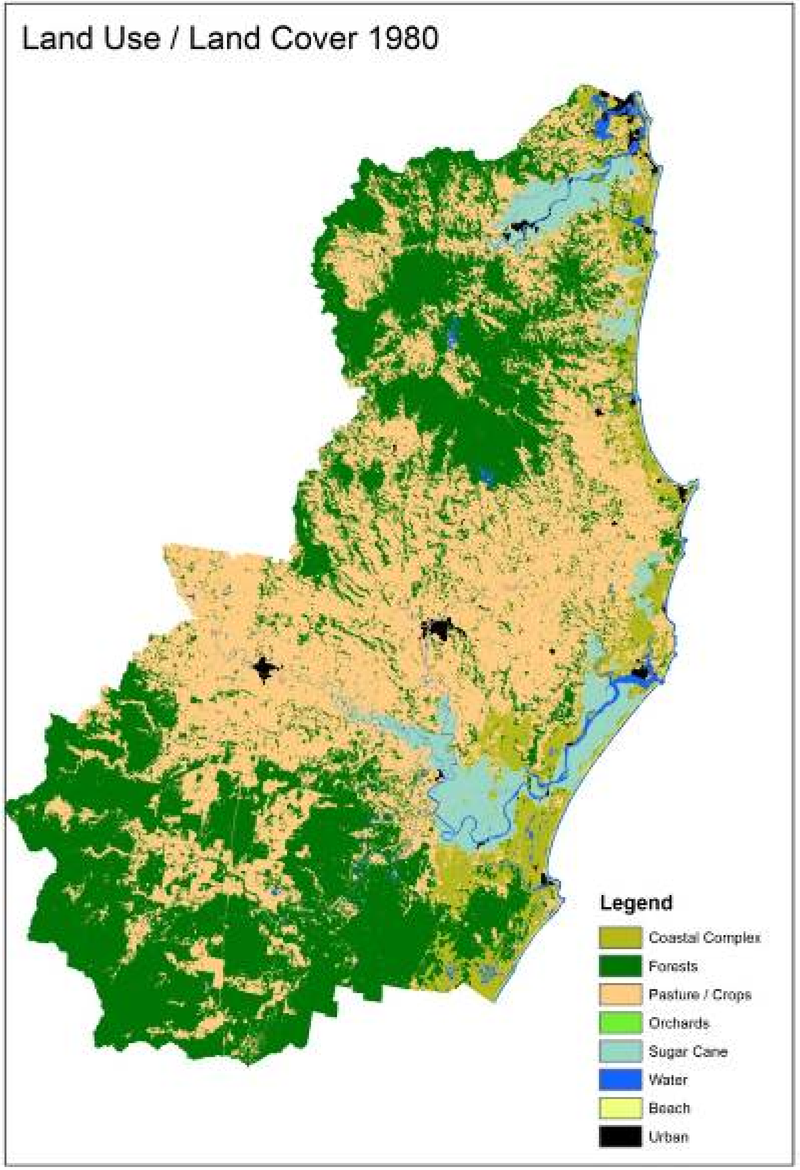
4.2 *LULC distribution and change*

The distribution of cover types for all time periods shows an abundance of vegetation in the forest and coastal complex cover types (Figures 4.1 to 4.4). Forest communities dominate mountain and escarpment areas, and inland locations largely devoid of human habitation. Sugar cane fields are present along the major rivers in the region with a concentration of fields located where the difference in elevation between river levels and the surrounding land is less than 10 meters. The pasture/crop cover type dominates areas located in relatively close proximity to residential urban areas in the lower elevations. In general, pasture / crop land covers are in areas of low slope, but there are exceptions where pastures extend into foothills. A summary of cover type area by time period is presented in Table 4.4.

TABLE 4.4. AREA (HECTARES) OF COVER TYPE BY TIME PERIOD.

	1980	1990	2000	2010
Coastal complex	41761	39713	42650	32064
Forest	283796	293898	293024	291892
Pasture / Crop	295480	280326	264528	271160
Orchard	0	3310	7146	8673
Sugar cane	33587	34451	40371	39205
Water	13825	12849	12824	12982
Beach	1315	719	694	739
Urban	4222	8920	12749	17272

Trends in cover types vary. In general, the urban and orchard cover types show a linear increasing trend with time. The urban cover type quadrupled between 1980 and 2010 predominantly in the north-east corner of the study area, as shown in Figures 4.5 and 4.6. Orchard cover types (for example, Macadamia) have grown considerably since just before 1985. The area of sugar cane fields grew steadily to 2000, after which it fell slightly. The combination of the more natural cover types (coastal complex, forest, and pasture) has declined by about 26,000 hectares, relative to the combination of the predominantly human-controlled cover types (urban, orchard, and sugar cane). Although the pasture/crop cover type may be presumed to be human induced the majority of the cover type is composed of grasses some of which naturally occur in the region.



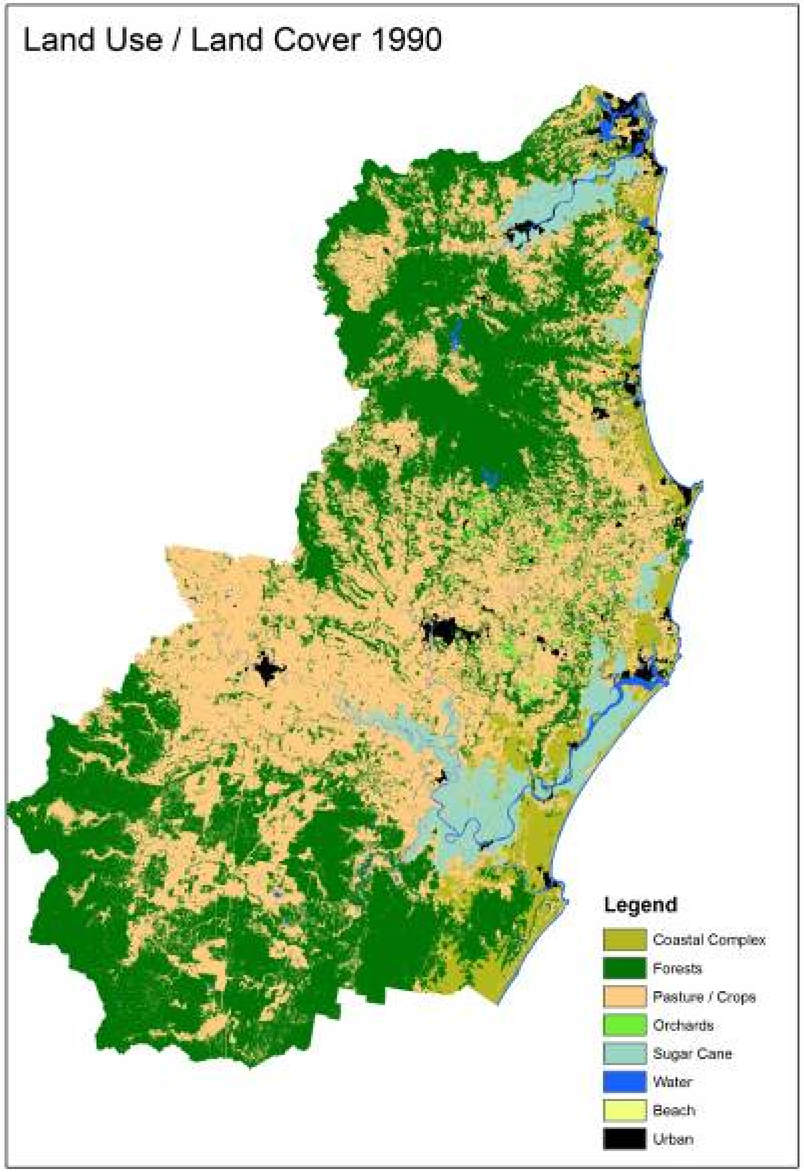
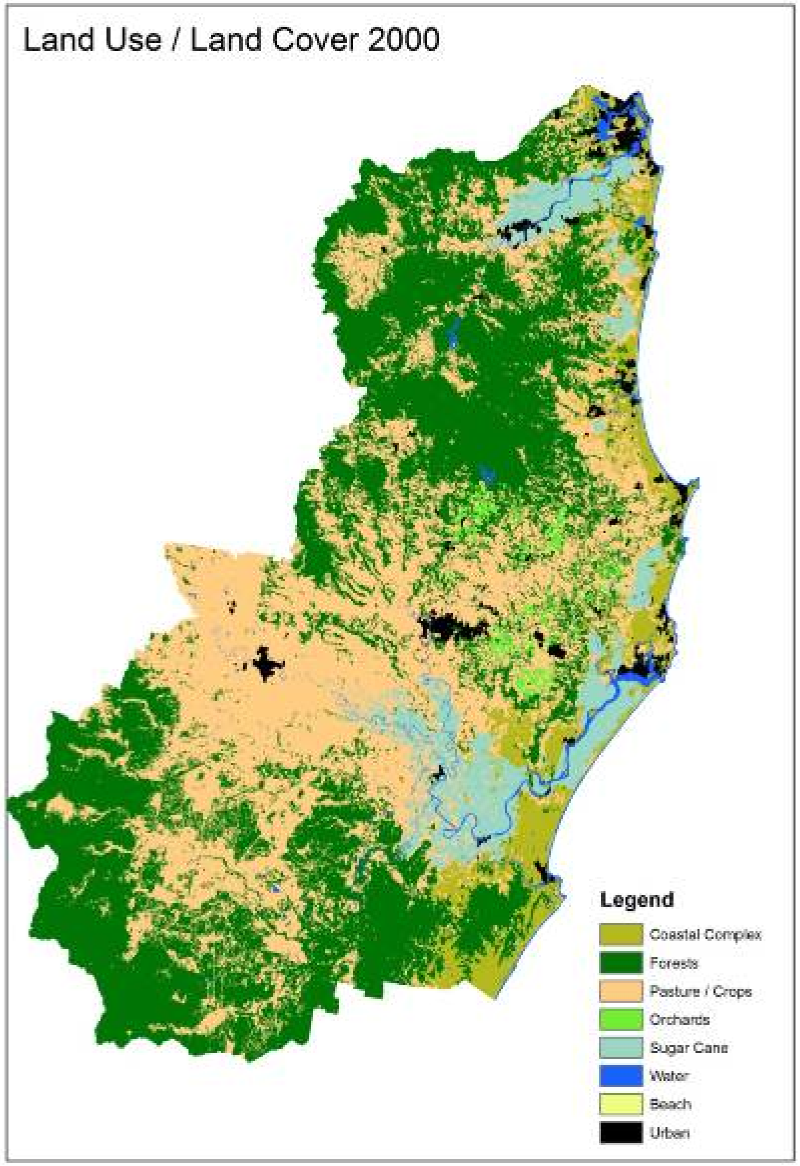
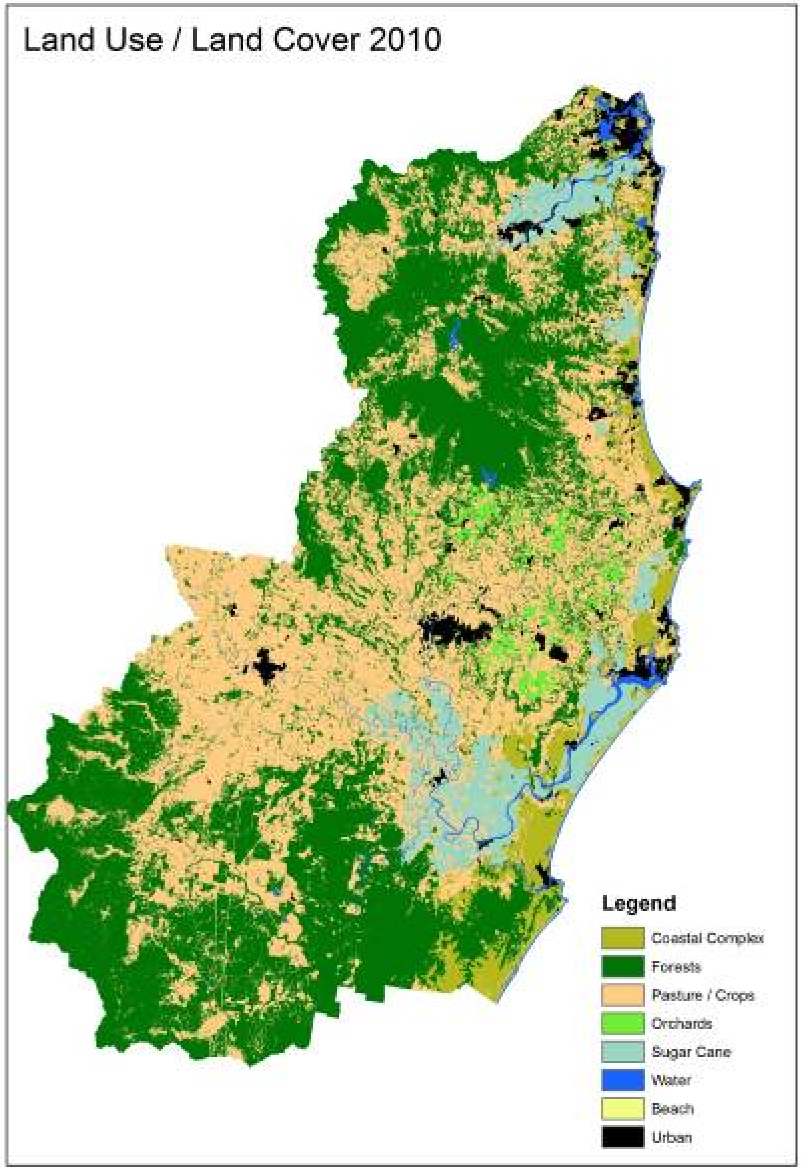
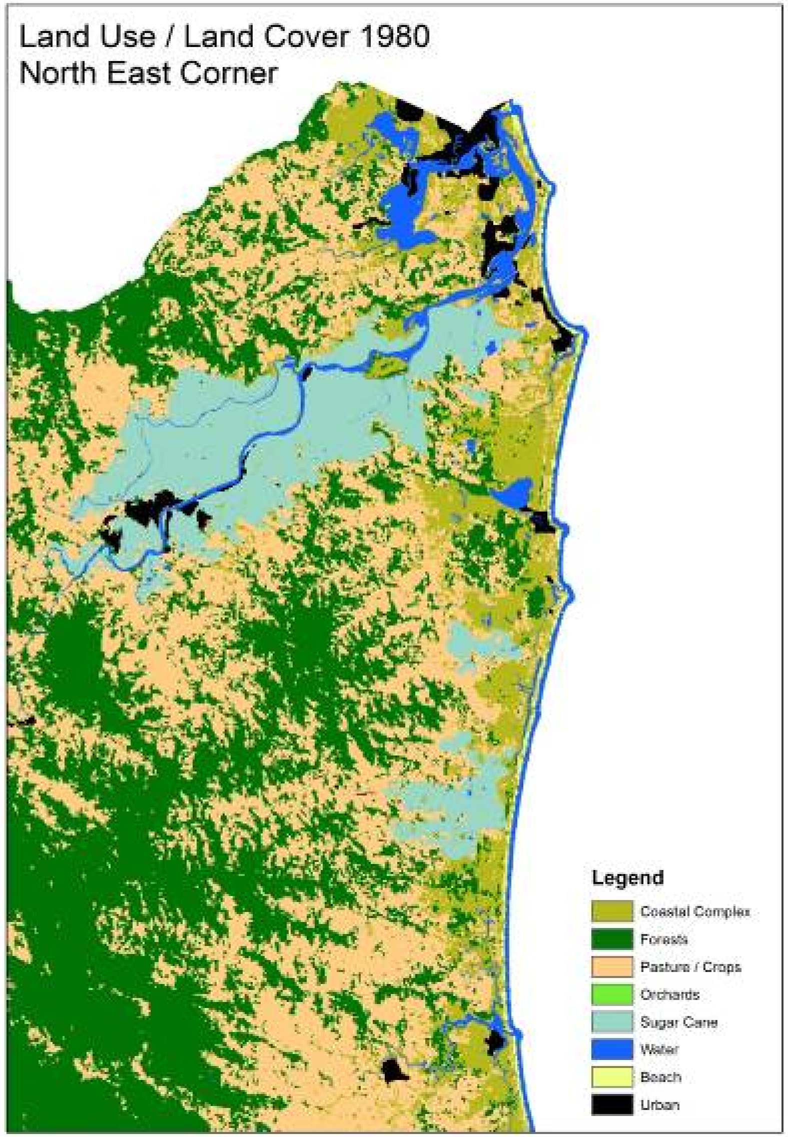


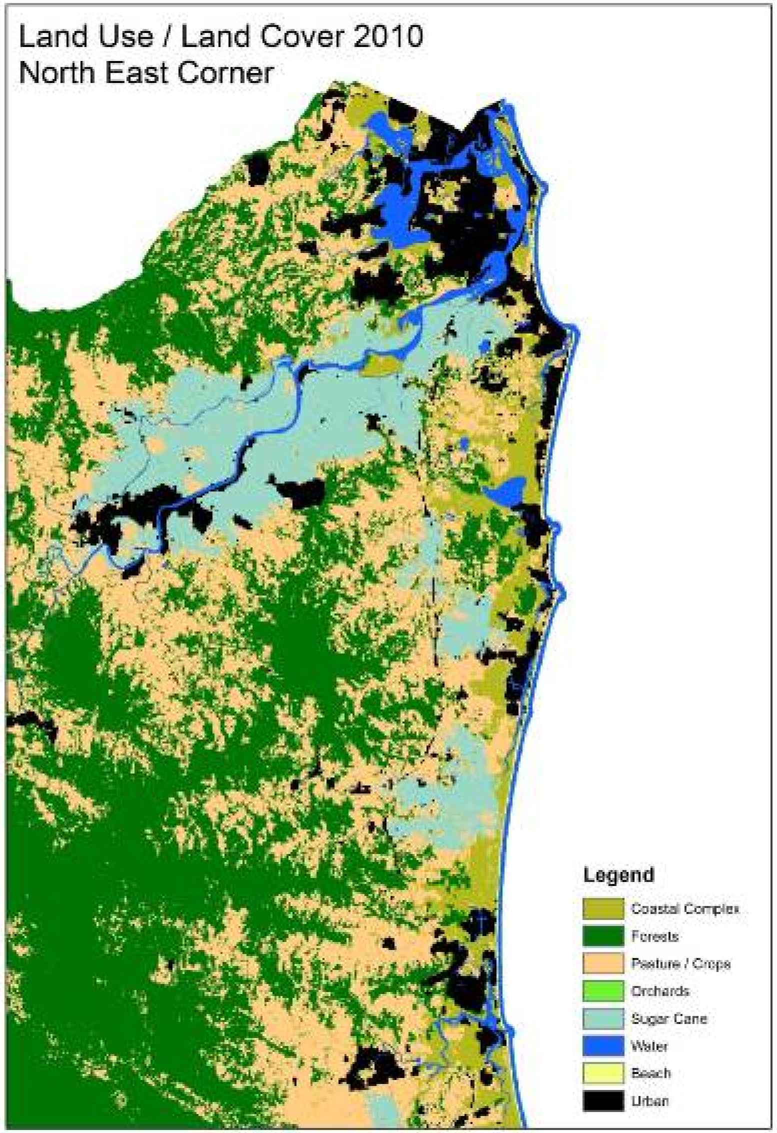
FIGURE 4.1 AND 4.2 LAND USE LAND COVER 1980 AND 1990





FIGURES 4.3 AND 4.4 LAND USE AND LAND COVER 2000 AND 2010





FIGURES 4.5 AND 4.6: COMPARISON OF URBAN EXTENT 1980 AND 2010 IN NORTH EAST CORNER OF STUDY AREA

4.3 *Relationship of urban land cover change with population change*

Census Collector District (CCD) information obtained from the Australian Bureau of Statistics Population Census provided a useful layer for comparison with the urban cover type identified in the land cover classification process. Overlays between the land cover and the collector district GIS layers allow for the changes in population and cover type to be compared. Using data from the Population Census the population changes were compared at a CCD scale.

An analysis of the change in urban area compared with the change in population shows that, overall for the region, as population increases so does the urban land cover type (Table 4.5). While the population almost doubled between 1980 and 2010, the urban area almost quadrupled. An initial linear regression analysis of change in urban area against population change by CCD shows that a significant relationship (p-values < 0.00) exists. Although regression for each time period range are significant the R^2 values are quite variable. While this might suggest a less predictive capacity for change in urban area with population change, there are other factors that might explain the spatially disparate nature of population growth and urbanisation.

TABLE 4.5 INCREASE IN POPULATION AND URBAN AREA 1980-2010

	1980	1990	2000	2010
Population	128,269	172,513	207,221	248,889
Urban area (ha)	4,246	9,168	13,039	16,531

Nationally there been a considerable growth in the number of one and two person households over the past three decades, as a result of population ageing with longer life expectancies, an increase in the number of single parent families and an increase in the number of couples without children (ABS 2012). The ABS expects this trend to continue beyond 2030 (ABS 2012). Together with a decline in the average size of family, an increase in the number of dwellings is necessary to house a given population. In addition, speculative housing development in fast growing areas may precede migration, which in turn fuels further development speculation and land releases.

Urban areas are also made up of a combination of dwellings of various types, infrastructure, utilities, roads, schools, light industry and commercial areas. Increasing (or decreasing) population might therefore be reflected in a proportionately larger increase (or loss) of the urban land cover type. The recent urban area growth along the coast depicted in Figure 4.5 shows the concurrent increase in “urbanised” areas that are known, from ground-truthing, to include large areas of commercial and light industry premises.

Regressions of population increase with urban area return stronger R values (around 0.5-0.6), but are probably still confounded because, in terms of urban area, the population reflects more than the dwellings in which they live. This appears to be well supported by a regression analysis of the relationship between population change and change in the number of dwellings (Figure 4.7) which shows a very strong correlation ($R^2 = 0.96$). Local governments and State planners confirm that there are various “multipliers” for infrastructure, roads and commercial premises that are applied to new urban land releases. It is therefore reasonable in the current study to use the observed trends for changes in population and urban area to describing future growth and alternative scenarios.

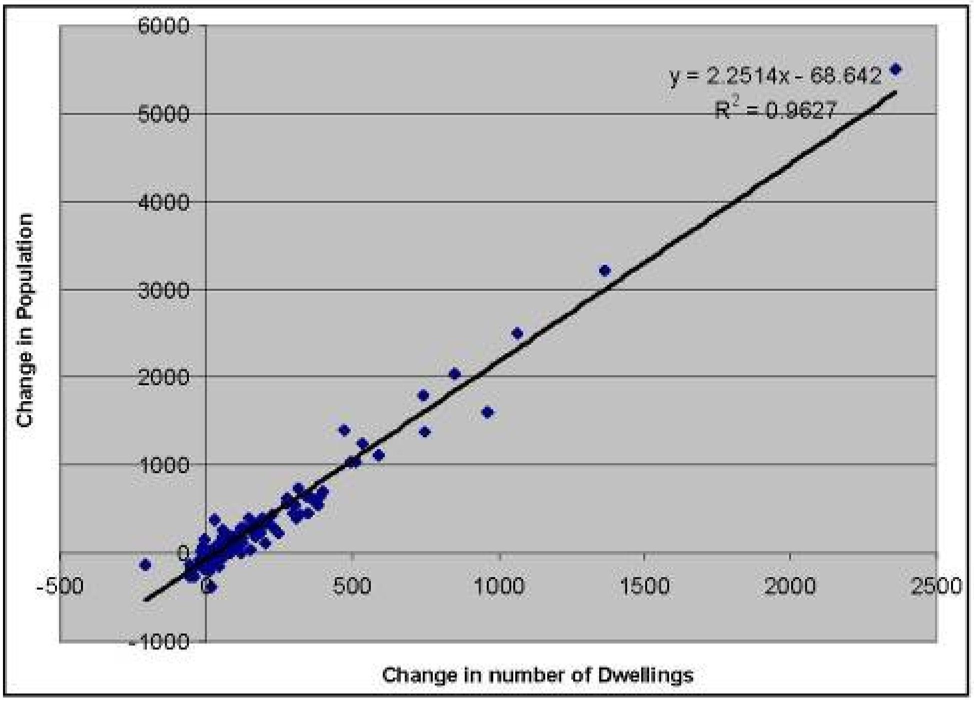


FIGURE 4.7. RELATIONSHIP BETWEEN CHANGE IN POPULATION AND CHANGE IN NUMBER OF DWELLINGS

4.4 *Discussion*

The region's land cover characteristics have changed considerably over the past thirty years. The increase in the area of human-controlled land cover types is resulting in a decrease in the aerial extent of vegetation communities throughout the region. This research quantitatively presents the change in LULC types. Residents and policy makers in the region will have to determine whether the amount and type of change is acceptable.

While the location of change also varies considerably, the greatest amount of urbanisation is occurring on the edges of existing coastal towns, in particular around Tweed Heads and Ballina. New settlements have also appeared and grown in more recent times. This increase in built-up area along the coast highlights the need for strong active planning in coastal towns. Future demand for coastal housing in the region might result in loss of rare vegetation communities and mangroves in estuarine areas. The trends also imply a potential future loss of agricultural land along the riverine areas between towns.

Modern urbanisation is much more than residential addresses. The relationship between increases in built-up area with increasing population suggests that urbanisation is using increasingly more land for a wide range of services such as roads, utilities, infrastructure and commercial areas than is required for dwellings.

The results are important and support the concept of population growth along Australia's east coast presented by Gaffin *et al.* (2006). The increase in urbanisation is likely to result in a concomitant change in coastal community lifestyle. The perception of increased in-migration is likely to continue if the recent population and land cover trends are followed. The results further point to the need for thoughtful long term planning of the placement and area used by services to the resident population.

The trend of loss in natural vegetation and increase in human land cover types is indicative of a growing region. Over the 30 years of the spatio-temporal study of landscape change, the Northern Rivers region has seen a net loss in area of coastal complex vegetation, Sclerophyll forest and ocean beaches. Over this period there have been small losses and gains in areas of pasture land and sugar cane. There has also been considerable development of orchards and other horticulture since about 1982, with many small blocks totalling almost 9,000 ha.

While a time consuming procedure, the history of land cover and land use change provides a comprehensive grounding for understanding probable future scenarios and alternative futures for the region. Regional planners, local institutions, and other stakeholders should consider exploring future scenarios of LULC change. Baker *et al.* (2004) and Steinitz *et al.* 2003 have shown how future projections in LULC can aid in planning for a region's future.

5. CLIMATE CHANGE IMPACTS

5.1 *Introduction*

Uncertainty abounds in issues related to climate change, the amount and impact of changes, the efficacy of mitigation and possible strategies that might be used to mitigate or adapt to change. While we still do not understand all the details, we can be certain that human activities have resulted in dramatic increases in the atmospheric concentration of carbon dioxide and greenhouse gasses. It is also certain that these increased concentrations are changing the climate, will continue to do so in the future and that one of the results of these changes will be an average warming on a planetary scale (Morgan & Mellon 2011).

Uncertainty is imbedded within both the IPCC forecasts and all the General Circulation Models (GCMs) (often referred to as Global Climate Models) currently used to model climate change. The IPCC specifically addresses uncertainty by expressing climate change as a range of scenarios. Each IPCC scenario contains different assumptions about the nature and rate of climate change. GCM scientists specifically address the uncertainty using a range of assumptions about atmospheric physics. Twenty-three GCMs are currently being analysed in accordance with the IPCC scenarios to encompass the uncertainty surrounding climate change and confidently identify the areas (and impacts) where multiple models agree.

Given these two primary sources of uncertainty (multiple scenarios, multiple models), quantifying the impacts of climate change for a specific geography can be quite challenging. In addition to the methodological biases of the various GCMs, is the geographical bias. GCMs vary in their focus (land vs ocean, elevation relief vs flat surface, tropical vs temperate, and so on) and in their spatial resolution (1.12º to 5º cells). This results in varying confidence and accuracy for any given region, especially smaller regions where model averaging becomes less useful.

Despite these complicated and necessary (as highlighted above) uncertainties, modelling the effects of climate change is a critical exercise for regional and urban planners. Although the uncertainty can create political obstacles, the opportunity for adaptation needs to be addressed iteratively to ensure the realised effects of climate change are not catastrophic. Thus, urban and regional planning needs to embrace the uncertainty inherent in climate change in a meaningful way to inform policies and the public at large.

5.2 *Methods*

While there are many approaches to studying the effects of climate change on settlements and infrastructure, many amplify the uncertainty already associated with climate change by only considering current population and settlements. Likewise, overemphasis on specific model outputs can lead to over-specific recommendations that are likely to change both as society changes and as climate science advances. A more generic, but equally valid approach is to assess the physical characteristics of a region that define the vulnerability of the landscapes. By focusing only on the physical landscape, this method avoids the uncertainty surrounding specific flood, sea-level rise or storm surge models, and expresses climate change impacts in a way that is flexible to all current and future climate change models. This is not a replacement for intensive modelling efforts, but the approach can provide a way to assess climate change impacts on a larger region in a rapid and cost effective manner. As climate science advances, intensive models will continue to be developed and used for site-specific planning. At a regional scale, a generic but informative approach is needed to identify regionally vulnerable landscapes in order to better plan for climate change.

5.3 *Climate Change Impact Models*

5.3.1 *General Circulation Models (GCMs)*

The first set of climate change impact models assessed potential impacts to a region through changed weather patterns. Although multiple weather outputs can be generated from GCMs, in this project we focus on the two most likely variables to impact landscapes and settlements: maximum temperature and annual rainfall. However, this requires careful consideration of both which GCM, and which emissions scenario, to utilize. First, instead of using outputs from all 23 of the GCMs, we focused only on the models that have proven effective at capturing Australia-specific climatic patterns (Suppiah *et al.* 2007). From the 15 GCMs that perform well in predicting Australian climate, we selected 3 that a) had fine spatial resolution and b) represented different rates (high, medium, low) of climate change. Rates of climate change were taken from the OzClim Science website (CSIRO 2011b). GCM outputs were also taken from the CSIRO-supported OzClim climate change scenario generator (CSIRO 2011a) as ASCII grids, then resampled (using bilinear interpolation) for visualization. The three models used in this analysis (and their rate of climate change) were:

- CSIRO Mk3.0 (Low; 1.7º C global increase from 560ppm CO_2)
    - Commonwealth Scientific and Industrial Research Organization, Australia
    - 1.8º horizontal resolution
- BCCR BCM2.0 (Medium; 2.6º C global increase from 560ppm CO_2)
    - Bjerknes Centre for Climate Research, Norway
    - 1.9º horizontal resolution
- CCR MIROC-H (High; 4.2º C global increase from 560ppm CO_2)
    - Center for Climate System Research, University of Tokyo, Japan
    - 1.1º horizontal resolution

We used a similar approach to identifying scenarios that had a high, medium and low rate of emission production. It is important to point out that these are separate from the rate of climate change considered within the GCMs themselves. The IPCC scenarios represent social drivers of emission production, while the GCM rates of climate change relate to assumptions as to how the climate will respond to the different levels of carbon dioxide. Thus, even though the CSIRO Mk3.0 model assumes a low rate of climate change, it can still be used to model the impacts of A1FI (the highest emission scenario). For the study we considered three emission scenarios: A1FI (high emissions), A2 (medium emissions) and B1 (low emissions), again to highlight the range of climates that may be experienced in the study area.

Furthermore, for practical reasons we only present model outputs for ‘extreme’ conditions under low, medium and high climate change scenarios (Table 5.1). By focusing only on the extremes of each scenario (i.e. low climate change modelled rate under the low emission scenario) we provide a bounding box for consideration of future climates. Average rainfall was calculated annually, while maximum temperature was averaged for the summer months (December – February) only. To remain consistent with other climate change studies, we assessed these climate variables at three time steps: 2030, 2070 and 2100.

TABLE 5.1: EXPECTED CLIMATE CHANGE IMPACTS UNDER DIFFERENT GLOBAL CLIMATE MODEL (GCM) AND IPCC SCENARIO ASSUMPTIONS. RATES OF GLOBAL WARMING TAKEN FROM OZCLIM.

	CSIRO Mk3.0	BCM2.0	MIROC-H
	Low (1.7° C)	Medium (2.6° C)	High (4.2° C)
B1 Low emissions	Least impact		
A2 Medium emissions		Medium impact	
A1FL High emissions			Most impact

5.4 *Sea-level and Flood Models*

While the GCM outputs provide insight into future climates, the majority of impacts to landscapes, settlements and infrastructure are likely to come from the indirect impacts of climate change. These include sea-level rise, storm surges, beach recession and possibly an increase in the magnitude and frequency of flood inundation. Thus, in this study, impact models are presented that provide insight into how these indirect impacts of climate change are likely to impact the north coast of New South Wales.

As over 80% of Australians live in coastal settlements (Harvey & Woodroffe 2008) an increase in mean sea-level is likely to have a range of significant impacts on human settlements (McInnes *et al.* 2003; Walsh *et al.* 2004). Relative mean sea-level rise can lead to the permanent inundation of low-lying areas and whilst the major influences of change in sea levels are long-term, increasing sea levels can also increase the impact of extreme events. Hazards such as extreme short term inundation pose risks to natural and built structures (DCC 2009). In this analysis, we focus primarily on the direct impact (loss of developed lands through inundation and beach recession) SLR might have on settlements and infrastructure. We use a high resolution (5-metre) digital elevation model (DEM) derived from 1-metre vertical resolution contour lines provided by the New South Wales Department of Land and Property Information (LPI).

In its Fourth Assessment Report, the IPCC (IPCC 2007) projections of sea level rise (across all emission scenarios and allowing for the dynamic response of ice sheets) ranged from 0.28 to 0.79 m. The New South Wales Government (DECCW 2009) created the New South Wales Sea level rise policy statement based on these levels (DECCW 2009a) with a maximum 0.9m level rise. Although it is no longer New South Wales policy, many councils follow these guidelines as standard for planning practice (Byron Shire Council 2009). However since the Fourth Assessment Report (IPCC 2007), the possible magnitude of sea-level rise has attracted considerable attention and has been widely debated. For example, Nicholls (2011) considers that for a 4° C change in average temperature 2m is plausible. For this project two levels were modelled, an initial level of 1m to represent the planning guidelines and the vertical resolution of the data as well as a worst case example of 2m. This 2m level is that suggested by Nicholls and approximately double the planning guidelines.

Our third impact model focused on the impacts of increased rainfall and potential for flooding in the region. It is important to understand the potential of flooding in conjunction with SLR to fully assess possible settlement displacement under a changed climate. Similar to the SLR impact assessment, this was done using a high resolution DEM, along with historical flood data from the multiple river systems in the study area. Issues with data availability meant that intensive 1D or 2D hydrologic modelling was not possible and flood areas had to be determined using a localised bathtub model. Major urban areas near large rivers were identified from the LULC map and used to develop an urban flood mask (Figure 5.1). These urban impact areas were then used to mask the DEM so a bathtub flood model could be performed for a localised area. Flood gauge information for flood events was obtained for major rivers near urban areas, and when available, 100-year flood levels adjusted for increased precipitation were also modelled.

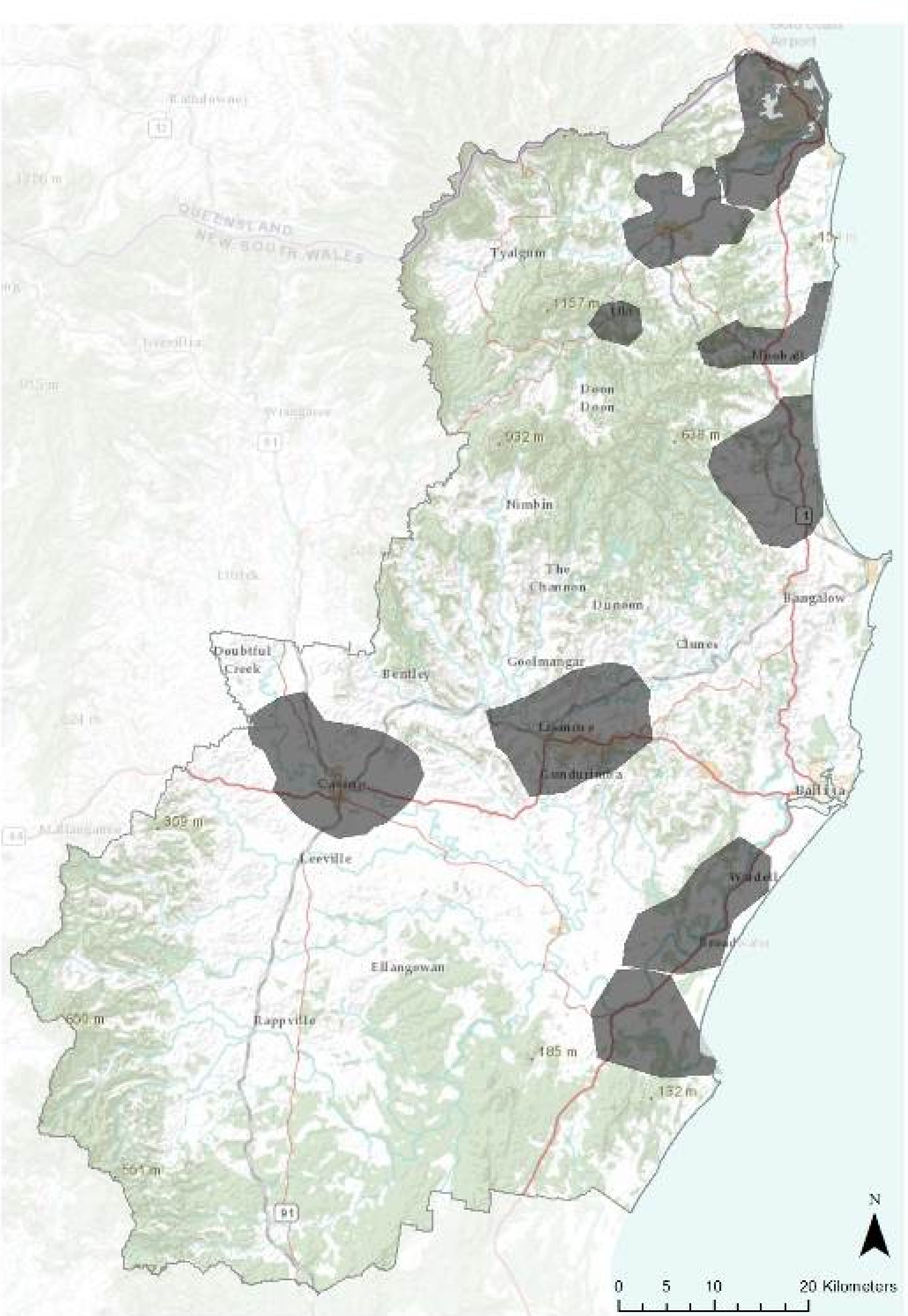


FIGURE 5.1LOCALIZED BATHTUB FLOOD MODEL AREAS. DETERMINED BASED ON FLOOD GAUGE INFORMATION AND PRESENCE OF URBAN AREA IN THE NORTH COAST, NSW.

5.5 *Beach Recession*

The movement of shorelines landwards (recession) or seawards (progradation) as a consequence of sea level rise is an important part of coastal climate change vulnerability assessment. First Pass assessment of the stability or otherwise of existing shorelines involves a simple classification of segments of the shoreline according to fundamental vulnerability factors that predispose shorelines to resist or recede with sea level rise (Sharples 2006).

For this study, the smartline (Sharples 2006) database was used to identify unprotected shoreline segments with sandy beaches backed by Quaternary alluvium. In addition the 1:250,000 Geological series sheets were used, together with visual interpretation of the air-photo mosaic areas to predict shoreline recession which might occur in coastal areas. The results of the two methods were then merged and a mid-range Bruun Rule factor of 1V:75H (Ranasinghe *et al*. 2007) was applied from mean sea level. Sea level rise values of 0.3m, 0.7m, 1.1m and an extreme case of 2m were used to generate recession levels of 23m, 53m, 83m and 150m respectively.

5.6 *GCM Results*

GCM results for the region are varied and represent the uncertainty involved in modelling climate change. Overall however, climate variability within each scenario and model output varied little within the study area. While maximum temperature varied substantially between scenarios and GCM (Table 5.2; Figures 5.2-5.5), it varied very little across the study area (Figure 5.5). Current maximum temperatures vary little across the study area (30ºC in Lismore/Casino and 28º C in Ballina), suggesting future climate may maintain current patterns. Given the minimal variation in temperature across the study area, alternative urban growth patterns are not likely to change the impact of increasing temperatures on settlements. Furthermore, as the current average maximum temperature is 30º C (inland settlements), the impacts to human health may not be as severe as forecasted in other parts of Australia.

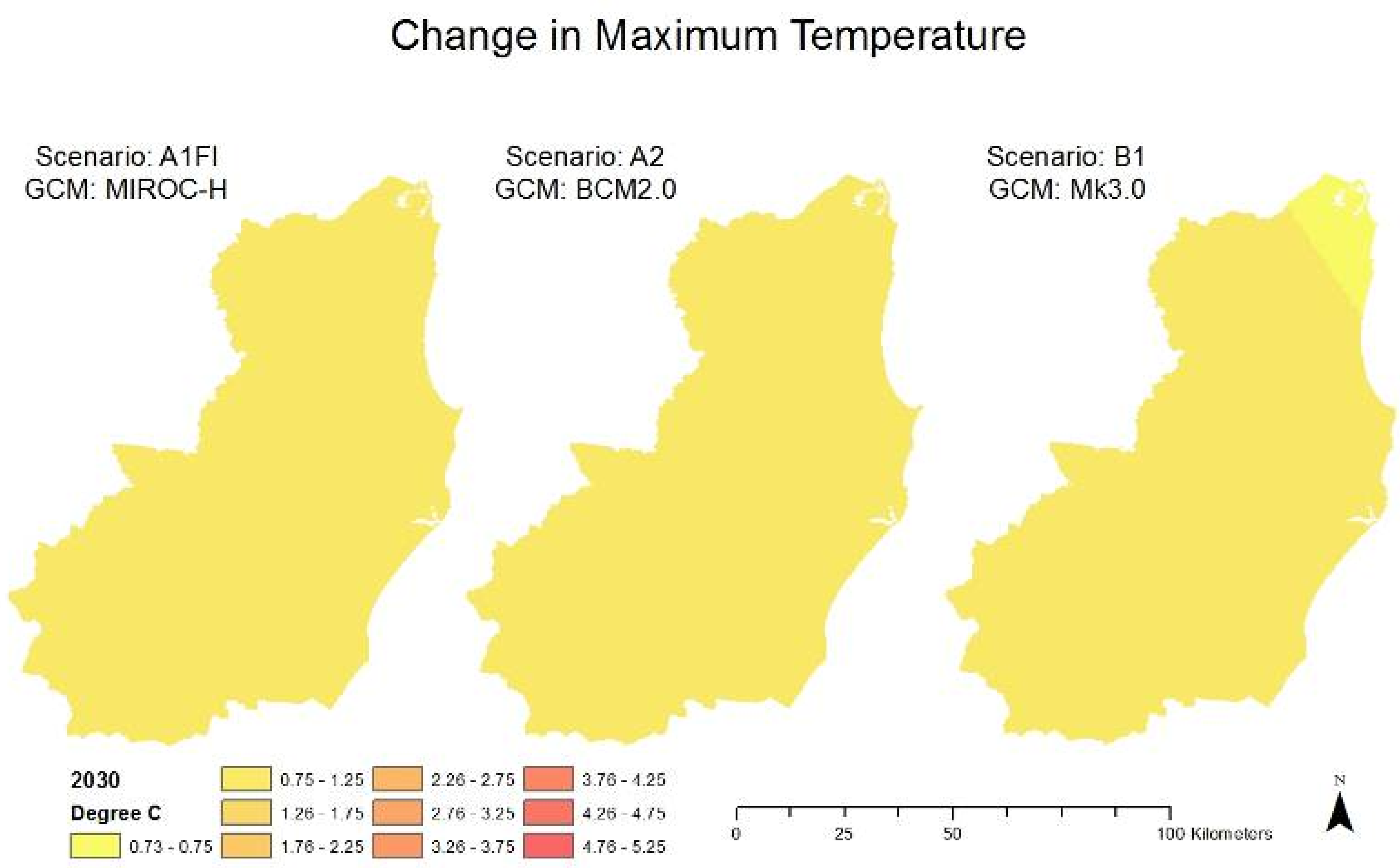


FIGURE 5.2 MODELLED INCREASE IN AVERAGE MAXIMUM TEMPERATURE DURING THE SUMMER MONTHS IN THE NORTH COAST, NSW BY 2030.

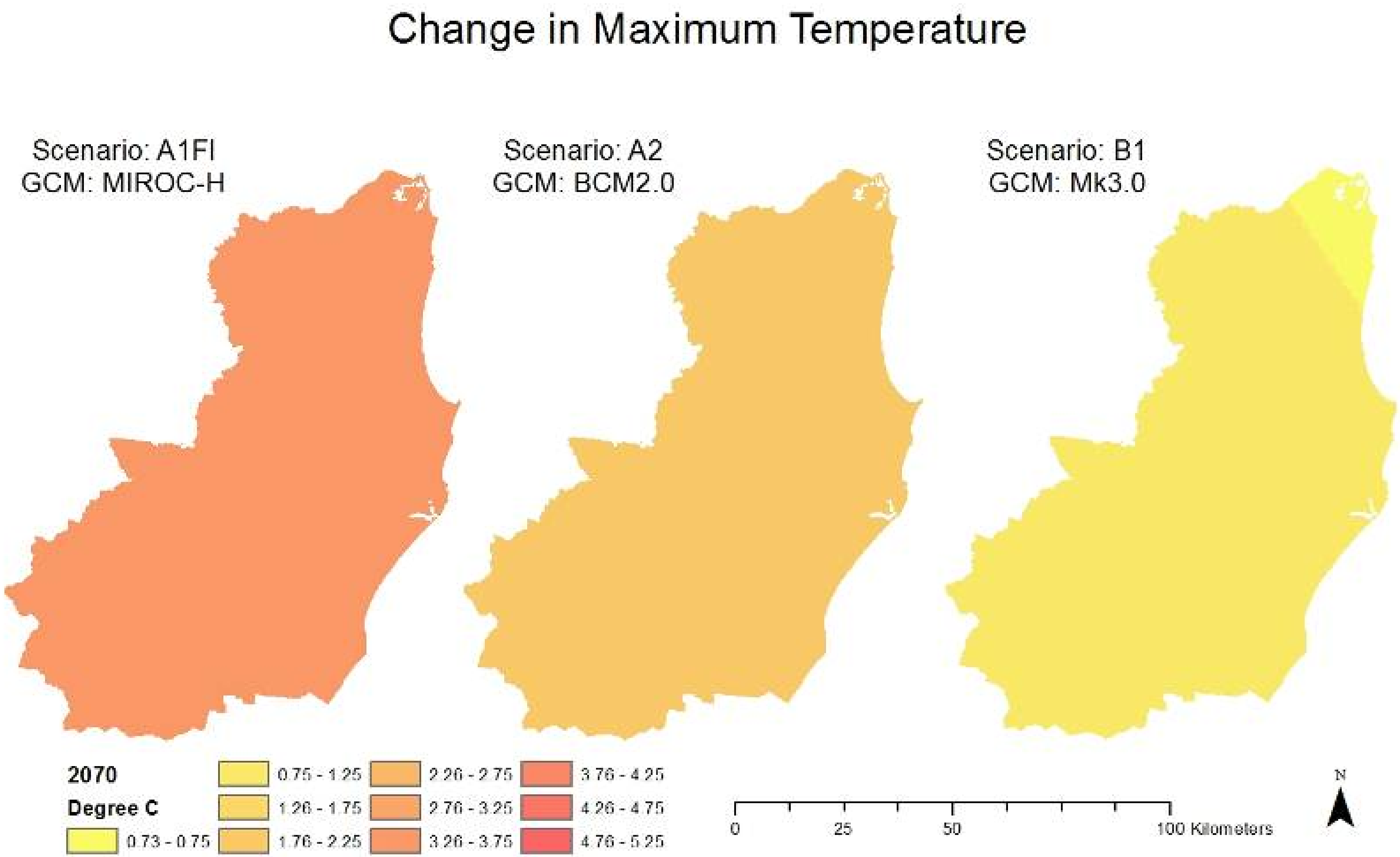


FIGURE 5.3: MODELLED INCREASE IN AVERAGE MAXIMUM TEMPERATURE DURING THE SUMMER MONTHS IN THE NORTH COAST, NSW BY 2070.

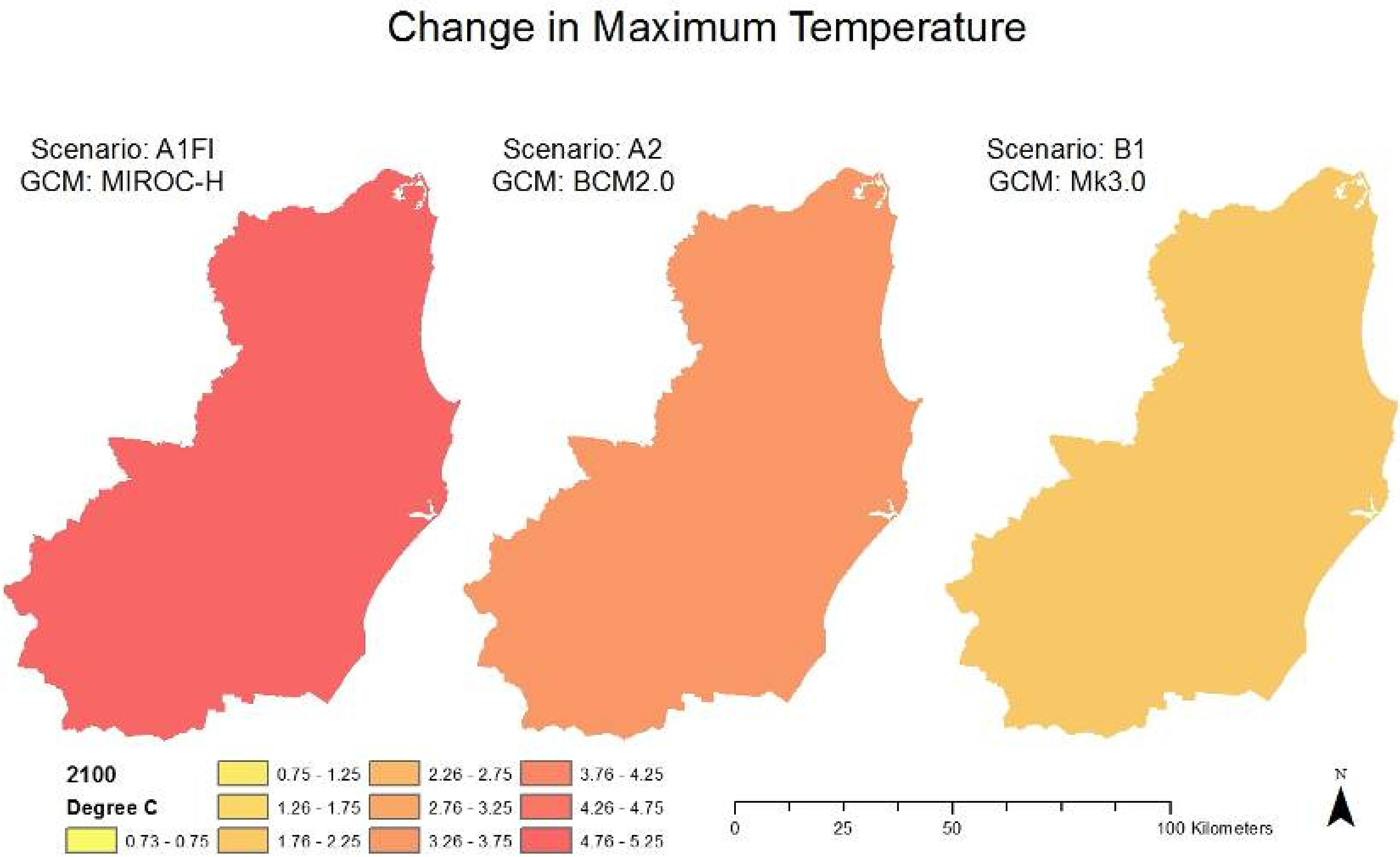


FIGURE 5.4: MODELLED INCREASE IN AVERAGE MAXIMUM TEMPERATURE DURING THE SUMMER MONTHS IN THE NORTH COAST, NSW BY 2100.

TABLE 5.2: INCREASE IN AVERAGE MAXIMUM TEMPERATURE EXPECTED IN THE STUDY AREA UNDER ALTERNATIVE SCENARIOS AND GCMS.

Maximum Temperature	Current	Mk3.0			BCM2.0			MIROC-H		
		2030	2070	2100	2030	2070	2100	2030	2070	2100
Low CC (B1)	28°-30°	0.7	0.8	2.0						
Moderate CC (A2)					0.8	2.2	3.7			
High CC (A1FI)								1.1	3.5	5.1

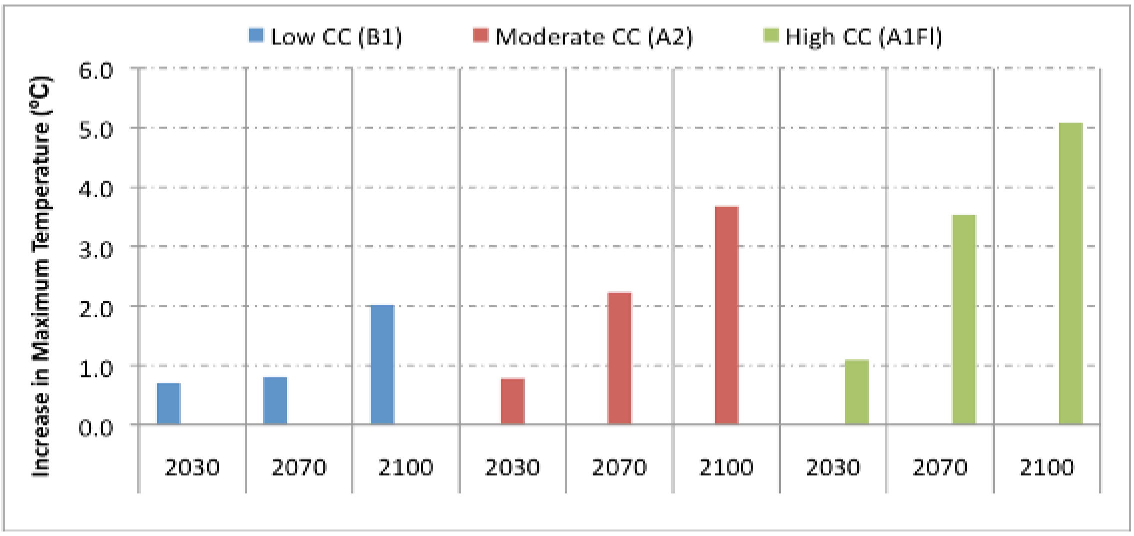


FIGURE 5.5: PREDICTED AVERAGE MAXIMUM TEMPERATURE FOR THE NORTH COAST OF NSW UNDER ALTERNATIVE SCENARIOS AND GCMS.

Changes in precipitation were more variable, with a sharp decrease (25% less) in the annual average precipitation predicted by the low rate of climate change model (CSIRO Mk 3.0). The other two models predict increases in precipitation, and in the case of the high rate of climate change model (MIROC-H), up to 25% more precipitation for the region.

Similar to maximum temperature, significant changes to annual precipitation aren't seen until 2070, except under the low climate change models (Table 5.3 and Figures 5.7 – 5.10) Although lower precipitation and subsequent water flows at this level are unlikely to have major effects on the quantity of drinking water for the region, there is the potential for cost increases, reduced water quality, increased fire risk and some possibility of agricultural supply and salinity problems.

Conversely, the significant increase in precipitation in the region under a high rate of climate change scenario could lead to increases in both the frequency and magnitude of flooding throughout the region. Figure 5.6 shows graphically how a 25% increase in rainfall changes the frequency of inundation events of a certain magnitude. A 1% chance (or 1 in 100 year) of reaching a previous level would become a 4% chance (or 1 in 25 year) and '1 in 20 year' event becomes '1 in 5'.

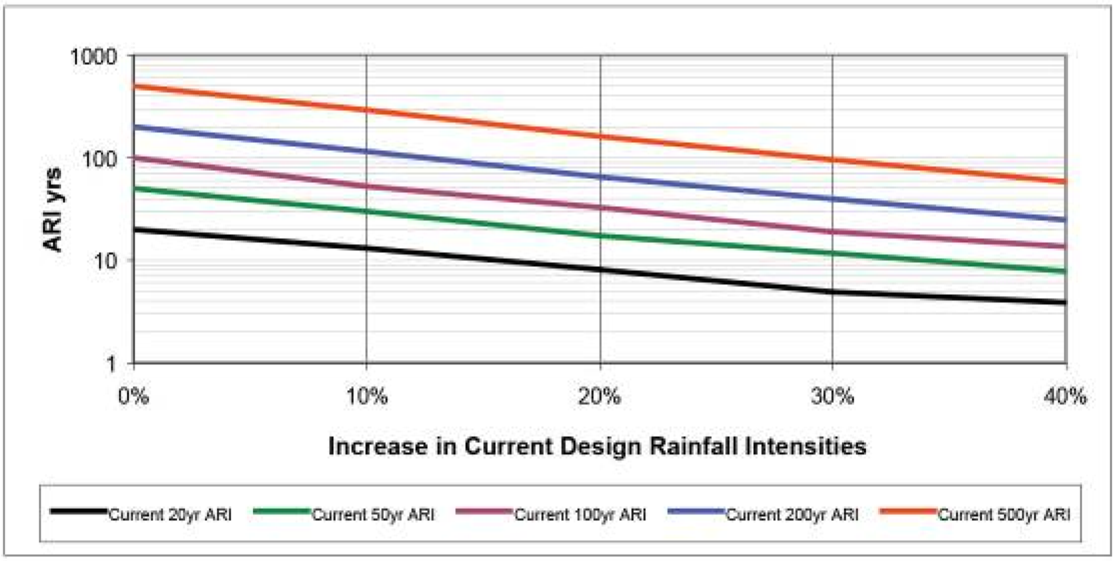


FIGURE 5.6 CHANGE IN FREQUENCY OF INUNDATION EVENTS (SOURCE MCLUCKIE 2005 IN DECCW 2010C)

TABLE 5.3: CHANGE IN AVERAGE ANNUAL PRECIPITATION FOR THE NORTH COAST OF NSW UNDER ALTERNATIVE SCENARIOS AND GCMS.

Annual Precipitation	Current	Mk3.0			BCM2.0			MIROC-H		
		2030	2070	2100	2030	2070	2100	2030	2070	2100
Low CC (B1)	1000-1600mm	-126	-238	-288						
Moderate CC (A2)					12.1	39.1	71.7			
High CC (A1FI)								63.8	217	316

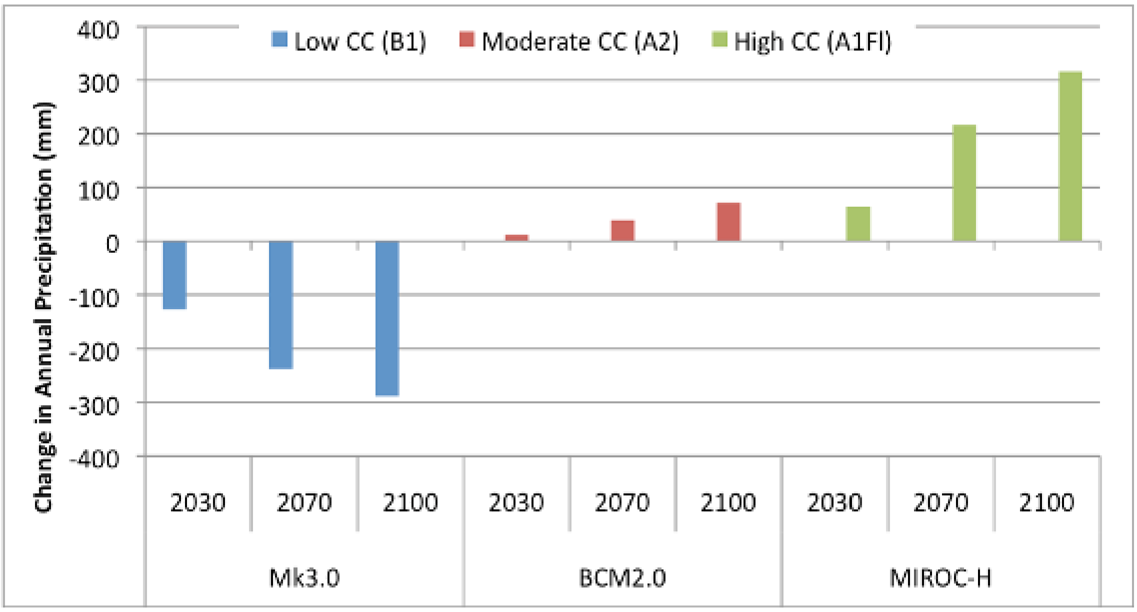


FIGURE 5.7: PREDICTED CHANGES IN ANNUAL AVERAGE PRECIPITATION FOR THE NORTH COAST OF NSW UNDER ALTERNATIVE SCENARIOS AND GCMS.

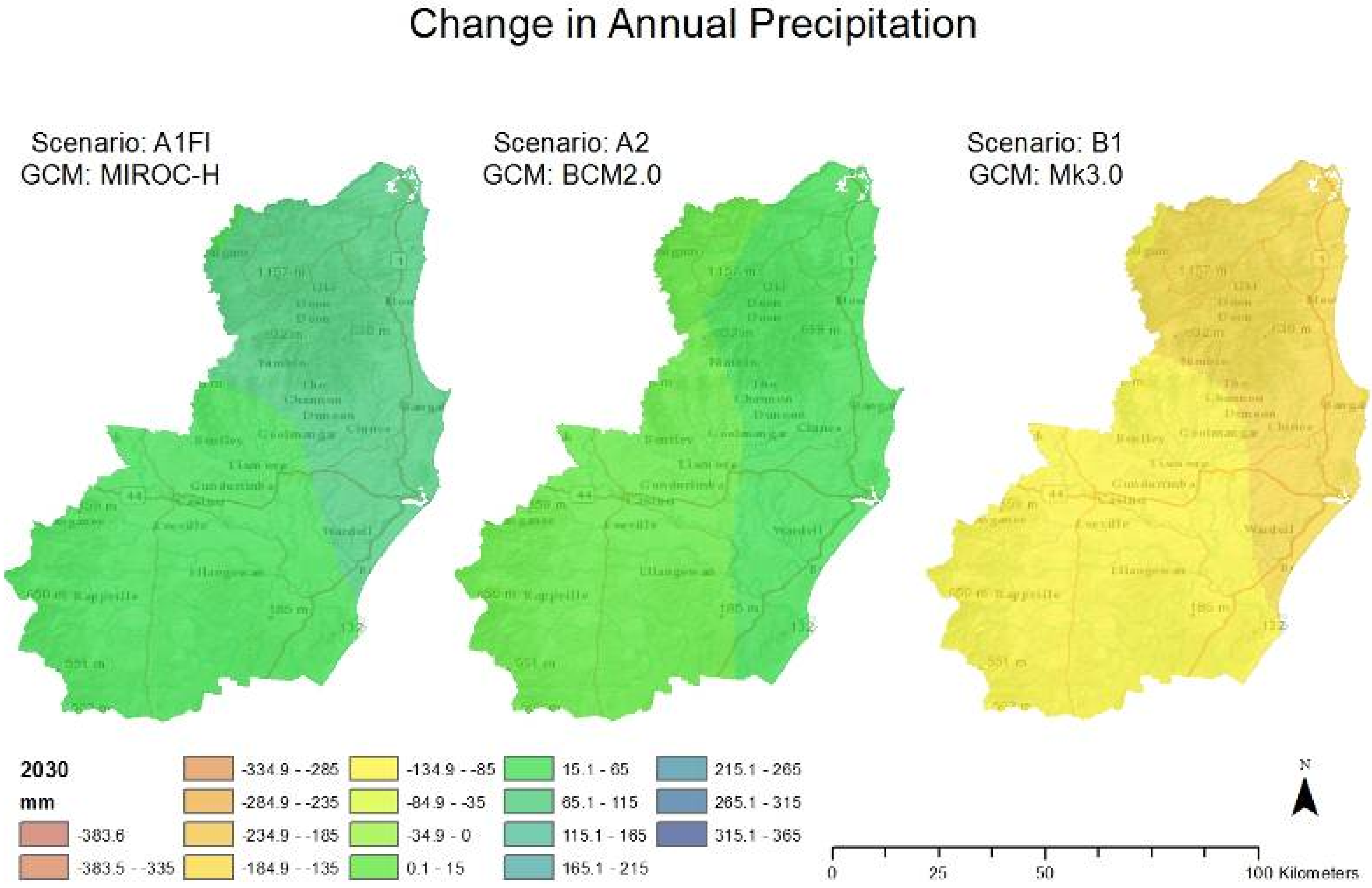


FIGURE 5.8: MODELLED CHANGES IN ANNUAL PRECIPITATION FOR THE NORTH COAST, NSW BY 2030.

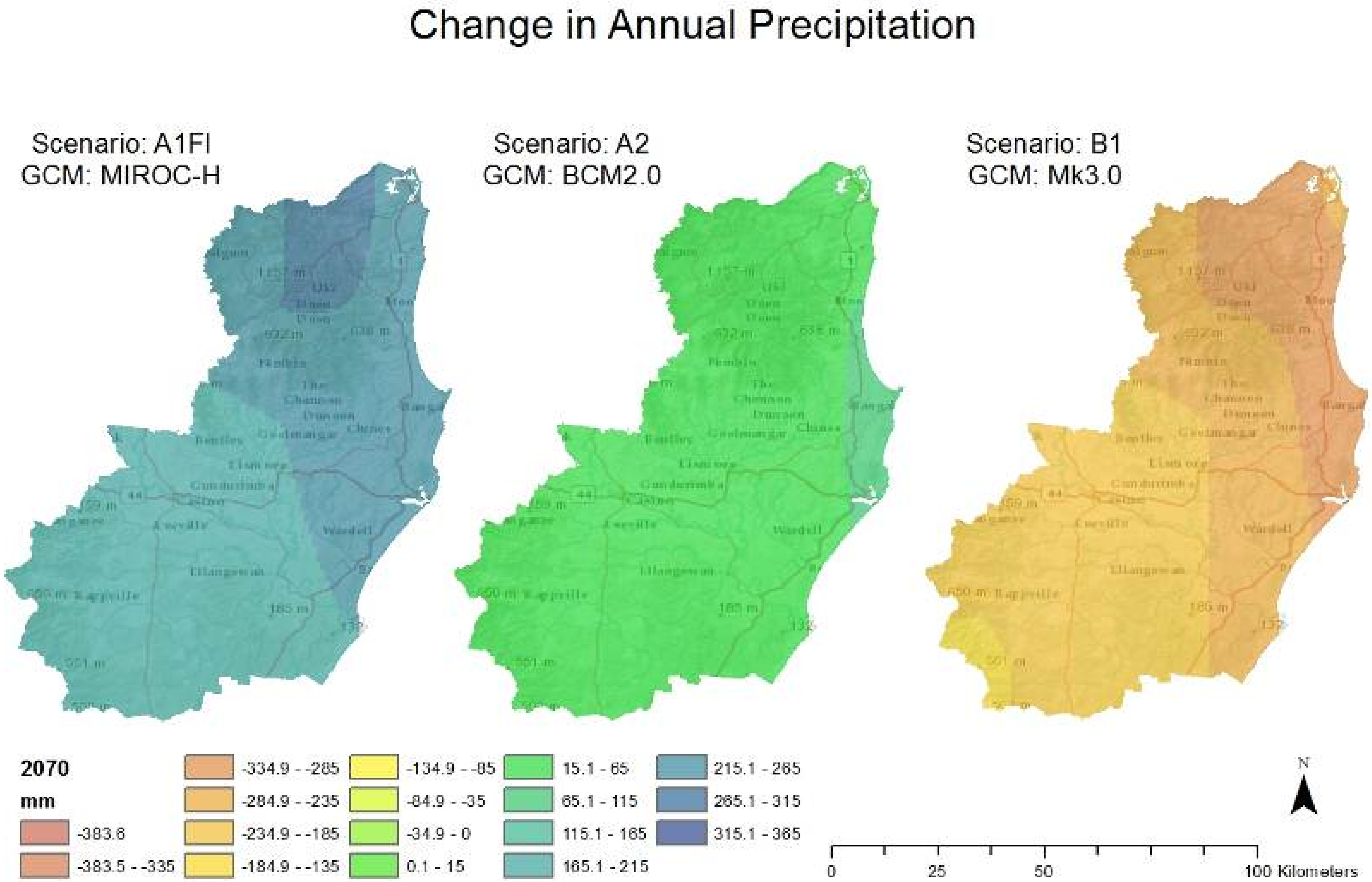


FIGURE 5.9: MODELLED CHANGES IN ANNUAL PRECIPITATION FOR THE NORTH COAST, NSW BY 2070.

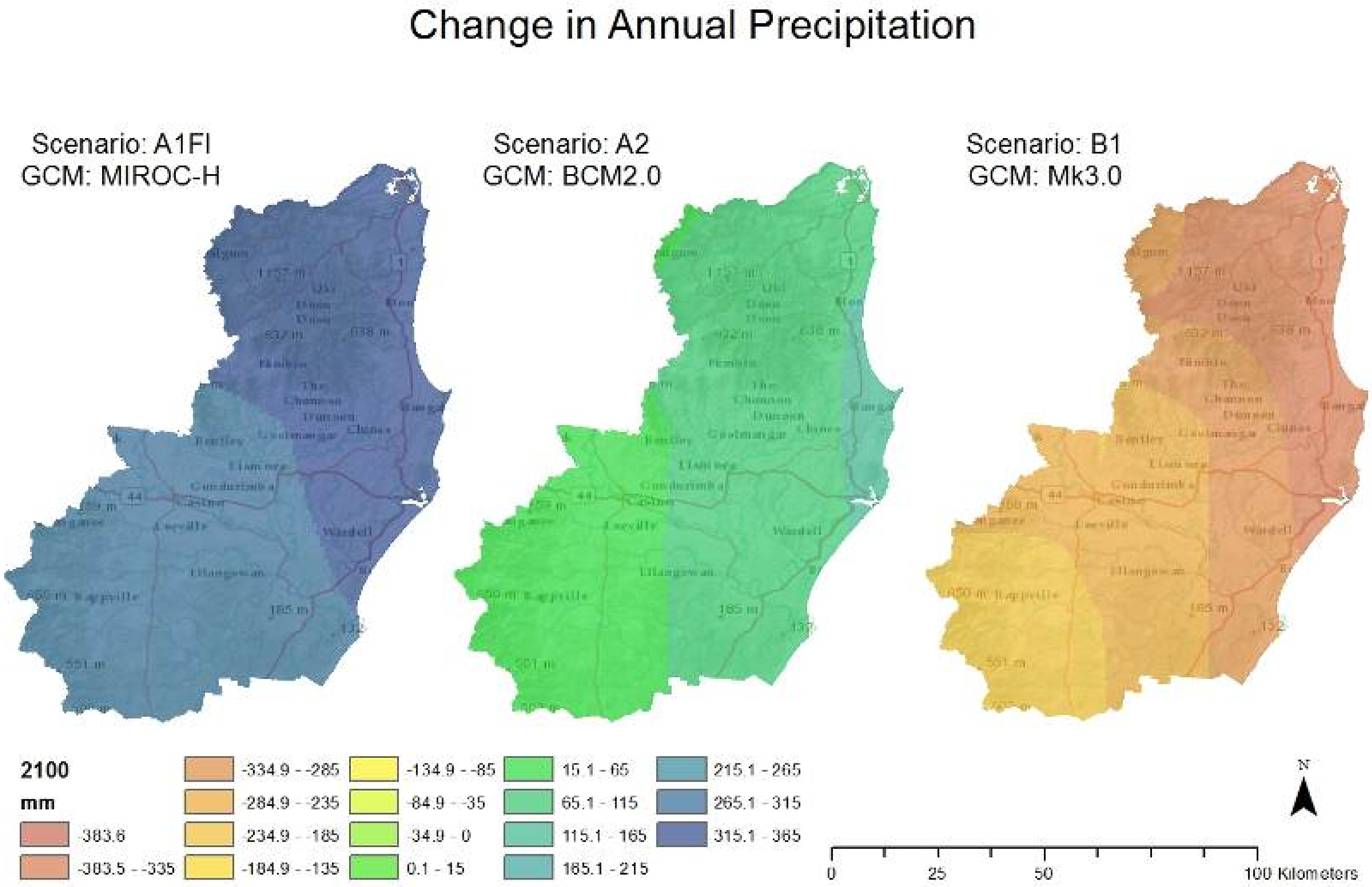


FIGURE 5.10: MODELLED CHANGES IN ANNUAL PRECIPITATION FOR THE NORTH COAST, NSW BY 2100

6. SOCIAL VULNERABILITY

6.1 *Introduction*

This chapter describes the analysis undertaken to improve the understanding of spatio-temporal patterns of vulnerability of human populations in the study area to future climate change. The premise underlying this analysis is that the vulnerability of a population is some function of the severity of the changes to which they are exposed and a number of socio-economic characteristics of the population itself, which determine the short term damage that might be incurred and the adaptation paths that occur in both the short and long term.

It is also assumed that these socio-economic characteristics change over time and space as populations age, as in- and out-migration occur and as economic structural change takes place.

The approach taken is to use Census data to quantify the pattern of socio-economic characteristics, the nature of change in these characteristics in recent times, to understand the socio-economic mechanisms that drive these changes, and to use this understanding to construct scenarios of how these characteristics might be distributed across the changing populations of the study area in the future.

6.2 *Concepts and terminology*

In the last decade, largely through the efforts in the field of climate change vulnerability, a consensus has emerged in the literature about the basic concepts through which the mechanisms of impact and adaptation can be understood. The conceptual model depicted in Figure 6.1 is now widely accepted (see, for example Smit & Wandel 2006; U.S. Agency for International Development 2009; Preston *et al.* 2008).

6.2.1 *Components of Climate Change Vulnerability*

Vulnerability may be described as the capacity of a system to cope with stress or change. In the context of climate change it is accepted that vulnerability is a function of the exposure to climate change hazards, the relative sensitivity to these hazards and the adaptive capacity which might ameliorate potential impacts (IPCC 2001; Smit & Wandel 2006; Preston *et al.* 2008; Allen Consulting 2005). It is a forward-looking concept that relates to the impacts of events and the likelihood of negative outcomes in the future because of exposure to such events (Alasia *et al.* 2008). These basic concepts are defined in greater detail below, while their relationship with vulnerability is depicted in Figure 6.1 below.

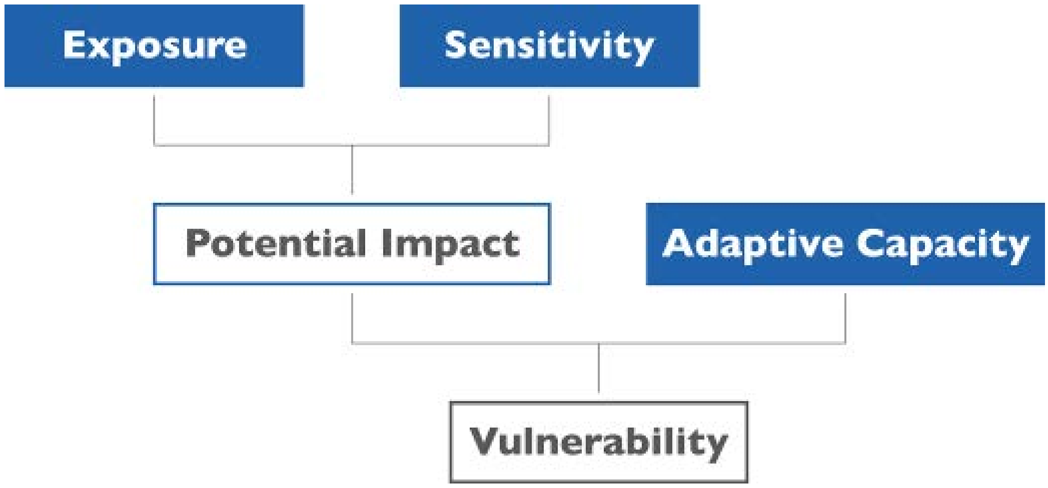


FIGURE 6.1: COMPONENTS OF VULNERABILITY (IPCC, 2001; ALLEN CONSULTING, 2005).

6.2.1.1 Exposure

Exposure refers to the degree of hazardous exposure to climate change. Sea levels worldwide are expected to continue to rise during the 21st century, and along with increasingly frequent extreme weather events and coastal erosion (Kaiser 2007). Isolated locations in Byron Bay and Ballina have in the past experienced damage to housing and infrastructure due to storm induced erosion.

Both the Tweed and Richmond Rivers are susceptible to flooding and the flood plain areas around Casino and Lismore are well known for the frequency of inundation. Although generally not as devastating as cyclone, tsunami or earthquake, flooding from high intensity rainfall or storms is a high risk hazard in the region, and can cause considerable economic loss and damage natural environments.

6.2.1.2 Sensitivity

Sensitivity refers to the responsiveness of a system to climatic influences. The degree of sensitivity is also location specific. The greater the sensitivity of a landscape, community or sector, the greater the impact of climatic events (Polsky *et al.* 2003; Allen Consulting 2005; Preston *et al.* 2008). For example, residential areas on unconsolidated beach sands behind frontal dunes may be more sensitive to sea level rise and coastal erosion than residential areas adjacent to stable cliffs.

6.2.1.3 Adaptive capacity

The adaptive capacity or 'resilience' of a community is a key element of understanding the vulnerability of an area, as the extent of a community's adaptive capacity will increase or decrease its vulnerability (Kaiser 2007). Resilience or coping capacity can be seen as the positive dimension of vulnerability, while the degree of susceptibility or risk is the negative dimension (Birkmann & Fernando 2007). Adaptive capacity is affected by the availability of mechanisms as well as the willingness and capacity of individuals, communities and institutions to change in the face of the shifting needs and uncertainties.

Communities that are able to respond to or cope with change quickly and easily may be regarded as having high adaptability or adaptive capacity. Adaptive capacity for settlements and communities may be enhanced through creating the information, social structures, leadership and governance that are needed as a foundation for delivering adaptation actions. Alternatively, it may be enhanced through delivering adaptation actions that help to reduce vulnerability or to exploit opportunities resulting from change.

6.2.1.4 Vulnerability

Exposure and sensitivity determine the magnitude of potential impact on a system while adaptive capacity refers to the resilience of the system to cope with, and manage, this impact. As such the vulnerability of a system is a function of the exposure and sensitivity of that system to and the ability, capacity or resilience of the system to anticipate, resist, adapt or recover from the effects of those conditions.

This then determines the overall vulnerability (Allen Consulting 2005; Preston *et al.* 2008). The advantages of this approach are the transparency of the indicator framework and the linkage of the framework with simulation models (existing knowledge).

6.2.2 *Temporal consistency*

Temporal consistency requires that the projected vulnerability at a point in the future be assessed using not only climate projections for that time point, but also projections of the landscape and community at that time. For example, to overlay projected 2100 coastline on a map of 2010 LULC is to ignore the impact of sea level rise on whatever suburban, commercial and industrial development might take place between 2010 and 2100. In practice, however, there are varying degrees of difficulty in attaining this temporal consistency. While the spatial patterns of the built-up area can be predicted with some degree of certainty by the forward projection of historical patterns of change it is almost impossible to predict what the nature of development might be. Similarly, for the society that will exist in 2100, it is very difficult to predict anything other than crude demographics. Important indicators in the assessment of vulnerability, such as residential mobility and perceptions of risk are impossible to predict. For these reasons, the approach taken in the study was to project patterns of human settlement forward for use with future climate projections, while using current information about the economy and the community as a proxy for the future projections that are impossible to obtain.

6.3 *Scope*

For coastal climate change vulnerability, the main emphasis is on the position of the coastline and periodic inundation in its vicinity. Climate change forecasts of increasing frequency and extent of flooding related to storm events, on top of sea-level rise, suggest there will be a major impact on coastal communities and industries. For this reason, projections relating to other climate change impacts, such as the frequency of heat wave periods, bushfires or drought have not been included in this study. Local government in the region, however, is already investing considerable resources into developing or acquiring sophisticated databases, techniques and specialised software for such purposes (e.g., Gibbins *et al*. 2008).

6.4 *Socio-economic factors influencing impact and adaptation*

To gain an understanding of how the individual and social characteristics of a community might influence how it responds in the short and long term to the stresses imposed by climate change it is necessary to draw from a wide range of disciplinary specialties, such as behavioural psychology, social psychology, sociology, third world development studies and natural hazards studies in geography.

An overview of this literature suggests that the influences on community responses to the types of stresses caused by climate change can be divided into three groups:

- attitudinal and perceptual characteristics that pre-dispose communities to vulnerability,
- individual and social characteristics that explain short term responses (e.g. natural disaster response) to specific events such as extreme weather events, and
- individual and social characteristics that explain longer term responses (e.g. residential mobility) over periods of decades.

These three groups of influences, which form the basis for the development of social vulnerability indicators, are now described in turn in the order above.

Risk perception is an important predictive indicator of the capacity of individuals and communities to adapt to climate change, and their ability to cope with natural disasters (Pijawka *et al.* 1988). Risk perception determines 'where people settle, how they are prepared, how they behave in case of an emergency, and finally what kind of risk they accept' (Kaiser 2007, 1). If particular risks are underestimated, individual adaptation responses may be insufficient.

Individuals may choose to disregard the potential risks associated with disasters (such as flooding), for a variety of reasons including their perceptions of previous events, their ability to take precautionary measures, the costs involved in doing so, and even 'wishful thinking' (Grothmann & Reusswig 2006). Etkin and Ho (2007) identified a number of important *attitudinal* factors that impact on individual risk perception as it relates to climate change, including:

- their view on the 'Myth of Nature' – individuals may subscribe to various 'myths', including nature as resilient, or nature as subordinate to human activity;
- their social values;
- their views and values regarding the environment;
- the type and magnitude of hazard faced (for example, involuntary, catastrophic, dreaded, fatal, known, delayed, controllable or old);
- their relative vulnerability (discussed above); and
- the perceived benefits of action (or inaction).

Furthermore, Etkin and Ho (2007) identify significant gaps in understanding the impact of climate change amongst the general public, in contrast to the scientific community. Consequently, a number of factors relating to the level of *knowledge* possessed by the individual can also inform perceptions of risk:

- uncertainty about what climate change is;
- uncertainty about the impact of climate change;
- uncertainty about what can be done to mitigate this impact;
- uncertainty about the impacts of action or inaction;
- poor access to relevant information; and
- unstated assumptions about climate change.

An individual's, or indeed a community's, evaluation of risk therefore influences both capacity to adapt to climate change, and ability to cope with particular natural disasters.

Socio-economic status is an important predictor of the physical and psychological impacts of an extreme weather event, and of vulnerability or adaptive capacity. Fothergill and Peek (2004) and Blaikie *et al.* (1994) suggest that any conception of a natural disaster as a socio-economic leveller is inaccurate. Instead, 'disasters are the products of the social, political, and economic environment, as well as the natural events that cause them' (Fothergill and Peek 2004, 89). Those with a relatively low socio-economic status are therefore most likely to suffer (both physically and psychologically) during a natural disaster, and to encounter greater obstacles during the disaster response, recovery and reconstruction phases (Fothergill & Peek 2004).

Other individual and social factors influencing short term responses include age, ethnicity, and female headed households (Masozera *et al.* 2006), as well as people with special needs, such as the physically and intellectually disabled (Cutter *et al.* 2000).

In the longer term, the main adaptive response to sea level rise and increased frequency of inundation in coastal area is residential re-location. Studies of residential mobility suggest that people's decisions to move to a new location are influenced by:

- satisfaction with their neighbourhood,
- satisfaction with their housing,
- size of household,
- tenure,
- income,
- age, and
- extent of friendship and kinship networks (Lu, 1998).

A wide range of socio-economic factors that contribute to the capacity to adapt to stresses generally, not just those due to climate change, have also been identified in the literature (Yohe & Tol 2002; Brooks 2003; Maguire & Cartwright 2008; Vinson 2009). These generally fall into four broad categories:

- human capital,
- social capital,
- institutional capital, and
- economic diversity.

6.4.1 *Indicators and indices*

Socio-economic indicators attempt to gauge the extent to which socio-economic factors described above are present in rural communities. The indicators are generally based upon measurable characteristics, such as those recorded in the Census, and attempt to provide a set of measures that covers the range of factors discussed above. The selection of the socio-economic indicators is made with regard to the source of stress being studied, e.g. adaptation to climate change requires some different indicators to adaptation than adaptation to structural change in agriculture would. Adaptation to structural change may require reskilling in the workforce, while adaptation to climate change may require working in the same industry in a different location.

In forming measures of sensitivity and adaptive capacity, it is assumed that the event that communities might be sensitive to, or may have to adapt to, is an inundation event, caused by flooding, storm surge or sea level rise or some combination of the three. It is also assumed that adaptation to inundation events involves both short and long term adaptation. The former involves preparation for inundation events so that inconvenience, damage and harm to people is minimised. Long term adaptation involves relocation to less exposed areas. Short term adaptive capacity is people's capacity to be prepared for inundation events and avoid harm. Long term adaptive capacity is their capacity to re-locate.

Events that might be an ultimate consequence of inundation events, e.g. the contraction of the sugar industry are not considered.

Unfortunately, secondary data sources, such as the Census, are rarely based on questionnaires designed with community adaptation in mind. Consequently, the range of socio-economic indicators available may not be ideal. One approach is to choose a wide range of indicators from the data that is available and examine their inter-relationships using principal components analysis (PCA), with a view to reducing the number of indicators to a compact set that reflects, to the greatest extent possible, the factors described above. This approach has been used for a number of years by the ABS in the construction of its SEIFA indices (ABS 2006), as well as in other studies (Fenton & Coakes 1998; Vinson 1999; Baum *et al.* 2008; Stenekes *et al.* 2010).

The use of terms in the remainder of this document is as follows:

- *data item* – a single number, such as number of people in the workforce,
- *indicator* – a single data item or a number derived arithmetically from more than one data items that is taken to indicate the level of simple concept, e.g. the proportion of unemployed in the workforce is an indicator of the level of unemployment,
- *sub-index* – a single indicator or a number derived arithmetically from more than one indicator, that is also combined with other sub-indices to calculate an index, e.g. the potential impact and adaptive capacity sub-indices are combined to obtain the vulnerability index,
- *index* – a single number representing a complex concept and obtained by combining sub-indices, and
- *measure* – a generic term referring to indicators, sub-indices and indices.

6.4.2 *Analysis of 2006 Census data*

Census data required to construct Census indicators was extracted from the ABS 2006 Census Data Packs (ABS 2007a) using code written in R (R Core Development Team 2011), followed by the calculation of Census indicators. A total of 30 Census indicators were chosen as possible constituents in the construction of indices of sensitivity and adaptive capacity (Table 6.1).

TABLE 6.1: 2006 CENSUS INDICATORS CHOSEN FOR ANALYSIS.

Relevant concept (s)	***Census variable (mnemonic)***	***Calculation***
LT adaptive capacity	Percentage of households rented (dwelrent)	Calculated as a percentage of total occupied private dwellings
LT adaptive capacity	Percentage of persons left school before 15 years of age (leftyr10)	Calculated as a percentage of persons aged 15 years and over
LT adaptive capacity	Percentage of persons without a post-school qualification (noqualif)	Calculated as a percentage of persons aged 15 years and over
LT adaptive capacity	Total unemployment rate (totunemp)	Unemployed persons as a percentage of the total labour force
LT adaptive capacity	Unemployment rate 15-19 years age (unem1524)	Unemployed persons 15-19 years of age as a percentage of the total labour force 15-19 years of age
LT adaptive capacity	Unemployment rate 20-64 years age (unem2064)	Unemployed persons 20-64 years of age as a percentage of the total labour force 20-64 years of age
LT adaptive capacity	Percentage of persons living in a different address five years ago (difad5yr)	Calculated as a percentage of all persons
LT adaptive capacity	Percentage of persons living in a different address one year ago (difad1yr)	Calculated as a percentage of all persons
Sensitivity	Percentage of households with no vehicle (novehic)	Calculated as a percentage of total occupied private dwellings
Sensitivity	Percentage of separated or divorced persons (separdiv)	Calculated as a percentage of persons aged 15 years and over
Sensitivity	Dependency ratio (depration)	Persons under 15 years of age and over 65 years of age as a proportion of those between 15 and 65 years of age
Sensitivity	Percentage of persons aged 65 years or more living in lone person households (lone65)	Calculated as a percentage of total persons
Sensitivity	Percentage of persons aged 65 and over (over65yo)	Calculated as a percentage of all persons
Sensitivity	Percentage of persons with a 'need for assistance' *(persons with a 'profound or severe disability' defined as needing assistance with self-care, mobility, and/or communication)* (needassi)	Calculated as a percentage of all persons

TABLE 6.1(CONTD): 2006 CENSUS INDICATORS CHOSEN FOR ANALYSIS.

Relevant concept (s)	***Census variable***	***Calculation***
Sensitivity	Child to carer ratio (chcaratio)	The ratio of children less than 15 years of age to the number of persons over 15 years of age undertaking unpaid child care for their own and/or other children
Sensitivity	Percentage of persons aged 5 years or less (less5yrs)	Calculated as a percentage of all persons
Sensitivity	Percentage of persons who speak English 'not well or not at all' (engnotwell)	Calculated as a percentage of all persons
Sensitivity	Percentage of residents who do not speak English at home (lotengli)	Calculated as a percentage of all persons
Sensitivity	Percentage of visitors (visitors)	Those staying at an address in the CCD on Census night that was not their usual place of residence, calculated as a percentage of all persons
Sensitivity	Percentage of lone person households (oneperso)	Calculated as a percentage of total occupied private dwellings
Sensitivity	Percentage persons commuting by car (commutecar)	Those who commute to work using a car calculated as a percentage of employed persons aged 15 years and over. Includes those who use a car as well as other methods of transport (e.g. train, bus)
Sensitivity	Number of children (numchild)	Number of persons under 15 years
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of families with weekly income less than $349 (lowincom)	Calculated as a percentage of the total count of families
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of labourers in the workforce (labourer)	Calculated as a percentage of employed persons aged 15 years and over
ST adaptive capacity LT adaptive capacity Sensitivity	Average household size (averhous)	(ABS calculation) Based on number of persons usually resident in occupied private dwellings

TABLE 6.1(CONTD): 2006 CENSUS INDICATORS CHOSEN FOR ANALYSIS.

Relevant concept (s)	*Census variable*	*Calculation*
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of caravans, cabins, houseboats, improvised homes, tents etc. (caravans)	Calculated as a percentage of total occupied private dwellings
ST adaptive capacity LT adaptive capacity Sensitivity	Median income as a fraction of the Australian median income (meaninco)	Median weekly household income expressed as a percentage of the Australian median weekly income.
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of single parent families (oneparen)	Calculated as a percentage of total families in family households
ST adaptive capacity Sensitivity	Percentage of single parent families with children less than 15 years of age only (onepal15)	Calculated as a percentage of total families in family households
ST adaptive capacity LT adaptive capacity	Percentage of persons working as volunteers in the previous 12 months (voluwork)	Calculated as a percentage of persons aged 15 years and over.

Some of these indicators are inevitably related to more than one of the concepts. For example, a single parent with a large number of children in the household might have difficulty with evacuation in a flood emergency (Sensitivity), but also be too busy with child care to make adequate preparations (Short term adaptive capacity) and not have the financial resources to consider re-locating (Long term adaptive capacity).

Principal components analysis (PCA) was used to reduce the list of 30 potential indicators of sensitivity and adaptive capacity shown in Table 6.1 to a set of small groups of indicators, where each set contains indicators that are correlated with each other, and the sets themselves are relatively uncorrelated, which means the set of indicators potentially represents a factor influencing sensitivity and/or adaptive capacity that is independent of the other factors represented by other sets of indicators.

PCA was carried out on the correlation matrix, with orthogonal varimax rotation to aid interpretation of the components. The software used was SPSS.

An initial analysis was undertaken with the number of components set by the criterion that their eigenvalues be less than one. The number of components to interpret was chosen by inspection of the scree plot, the interpretability of the components, and the presence of components with loading on only a small number of variables. Where these criteria permitted the possibility of several different solutions, each with a different number of components, each solution was examined and the solution providing the most readily interpreted components chosen. A conservative loading threshold of 0.7 was set for interpretation of components.
A seven component solution was chosen as the best in meeting these criteria (Table 6.2). The interpretation of the seven components in terms of the factors affecting sensitivity and adaptive capacity is set out in Table 6.3.

TABLE 6.2: RESULTS OF PCA – ROTATED COMPONENT MATRIX.

Variable mnemonic	Component						
	1	2	3	4	5	6	7
over65yo	.936						
loneho65	.905						
depratio	.836						
averhous	-.740	-.419		-.388			
needassi	.727						
oneperso	.673	.508		.383			
less5yrs	-.548			-.339			
chcaratio	-.420		.356	-.390			-.303
oneparen		.862					
onepal15		.834					
dwelrent		.725				.397	
separdiv		.606		.396	.306		
lowincom	.516	.587		.312			
meaninco	-.500	-.579	-.301				
novehicl	.536	.556	.376				
leftyr10	.408		.792				
noqualif	.439		.716				
labourer			.711				
voluwork		.408	-.566			-.403	
visitors				.777			
caravans				.684			
numchild	-.373			-.508			
commutecar		-.362		-.446			
totunemp		.417			.812		
unem1524					.811		
unem2064		.432			.729		

TABLE 6.2 (CONTD): RESULTS OF PCA – ROTATED COMPONENT MATRIX.

	Component						
	1	2	3	4	5	6	7
difad5yr						.889	
difad1yr		.326				.829	
engnotwell							.836
lotengli			-.333				.685

TABLE 6.3: INTERPRETATION OF COMPONENTS.

Component	***Relevant concept (s)***	***Interpretation***
1	Sensitivity	Sensitivity due to physical infirmity.
2	ST adaptive capacity LT adaptive capacity Sensitivity	Sensitivity and adaptive capacity related to socio-economic advantage or disadvantage
3	LT adaptive capacity	Long term adaptive capacity related to educational qualification and ability to find work in another location
4	Sensitivity	Sensitivity related to lack of local knowledge among visitors and transients.
5	LT adaptive capacity	Long term adaptive capacity related to ability to find work in another location
6	LT adaptive capacity	Long term adaptive capacity related to propensity to relocate
7	Sensitivity	Sensitivity related to inability to comprehend emergency warnings due to poor English.

The vulnerability index is calculated from the component scores as (1+4+7) – (3+5+6) + 2. In the absence of any guidance from research to date in the literature as to the relative contribution to vulnerability of the individual sensitivity and adaptive capacity factors listed in Table 6.3, the components were not weighted in constructing the vulnerability index.

6.4.3 *Analysis of 2001 Census data*

Census data required to construct Census indicators for 2001 were obtained by first downloading all the relevant Usual Resident Profiles and Basic Community Profiles at CCD level for the study region using code written in R (R Core Development Team 2011). These profiles are available as Microsoft Excel workbooks. A Visual Basic macro within Excel was used to extract data from the workbooks and calculate the indicators. Of the 30 indicators used in the analysis of 2006 Census data, 25 were available in 2001 in a form identical, or very close to those in 2006. These are listed in Table 6.4.

Three indicators were available in 2006 but not in 2001 (Table 6.5).

Two indicators were available in both 2006 and 2001, but were asked or categorised differently (Table 6.6). In 2006, the categories “Car, as driver” and “Car, as passenger” were listed in both the “One method” and “Two methods” group. In 2001, the two categories were only listed in the “One method” group.

Because family income was categorised differently in 2001, compared to 2006, the nearest approximation for the percentage of low income families is <$300 weekly income in 2001, and <$349 in 2006.

TABLE 6.4: 2001 CENSUS INDICATORS CHOSEN FOR ANALYSIS

Relevant concept (s)	***Census variable***	***Calculation***
LT adaptive capacity	Percentage of households rented	Calculated as a percentage of total occupied private dwellings
LT adaptive capacity	Percentage of persons left school before 15 years of age	Calculated as a percentage of persons aged 15 years and over
LT adaptive capacity	Percentage of persons without a post-school qualification	Calculated as a percentage of persons aged 15 years and over
LT adaptive capacity	Total unemployment rate	Unemployed persons as a percentage of the total labour force
LT adaptive capacity	Unemployment rate 15-19 years age	Unemployed persons 15-19 years of age as a percentage of the total labour force 15-19 years of age
LT adaptive capacity	Unemployment rate 20-64 years age	Unemployed persons 20-64 years of age as a percentage of the total labour force 20-64 years of age
LT adaptive capacity	Percentage of persons living in a different address five years ago	Calculated as a percentage of all persons
LT adaptive capacity	Percentage of persons living in a different address one year ago	Calculated as a percentage of all persons
Sensitivity	Percentage of households with no vehicle	Calculated as a percentage of total occupied private dwellings
Sensitivity	Percentage of separated or divorced persons	Calculated as a percentage of persons aged 15 years and over
Sensitivity	Dependency ratio	Persons under 15 years of age and over 65 years of age as a proportion of those between 15 and 65 years of age

TABLE 6.4 (CONTD): 2001 CENSUS INDICATORS CHOSEN FOR ANALYSIS

Relevant concept (s)	*Census variable*	*Calculation*
Sensitivity	Percentage of persons aged 65 years or more living in lone person households	Calculated as a percentage of total persons
Sensitivity	Percentage of persons aged 65 and over	Calculated as a percentage of all persons
Sensitivity	Percentage of persons aged 5 years or less	Calculated as a percentage of all persons
Sensitivity	Percentage of persons who speak English 'not well or not at all'	Calculated as a percentage of all persons
Sensitivity	Percentage of residents who do not speak English at home	Calculated as a percentage of all persons
Sensitivity	Percentage of visitors	Those staying at an address in the CCD on Census night that was not their usual place of residence, calculated as a percentage of all persons
Sensitivity	Percentage of lone person households	Calculated as a percentage of total occupied private dwellings
Sensitivity	Number of children	Number of persons under 15 years of age.
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of labourers in the workforce	Calculated as a percentage of employed persons aged 15 years and over
ST adaptive capacity LT adaptive capacity Sensitivity	Average household size (persons)	(ABS calculation) Based on number of persons usually resident in occupied private dwellings
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of caravans, cabins, houseboats, improvised homes, tents etc.	Calculated as a percentage of total occupied private dwellings
ST adaptive capacity LT adaptive capacity Sensitivity	Median income as a fraction of the Australian median income	Median weekly household income expressed as a percentage of the Australian median weekly income.

TABLE 6.4 (CONTD): 2001 CENSUS INDICATORS CHOSEN FOR ANALYSIS

Relevant concept (s)	***Census variable***	***Calculation***
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of single parent families	Calculated as a percentage of total families in family households
ST adaptive capacity Sensitivity	Percentage of single parent families with children less than 15 years of age *only*	Calculated as a percentage of total families in family households

TABLE 6.5: INDICATORS AVAILABLE IN 2006, BUT NOT IN 2001.

Relevant concept (s)	***Census variable***	***Calculation***
Sensitivity	Percentage of persons with a 'need for assistance' *(persons with a 'profound or severe disability' defined as needing assistance with self-care, mobility, and/or communication)*	Calculated as a percentage of all persons
Sensitivity	Child to carer ratio	The ratio of children less than 15 years of age to the number of persons 15 years of age and over undertaking unpaid child care for their own and/or other children
LT Adaptive capacity ST Adaptive capacity	Percentage of persons who had worked as a volunteer in the previous 12 months	Calculated as a percentage of persons 15 years and over

TABLE 6.6: INDICATORS AVAILABLE IN 2006 AND 2001, BUT ASKED OR CATEGORISED DIFFERENTLY.

Relevant concept (s)	***Census variable***	***Calculation***
Sensitivity	Percentage persons commuting by car	Those who commute to work using a car calculated as a percentage of employed persons aged 15 years and over. Includes those who use a car as well as other methods of transport (e.g. train, bus)
ST adaptive capacity LT adaptive capacity Sensitivity	Percentage of families with weekly income less than $349	Calculated as a percentage of the total count of families

Median weekly income in 2006 was provided by ABS as a single figure. In 2001, it was provided as an income range. To calculate median income as a fraction of the Australian median, the midpoints of the ranges are used.

Whereas the Basic Community Profiles in 2006 contained place of usual residence data, the 2001 Census was reported across a mixture of usual residence and place of enumeration tables. Where 2001 place of enumeration data had be used in the calculation of Census indicators, these indicators mostly related to characteristics relating to dwellings rather than persons, so are likely to be unaffected by the use of place of enumeration data.

It was possible in some place of enumeration tables to correct the Census indicator to place of usual residence, since the table carried counts of Australian and overseas visitors. For 2001, the table of relationship in household by age by sex was used to calculate the proportion of people in lone person households, whereas a table of household composition by number of people usually resident was available for 2006.

CCD 1062110 was omitted because the ABS website only has the Usual Residence Profile.

The 2001 Census indicators were analysed using PCA in the same way as for 2006. A six component solution was selected as best meeting the criteria used in the 2006 analysis. As might be expected, the loadings and coefficients were different for 2001 and 2006, although there were many broad similarities between the rotated component matrices for 2001 and 2006.

6.4.4 *Comparison of 2001 and 2006 indices*

To ensure that any comparison of the vulnerability index and constituent sub-indices based on components was not affected by the different coefficients in 2001 and 2006, the rotated component matrices for the two years were juxtaposed (Table 6.7) and a subset of Census indicators that had loadings greater than 0.6 in both years were chosen to represent each of the seven components yielded by the 2006 PCA. In Table 6.7 light blue shaded loadings lie between 0.60 and 0.79, and dark blue shaded loadings are greater than 0.80. The diagonally hatched indicators in the leftmost column are those that did not have a loading greater than 0.6 in both years.

The vulnerability indices were calculated again from the component scores as (1+4+7) – (3+5+6) + 2, but using only the subset of variables with loadings greater than 0.6 in both 2001 and 2006, as shown in Table 6.7.

An important issue in comparing indices between the 2001 Census and the 2006 Census is the spatial comparability of the Census Collector Districts (CCDs) themselves. CCDs are primarily collection units and their boundaries are changed to produce convenient areas for a Census collector to cover during the Census period (ABS 2007b). Consequently, CCDs may be split up in areas where population is growing, or amalgamated in areas where population is declining, or adjusted to reflect changes in suburb or local government boundaries.

If the geographical area in which the people and households counted for the aggregate data in an individual CCD changes, then changes in Census indicators and the indices calculated from them may reflect the different set of households rather than changes in the circumstances of the same set of households.

TABLE 6.7: JUXTAPOSED ROTATED COMPONENT MATRICES FOR 2001 AND 2006 PCA.

Variable mnemonic	2001						2006						
	1	2	3	4	5	6	1	2	3	4	5	6	7
over65yo	-0.31	0.54	0.16	0.67	0.18		0.94						
loneho65	-0.14	0.59	0.25	0.66	0.15		0.91						
averhous	-0.19	-0.32	-0.43	-0.71	-0.21		-0.74	-0.42		-0.39			
depratio	-0.36	0.55		0.46	0.14		0.84						
needassi							0.73						
oneperso	0.31	0.45	0.37	0.61	0.19		0.67	0.51		0.38			
less5yrs				-0.81			-0.55			-0.34			
chcaratio							-0.42		0.36	-0.39			-0.30
oneparen	0.62	0.13	0.63		-0.20			0.86					
onepal15	0.61		0.58	-0.15	-0.23			0.83					
dwelrent	0.29	0.22	0.77	0.14				0.73				0.40	
separdiv	0.58		0.48		0.23			0.61		0.40	0.31		
lowincom	0.64				-0.22		0.52	0.59		0.31			
meaninco	-0.56	-0.56	-0.16	-0.34	-0.10		-0.50	-0.58	-0.30				
novehicl	0.30	0.63	0.43	0.37			0.54	0.56	0.38				
leftyr10		0.90	-0.11	0.13			0.41		0.79				
noqualif	-0.11	0.86		-0.12			0.44		0.72				
labourer	0.28	0.61		-0.21	-0.14				0.71				
voluwork								0.41	-0.57			-0.40	
caravans	0.11				0.82					0.68			
visitors	0.16	-0.10	0.25	0.39	0.57					0.78			
numchild	-0.22	-0.11	0.20	-0.75			-0.37			-0.51			
commutecar	-0.53		0.33	-0.27	-0.30	-0.16		-0.36		-0.45			
totunemp	0.79	0.17	0.19		0.21			0.42			0.81		
unem2064	0.78	0.17	0.17	0.11	0.18			0.43			0.73		
unem1524	0.40			-0.20	0.20						0.81		
difad5yr	0.16	0.12	-0.83		-0.22							0.89	
difad1yr		0.13	-0.87					0.33				0.83	
engnotwell						0.92							0.84
lotengli	0.22	-0.17				0.86			-0.33				0.69

For the study area, 75 per cent of CCDs had no, or minimal, boundary changes between 2001 and 2006 (Figure 6.2). Two different approaches were taken for comparing the stable CCDs and those where significant boundary changes had taken place. The former CCDs were amenable to numerical analyses focusing on the vulnerability index, its constituent sub-indices based on components, and Census indicators. For the latter CCDs, those where boundary changes were significant, we used daysemetric mapping (Chen *et al.* 2004; Maantay & Maroko 2009; Mennis 2003; Syphard *et al.* 2009; Yang 2009). Utilizing an address database provided by New South Wales Department of Primary Industry, we assigned each socially relevant census variable and the calculated social vulnerability at individual address locations (Zandbergen 2011).

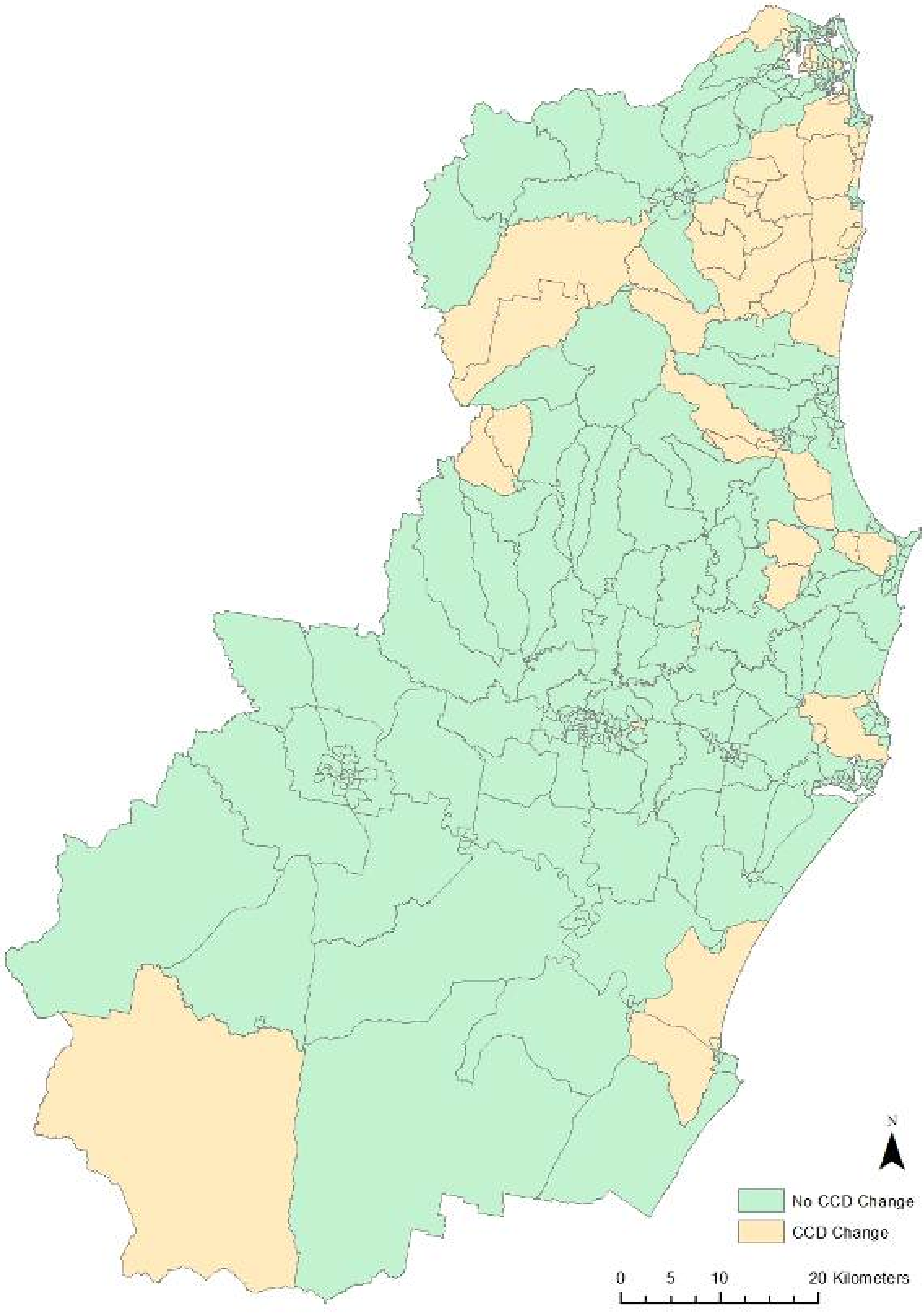


FIGURE 6.2: CCD BOUNDARIES IN THE NORTH COAST, NSW THAT REMAINED STABLE (GREEN) AND THAT CHANGED (ORANGE) BETWEEN 2001 AND 2006.

6.4.5 *Spatial Pattern of Social Vulnerability*

In addition to examining social vulnerability over time, the spatial pattern of social vulnerability was assessed. Although social patterns can change over time, overall clustering of social vulnerability has been observed for larger geographic regions (Cutter & Finch 2008). By modelling the spatial patterns of social vulnerability as they exist now, high-risk areas (those with high social vulnerability and high climate change impact potential) can be modelled under alternative future scenarios to better inform decision makers of the potential risks climate change poses to vulnerably people.

Using the vulnerability index at the address-level, we extracted multiple physical landscape indicators. These indicators are variables that represent landscape susceptibility to natural disasters. These indicators include: distance to rivers, distance to tidal waters, and current 100-year flood areas. Distances were spatially weighted to the address points by intersecting the points with Euclidean distance grids generated from a hydrographic dataset for the region, then averaging by CCD. Current 100-year flood levels were collected for all towns/cities near a river from the local planning jurisdiction (see Impacts chapter). Together these indicators allow for assessment of social patterns under alternative urban patterns to provide additional understanding of how the future physical and social landscape is to be likely impacted by climate change.

6.5 *Comparison of the CCDs with stable boundaries*

The vulnerability index in 2006 was fairly closely related to the vulnerability index in 2001 (Figure 6.3). Examination of the component changes contributing to the vulnerability change (Figure 6.4) showed that change in components 1 and 3 was generally unrelated to whether or not the overall vulnerability index changed (r=0.02 and r=0.20, respectively). Other component changes, such as in component 5 and component 7, had relatively strong contributions to the overall change in the vulnerability index (r=0.46 and r=0.48, respectively).

This pattern is reflected in the individual census indicators comprising the components. For example, the change in the proportion of people over 65 (a Census indicator in component 1) between 2001 and 2006 is no different among CCDs with an increase in the vulnerability index, and CCDs with a decrease in the vulnerability index (Figure 6.4)

On the other hand, the change in the proportion of people speaking English “not well” or “not at all” (Figure 6.5) is related to the overall vulnerability index change, with those CCDs experiencing an increase in vulnerability (red dots) also experiencing an increase in the proportion of poor English speakers.

The relative variability of the changes in seven components between 2001 and 2006 (and in their constituent Census indicators) reflects the differences between societal characteristics linked to relatively slow moving processes (e.g. age structure and levels of education) and characteristics linked to more rapid processes (e.g. economic fluctuations that affect employment, or the establishment of caravan parks, or in- or out-migration of non-English speaking families).

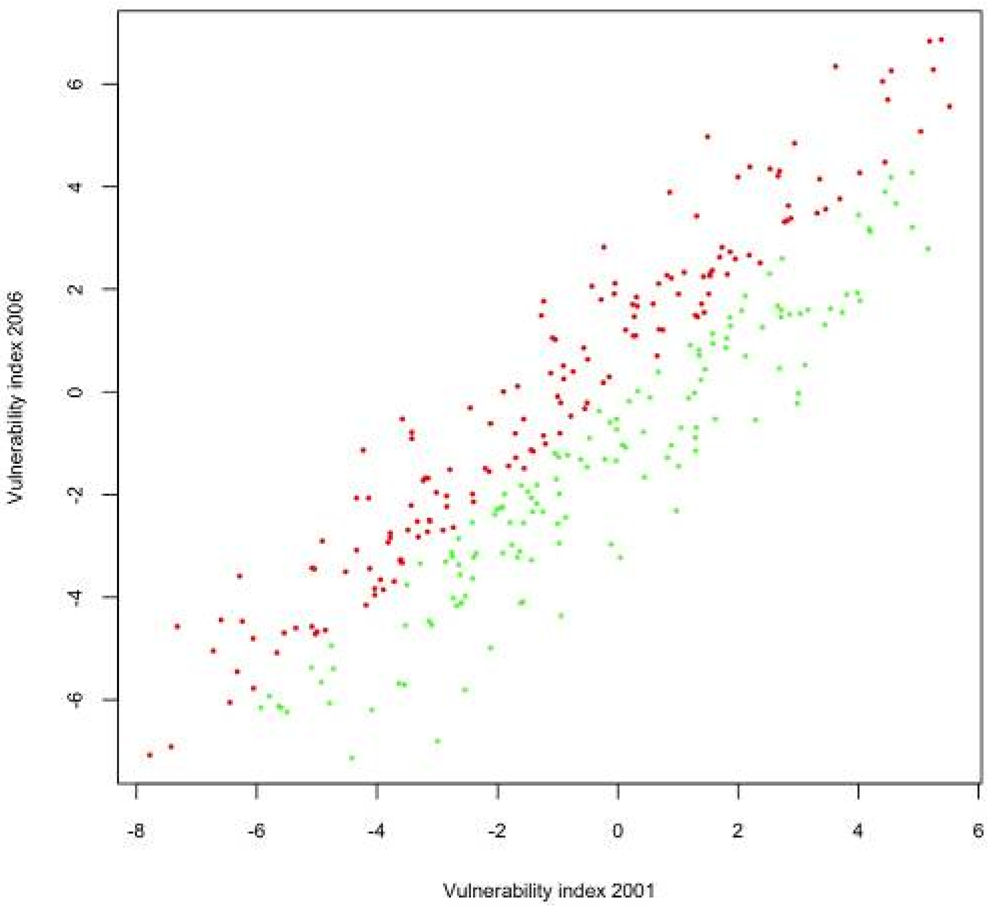
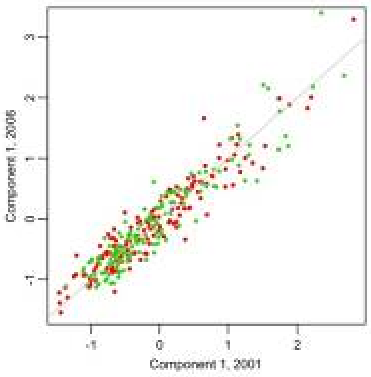


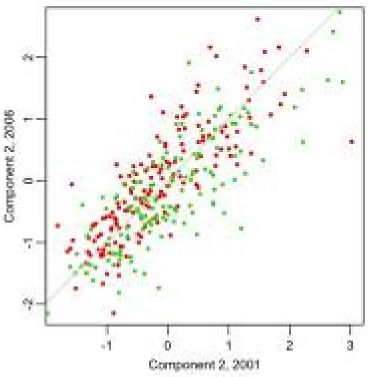
FIGURE 6.3: COMPARISON OF VULNERABILITY INDICES OF CCDS IN 2001 AND 2006. RED DOTS DENOTE CCDS WITH INCREASING VULNERABILITY, GREEN DOTS DENOTE CCDS WITH DECREASING VULNERABILITY.

To understand the nature of these changes in the study region, it is necessary to examine the individual CCDs where changes have taken place to identify, where possible, the social and economic processes that lie behind these changes.

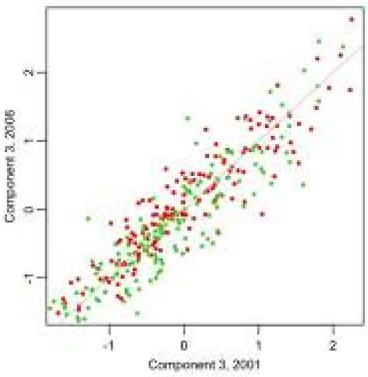
In the first instance, it can be noted that CCDs do not fall into distinct clusters based on the changes in the seven components between 2001 and 2006. The possibility of clustering among the CCDs was investigated using “partitioning around medoids”, as implemented in the R statistical package (R Development Core Team, 2011). This method is similar to the well-known k- means iterative re-allocation method (Hartigan & Wong, 1979), but has the advantage of greater robustness and a derived silhouette coefficient which provides guidance as to the number of clusters that best represent the structure in the data (Kaufman & Rousseeuw, 1987). The silhouette coefficient was 0.12, which is indicative of no cluster structure.



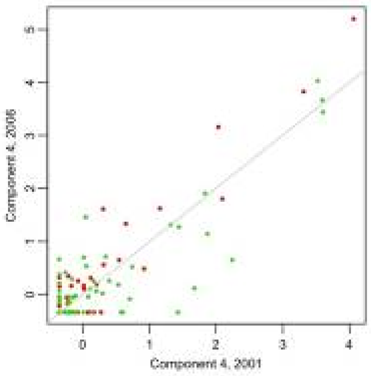
Sensitivity due to physical infirmity



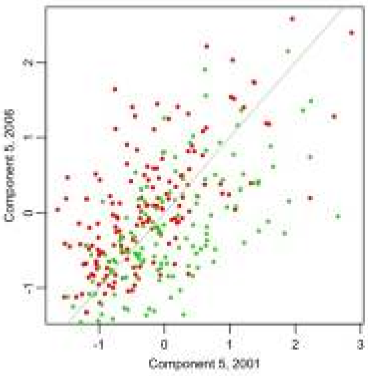
Sensitivity and adaptive capacity related to socio-economic advantage or disadvantage



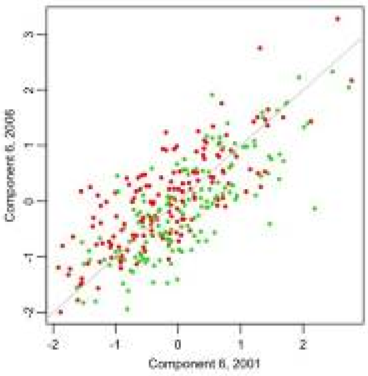
Long term adaptive capacity related to educational qualification and ability to find work in another location



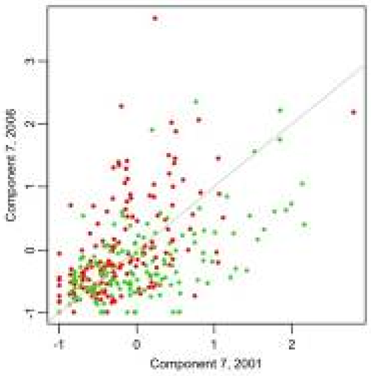
Sensitivity related to lack of local knowledge among visitors and transients.



Long term adaptive capacity related to ability to find work in another location



Long term adaptive capacity related to propensity to relocate



Sensitivity related to inability to comprehend emergency warnings due to poor English.

FIGURE 6.4: COMPONENT CHANGES FROM 2001 TO 2006 FOR CCDS WITH INCREASING VULNERABILITY (RED DOTS) AND DECREASING VULNERABILITY (GREEN DOTS).

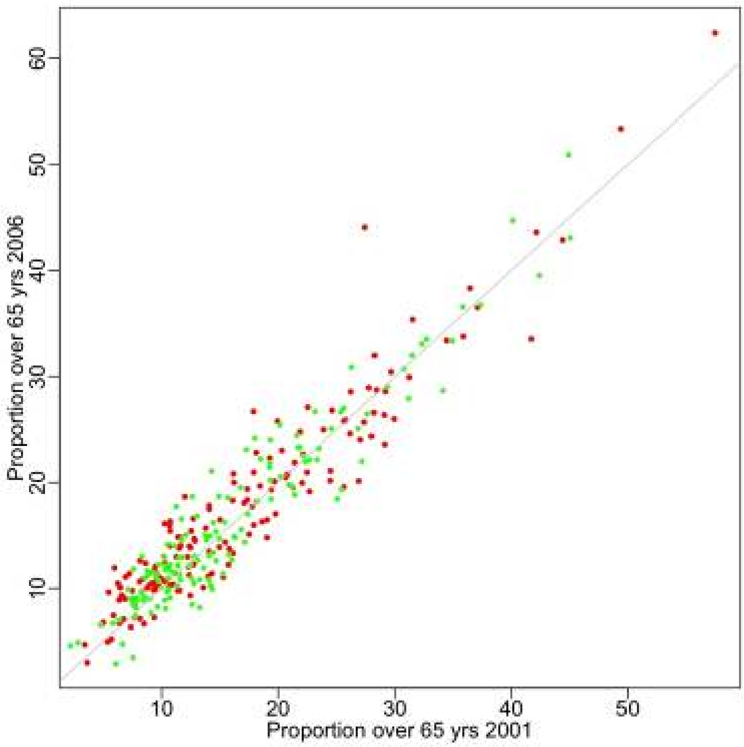


FIGURE 6.5: CHANGE IN PROPORTION OF PEOPLE OVER 65 FROM 2001 TO 2006 FOR CCDS WITH INCREASING VULNERABILITY (RED DOTS) AND DECREASING VULNERABILITY (GREEN DOTS).

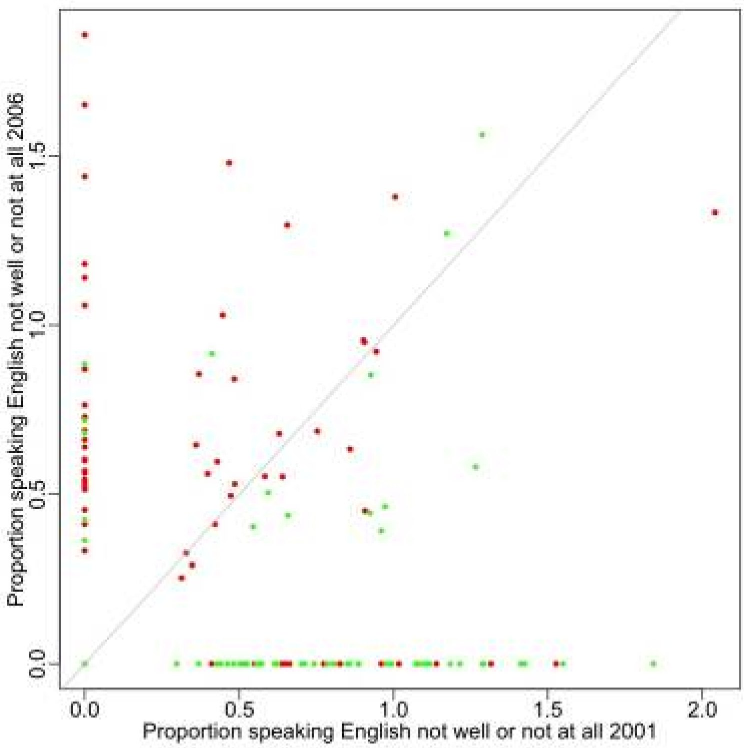


FIGURE 6.6: CHANGE IN PROPORTION OF PEOPLE SPEAKING ENGLISH "NOT WELL" OR "NOT AT ALL" FROM 2001 TO 2006 FOR CCDS WITH INCREASING VULNERABILITY (RED DOTS) AND DECREASING VULNERABILITY (GREEN DOTS).

In the absence of any possibility of identifying CCDs with particular patterns of changes in the seven components, it was then necessary to examine the individual CCDs involved in relatively large changes in one or more of the seven components. For parsimony and ease of interpretation, this was done using the single Census indicator for each component that had the largest loadings with each component (i.e. was most strongly correlated with each component). For each CCD where large changes in particular Census indicators had occurred, Google Street View was used to examine the nature of the urban areas within the CCD. It was possible to draw inferences about the recent socio-economic history of these areas from the age of housing, the size and type of construction of dwellings, and the type of rental dwellings (holiday rental or otherwise). Many multiple occupancy sites, such as tourist parks, caravan parks, holiday flats have signs and/or advertising on the street which enables inferences to be drawn about the occupants. From this analysis, it was possible to identify a number of socio-economic and demographic processes that influence the spatio-temporal patterns in vulnerability.

6.5.1 *Vulnerability related to aged populations*

A range of types of housing developments for retirees and the elderly bring increases in the relative physical infirmity of the population at different points within urban areas. These include:

- multi-story strata title units in central locations within coastal urban areas,
- retirement villages or subdivisions on the peripheries of coastal urban areas, and
- part and full care institutions for the frail elderly which tend to be located more centrally than on the peripheries of coastal urban areas.

Residential developments for independently living retirees compete upon, among other things, the environmental amenity and proximity to services. Given that these services are located in major regional centres, most of which are located on coastal inlets or river mouths, and that water views are an attractive aspect of environmental amenity, it is inevitable that much of the residential development for retirees occurs on flat areas close to sea level.

Part and full care institutions for the frail elderly also need access to services, but require flat sites for ease of movement of the residents. This again results in the tendency for these institutions to be located in flat areas close to sea level.

However, the long term evolution of urban settlements can also see declines in the aged population in flat, low lying areas within regional centres. As the development and growth of CBDs in regional centres takes place, property values increase and traffic and noise increase with the result that part and full care institutions may be re-located further from the CBD.

These types of locational processes that affect the proportion of aged population in urban settlements are particularly prevalent in the Tweed Heads area.

6.5.2 *Vulnerability related to socio-economic disadvantage*

A number of regional centres have inner residential areas that experienced increases in the level of socio-economic advantage, manifested in Census indicators by increases in the proportions of single parent and low income families. This occurred in Tweed Heads, Murwillumbah and Ballina. As these coastal cities have developed, with growing and economically diverse CBDs and with new suburbs on the outer peripheries, some of which have attracted in-migrant retirees, the property values of the inner residential areas have declined in relative terms. These areas, characterised by 1930s to 1950s weatherboard and fibro construction, are likely to eventually undergo redevelopment and gentrification. However, in the interim, property values have come to comprise mainly the land value. Properties within these areas are within the reach of some lower income families, or are bought by investors and converted to rental properties. Family break up can mean that some properties become single parent households. In some, but not all cases, the original 1930s to 1950s development was immediately adjacent to rivers and estuaries, resulting today in a socio-economically disadvantaged population in areas close to sea level or on flood prone locations.

Tweed Heads experiences some additional factors that are not as relevant to Murwillumbah or Ballina. Growth in the large conurbation of the Gold Coast may have displaced low income families across the border to areas with lower property values. Others, from the New South Wales North Coast, may settle in Tweed Heads to access the better quality health services in Queensland, or to avail themselves of the greater job opportunities within commuting distance in Queensland.

The process by which levels of socio-economic disadvantage increase in the inner residential areas of the major regional centres is reversed when re-development takes place and new families move into the area. This appears to have happened in parts of Byron Bay.

Unemployment also contributes to socio-economic disadvantage, but the processes that lead to marked changes in the levels of unemployment are distinct from those described above. The construction industry is a major part of the economy of the New South Wales North Coast, but is also subject to expansion and contraction over time. This affects levels of unemployment in the industry, including amongst independent contractors and tradespersons. A considerable number of households in the newer residential areas around the regional centres have employment in the construction industry, and fluctuations in the fortunes of the construction industry will lead to periods of higher unemployment in these areas. However, these episodes of unemployment are unlikely to contribute to the vulnerability of the population in the same way that long-term chronic unemployment does.

6.5.3 *Vulnerability related to caravan parks*

Usual residence Census data that gives type of housing as temporary dwellings including caravans, does not include tourists and holiday makers staying in caravan parks. Permanent residence in caravan parks is a lower cost form of housing that can be attractive to low income families and retirees. Some caravan park permanent residents may be people who have moved to a region for work, and have not yet obtained permanent housing, or people such as road construction workers who may be in an area for a year or so during major reconstruction of sections of the Pacific Highway. Increases in the proportion of the population in temporary dwellings appear to have occurred in Bangalow around the time of the Pacific Highway reconstruction there, and in Broadwater in the vicinity of the sugar mill.

Declines in the proportion of the population in temporary dwellings occur when caravan parks undergo redevelopment to capitalise on the tourist trade (e.g. Byron Bay and Ballina), or are removed completely and replaced by residential development (e.g. Tweed Heads).

6.5.4 *Vulnerability related to mobility*

The available Census indicators of change of residential location in the last one and five years are relatively crude measures of mobility, which convey little information as to actual levels of place attachment that might affect vulnerability to climate change. For families that have relocated for work, a change of location in the last five years may be a reasonable indication of preparedness to relocate again. The same may not be the case for retirees, who may have intended to “age in place” in their new location. The changes in Census indicators of mobility in the region are closely related to the age of residential subdivisions. New subdivisions established in the five years before 2001 experience a sharp decline between 2001 and 2006 in the proportion of the population living at a different address five years previously. Subdivisions established between 2001 and 2006 show a sharp increase in the proportion of the population living at a different address five years previously. Overall, urban peripheries will always contain a greater proportion of people who lived at a different address five years previously.

6.5.5 *Vulnerability related to poor fluency in English*

Proportions of non-English speakers are generally low in the New South Wales North Coast. The highest proportion (11.8 per cent in 2006) is in a Byron Bay CCD and appears to be related to the nearby Byron Bay English Language School. The largest increase in the proportion of non-English speakers also occurs in this CCD and is probably related to employment at the Byron Bay English Language School. For the remainder of the region changes in the proportion of non-English speakers involve very small numbers of people and the processes behind these changes, as well as being very difficult to infer, are likely to have little relevance to overall population vulnerability.

6.6 *Comparison of the CCDs with changed boundaries*

Dasymetric modelling provided insight into the spatial distribution of population in each CCD; however, it did not solve the issue of changing boundaries. Dasymetric modelling was originally developed to model population density, using land use data as ancillary datasets to assign census population estimates to specific locations. However, assumptions about the distribution of social variables across the population are not appropriate, as there are no ancillary datasets to suggest that, for example, people aged over 65 congregate to an specific place in the urban environment. Thus, while dasymetric modelling did ensure social variables are not uniformly presented across a landscape where there are no people, it did not allow for direct comparison of social vulnerability in CCDs where the boundaries changed.

6.7 *Spatial distribution of vulnerability in 2001 and 2006*

Figure 6.7 and Figure 6.8 show the distribution of vulnerability across the study area. In general, highly vulnerably CCDs are confined to urban areas, with most of the rural CCDs having zero or negative vulnerability index scores. Given the various Census indicators that make up the vulnerability index, the spatial clustering of vulnerable populations within urban cores makes sense. Furthermore, these patterns validate the observations (detailed above) of how the different Census indicators impact vulnerability. Given the natural evolution of cities (as they grow outwards, inner residential amenity may decline and older housing is converted to cheap rental properties, resulting in increases in levels of socio-economic disadvantage), the vulnerability patterns observed here follow conventional wisdom about urban demographic patterns.

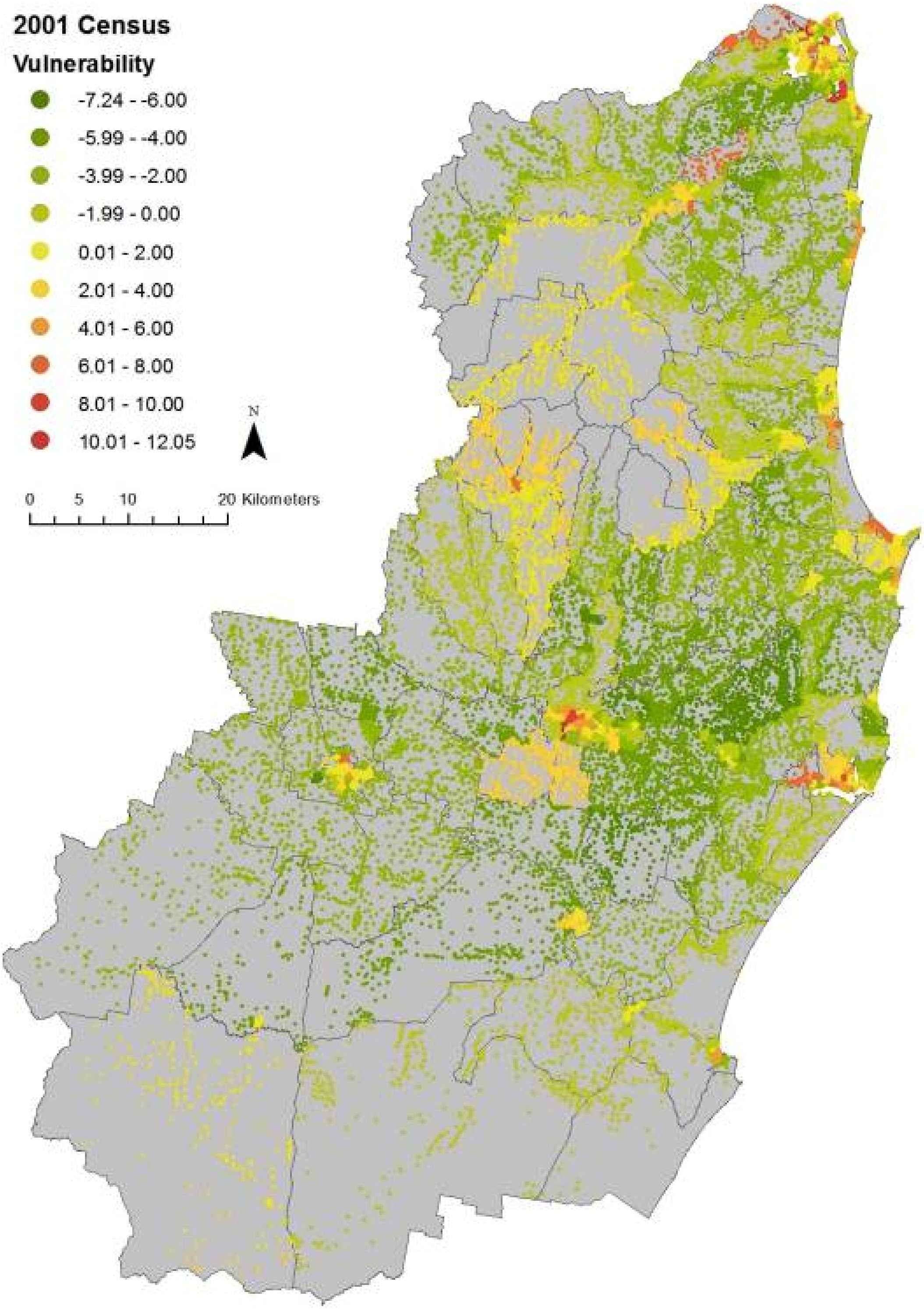


FIGURE 6.7: SOCIAL VULNERABILITY, CALCULATED FROM THE 2001 CENSUS, MODELLED AS ADDRESSES WITHIN THE STUDY AREA. ALTHOUGH THIS APPROACH DID NOT SOLVE THE ISSUE OF CHANGING CENSUS DISTRICT BOUNDARIES, IT DOES HELP VISUALISE WHERE THE POPULATION EXISTS WITHIN THE DISTRICTS.

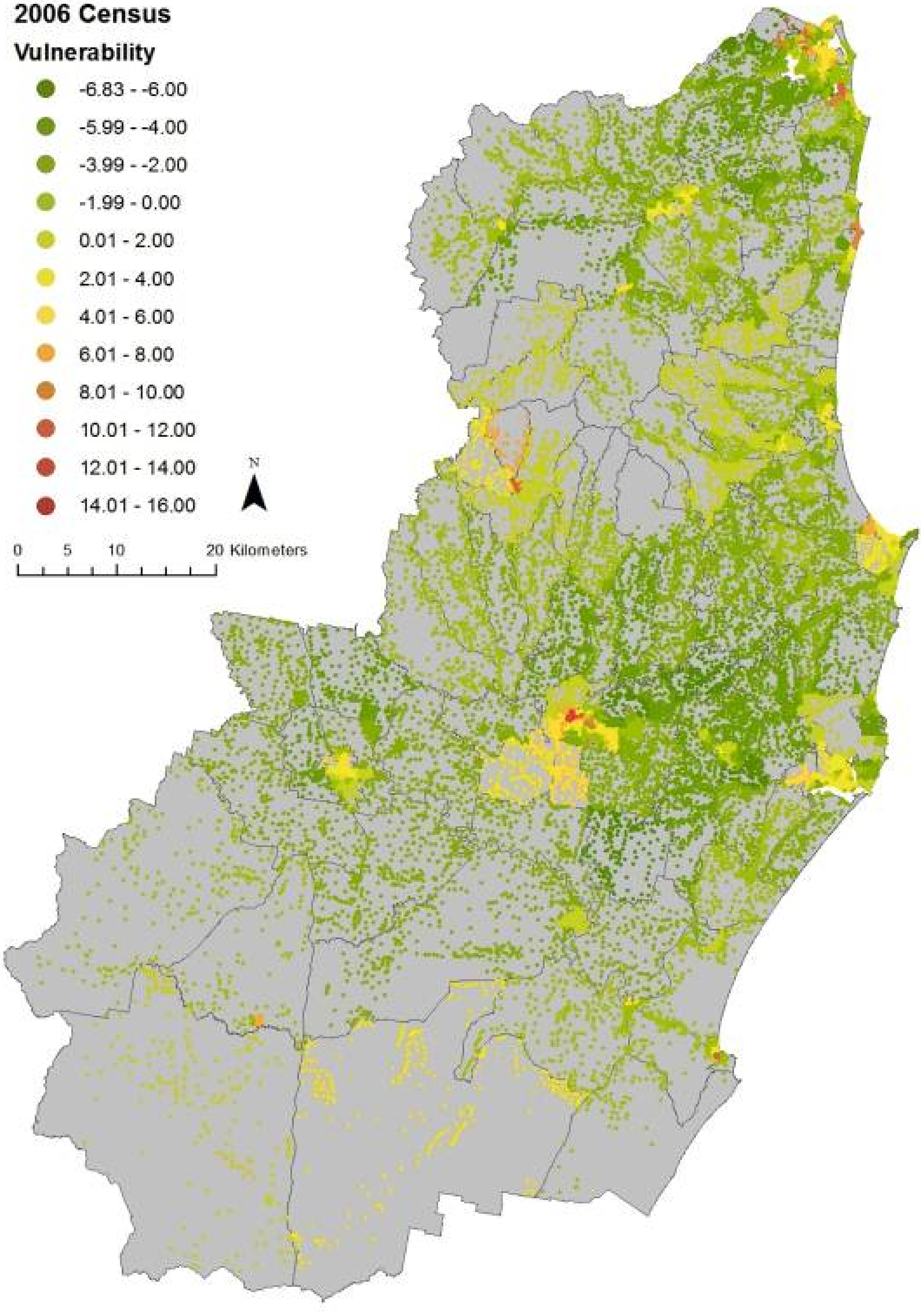


FIGURE 6.8: SOCIAL VULNERABILITY, CALCULATED FROM THE 2006 CENSUS, MODELLED AS ADDRESSES WITHIN THE STUDY AREA. THIS DATA WAS USED IN CALCULATING VULNERABILITY WITHIN CURRENT FLOOD PRONE AREAS, AS WELL AS MEAN DISTANCE TO RIVERS AND TIDAL WATERS.

Further assessment of the current distribution of urban development in the study area identified additional important patterns. The first was the relationship between distance to water (rivers and tidal) and social vulnerability. Regression tree analysis showed that, for both fresh and tidal water, vulnerability was significantly higher (Student t-test, $p<0.001$) in addresses closer to water (Table 6.8).

TABLE 6.8 DETAILS OF REGRESSION TREE ANALYSIS OF VULNERABILITY INDEX AND DISTANCE FROM RIVERS AND TIDAL WATERS.

Position of CCDs	*Number of CCDs*	*Mean vulnerability index*
420m or more from rivers	370	– 0.23
Less than 420m from rivers	37	2.32
430m or more from tidal waters	289	– 0.76
Less than 430m from tidal waters	118	1.86
Less than 430m from tidal waters	118	1.86

Although this doesn't take into account elevation, and thus cannot provide a specific flood threshold, it does suggest that environmentally vulnerable places have higher levels of socio-economic disadvantage.

This observation was further validated by the relationship between social vulnerability and current 100-year flood zone (Figure 6.9). Nearly 14% of the current population lives within the 100-year flood areas, and average social vulnerability within those areas is 2.6, compared to 0.07 for the rest of the study area.

In both cases, historical patterns of development may explain the vulnerability concentrations around flood-prone areas. Most towns are established along a waterway, either to provide water for consumption, for transportation, or for fishing/food production. Thus, in most cases, the oldest parts of town are those along the waterway. As towns grow, older homes (and those on the interior) lose value. Thus, these patterns suggest that not only are urban demographic patterns in the north coast similar to traditional urban evolution, but these patterns might increase the exposure of climate change events to already socially vulnerable populations.

6.8 *Social Vulnerability under Alternative Landscape Futures*

While predicting social change is a bit like looking into a crystal ball, we can take some important lessons from current demographic patterns, and extrapolate the drivers of those patterns into the future. There are clear patterns both in the drivers of vulnerability, and in the spatial patterns of vulnerability, that provide a foundation for examining future social vulnerability under climate change scenarios.

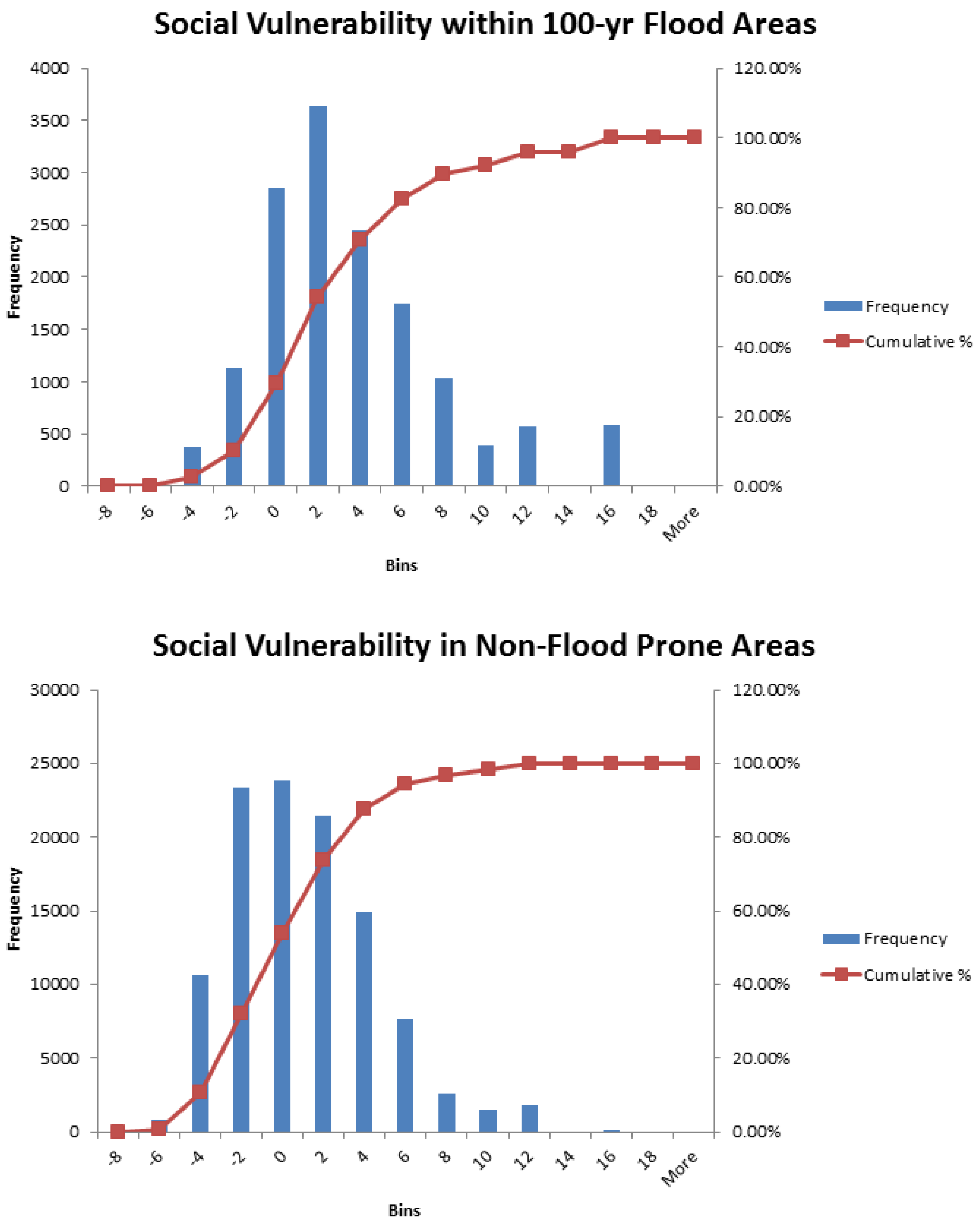


FIGURE 6.9: SOCIAL VULNERABILITY (IN 2006) WITHIN AND OUTSIDE THE CURRENT 100-YEAR FLOOD AREAS. SOCIAL VULNERABILITY IS GENERALLY HIGHER IN THE FLOOD PRONE AREAS.

Integrating the observed patterns mentioned above, it is clear that socially vulnerable populations are currently concentrated in physically vulnerable places (those with high potential for exposure). Combining this with the impacts reported in Chapter 5, we can confidently anticipate higher levels of exposure to the impacts of climate change for socially vulnerable populations. With 14% of the current population existing in the current 100-yr floodplain, and the expectation that growth will continue in those flood-prone areas, it will likely be the socially vulnerable members of society that suffer under changed climate. Likewise, since most of the settlements in the study area are in lower elevations close to water, SLR and storm surges are expected to impact those with higher levels of socio-economic disadvantage, of whom a disproportionately higher number live within 0.5km of tidal waters.

6.9 *Discussion*

Climate change threatens both biophysical and socioeconomic factors. While previous chapters have outlined the impacts to the biophysical world, this chapter provides an insight into how social factors are likely to be impacted by climate change. Specifically, by assessing social vulnerability separate from exposure, we see ways in which social vulnerability can be reduced through planning and social programs. However, when we combine the spatial distribution of social vulnerability with the spatial impacts of climate change events, we see that climate change will disproportionately impact low socioeconomic populations. It is apparent that the locational factors that attract the socioeconomically disadvantaged are the same factors that increase the likelihood of climate change exposure.

Given these findings, policies need to, at minimum, focus on ensuring that 1) government sponsored housing is not built in physically vulnerable places and 2) information on climate change adaptation is made available to these areas that are physically and socially vulnerable. Additionally, with analyses like these, targeted information concerning the nature and adaptation options for the specific climate change impacts expected could be distributed based on location and social vulnerability indicators.

7. LANDSCAPE FUTURES SCENARIOS

7.1 *Land Use Planning and Future Land Use*

Land-use planning systems are a framework to guide the future growth and development of Australian settlements. Local governments need to manage numerous and often competing factors such as demographic changes, economic growth, and the provision of infrastructure services when planning future land use (Norman 2010, Productivity Commission 2012).

At present there is no connection between developments in climate change science and the day-to-day decision making that influences land use activity in cities and regions (Norman 2010). Recognising the potential impact of climate change and natural hazards, most Councils now have implemented some predictive and precautionary revisions to planning schemes (Productivity Commission 2012). However the roles and responsibilities of local government are not particularly clear and individual councils vary in the extent to which they plan for climate change adaptation. It is important that climate change adaptation is incorporated into all councils' broader risk management and land use planning strategies.

A number of local governments have identified 'risk management' as an important approach in their adaptation plans (Productivity Commission 2012). Certainly, well-structured risk based adaptive planning can be shown to reduce the potential for future damage to urban areas by as much as 46 per cent (Brunckhorst *et al.* 2009). A key element of adopting this style of approach to planning is to match the timeframe of the relevant land use and its associated potential risks. Land-use planning provides for the development of a structure with a limited lifespan, but the zoning of that land generally provides for an ability to build and rebuild indefinitely. To implement methods of adaptive planning incorporating risk management, many local governments may need to consider new planning instruments (Productivity Commission 2012).

Spatial land use change modelling is one new approach which might be used. When conducted in an integrated and multi-scale manner, it is an important technique for the projection and visualisation of future landscapes (Veldkamp & Lambin 2001). A common and ongoing area of research, there are numerous methods and applications for the modelling and future prediction of land use changes within the academic literature (for example see Kok *et al.* 2001; Kok & Veldkamp 2001; Schoorl & Veldkamp 2001; Irwin & Geoghegan 2001; Veldkamp & Lambin 2001; Jackson *et al.* 2004; Syphard *et al.* 2005, Santé *et al.* 2010, Morley & Brunckhorst 2010).

7.1.1 *Cellular Automata*

Many recent spatial land use modelling methods incorporate the use of a cellular automaton (CA) algorithm. Cellular automata are a class of mathematical models in which the discrete state of cells in a matrix is generated by deterministic and probabilistic rules. The traditional CA framework is an iterative process that determines the discrete state of a cell based on the value of its surrounding cells in accordance with the predetermined rules for the model (Xu 2001; Jantz & Goetz 2005). After many iterations, these systems yield complex and highly structured patterns (Irwin & Geoghegan 2001) that have also been shown to spatially resemble urban forms, development densities (Yeh & Li 2002) and urban growth over time (Batty *et al.* 1999, Clarke *et al.* 1997, White & Engelen 2000; Xu, 2001).

CA models are attractive as planning tools as they are interactive, allow modification of rules and constraints, and with the use of GIS, results can be quantified and visualised (Jantz & Goetz 2005). In this project the transition potential (or capacity for development) of each cell was represented in a 25 metre raster grid. A CA algorithm then allocates new urban development using a pattern-extrapolation model that considers spontaneous growth, new spreading centre growth, edge growth and road-influenced growth. A stochastic disturbance parameter is used to model the uncertainty associated with urban processes. After calibration based on a monte-carlo method of deriving the 2010 land use map from the changes that occurred between 1980 and 2000, the process provides a useful model for visualising the future landscape.

Although based on the changes that have occurred in the past, the transition of a land unit to urban area is inherently complex with numerous factors that cannot be predicted and CA systems can only provide a simulation of future transitions and not a spatially definitive representation of future change (Irwin & Geoghegan 2001). However models such as these provide a tool with great potential for the development of operational models that generate realistic urban patterns. With the capacity to change the transition rules, these systems allow for the exploration of various land use planning decisions and the visualisation of numerous future scenarios that in a planning context may be able to be achieved or avoided through various planning mechanisms.

7.2 *Scenarios and planning*

Traditional linear decision-making methods have developed from an approach of expert knowledge and analysis to plan for future conditions. However, as climate change will occur gradually over a long time frame and have numerous, diverse and complex social, economic, political and environmental impacts, these approaches are unlikely to be effective (Chakraborty 2010). Scenario-based approaches are therefore being used as a key tool for decision-making under uncertainty.

Scenarios are generally thought of as cogent stories intended to aid decision makers. They can be classified as predictive (forecasting), normative (transforming), and or explorative (strategic) (Chakraborty 2010). Each type of scenario planning requires a different mode of operation with their purposes determining the process of construction. Unfortunately many scenario processes are driven by a desire to determine the 'most likely' future scenario consistent with a 'predict-then-act' model of problem solving (Couclelis 2005, Hopkins & Zapata 2007, Chakraborty 2010). This method greatly devalues the fundamental purpose of the scenario process which is to the provide capacity to overcome 'predictive' mindsets, explore possibilities and engage with potential futures.

The use of scenarios in land use planning allows this move away from ordinary predictions about the distant future by investigating what a desirable future would be, and then tries to figure out how to make it feasible. By describing processes, events and actions over time, it becomes possible to visualise the consequences of current decisions and compare a variety of alternative future situations (Nassauer & Corry 2004, Steinitz 1997, 2003). As such, a set of scenarios can be used to help test the possible long-term consequences of specific decisions in each of the scenario, or to determine what policies might be required to prevent or achieve a specific long-term outcome (Hulse *et al.* 2004; Dunlop & Turner 2004).

Scenario planning requires knowledge of the region, the drivers shaping change, and how these drivers might possibly combine into scenarios. The process of evaluating and comparing alternative futures allows decision-makers to anticipate their reactions to different future possibilities, anticipate time-frames beyond the immediate future, and to make more clearly informed choices (Schwartz 1996; Steinitz 2002; Peterson *et al.* 2003). Whilst fictional, scenarios are designed to represent plausible changes of over time in a transparent and accessible manner (Brewer 2007) as well as organise information within a defined framework (Hulse *et al.* 2004, Shearer *et al.* 2006). The ultimate aim, of course, is to be better informed in making appropriate long term policies and taking strategic action (Dunlop *et al*. 2002).

The conceptual framework of alternative landscape futures is represented graphically in Figure 7.1 where the mesh grids represent all possible futures along a central continuum extending from the past into the near and distant future. The blue and green dashed lines represent deviations from the current future trajectory to defined alternative future scenarios for which LULC representation are produced and can be compared to the expected future situation.

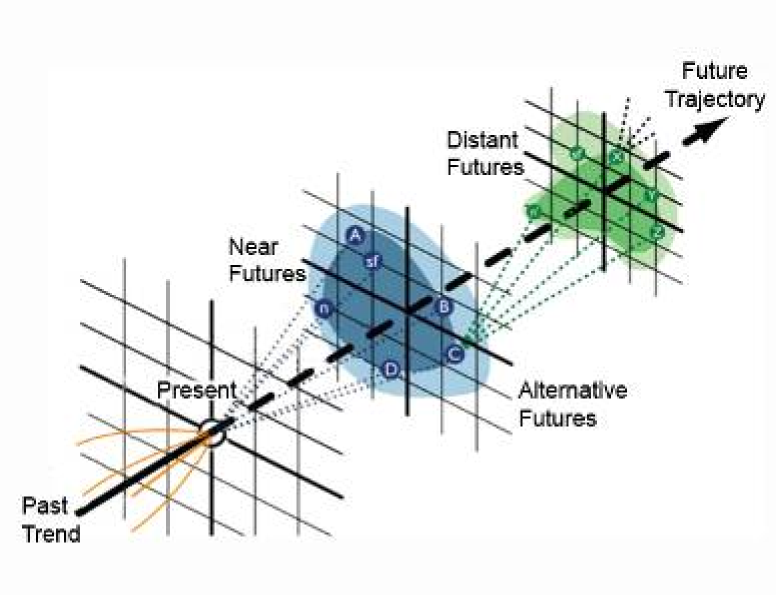


FIGURE 7.1 LANDSCAPE FUTURES CONCEPTUAL MODEL OF TRENDS, SCENARIOS AND FUTURE TRAJECTORY (ADAPTED AFTER SHEARER 2005)

7.2.1 *Outline of approach to alternative landscape futures techniques*

Professor Carl Steinitz (Harvard University) has developed and used in many regions around the world an alternative landscape futures scenario analysis and design approach. The Steinitz research framework (Figure 7.2) is the primary methodological driver of the alternative landscape future process and it provides a clear direction while allowing flexibility to deal with case-study specific context and issues (sometimes referred to as 'critical uncertainties') that will inevitably arise. The framework for design analysis identifies several different questions; each is related to a theory-driven modelling type (Figure 7.3 boxes).

After recognising and describing the context and scope of purposeful landscape change, decision makers and stakeholders need a means of deciding on whether or what to change and a way to compare alternatives. Deciding how to answer the questions, what data is needed, and how it might be examined or synthesised is the next part of the process. Therefore the path now reverses to travel upwards to define data needs and specific methodologies of assessment. These strategic elements (type of data, methods for analysis, mapping and design) required to undertake the design analysis are specified and organised by proceeding upward through the levels of inquiry. Each level defines its necessary contributing products from the models next above in the framework (Steinitz 1990, 1993; Steinitz *et al.* 1996, 2003).

Then, in order to be effective and efficient, a landscape futures design and planning project should progress downward at least once through each level of inquiry, applying the appropriate modelling types (Steinitz 1990, 1993; Steinitz *et al.* 1996, 2003).

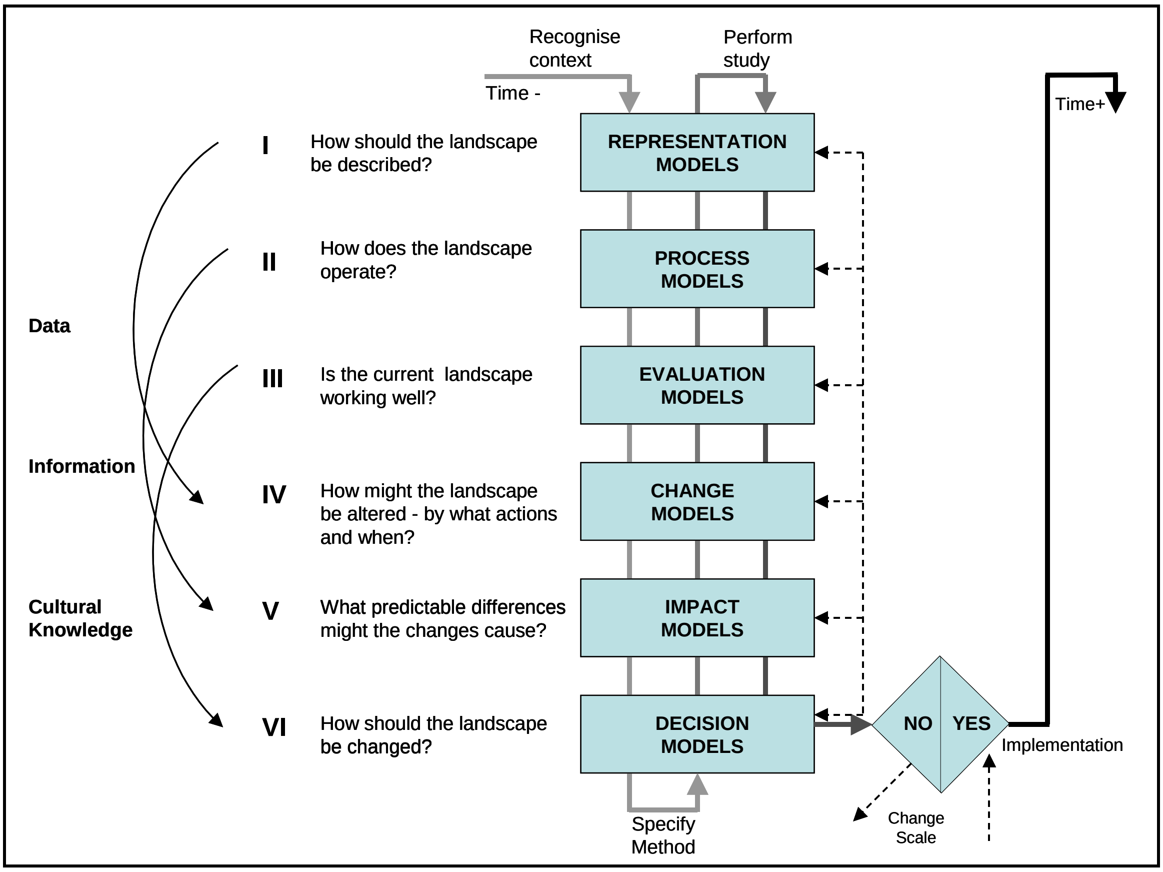


FIGURE 7.2 THE STEINITZ ALTERNATIVE LANDSCAPE FUTURES ANALYTICAL FRAMEWORK (STEINITZ *ET AL.* 2003 P.14)

While implementation might be considered a further level, the iterative cyclic nature of this framework considers implementation as feedback to the first level. The time-scale relationships assume that the design and implementation actions were preceded by similar considerations, and that they will in the future, be reconsidered in a continual adaptive management context (Walters & Holling 1990).

Visualisation, analysis and evaluation is accomplished using GIS techniques and performed iteratively. Alternative landscape futures scenarios are assessed and either discarded or identified for further design alternatives and assessment. At each stage of the iterative cycle two decisions present themselves: "no" and "yes." A "no" implies a backward feedback loop and the need to alter a prior level (Steinitz *et al.* 2003). All six levels can be the focus of feedback; hence, "redesign" is a frequently applied feedback response. Through prior and/or on-going consultation of communities/stakeholders “preferred” futures, it is expected that several alternative future patterns of land uses and development might be identified. The resultant impacts that “preferred” scenarios might have on patterns of ecological resource issues, regional development and socio-economic factors can be assessed and options reconfigured to elaborate the ‘best’ alternative scenarios – ones that might be acceptable for implementation.

For this project, the model developed was applied to the northern New South Wales coast, generating new knowledge for understanding possible futures for that rapidly changing region. With the size of this region, the method also developed a multi-scaled approach to multi-population growth scenarios. A generalised representation of the methodology is shown in Figure 7.3.

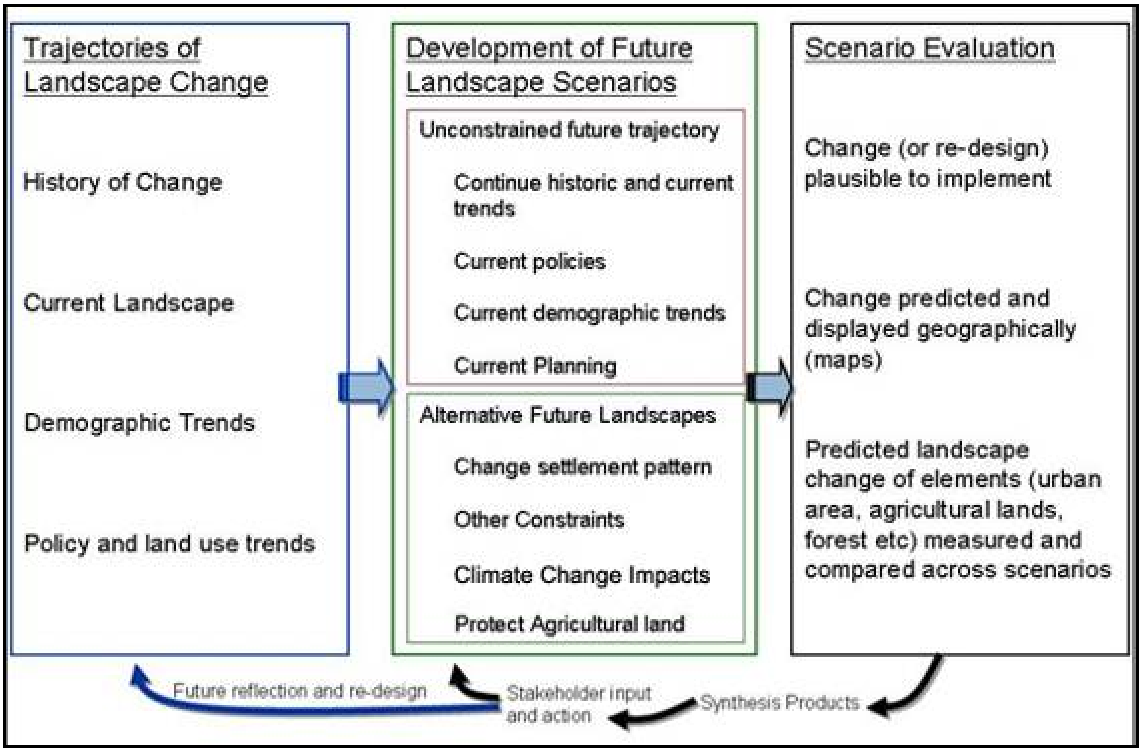


FIGURE 7.3 GENERALISED PROCEDURE OF TRAJECTORIES OF CHANGE AND ALTERNATIVE LANDSCAPE FUTURES MODELLING

7.3 *Population Growth*

A key driver of LULC change across the region is the expansion of urban areas due to the growing population, therefore the past and future trends of this growth must be determined in order to create and evaluate future landscape changes.

There are various methods to estimating population growth. The Australian Bureau of Statistics utilises a number of methods that incorporate birth and death rates, in-migration and emigration, life expectancy as well as other factors (ABS 2009). This study is interested in LULC change which is driven by total population growth (births and in-migration), that in turn dictates how much space is converted to human community residential requirements (including related shopping centres, infrastructure and services).

An examination of the growth in urban or built-up area shows that for the 30 years from 1980 to 2010 there has been an increase of approximately 2.7% per annum. However much of this growth occurred during the late 1980s and the rate has decreased since. Modelling a least squares trend shows an expected trend of approximately 1.45% from 1980 to 2100. In designing future growth scenarios, it was therefore decided to model growth at 1%, 1.5% and 2% per annum. These figures allow for higher and lower growth rates as well as increased levels of population density to be visualised. Figure 7.4 charts the urban growth models (in hectares) over time.

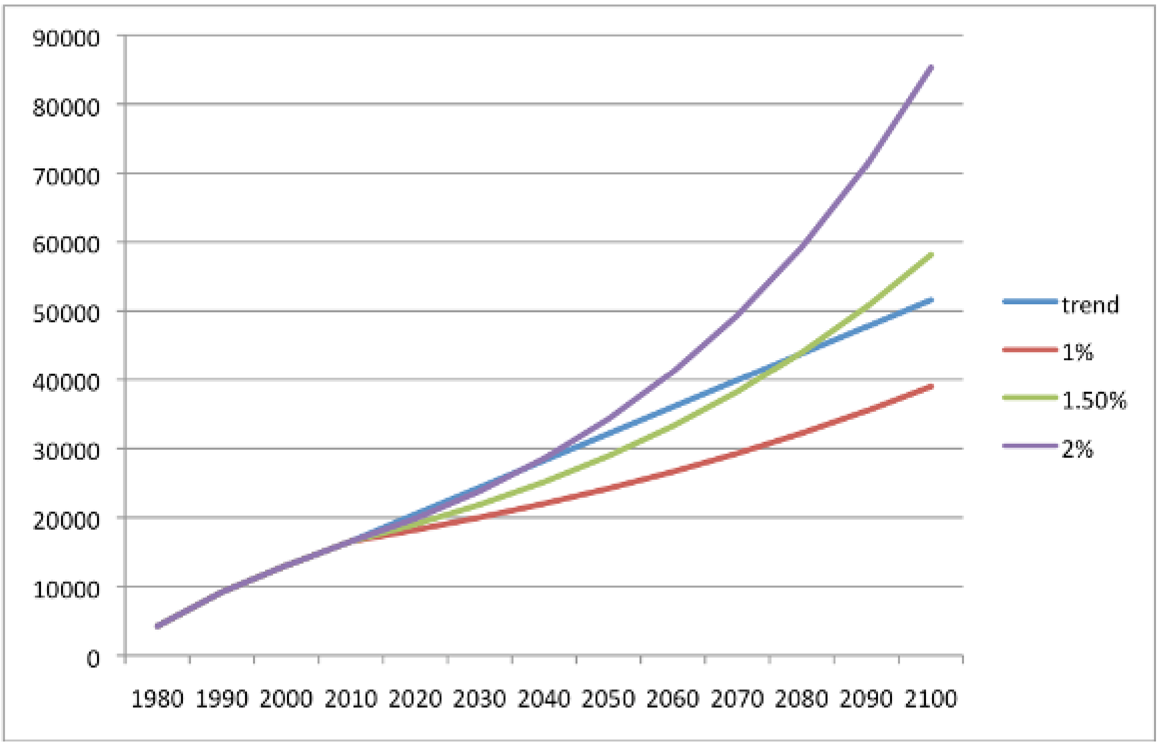


FIGURE 7.4 MODELLED URBAN GROWTH TRENDS (HECTARES) OVER TIME

7.3.1 *Zoning*

It would be inaccurate to calculate future population levels for a large region as a singular whole area because of the considerable diversity and heterogeneity of settlement patterns across the region. The inherent differences in growth rates between specific interregional areas would create a high level of inaccuracy, which is propagated when the new growth is placed uniformly throughout the region, regardless of the settlement pattern of any specific area. Therefore the region had to be scaled down to smaller zones with higher levels of homogeneity of population growth and settlement allowing calculations to be made which provide an acceptable level of numerical and spatial accuracy.

The region contains five Local Government Areas (LGA's). However LGAs also tend to lack homogeneity within their boundaries in relation to the distribution of population. Many LGA's have some areas experiencing population growth while other areas are in decline. This is even more prevalent in non-urban regional LGAs that have a large spatial area in relation to population as is seen within the study area. Census collection districts (CCD's) provide a finer scale of population data on which to assemble zones of similar population change characteristics. Calculating estimates of population change characteristics for each of the CCD's resulted in statistical errors as some spatially small areas have experienced an extremely high population growth trend. The past growth trend quickly extrapolated to a point in the near future in which some collection districts gained population levels well beyond the available space to accommodate them.

Spatially reducing the size of the area for which calculations could be made also creates an edge or boundary effect due to varying population levels between adjacent areas. The allocation of new housing or built up area within a specific location that is on the boundary of its zone is abruptly cut off along the boundary line, whereas flow on effects into adjacent areas are more plausible. This problem is exacerbated when the difference between population levels is large and / or the spatial area of zones is small. To reduce these issues, CCDs were amalgamated into larger spatially homogenous zones to achieve a balance between sample size and resolution. Allocation of CCDs to zones was conducted by examining the change over time for each CCD's population according to the census data and examining the change in each CCDs built up area from the LULC model. This formed a trial and error process through spatial inspection and then subsequent testing. After extensive testing and refinement it was found that dividing the region into four specific zones provided the best balance between having a large enough extent to match realistic estimations of growth (although there are boundary issues in high growth models), and being small enough to allow for the large levels of variation across the region (Figure 7.5).

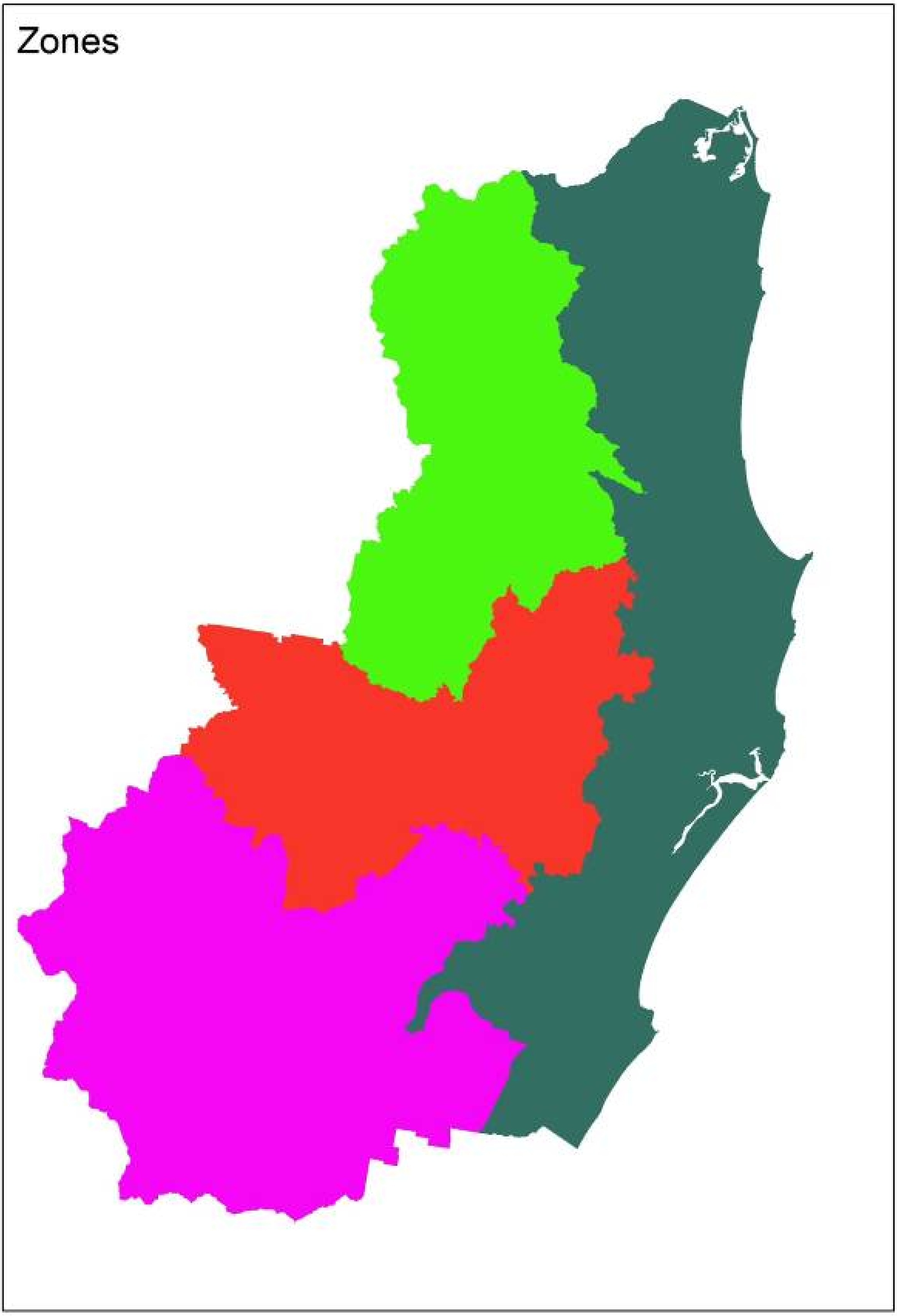


FIGURE 7.5 MAP OF URBAN ZONES USED FOR POPULATION DERIVED FROM HOMOGENOUS CENSUS COLLECTION DISTRICTS

7.4 *Orchards*

Since the mid 1980's, the area around Lismore through to Ballina and Byron Bay has seen large areas of mostly grazing pasture reallocated to macadamia and avocado orchards. Whilst the growth of orchards within the region has been rapid and now incorporates a large area, it is expected that the future growth of this industry will be at a considerably slower rate than what has previously transpired (DIPNR 2007).

It is also apparent that in the long term, the growth of these orchard industries will compete for space directly with urban development. Whilst orchards produce high value products, market economies are likely to favour conversion to residential development (Murphy 2002). For the scenarios in this project, the growth of orchards was modelled and allowed to grow in agricultural areas within a close proximity to current plantations. As the rate of growth was expected to decrease over time, the value of for each time period was produced by adding 50% of the projected growth to the previous decades value, expressed in the equation:

$$V_t = V_{t-1} + (0.5 * V_t(\text{trend}))$$

Where V_t is the value at that time period, V_{t-1} the value of the previous time period and V_t(trend) the value of the trend function for that time period.

As it is expected that these areas may be urbanised at a later date, the growth of orchards is carried out first and the orchard land class is not excluded from future urban development (with the exception of protected agricultural land in some scenarios). The results of this growth are shown in Figure 7.6.

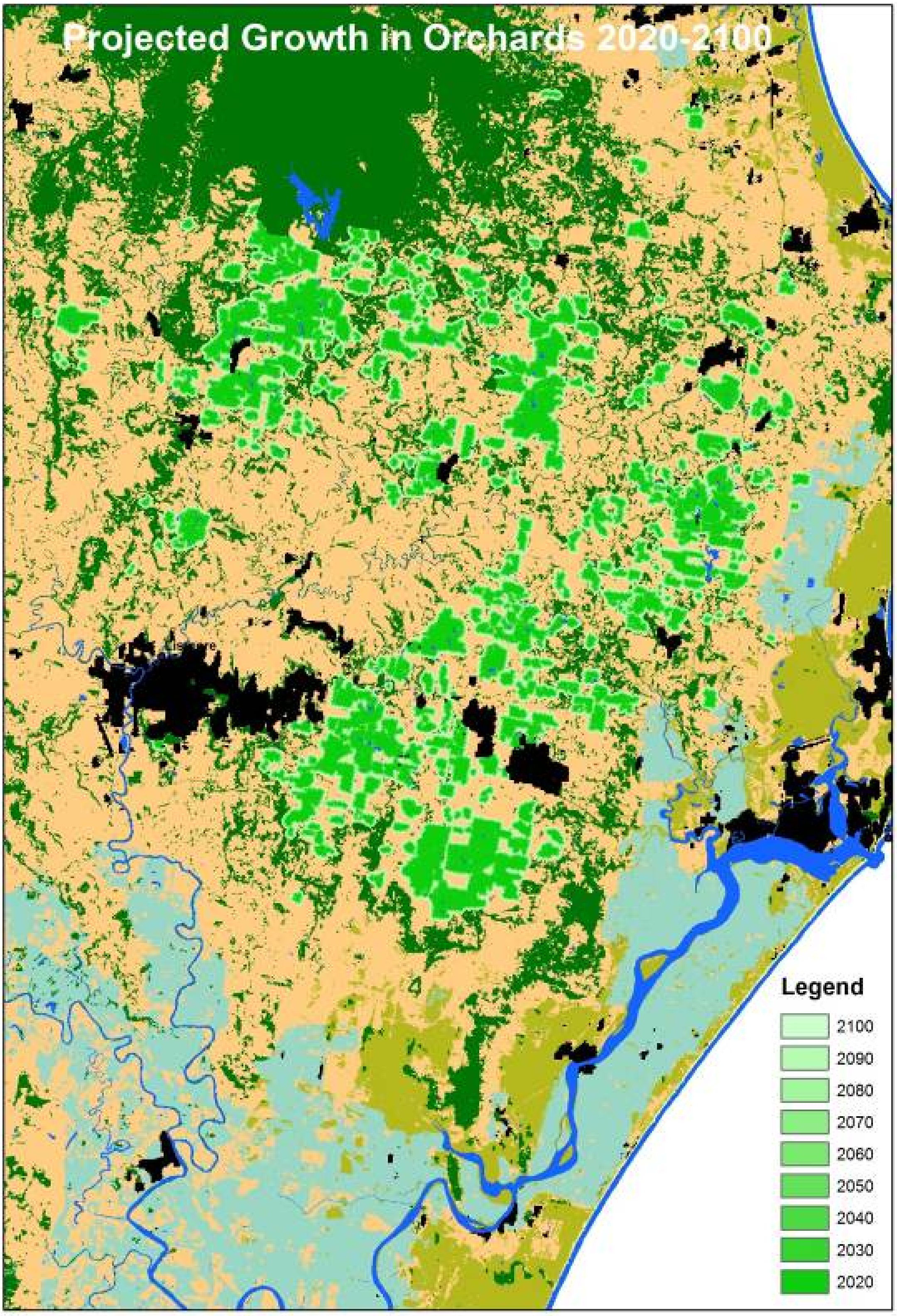


FIGURE 7.6: PROJECTED GROWTH OF ORCHARDS TO 2100

7.5 *Scenarios*

The capacity to generate multiple future scenarios provides the flexibility to introduce changes to constraints or population and then create "what if" scenarios. The process described in 7.2.1 above reflects the iterative nature of scenario development with scenarios designed, modelled, tested and then redesigned. The model uses a CA algorithm to grow the existing areas and adds a small random element until the population or levels of urban growth within a zone has reached a predetermined level. Constraints to development are incorporated by removing areas of available land from the areas considered 'buildable' by the algorithm.

While that process has been conducted iteratively, for simpler reporting the scenarios developed are presented in a linear fashion and without showing the individuals steps of testing, redevelopment and new scenario production that occurs between each stage. In the remainder of this chapter, the visual outputs are given and the full analysis of results shown is presented in chapters 8 and 9.

7.5.1 *Deregulated Development Restriction Scenario*

The deregulated development scenario simulates what happens if controls such as council regulations are removed and urban development is allowed to occur with minimal constraints. As councils are often under pressure to promote and approve new development proposals (Abel *et al.* 2011, Measham *et al.* 2011) this scenario also demonstrates an extreme example of the 'tyranny of small decisions' (Kahn 1966). This is where numerous approvals are granted despite regulations and better judgement, and they cumulatively erode the planning process.

7.5.1.1 Development Constraints

As this is a deregulated scenario, the constraints in available land area for new urban development are minimal. These are the current national parks estate and state forests as well as existing urban area, major roads and areas with a slope greater than 25% (which are predominately located within national parks). Figure 7.7 shows these restrictions.

7.5.1.2 Results

Modelled at the growth rates of 1, 1.5 and 2 percent, the model shows relatively uniform growth throughout the region (Figures 7.8, 7.10, 7.12) although concentrating in the north east coastal areas (Figures 7.9, 7.11, 7.13). Also prevalent is a strong ribbon development along the northern parts of the Pacific highway.

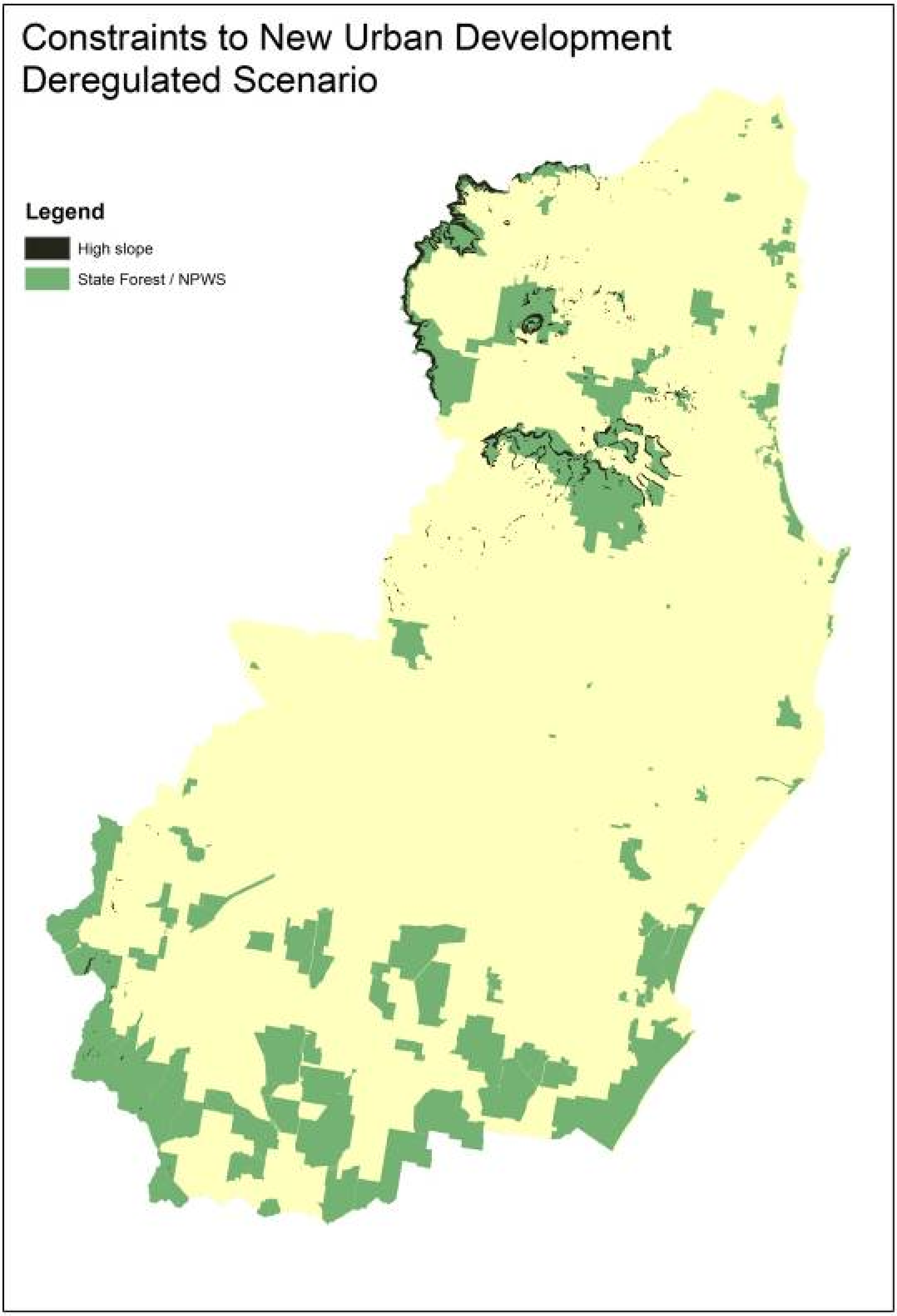


FIGURE 7.7 CONSTRAINTS TO DEVELOPMENT, DEREGULATED SCENARIO

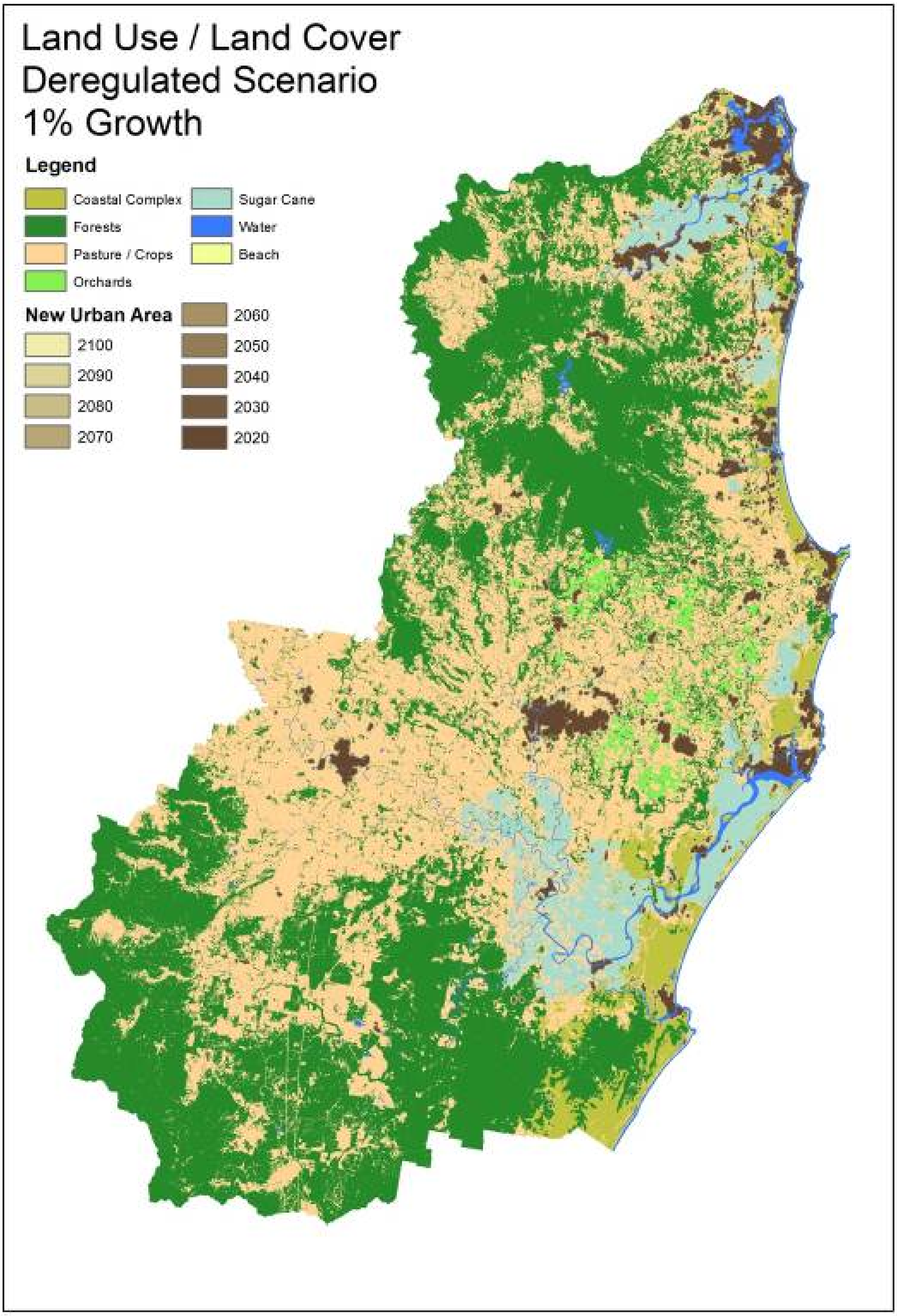


FIGURE 7.8 DEREGULATED SCENARIO, WHOLE REGION, 1% GROWTH

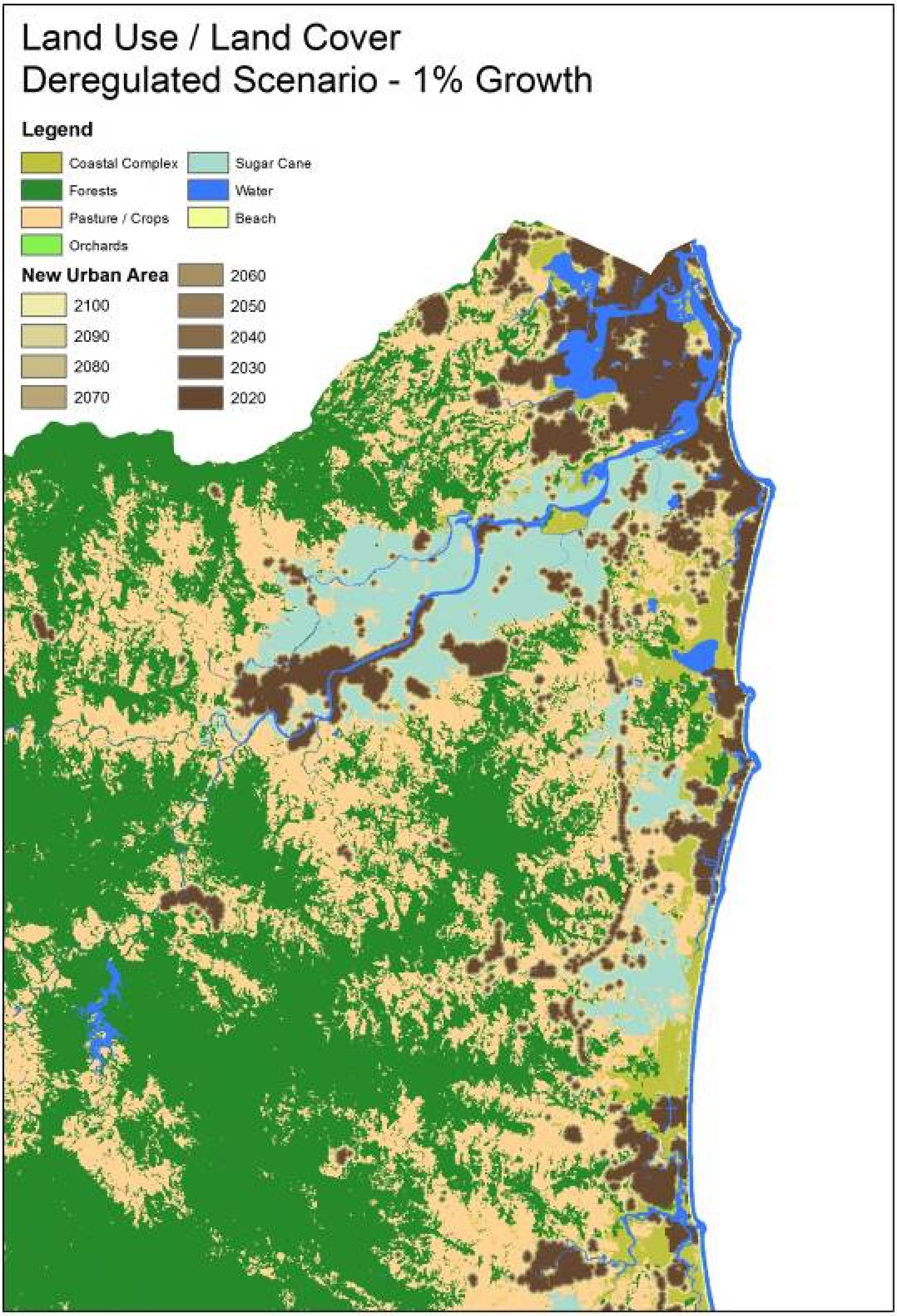


FIGURE 7.9 DEREGULATED SCENARIO, NORTH EAST CORNER, 1% GROWTH

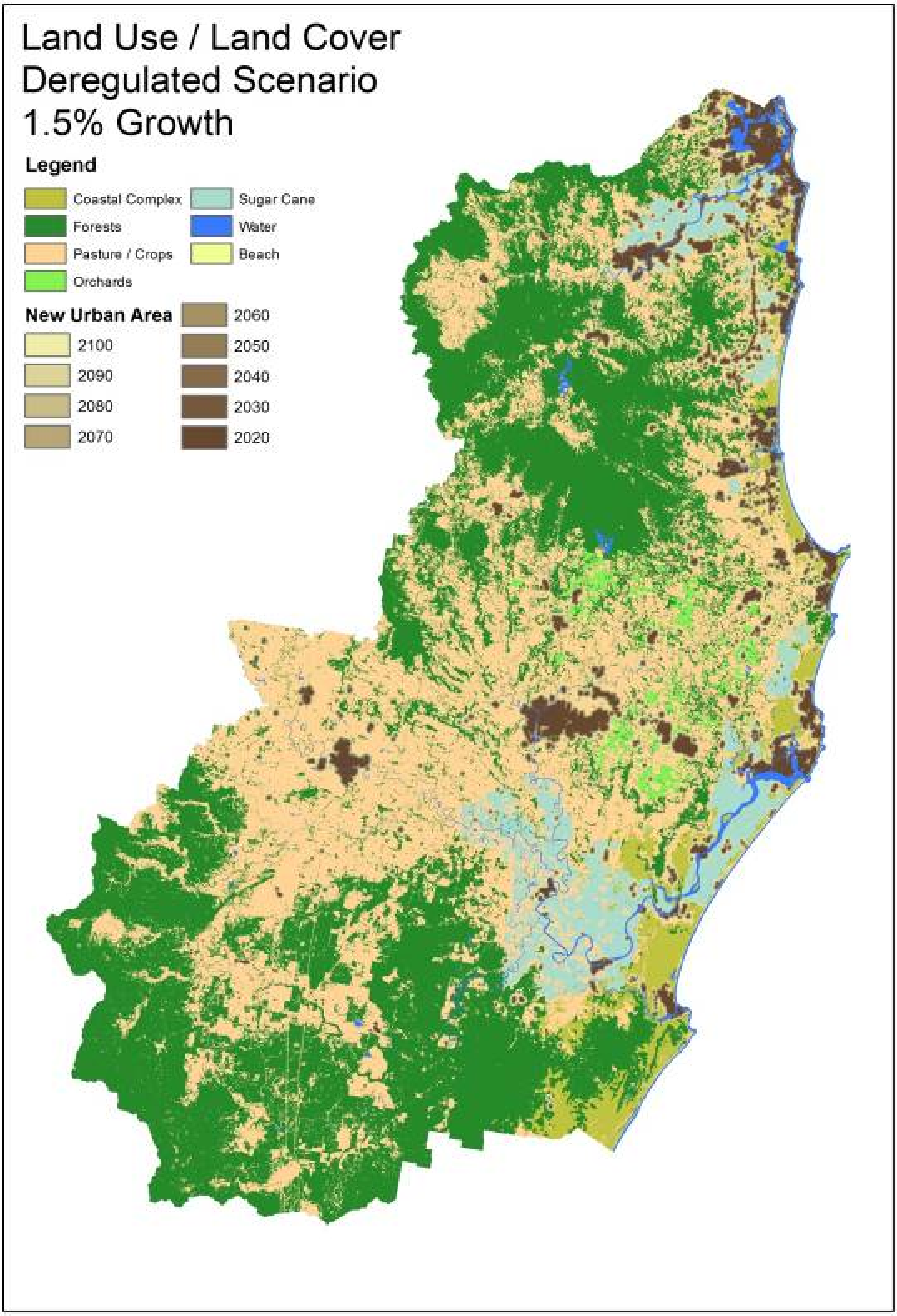


FIGURE 7.10 DEREGULATED SCENARIO, WHOLE REGION, 1.5% GROWTH

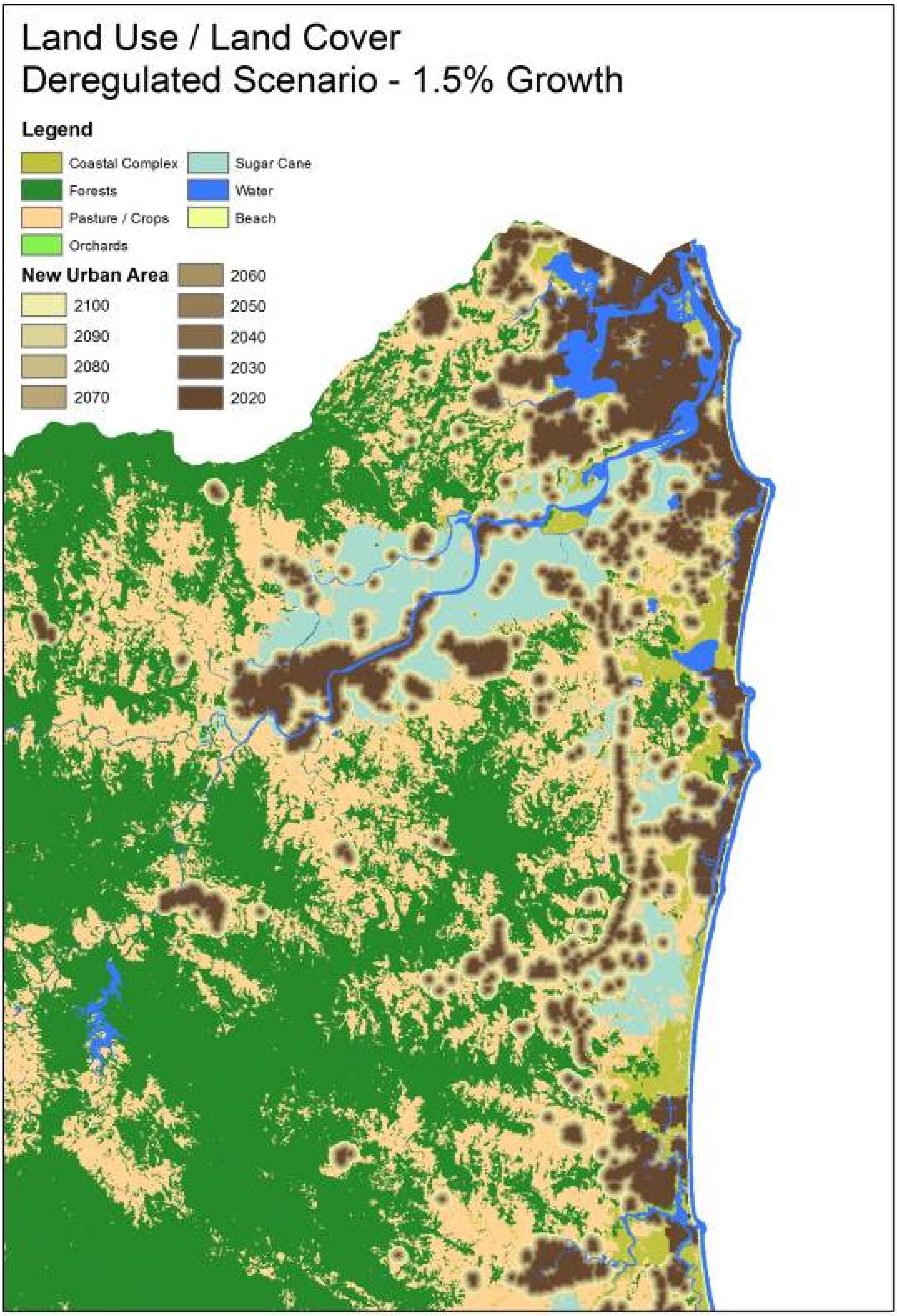


FIGURE 7.11 DEREGULATED SCENARIO, NORTH EAST CORNER REGION, 1.5% GROWTH

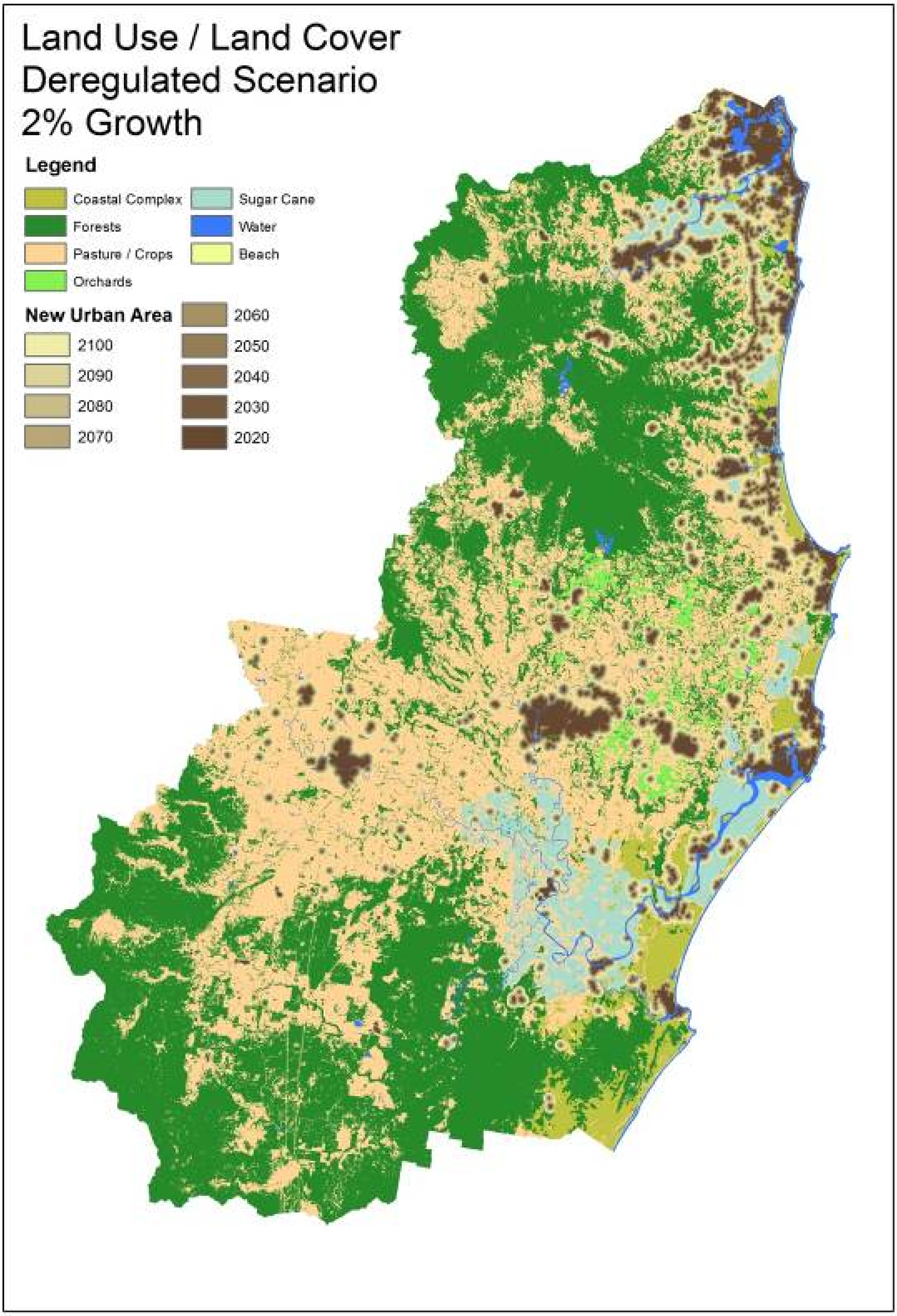


FIGURE 7.12 DEREGULATED SCENARIO, WHOLE REGION, 2% GROWTH

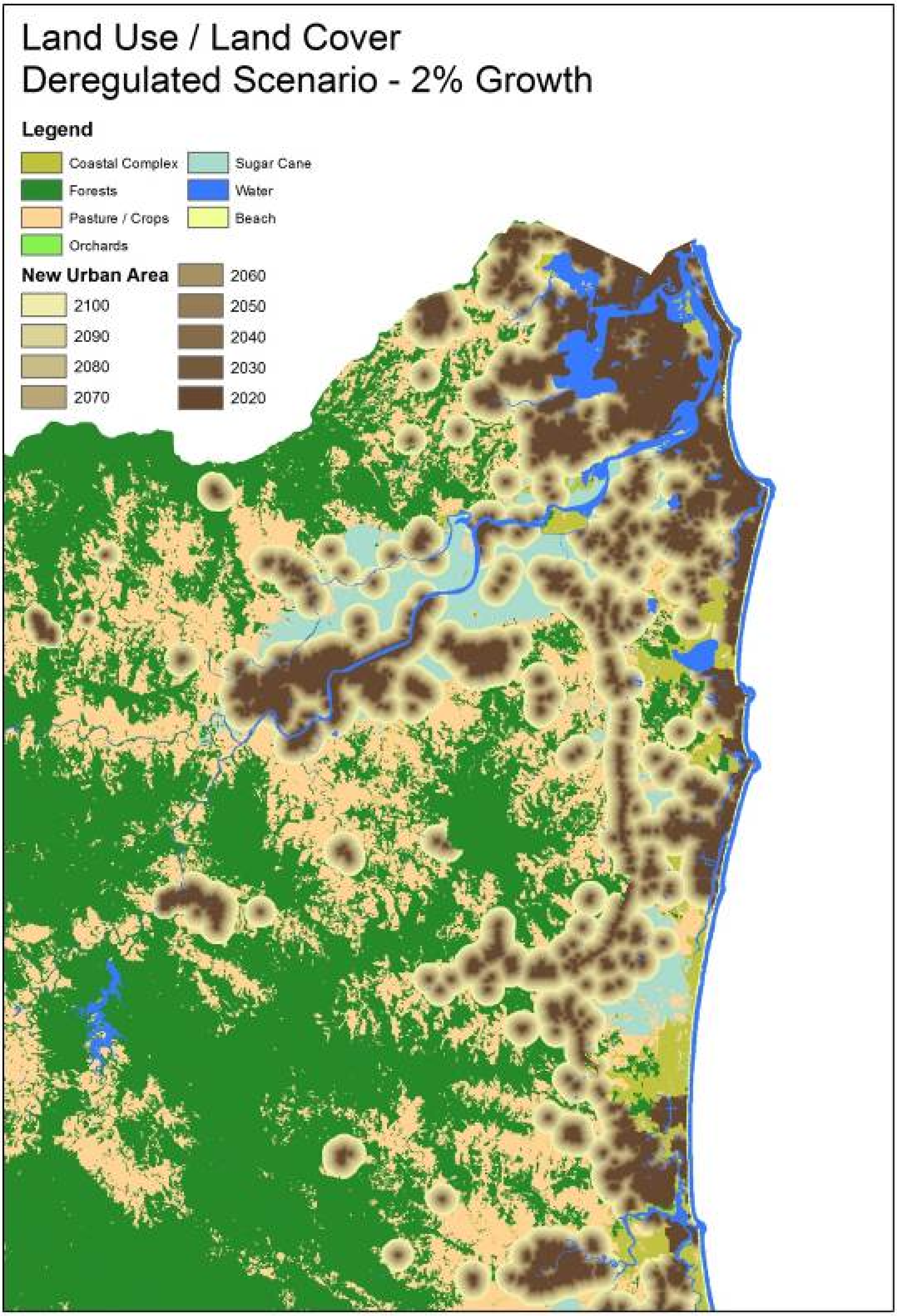


FIGURE 7.13 DEREGULATED SCENARIO, NORTH EAST CORNER, 2% GROWTH

7.5.2 *Far North Coast Regional Plan Scenarios*

The overriding strategic planning document for the region is the Far North Coast Regional Plan (DIPNR 2007) which aims to manage the urban growth by addressing concerns in key areas. Some key relevant aims of the plan are:

- Ensure adequate infrastructure and accessibility to new urban developments
- Encourage urban growth away from the coast and restricts coastal development to within the current town boundaries
- Allow for a mix of suitable housing types and population density
- Protect employment related areas including highly productive and / or culturally significant agricultural land
- Prohibit development on land that is prone to being affected by natural hazards including areas with a high slope or within 1:100 year flood zone.
- Protect areas recognised as being important to the conservation of biodiversity, including recognised wildlife corridors.
- Restrict development on acid sulphate soils.
- Prohibit 'ribbon' development along road edges.

Overall the plan aims to provide an optimal target for locating new development within the region. This scenario models most of the goals of the plan with a few caveats. The timeframe of the regional plan is 2006-2031 whereas this project considers growth to 2100. As the built up area is growing even without population increases and considering the amount of population growth expected over that timeframe, the restriction to new development within existing town boundaries becomes impossible to meet. The plan also prohibits new development within the 1:100 year flood zone, however a small amount of urban growth has occurred within that area during the time of the plan and many areas within town boundaries fall into this category.

7.5.2.1 Development Constraints

To simulate the regional plan, the modelled constraints (Figure 7.14) are

- Protected agricultural land (as specified by the plan)
- Areas of high risk of having acid sulphate soils
- Biodiversity Corridors as recognised by the New South Wales National Parks and Wildlife Service
- Important Wetlands
- Existing national parks and state forests
- Areas of high slope
- Land affected by sea level rise of 1m

In a number of cases areas within these categories overlap. For example an area may be simultaneously recognised as wetland, biodiversity corridor and national park.

7.5.2.2 Results

Modelled at the growth rates of 1, 1.5 and 2 percent (Figures 7.15-7.20), the model shows relatively uniform growth throughout the region at 1% growth rate. At the higher growth rates the restrictions to development on acid sulphate soils and protecting agricultural land has meant higher levels of development in the north east corner and in the south, west of Evans Head. Despite this increase in development, the ribbon development along the Pacific Highway visible in the deregulated scenario has not occurred.

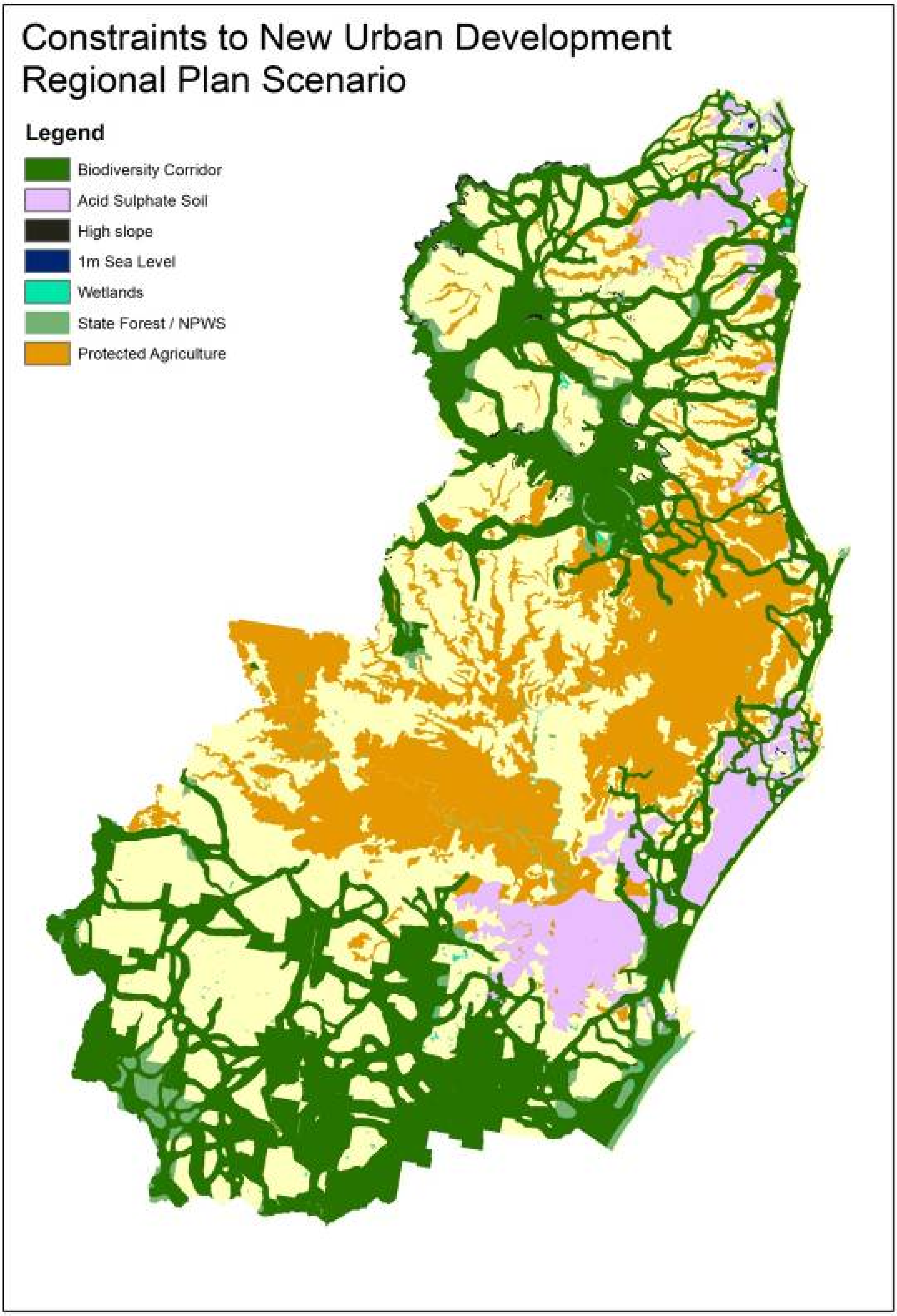


FIGURE 7.14 CONSTRAINTS TO DEVELOPMENT, REGIONAL PLAN SCENARIO

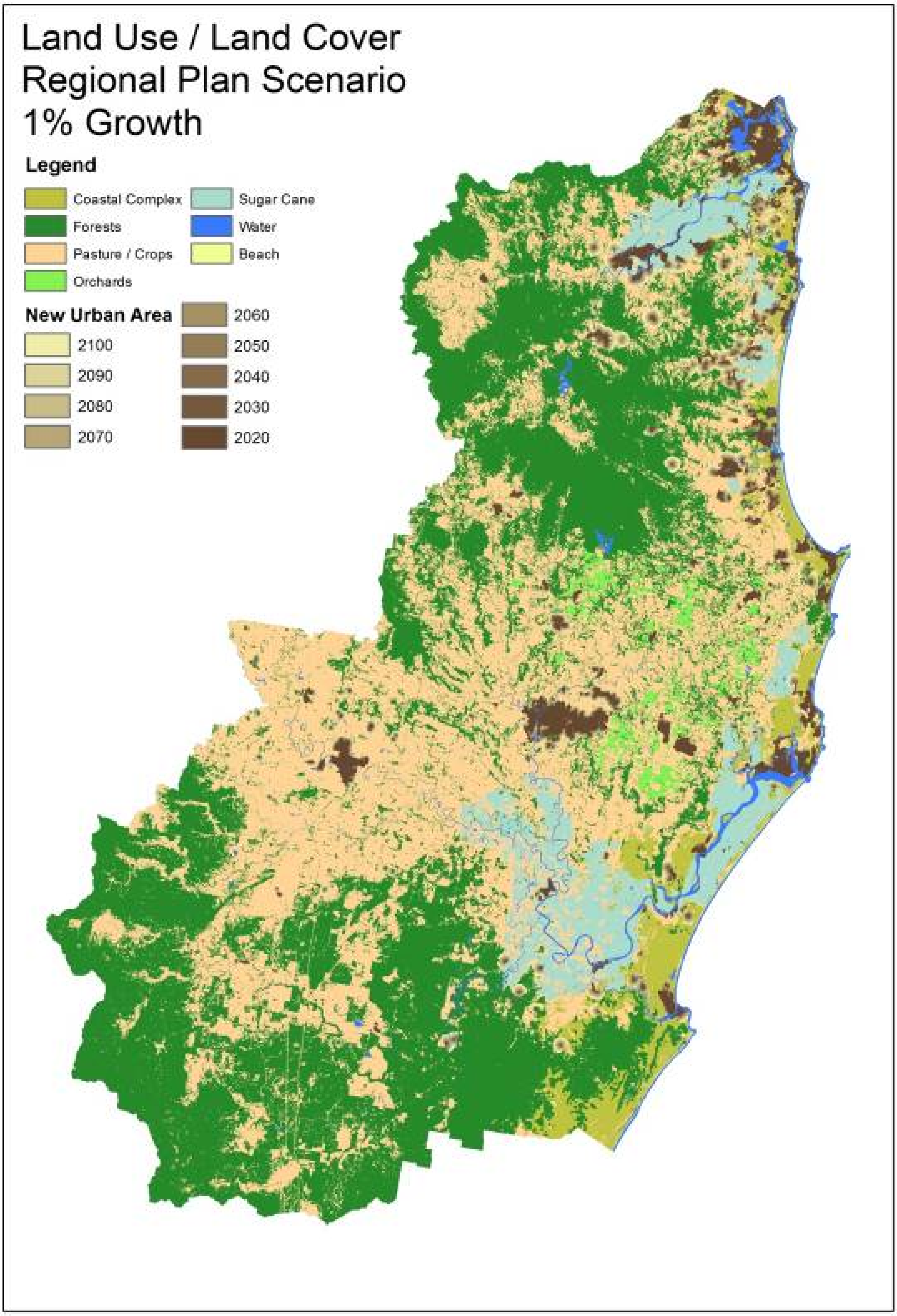


FIGURE 7.15 REGIONAL PLAN SCENARIO, WHOLE REGION, 1% GROWTH

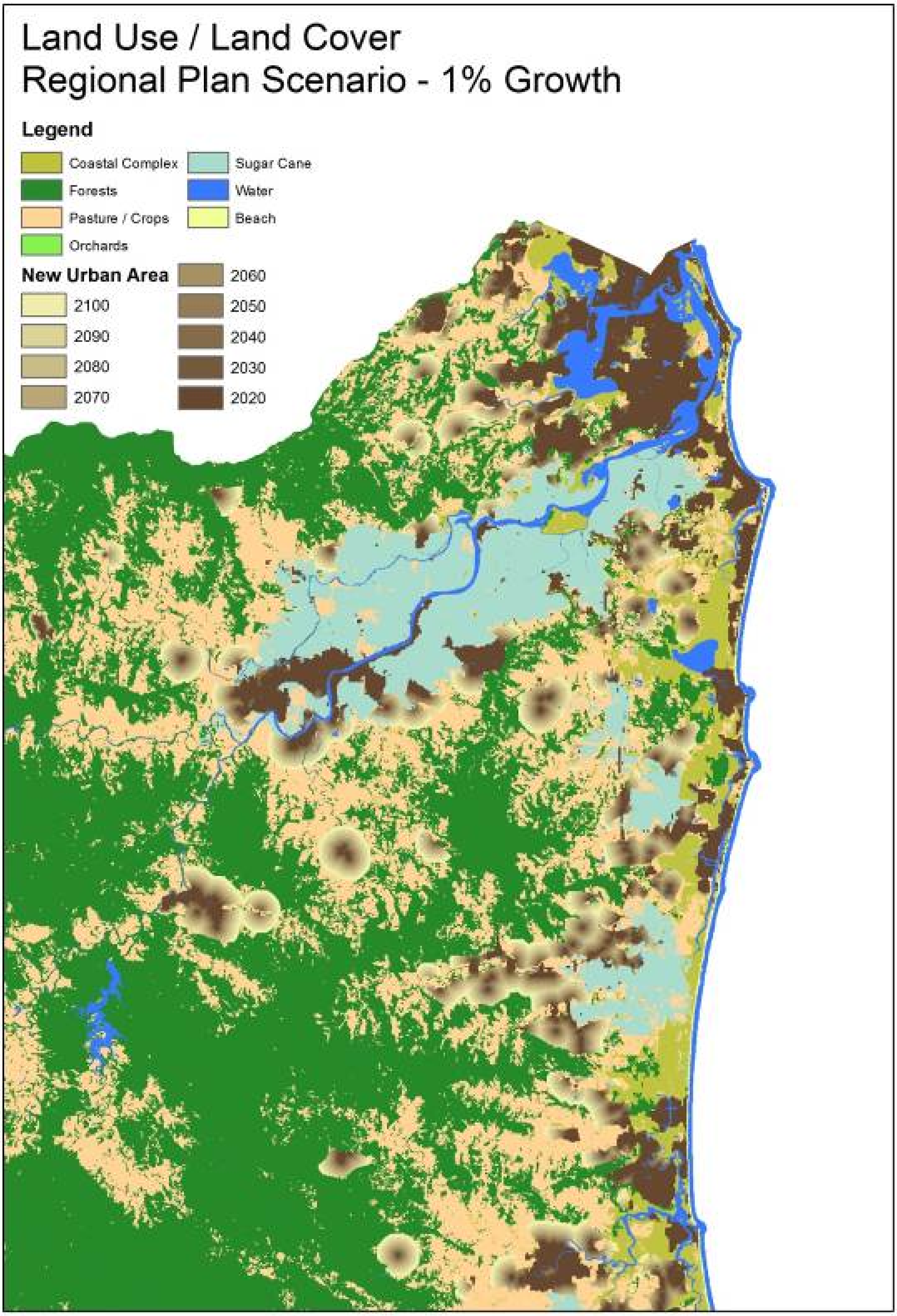


FIGURE 7.16 REGIONAL PLAN SCENARIO, NORTH EAST CORNER, 1% GROWTH

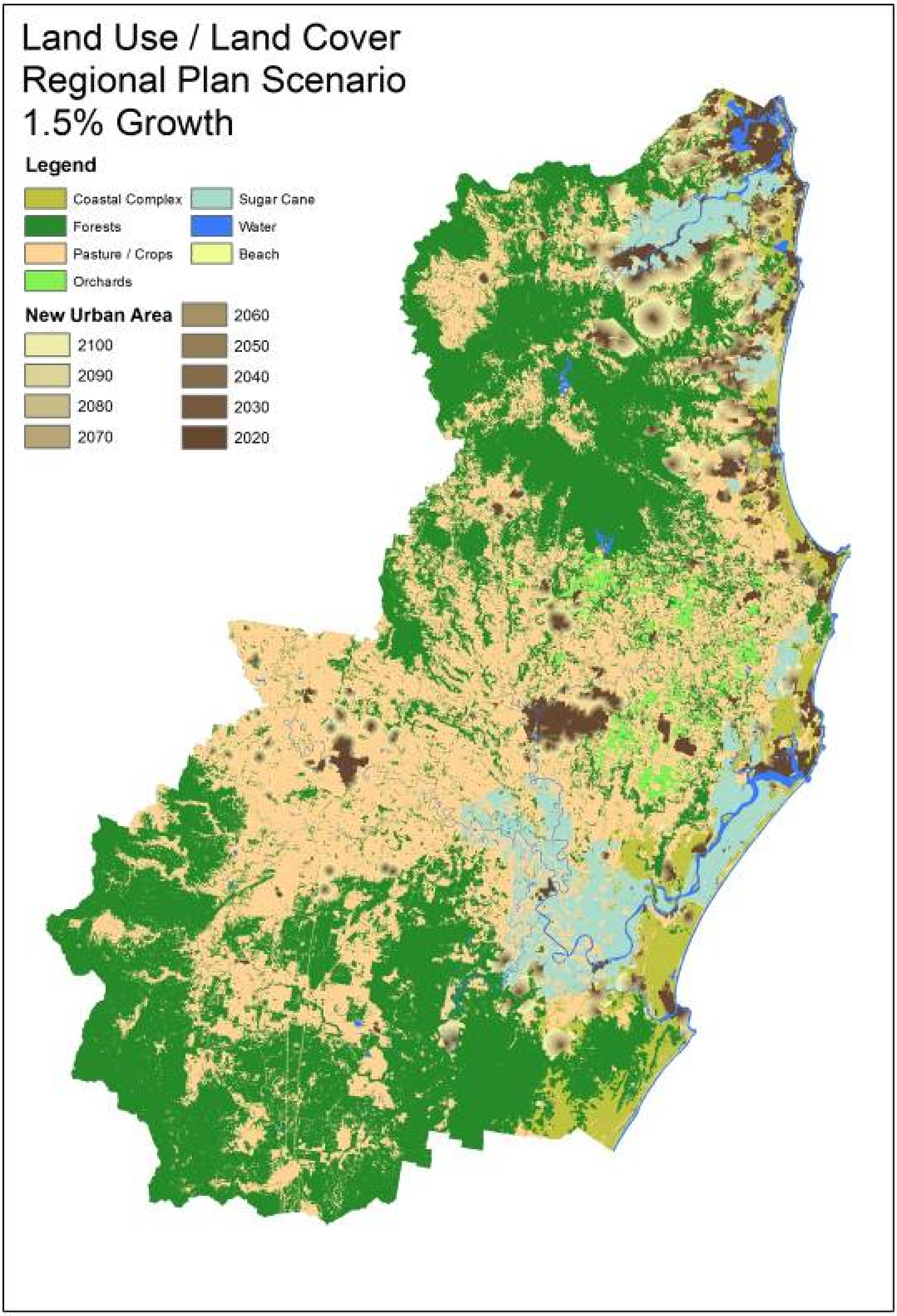


FIGURE 7.17 REGIONAL PLAN SCENARIO, WHOLE REGION, 1.5% GROWTH

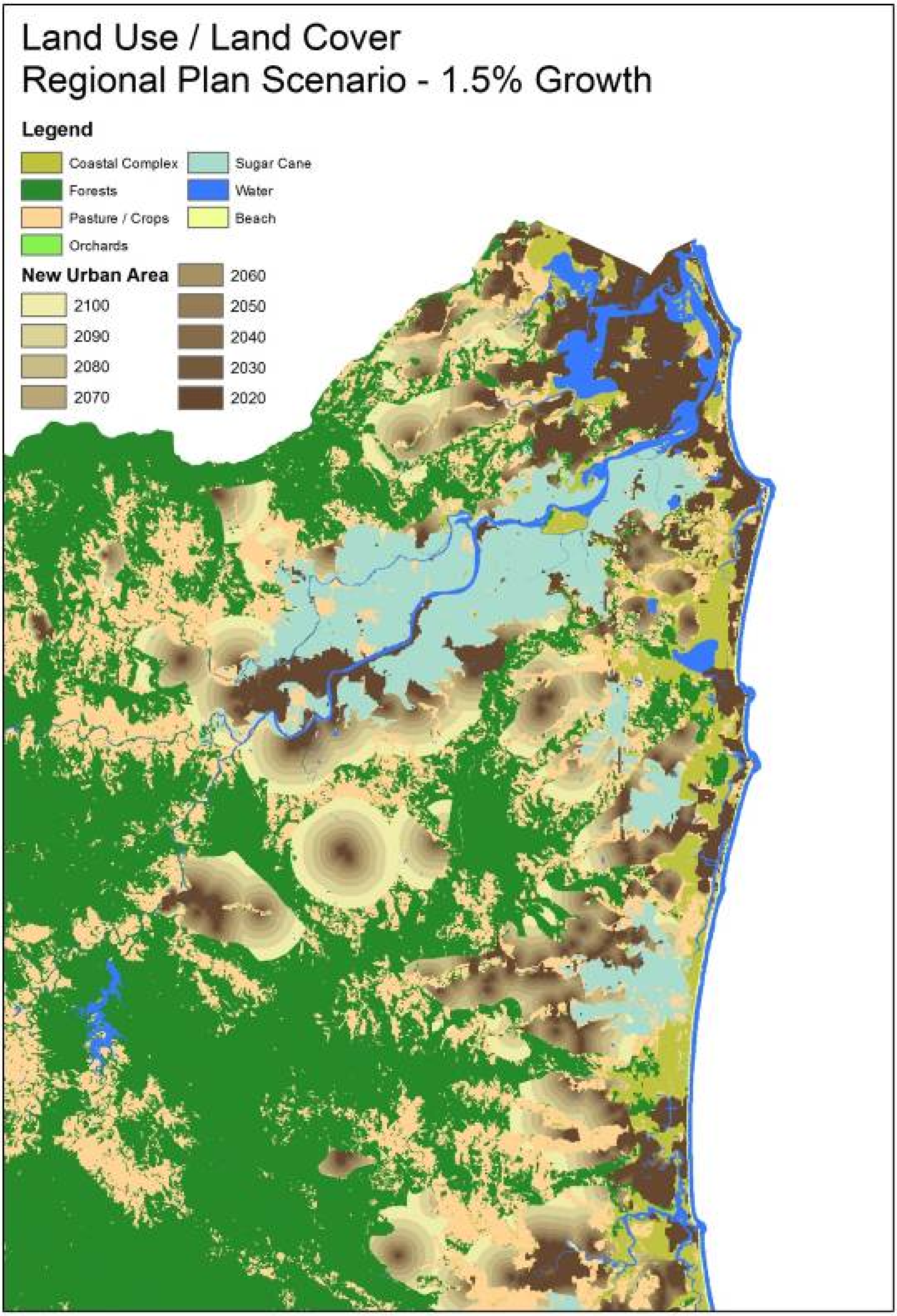


FIGURE 7.18 REGIONAL PLAN SCENARIO, NORTH EAST CORNER, 1.5% GROWTH

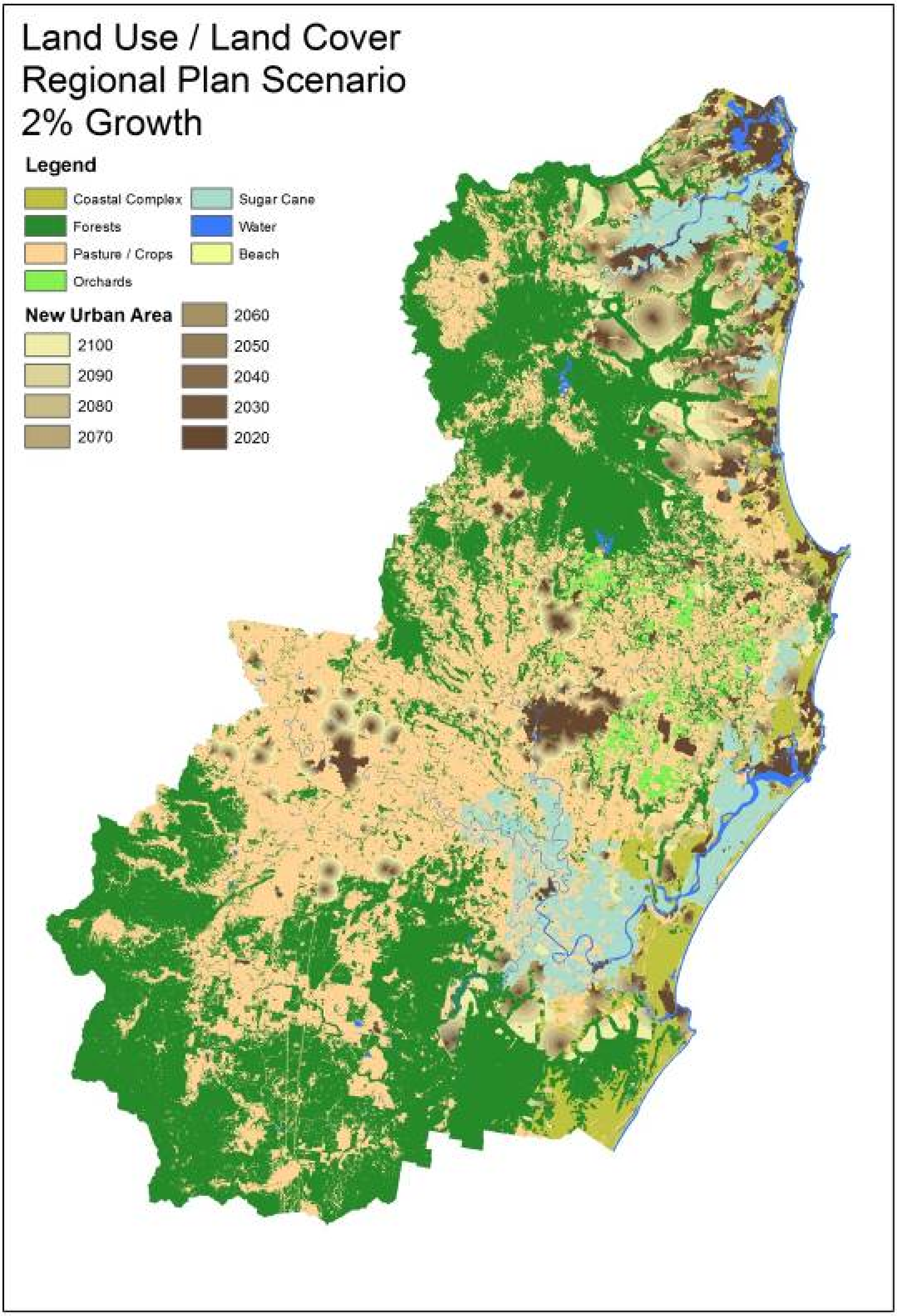


FIGURE 7.19 REGIONAL PLAN SCENARIO, WHOLE REGION, 2% GROWTH

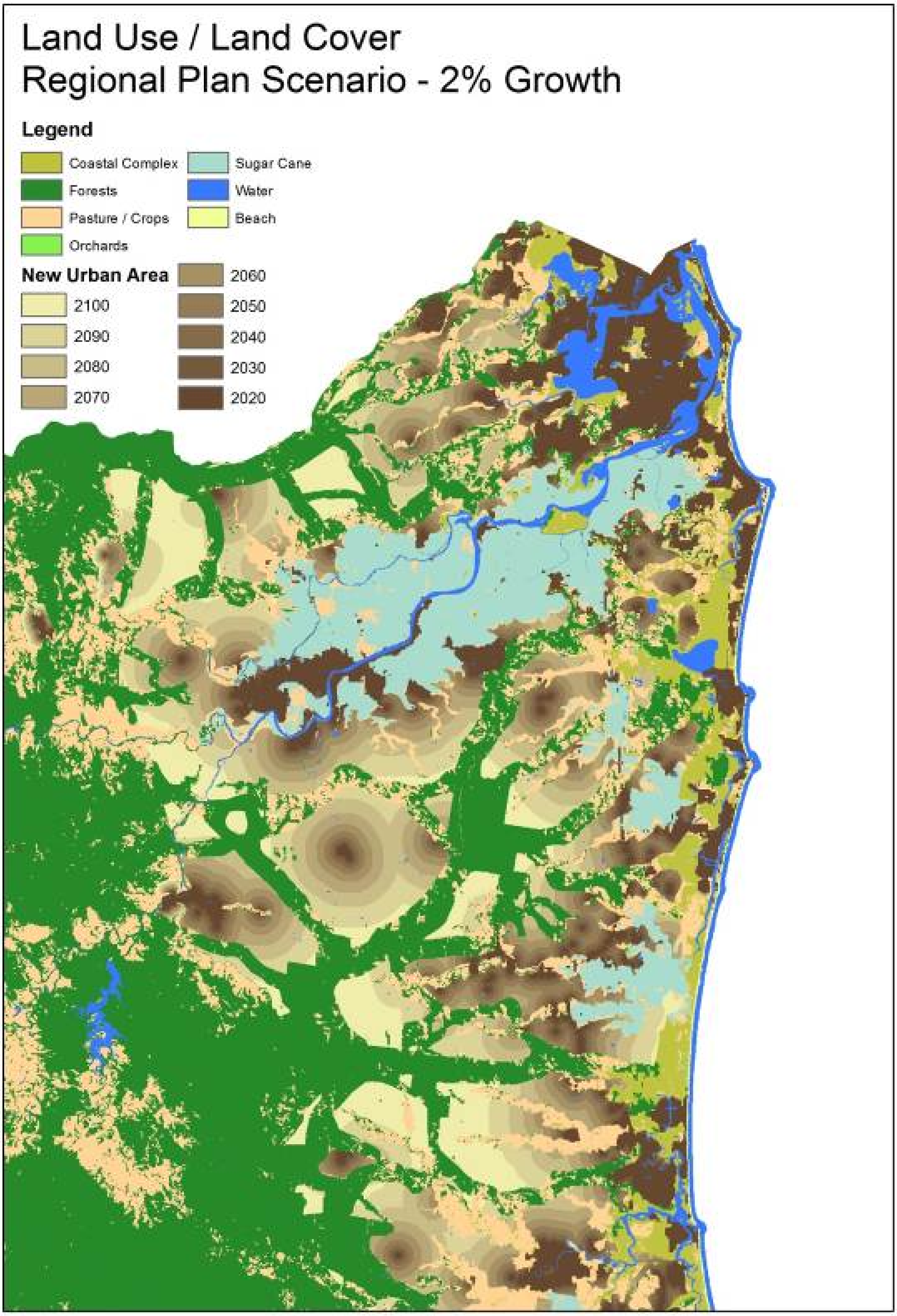


FIGURE 7.20 REGIONAL PLAN SCENARIO, NORTH EAST CORNER, 2% GROWTH

7.5.3 *Controlled Density Scenario*

This scenario builds upon the regional plan by increasing the population density within the coastal zone. A single urban growth model is used with new development growing at a constant 2% throughout the region. However in the coastal zone, population density has been doubled. In the short term this would be difficult to achieve, however over the long term this goal could be realised with infill and redevelopment. Development constraints remain the same as the regional plan scenario. Results are shown in Figures 7.21 and 7.22 and they reveal the significant reduction in new land for urban development within the coastal zone.

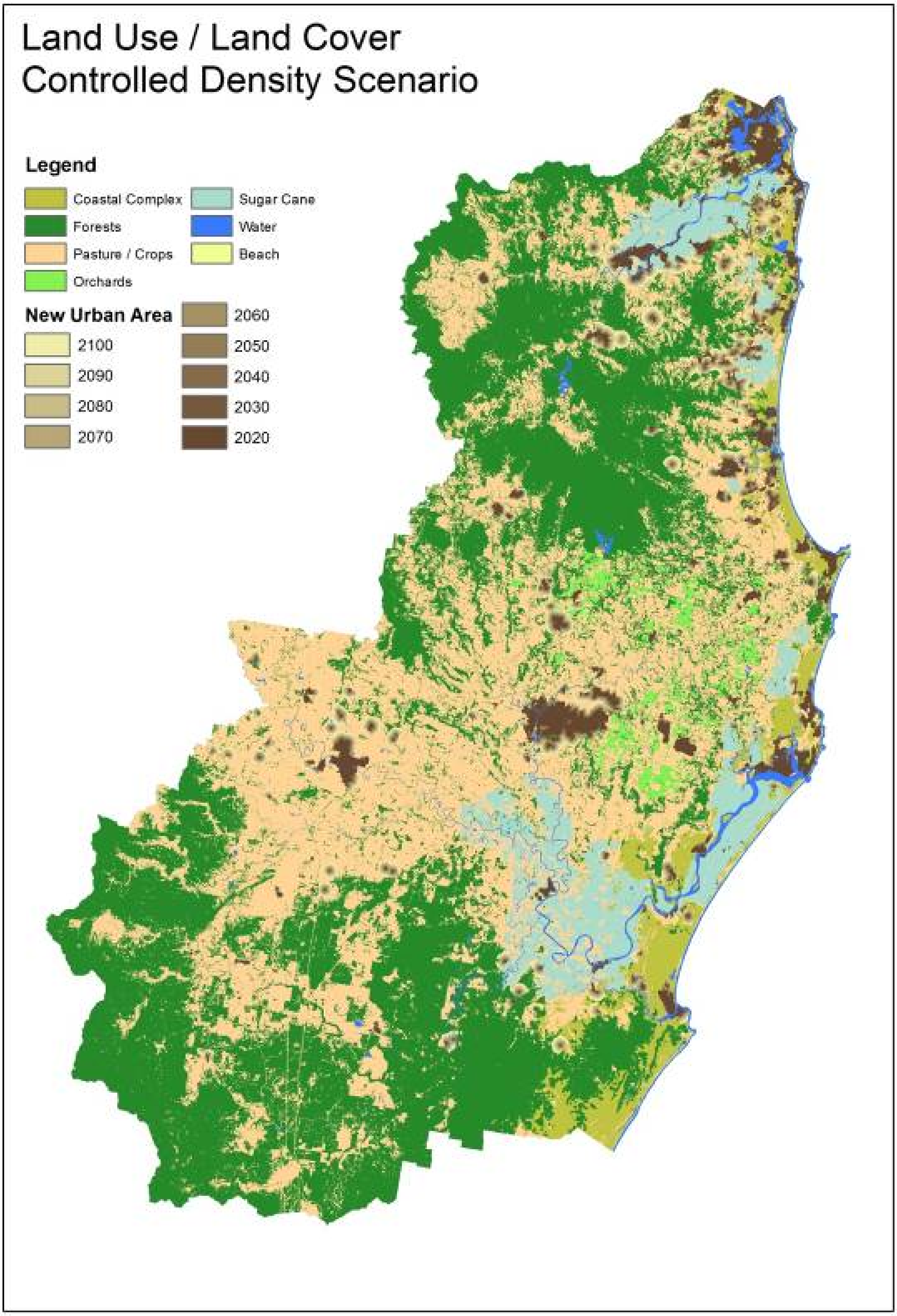


FIGURE 7.21: CONTROLLED DENSITY SCENARIO, WHOLE REGION

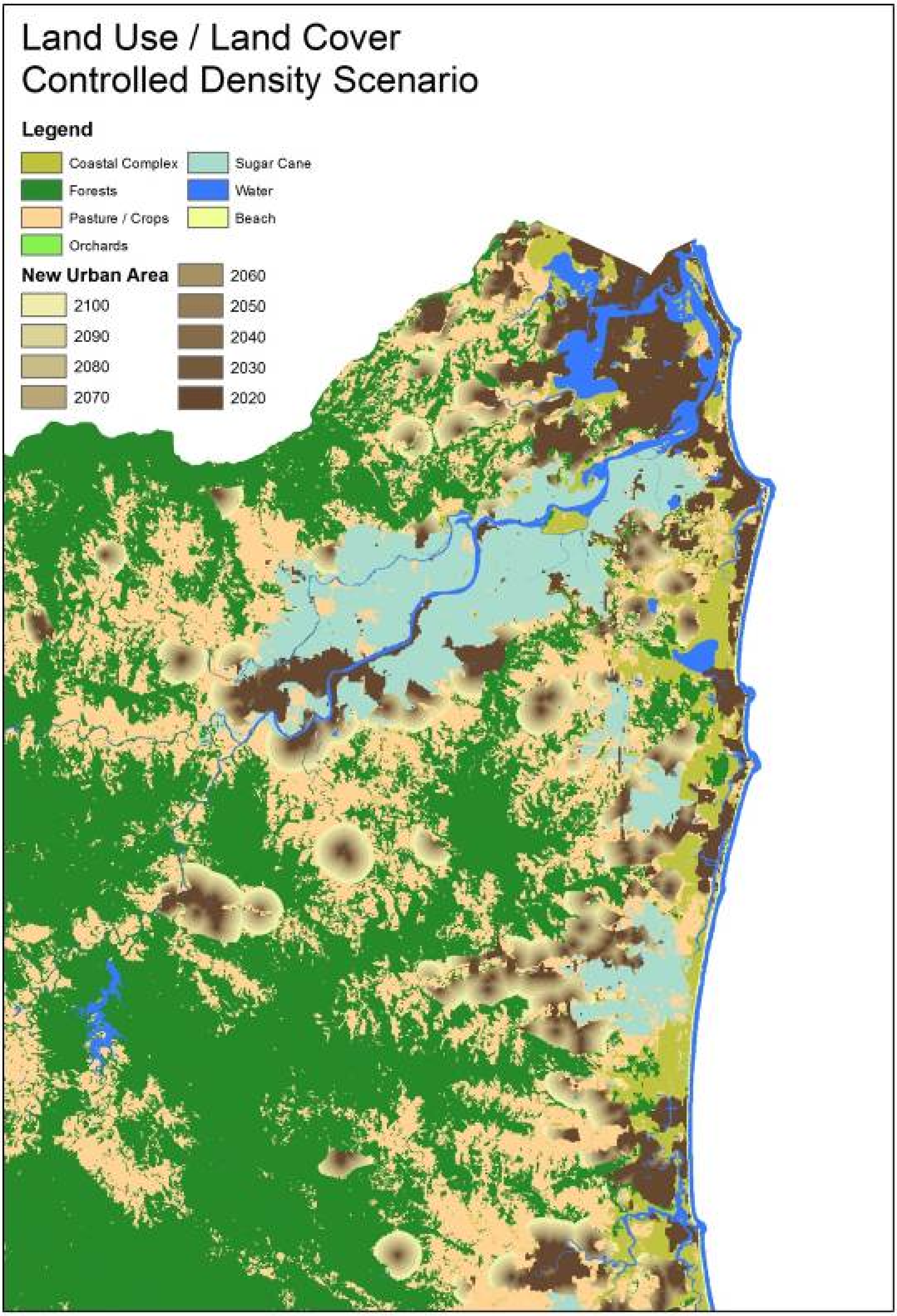


FIGURE 7.22: CONTROLLED DENSITY SCENARIO, NORTH EAST CORNER

7.5.4 *Energy Development Scenario*

Building on the regional plan scenarios with the same constraints to development, the energy development scenario simulates a boom cycle created by the growth of the coal seam gas industry. Predominately in the agricultural areas around Casino and Lismore there are a number of locations within the region that have mining leases and possible potential for coal seam gas extraction.

It is expected that the employment opportunities generated would see strong growth within the central region and a possible reduction in the growth rate of the coastal zone due to in-migration and the perceived opportunities inland. To simulate this, urban development for the central zone has been modelled at a 2.5% growth rate until the year 2050 and then reduced 1% thereafter. The coastal zone has been modelled at 1.25% growth until 2050 and then 1.75% thereafter, simulating migration to the coastal zone after the coal seam gas has completed. Results are shown in Figure 7.23 with close-ups of the north coast and central areas in the Figures 7.24 and 7.25 respectively.

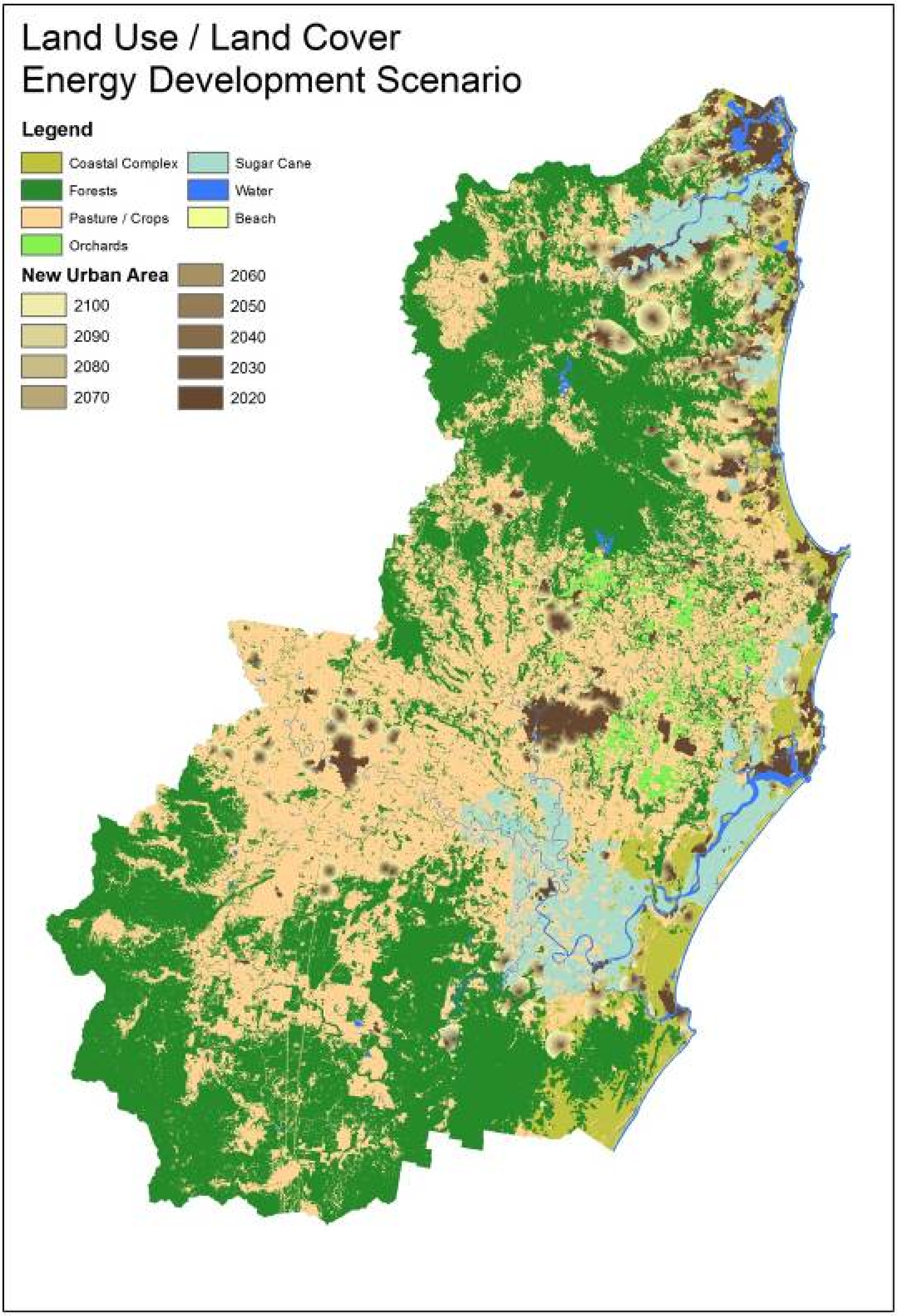


FIGURE 7.23: ENERGY DEVELOPMENT SCENARIO, WHOLE REGION

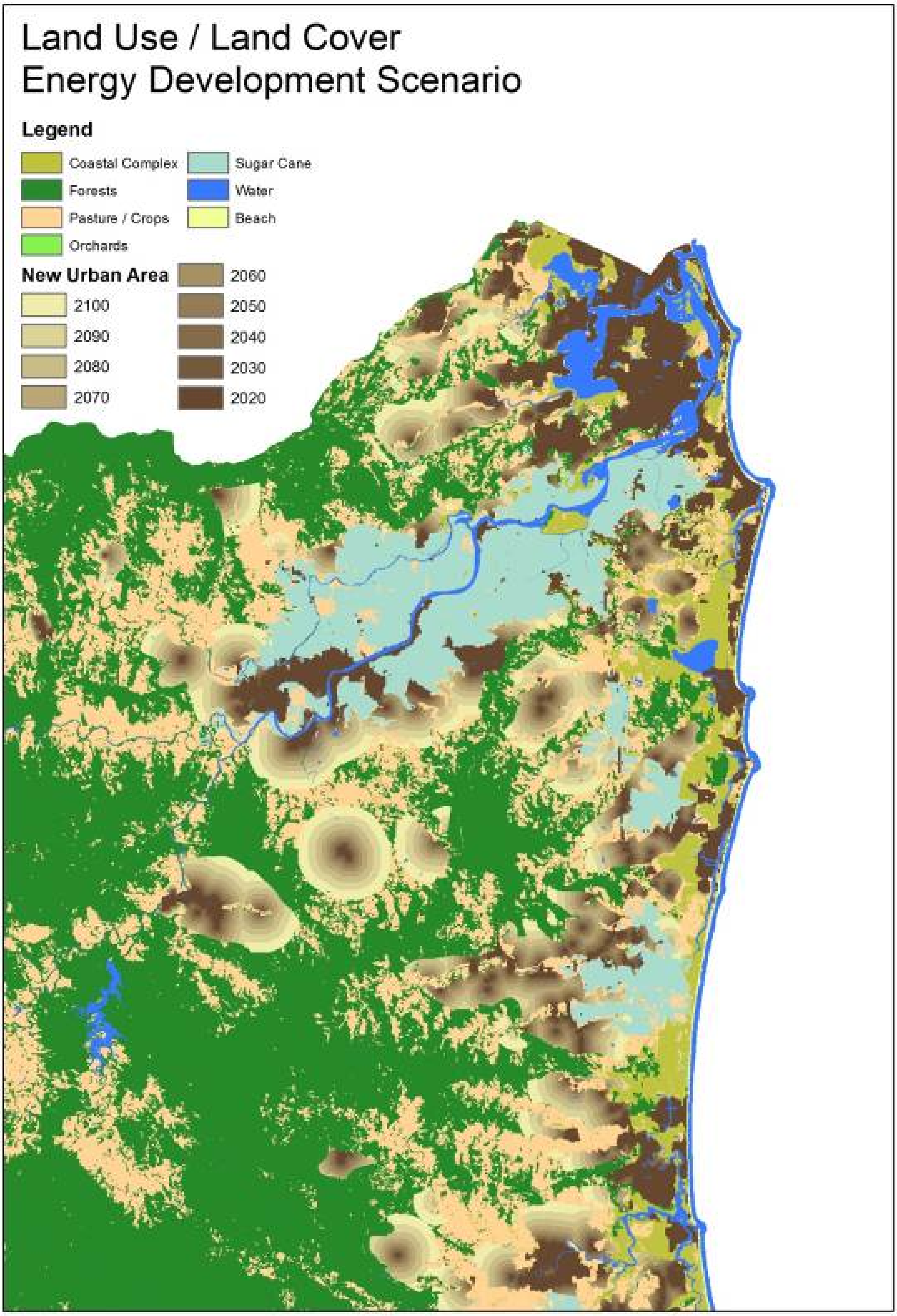


FIGURE 7.24: ENERGY DEVELOPMENT SCENARIO, NORTH EAST CORNER

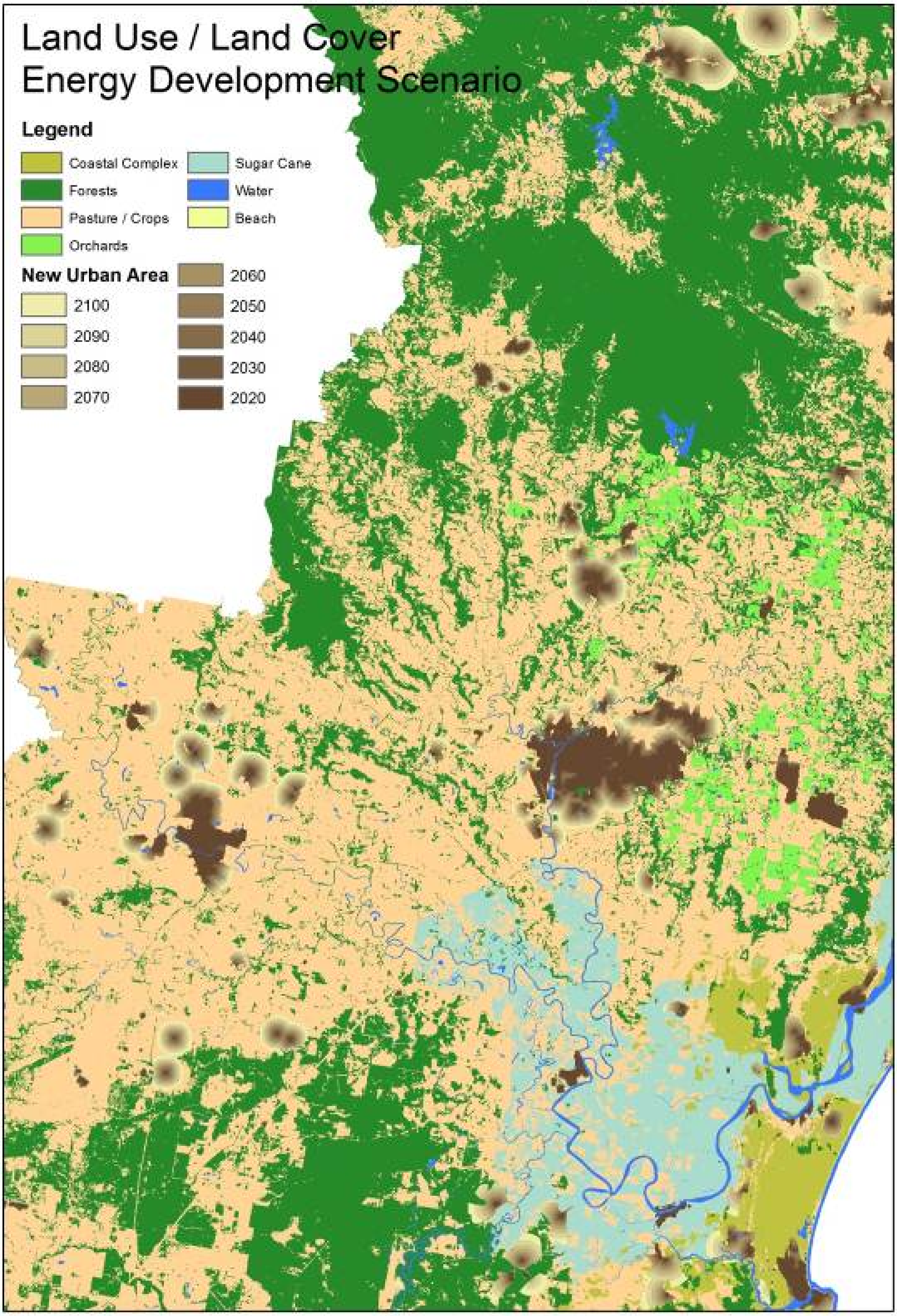


FIGURE 7.25: ENERGY DEVELOPMENT SCENARIO, CENTRE OF REGION

7.5.5 *Climate Adapted Scenarios*

Assessment of climate change related impacts and vulnerabilities with analysis of previous scenarios (see chapters 8 and 9) allowed for a number of climate adapted scenarios to be developed. Two variants are presented at 1%, 1.5% and 2% growth rates in Figures 7.26 – 7.38.

7.5.5.1 Constraints to Development

Both scenarios build upon the constraints to development imposed under the regional plan scenario. The first variant allows for a low-medium level of adaptation to climate change by increasing restrictions imposed by sea level rise, beach recession and a moderately increased flood zone (Figure 7.26). The second scenario simulates restrictions placed to protect development from high to extreme climate induced events. This is achieved by;

- Increasing sea level rise to 2m
- Simulating a 3m storm surge.
- Increasing coastal recession to 150m.
- Increasing the flood zone to maximum levels.

Constraints for the climate adapted – high variant scenario are shown in Figure 7.33.

7.5.5.2 Results

The reduced amount of land available for new development has further increased the strong levels of development in the north east corner of the region and west of Evans Head in both scenarios. The 2% growth model (particularly for the high growth variant – Figures 7.38 and 7.39) shows the boundary issues associated with zoning, with a sharp line of new development along the western edge of the coastal zone. In reality, this growth would spread further west of Murwillumbah than what the zoning has allowed. Both scenarios highlight the need for a concerted effort in increasing the population densities of the coastal areas over the long term.

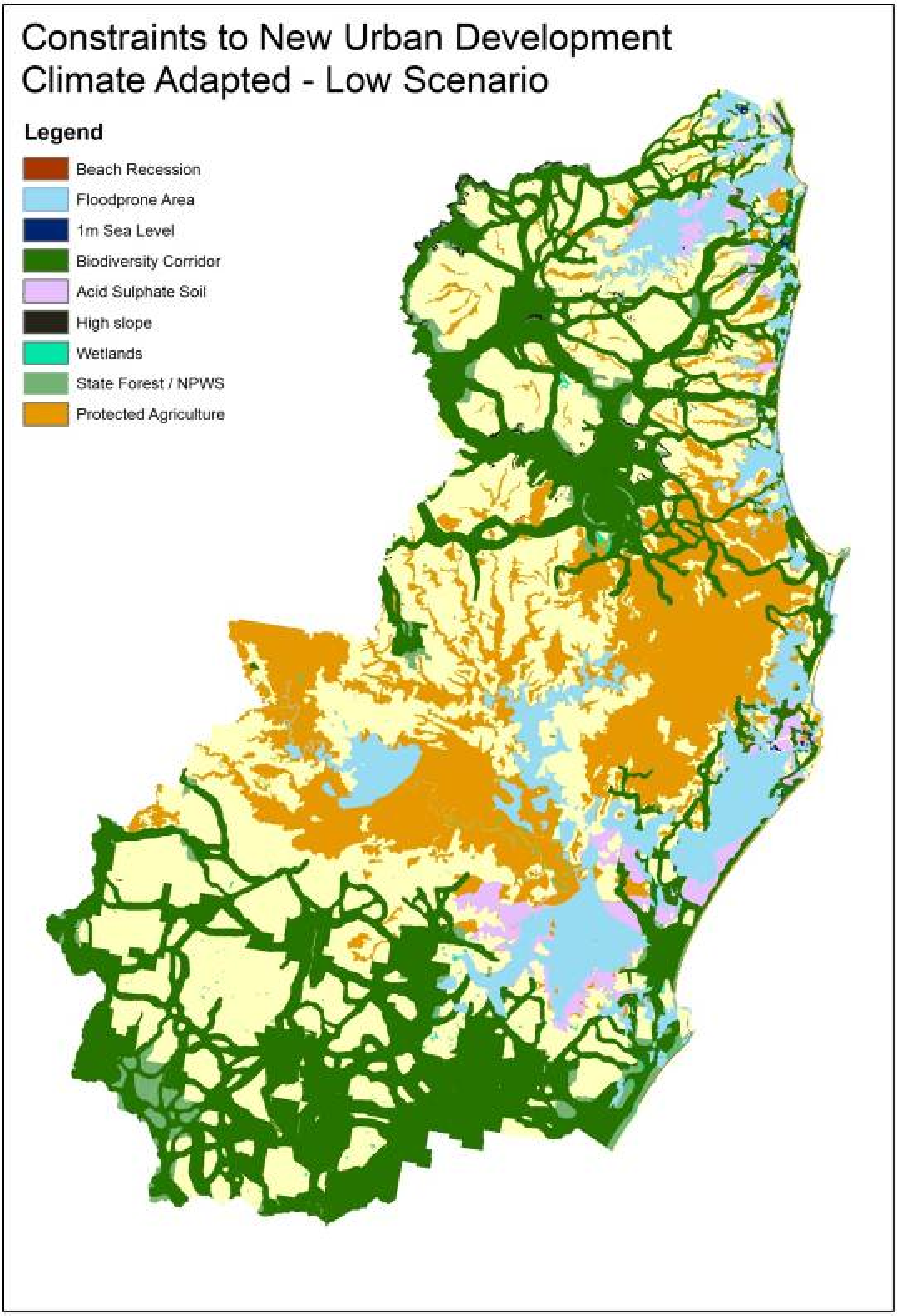


FIGURE 7.26: CONSTRAINTS TO DEVELOPMENT, CLIMATE ADAPTED - LOW SCENARIO

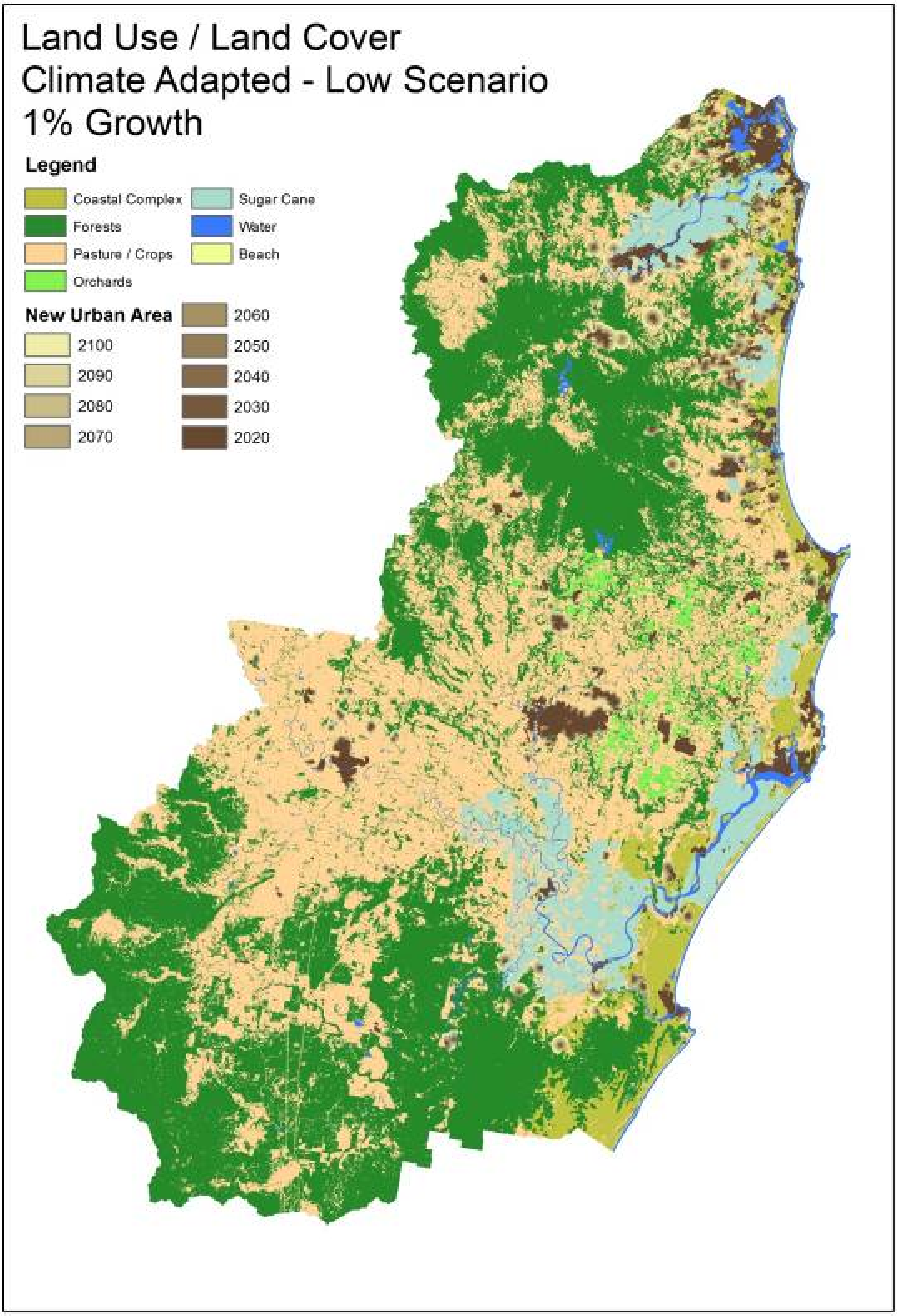


FIGURE 7.27: CLIMATE ADAPTED – LOW SCENARIO, WHOLE REGION, 1% GROWTH

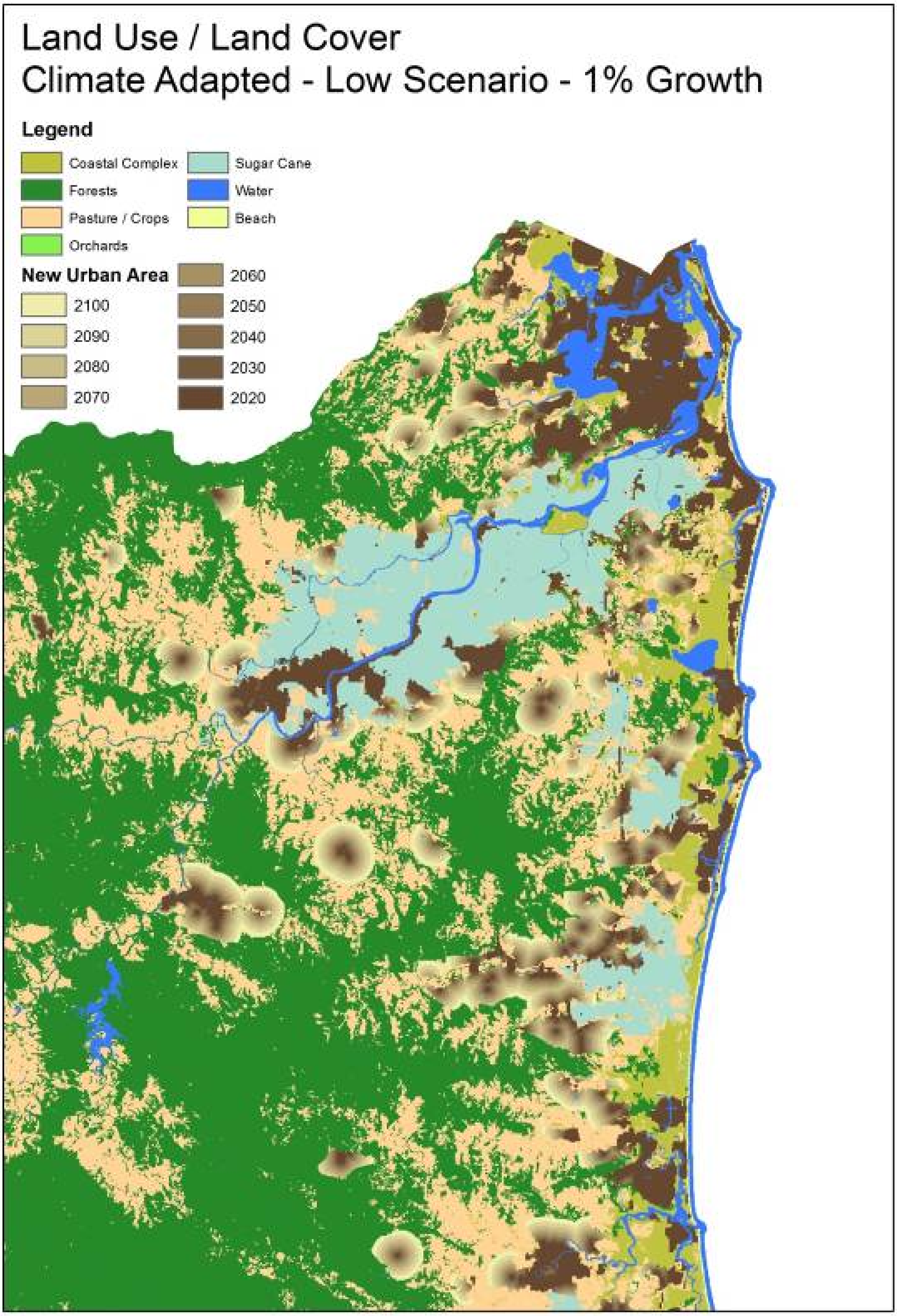


FIGURE 7.28: CLIMATE ADAPTED – LOW SCENARIO, NORTH EAST CORNER, 1% GROWTH

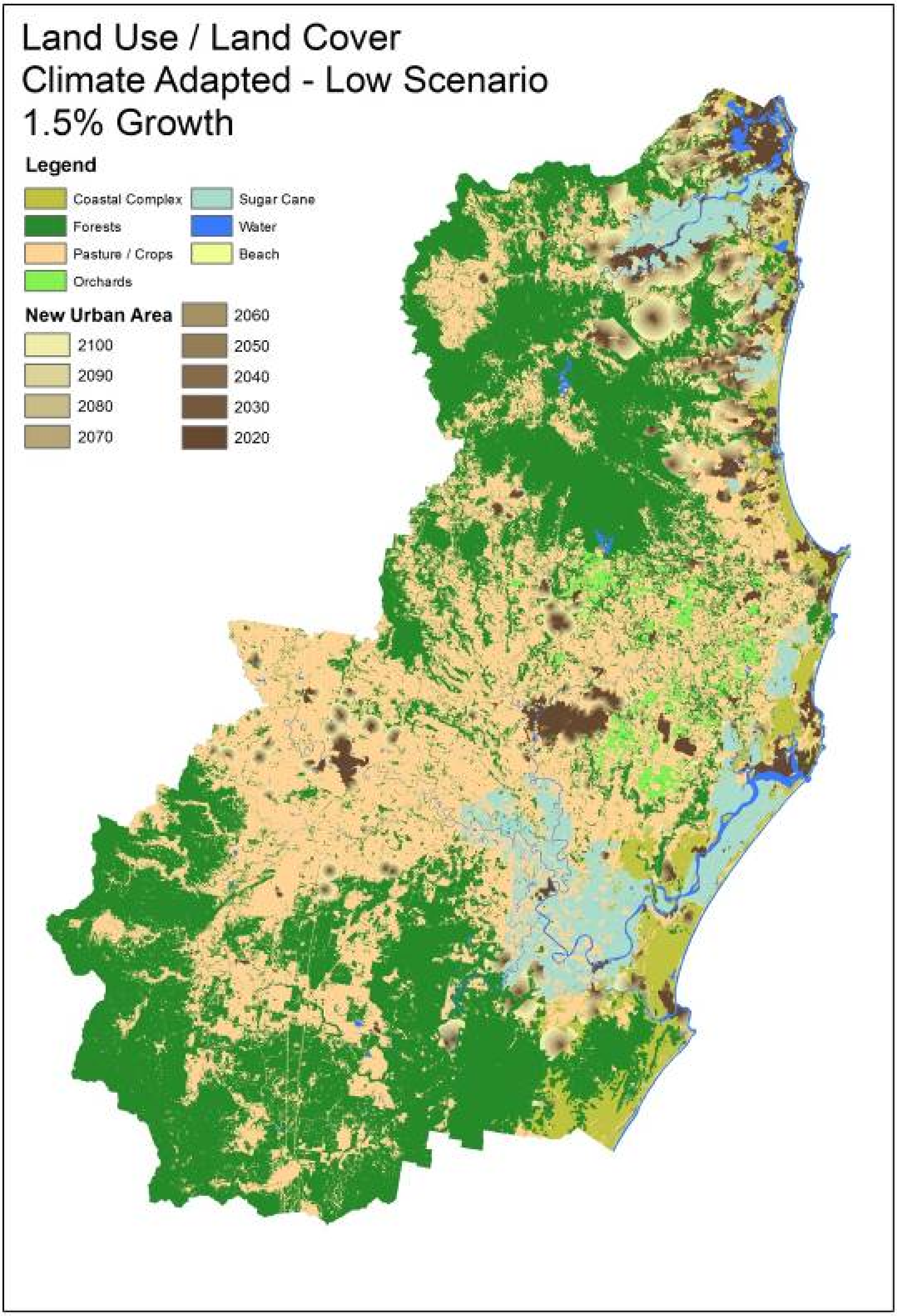


FIGURE 7.29: CLIMATE ADAPTED – LOW SCENARIO, WHOLE REGION, 1.5% GROWTH

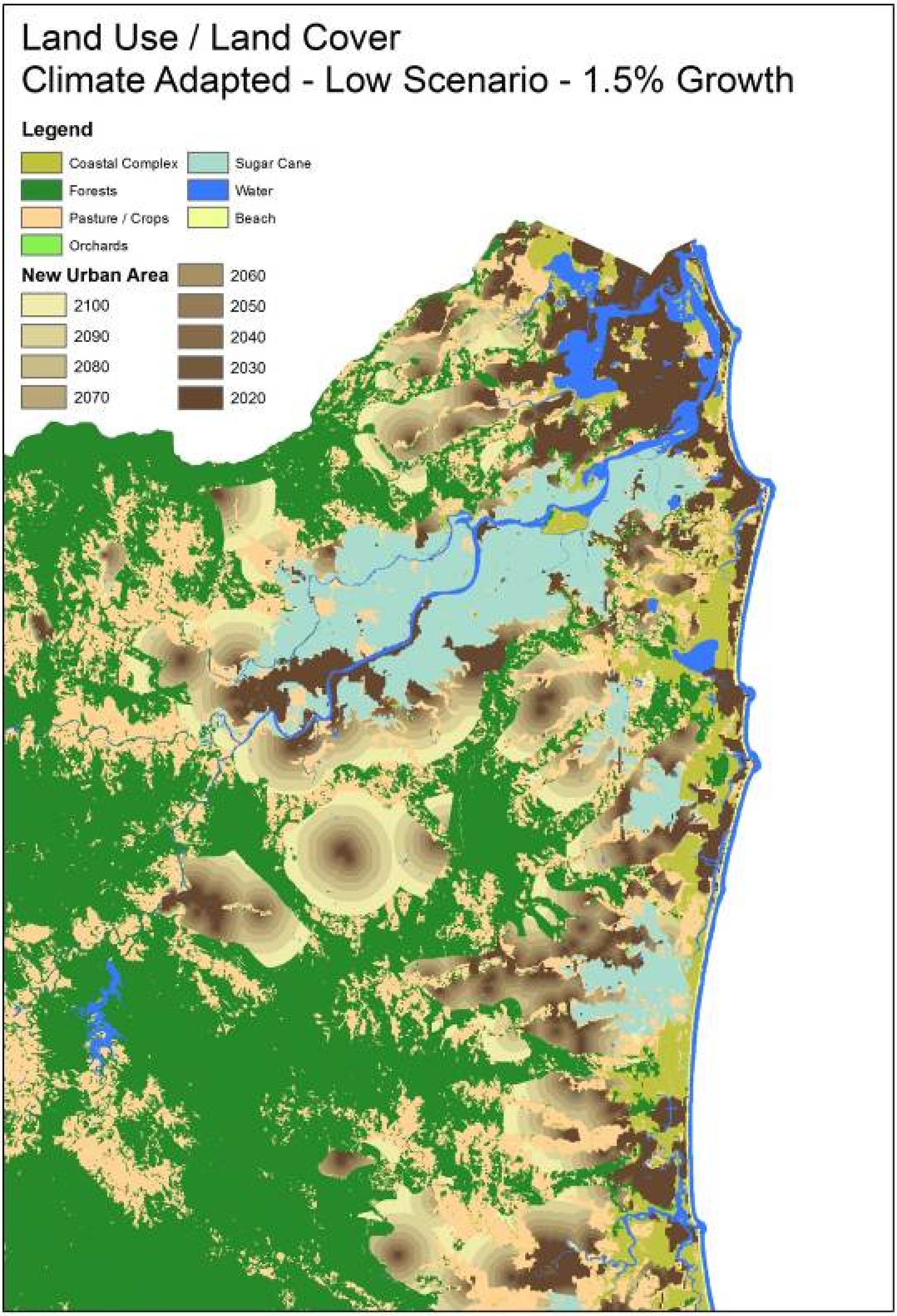


FIGURE 7.30: CLIMATE ADAPTED – LOW SCENARIO, NORTH EAST CORNER, 1.5% GROWTH

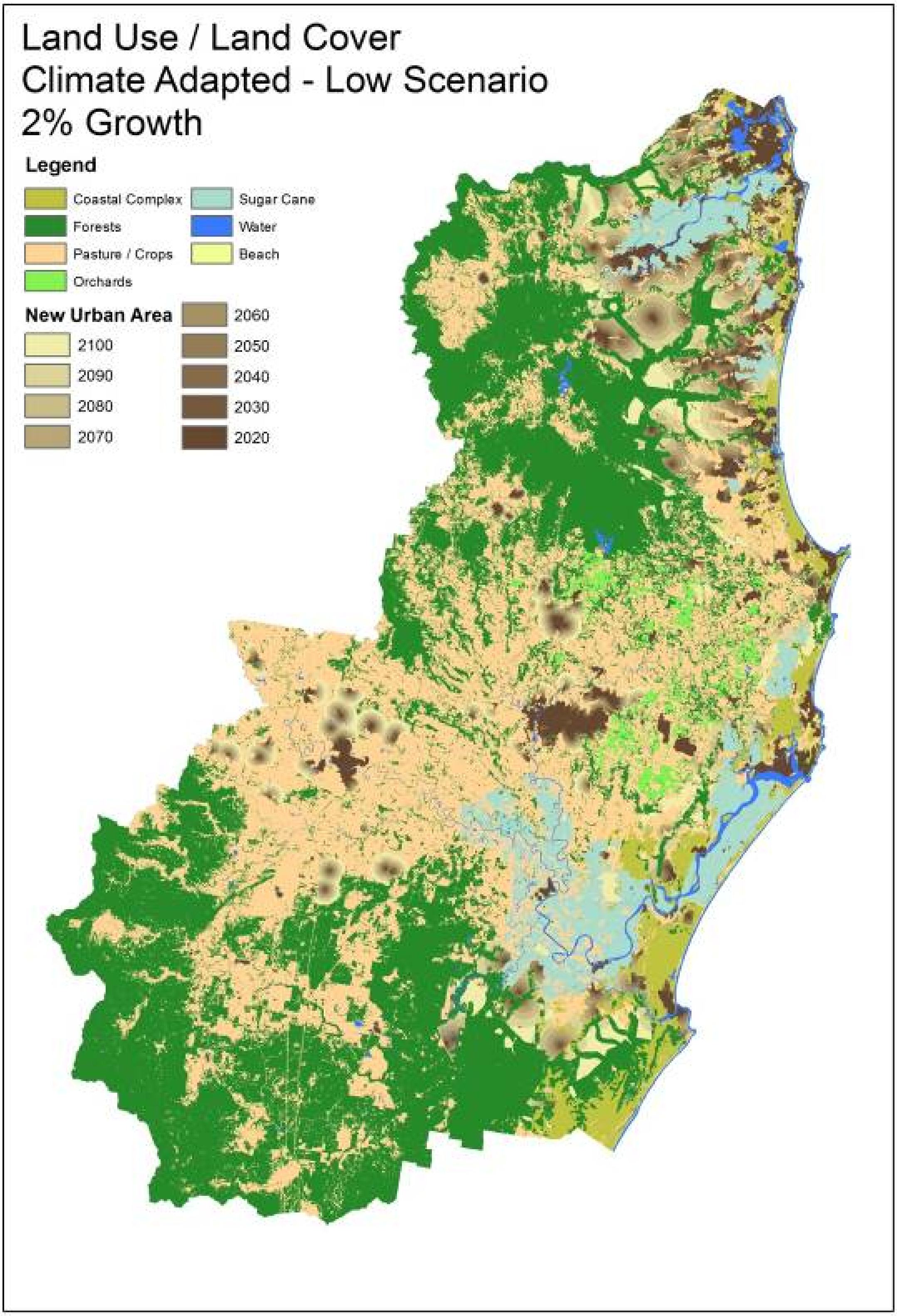


FIGURE 7.31: CLIMATE ADAPTED – LOW SCENARIO, WHOLE REGION, 2% GROWTH

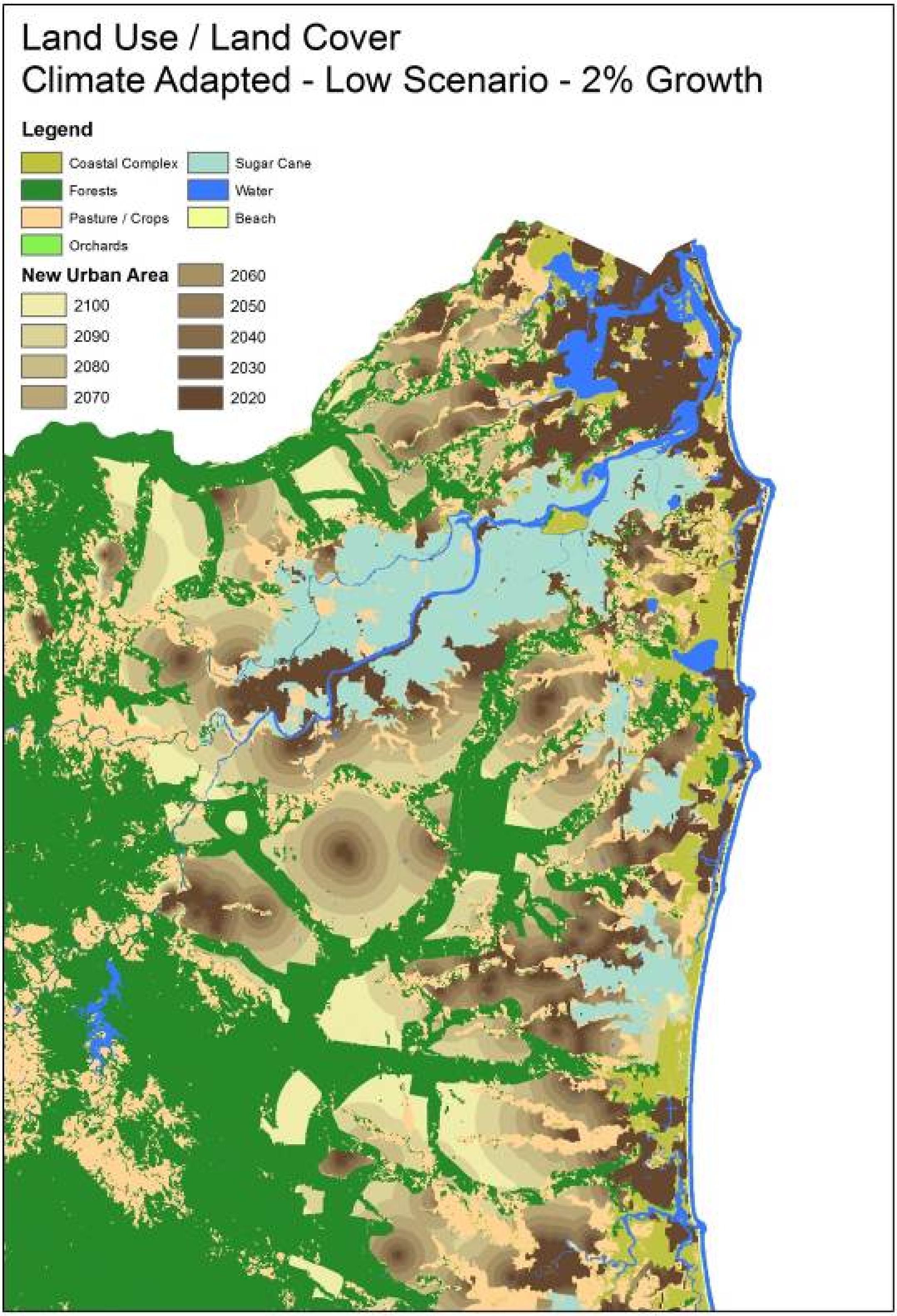


FIGURE 7.32: CLIMATE ADAPTED – LOW SCENARIO, NORTH EAST CORNER, 2% GROWTH

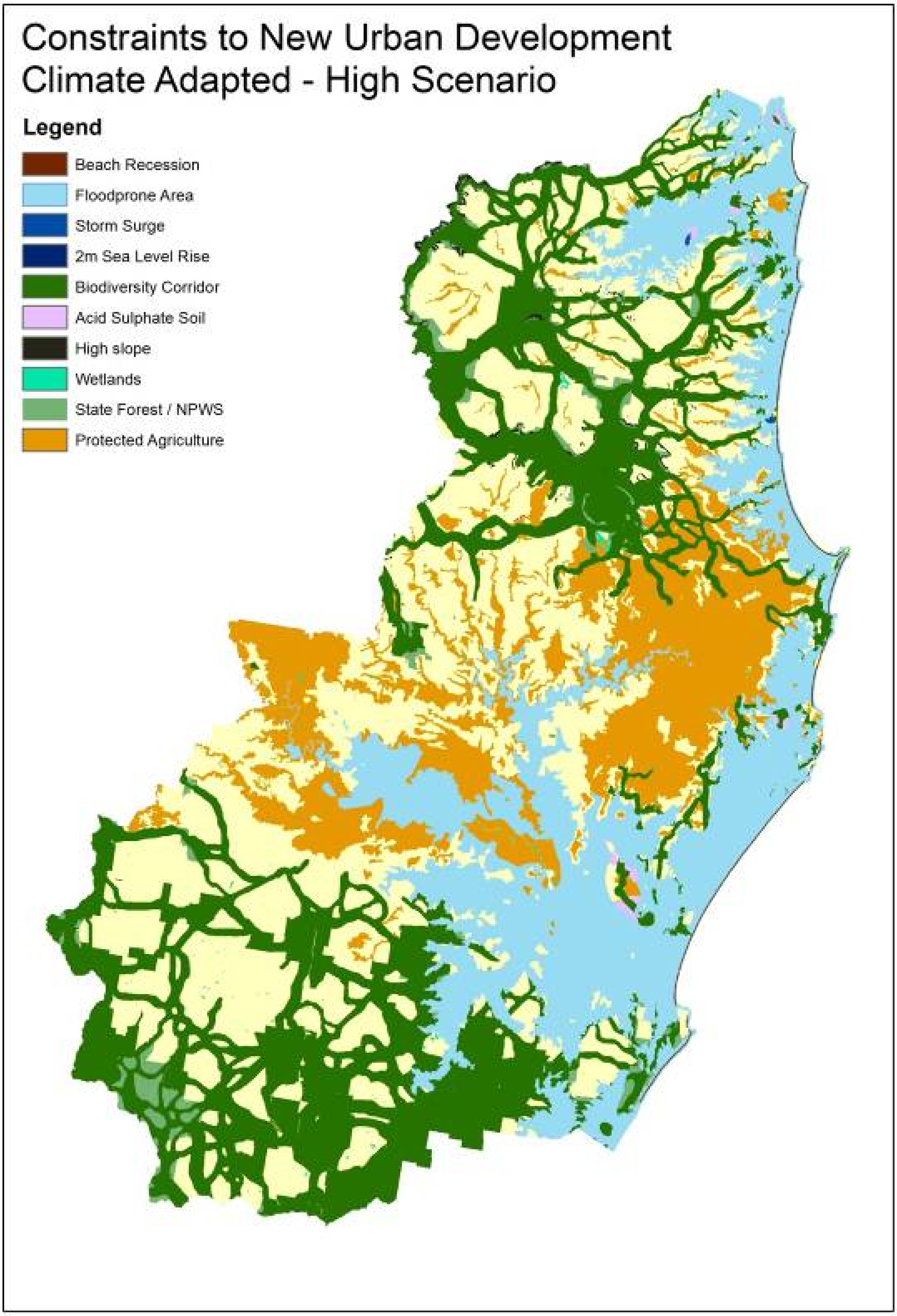


FIGURE 7.33: CONSTRAINTS TO DEVELOPMENT, CLIMATE ADAPTED – HIGH SCENARIO

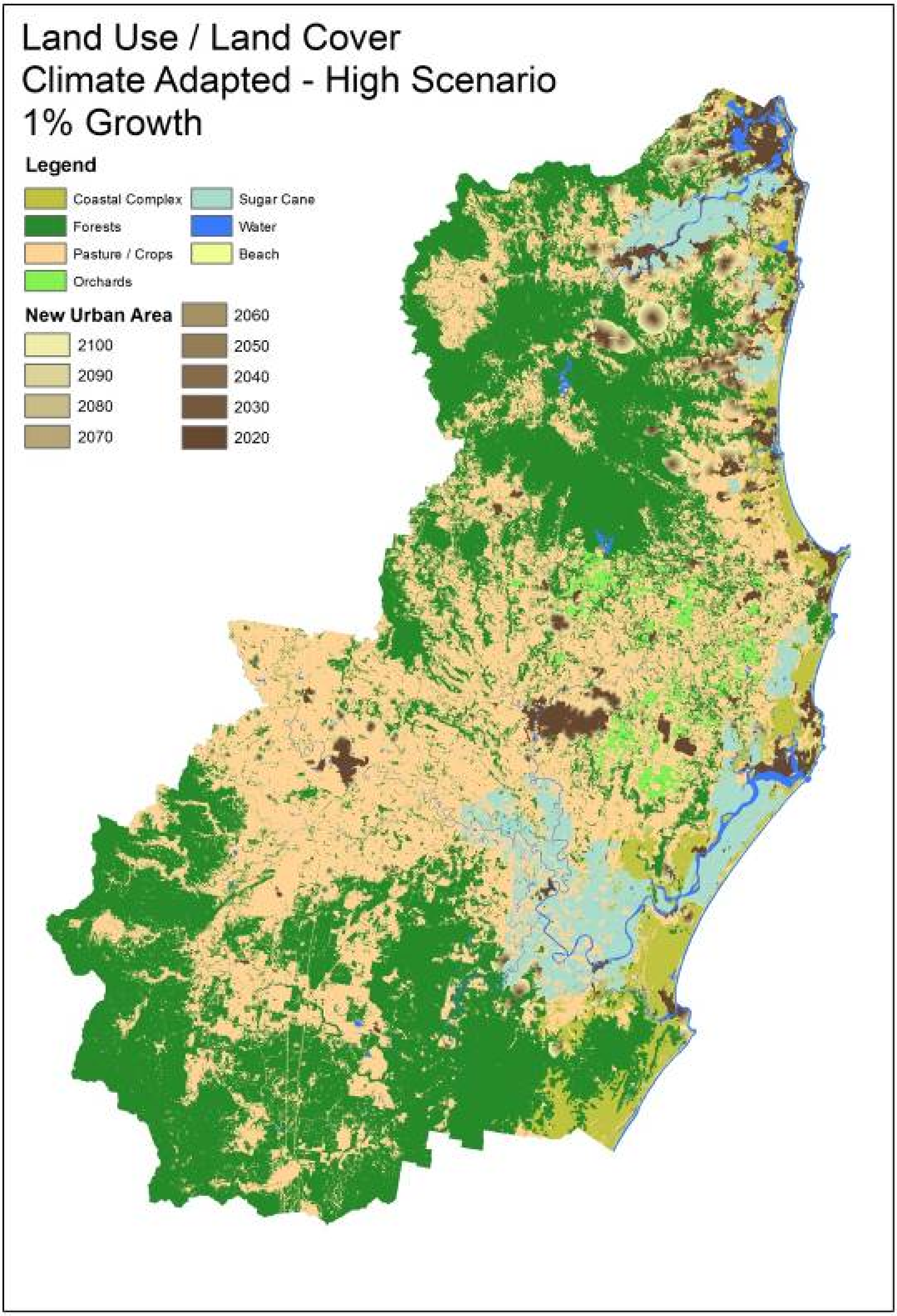


FIGURE 7.34: CLIMATE ADAPTED – HIGH SCENARIO, WHOLE REGION, 1% GROWTH

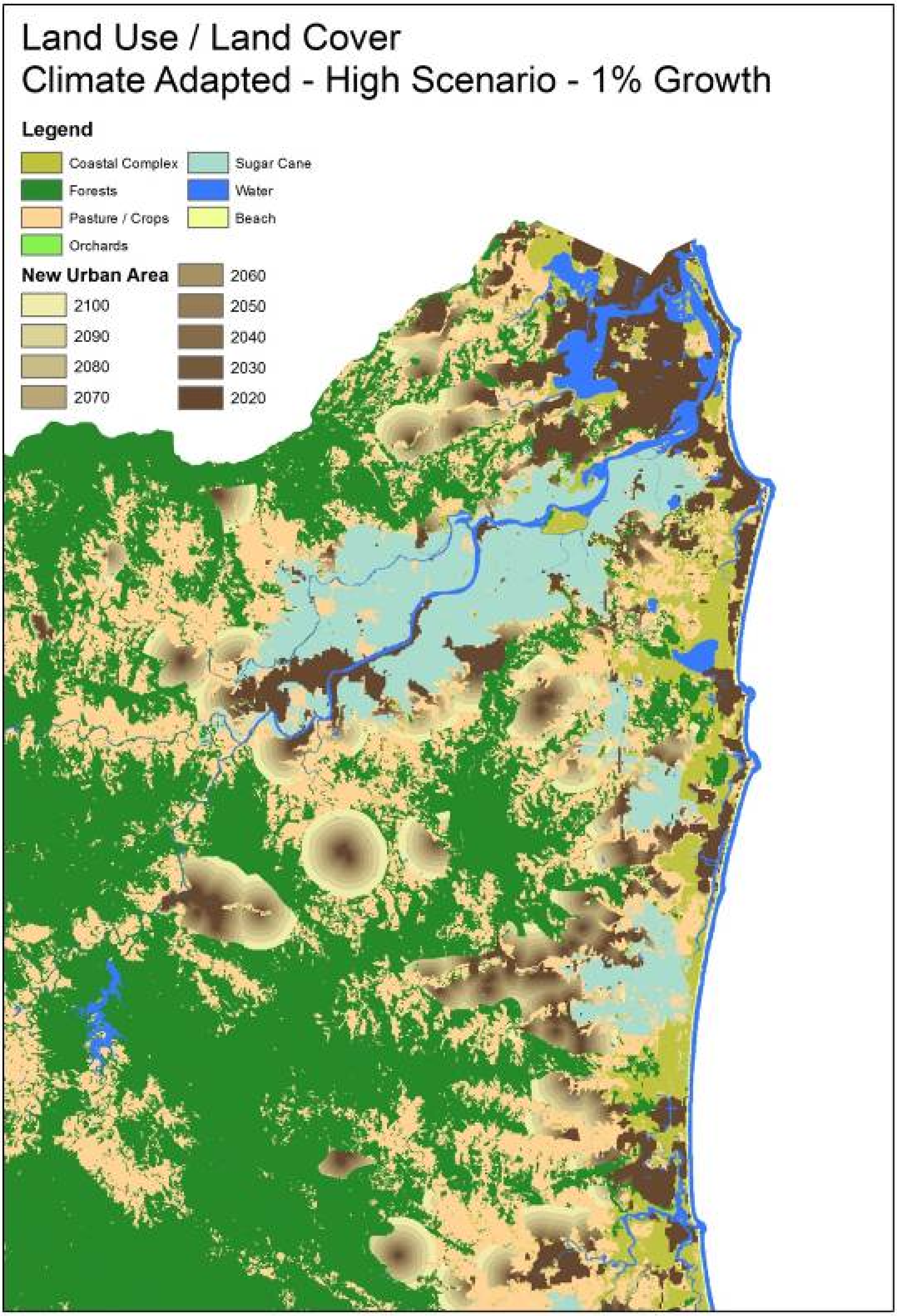


FIGURE 7.35: CLIMATE ADAPTED – HIGH SCENARIO, NORTH EAST CORNER, 1% GROWTH

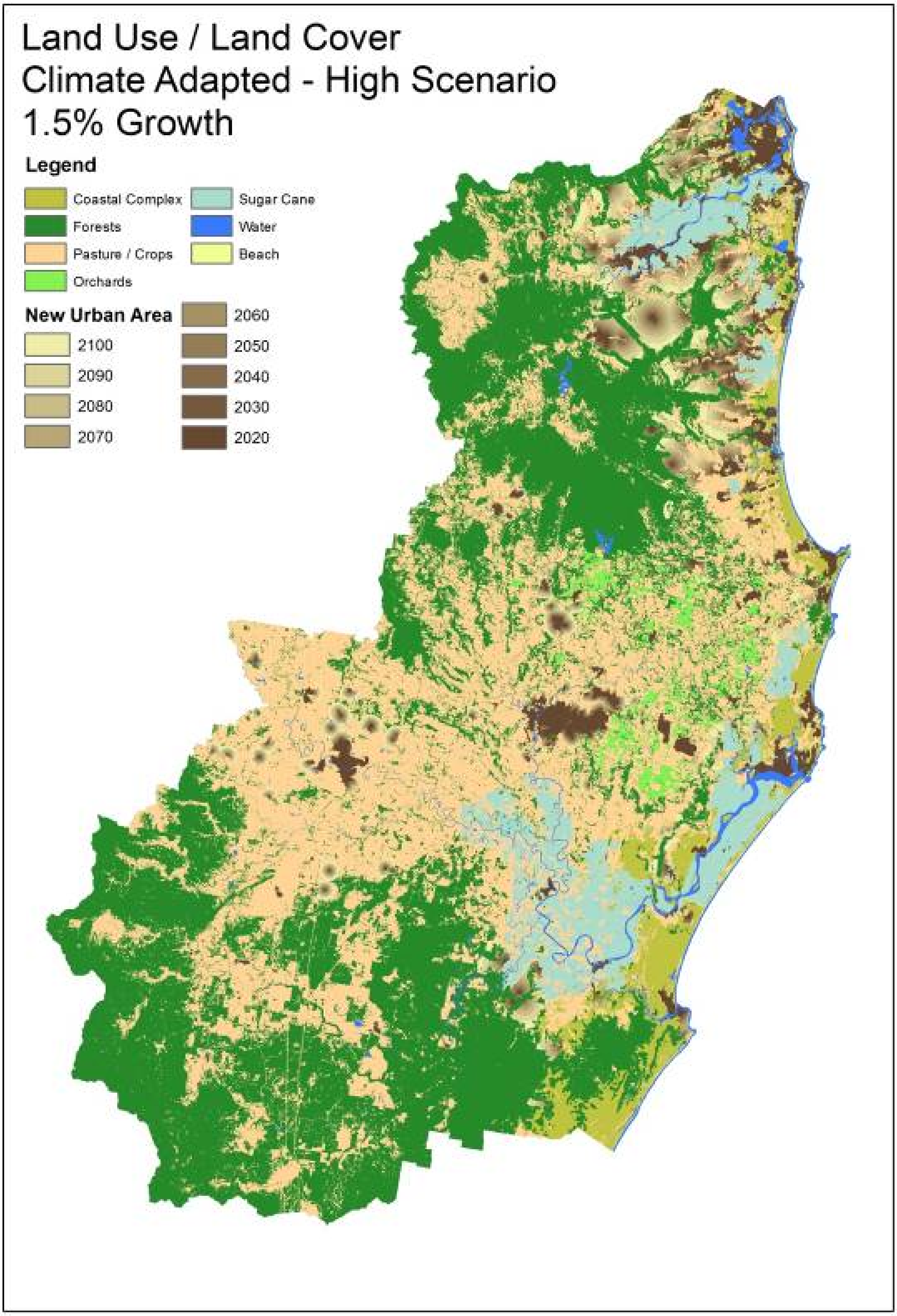


FIGURE 7.36: CLIMATE ADAPTED – HIGH SCENARIO, WHOLE REGION, 1.5% GROWTH

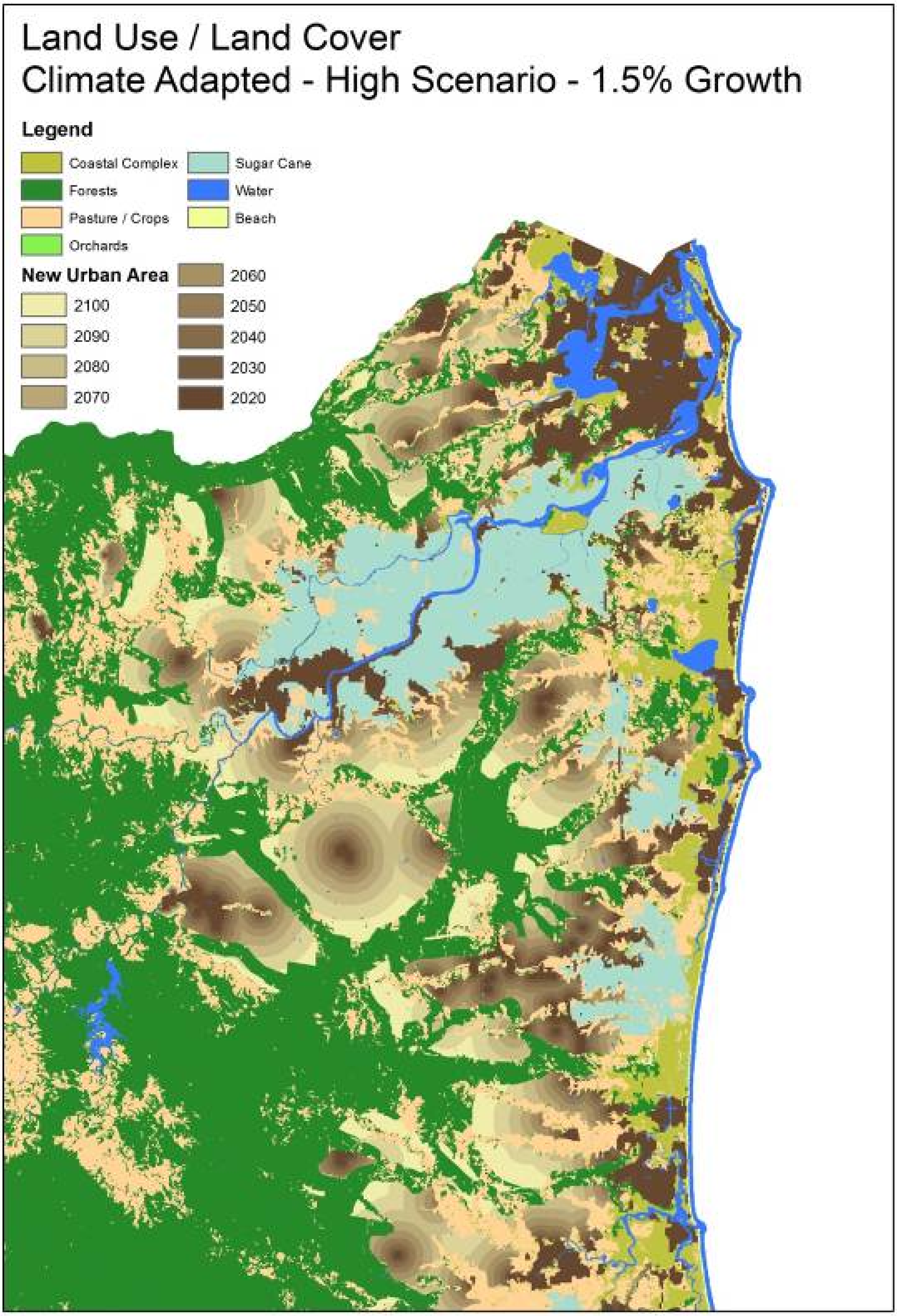


FIGURE 7.37: CLIMATE ADAPTED – HIGH SCENARIO, NORTH EAST CORNER, 1.5% GROWTH

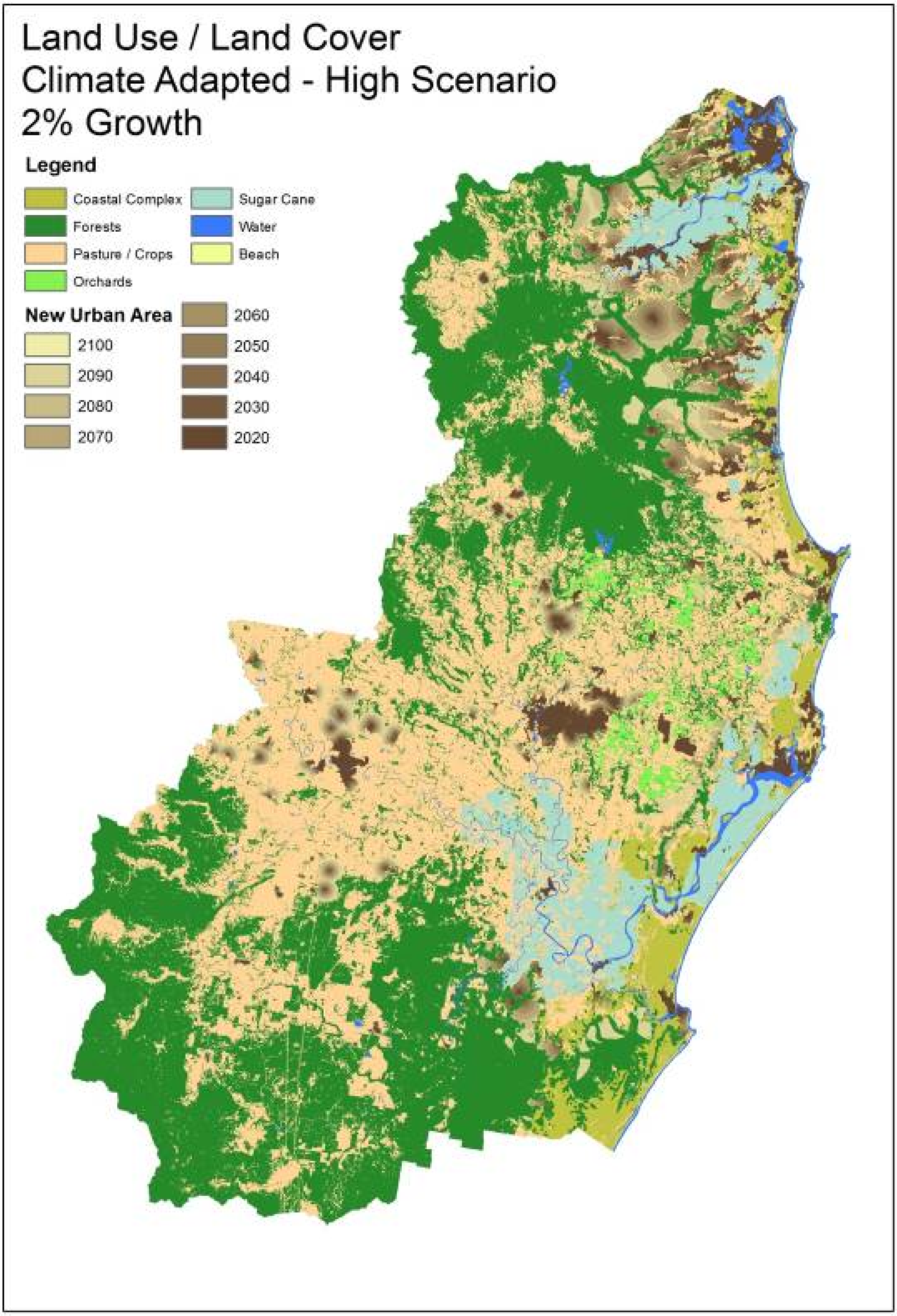


FIGURE 7.38: CLIMATE ADAPTED – HIGH SCENARIO, WHOLE REGION, 2% GROWTH

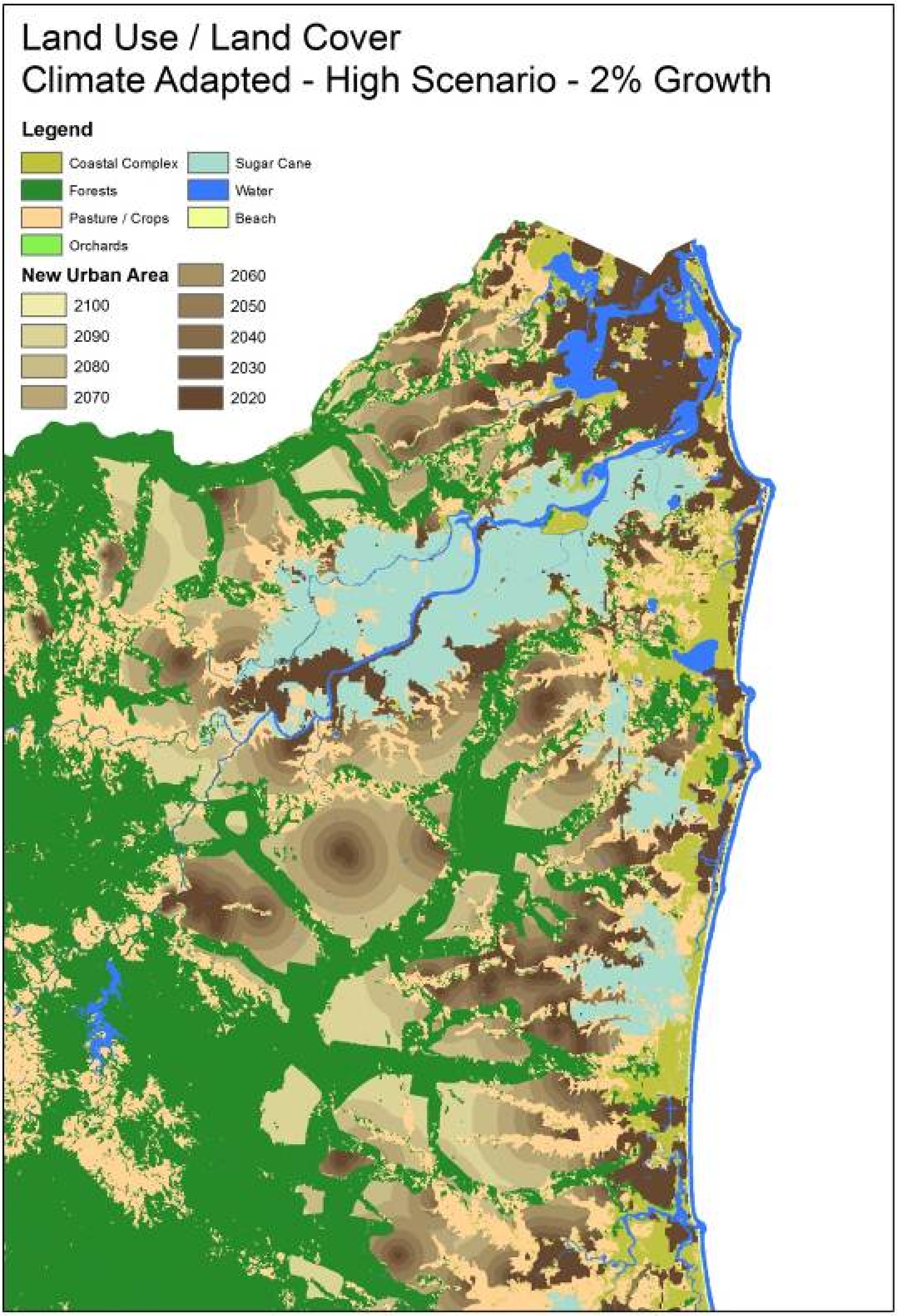


FIGURE 7.39: CLIMATE ADAPTED – HIGH SCENARIO, NORTH EAST CORNER, 2% GROWTH

7.5.6 *Food Security Scenarios*

The food security scenario simulates an increase in value from the horticultural and agricultural products of the region. The amount of land designated to the orchard land class has been increased at a growth rate of 1.5% giving a total that is approximately 150% of current expectations by 2100 (Figure 7.40). This scenario also has the premise that land being used for orchards and food production is more valuable and not available for use in urban development. As the regional plan scenario protects the most valuable agricultural land and prohibits development on acid sulphate soils (predominately used for sugar cane production), the constraints of the plan have been used with the additional orchards (Figure 7.41).

7.5.6.1 Results

Modelled at the growth rates of 1, 1.5 and 2 percent (Figures 7.42-7.47), this scenario again has strong growth in the north east corner and west of Evans Head. Similar to the climate adapted scenarios, the limits in available land under our numerous constraints are visible. This emerging growth pattern through these scenarios highlights the issues of competing land uses and the need for strong long term planning.

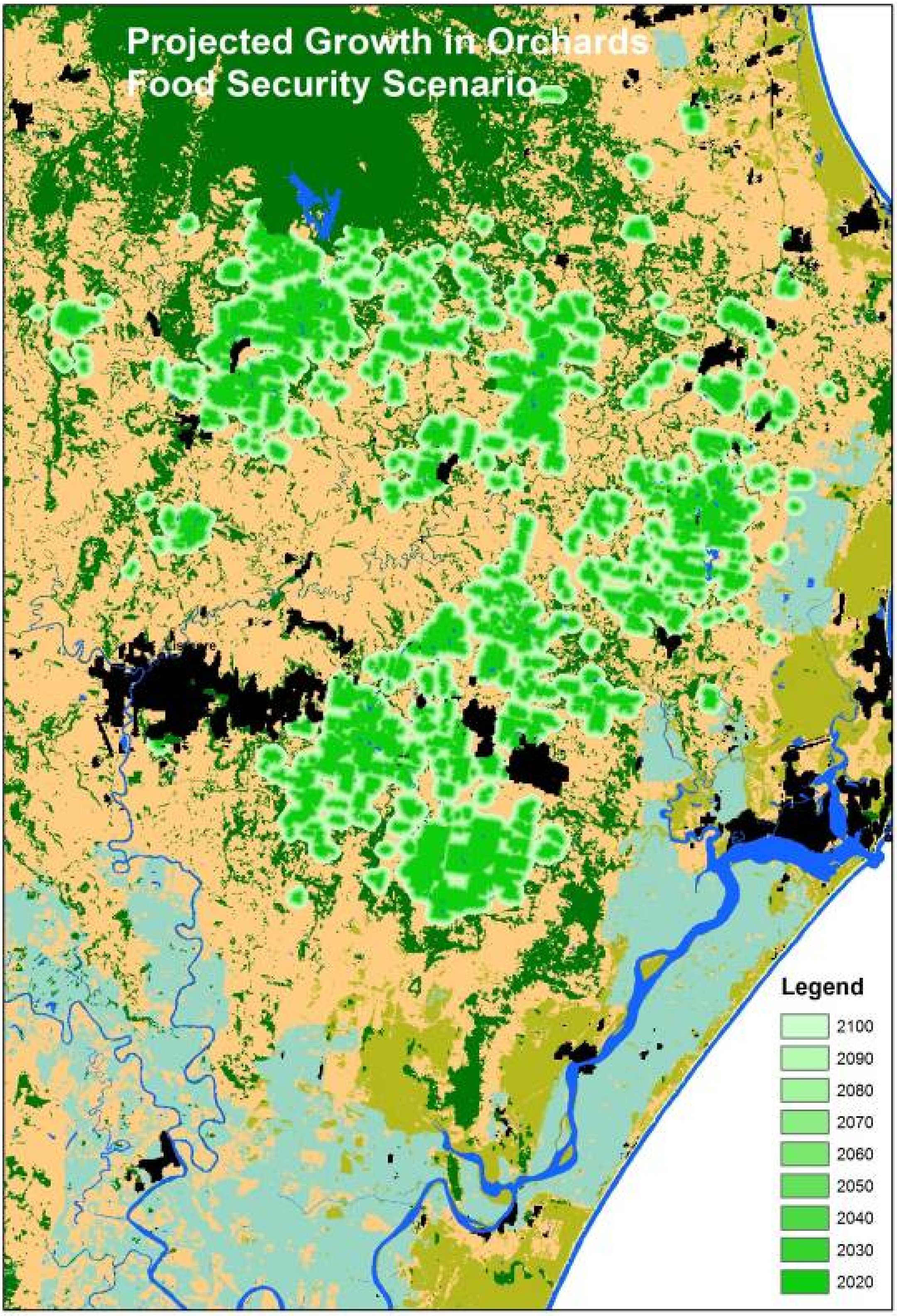


FIGURE 7.40: PROJECTED GROWTH IN ORCHARDS – FOOD SECURITY SCENARIO

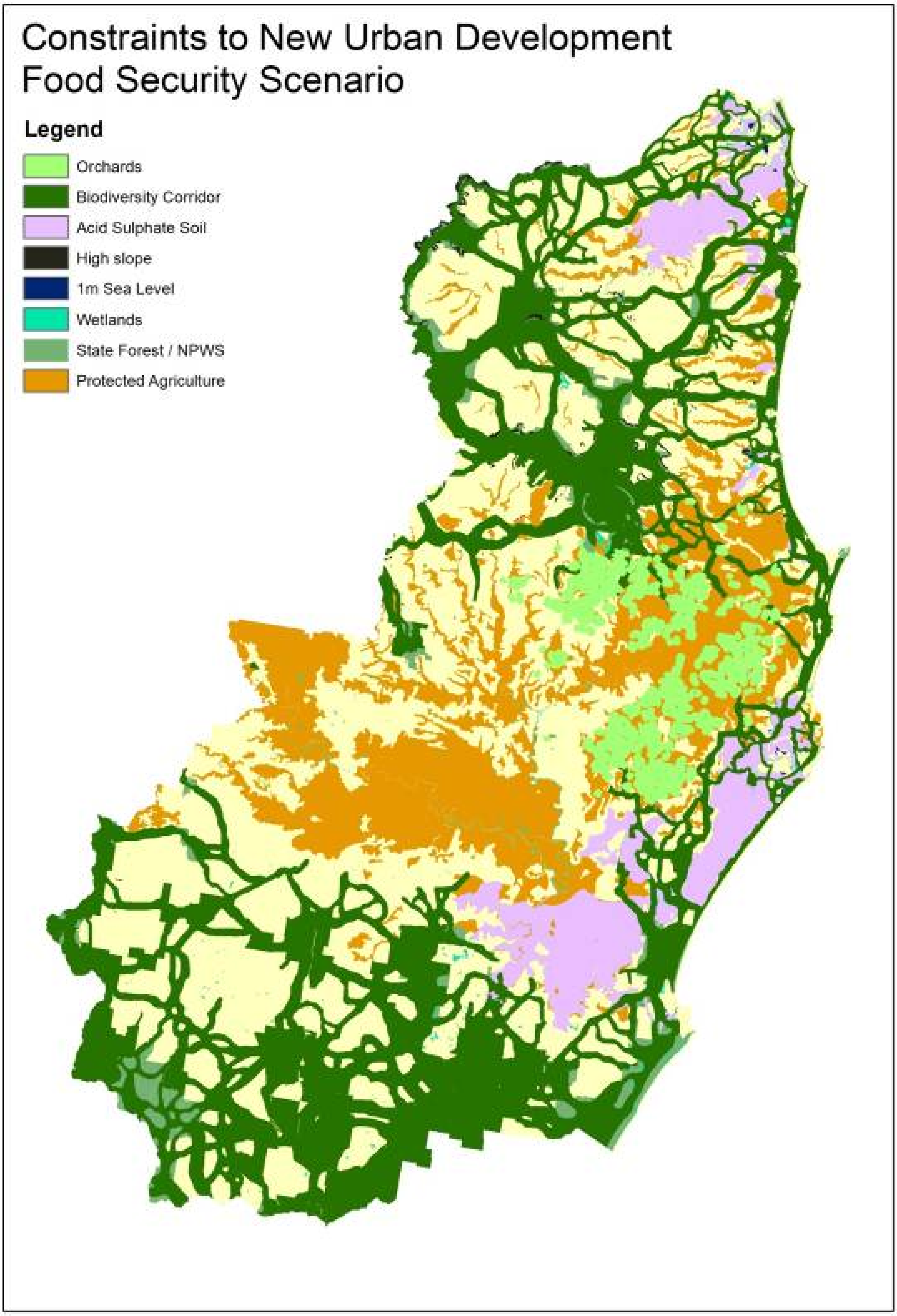


FIGURE 7.41: CONSTRAINTS TO DEVELOPMENT, FOOD SECURITY SCENARIO

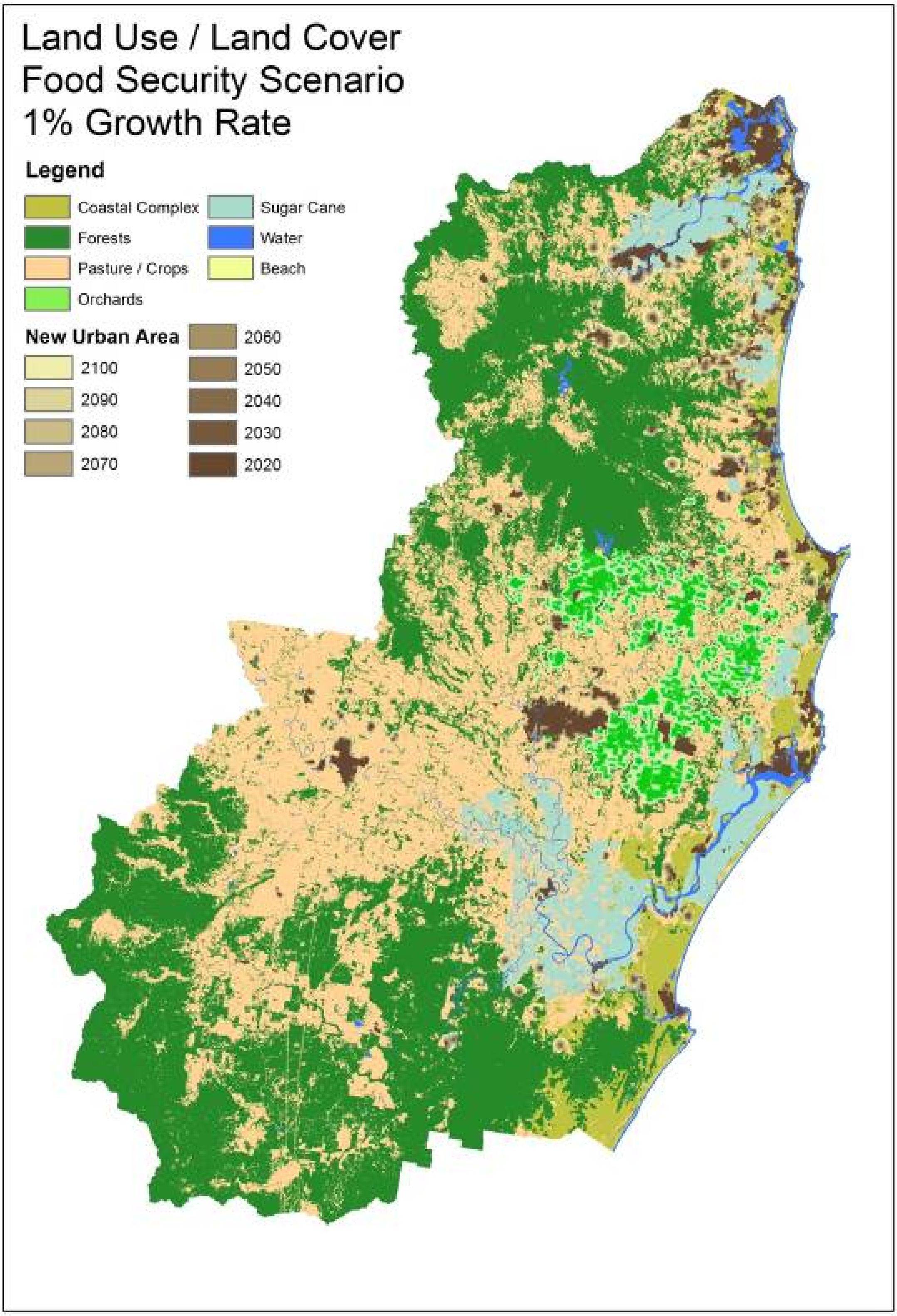


FIGURE 7.42: FOOD SECURITY SCENARIO, WHOLE REGION, 1% GROWTH

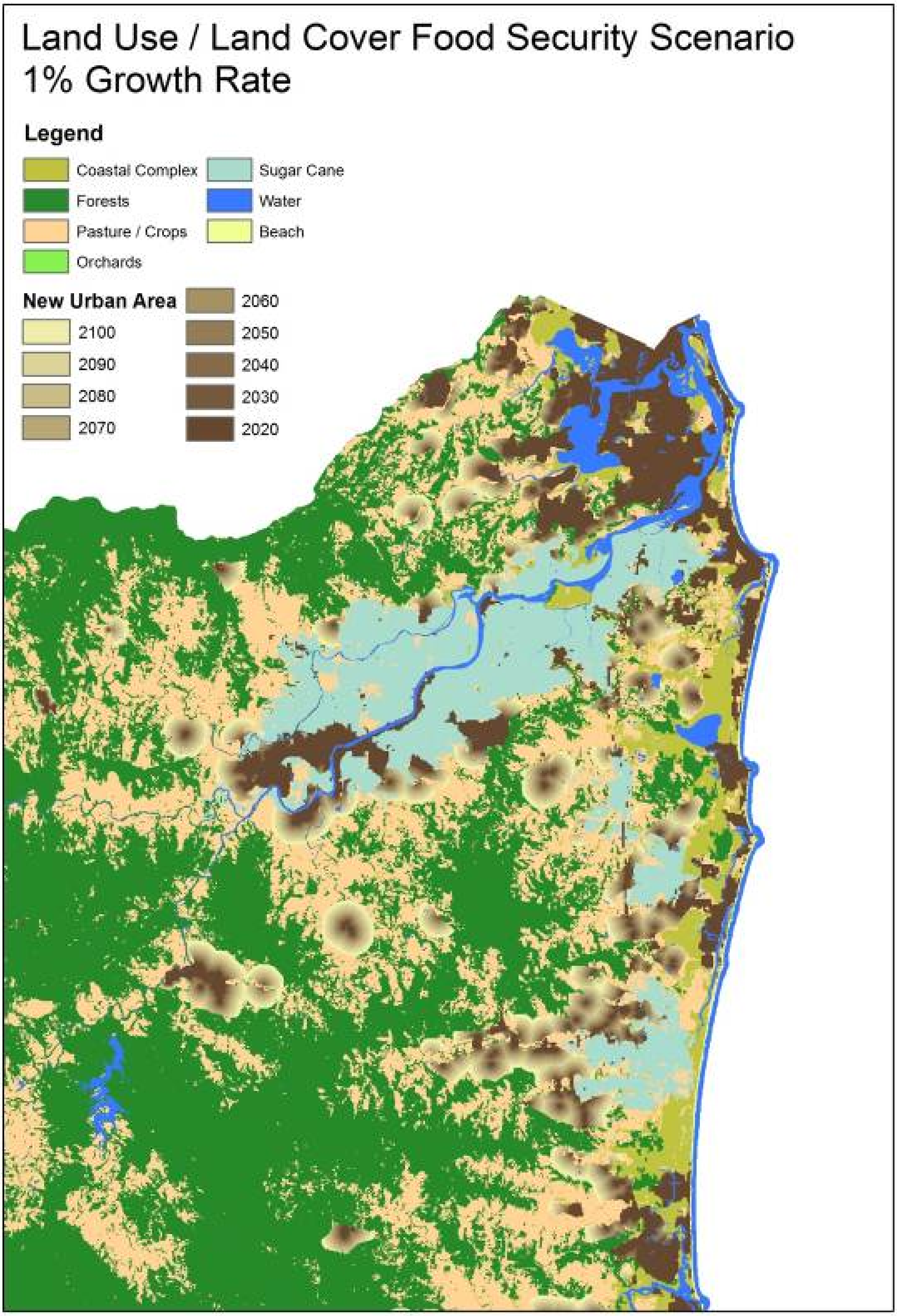


FIGURE 7.43: FOOD SECURITY SCENARIO, NORTH EAST CORNER, 1% GROWTH

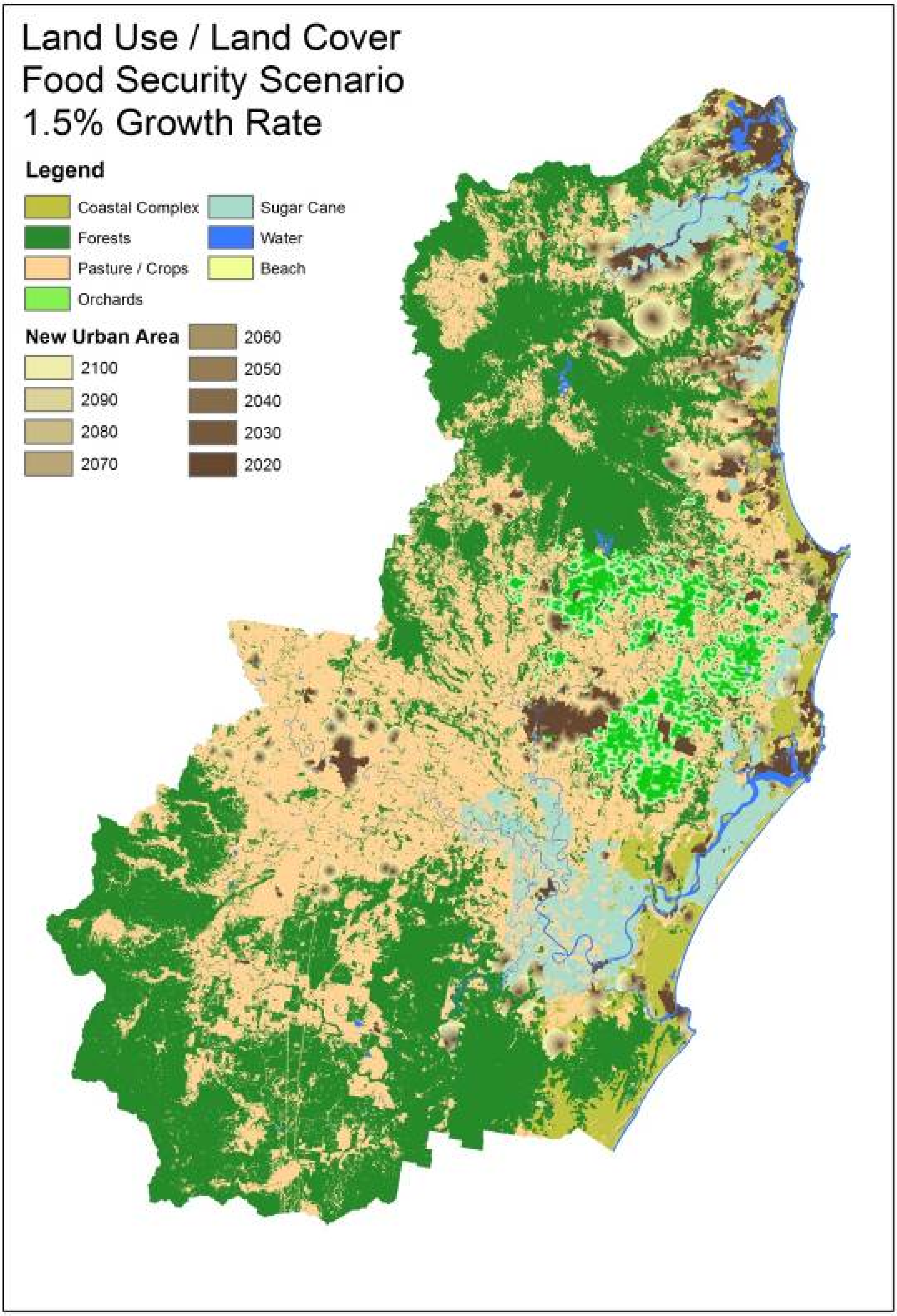


FIGURE 7.44: FOOD SECURITY SCENARIO, WHOLE REGION, 1.5% GROWTH

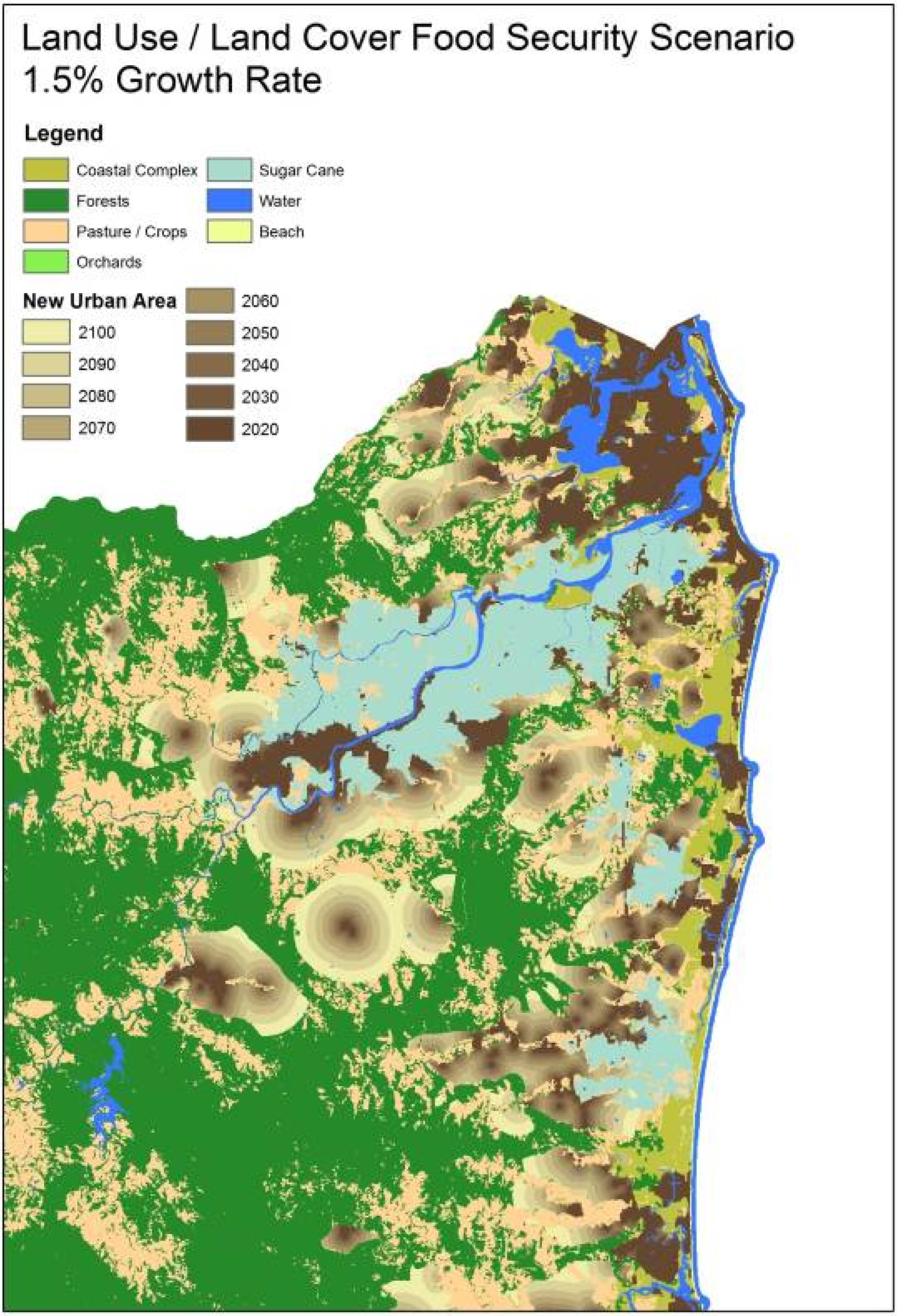


FIGURE 7.45: FOOD SECURITY SCENARIO, NORTH EAST CORNER, 1.5% GROWTH

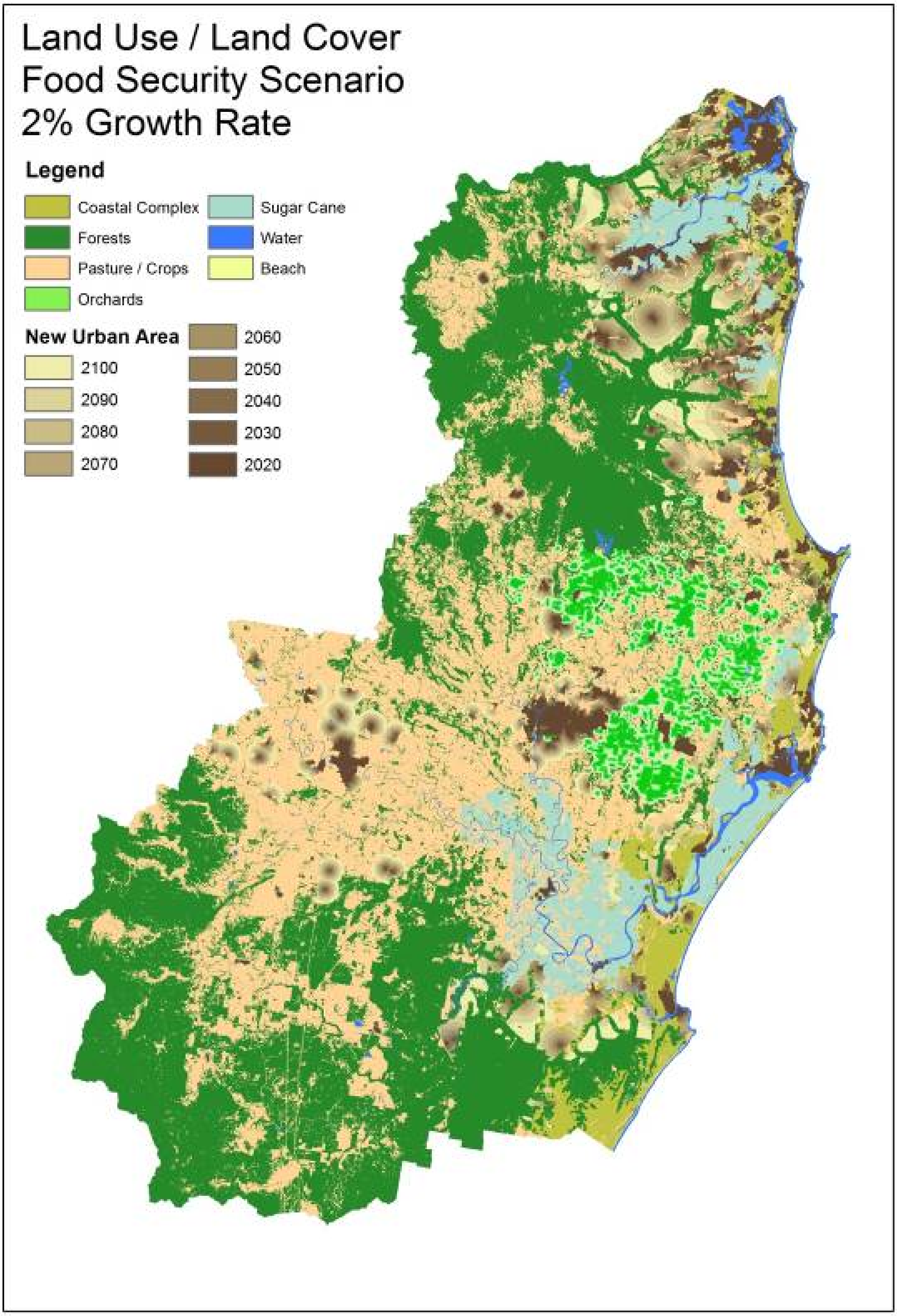


FIGURE 7.46: FOOD SECURITY SCENARIO, WHOLE REGION, 2% GROWTH

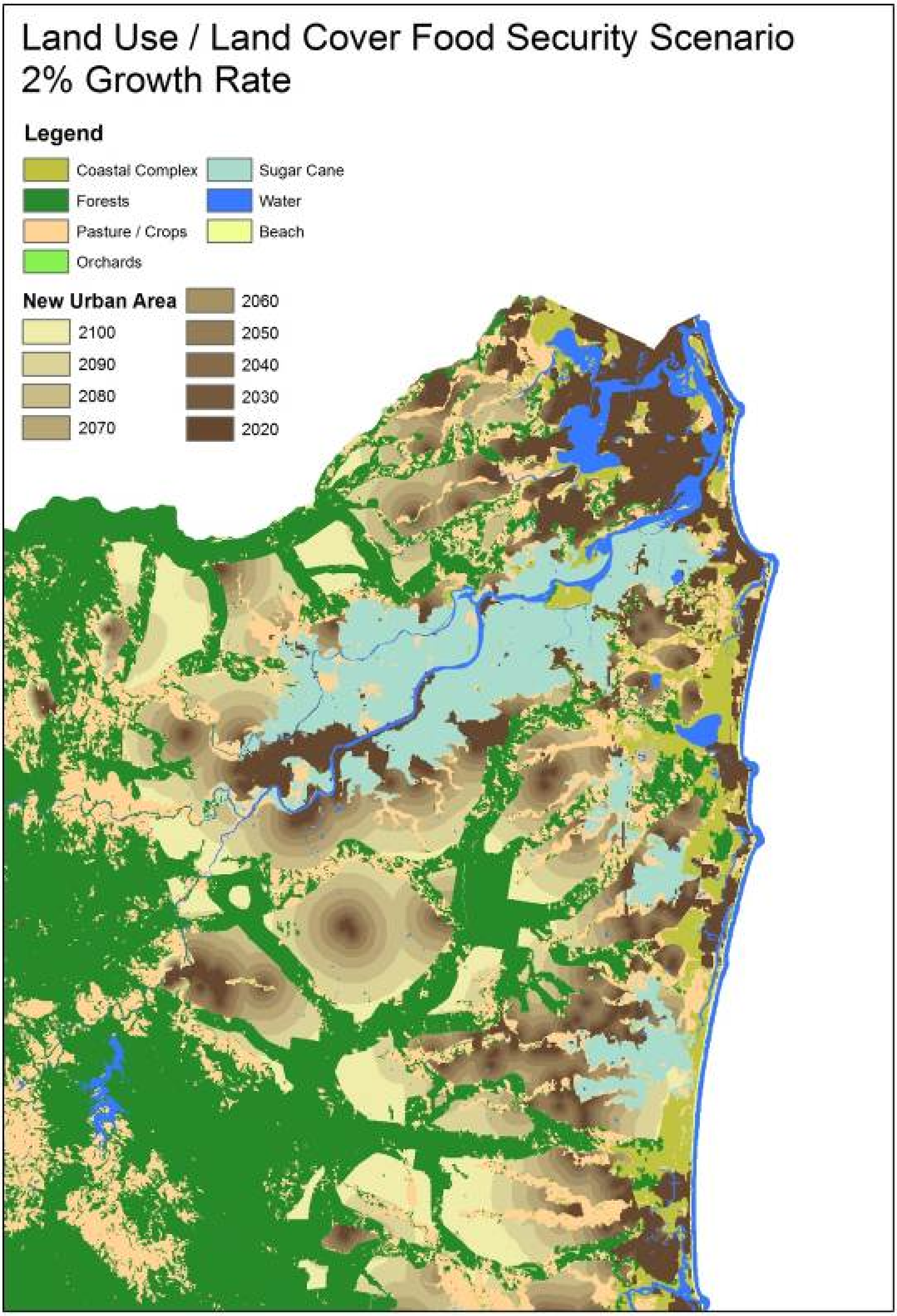


FIGURE 7.47: FOOD SECURITY SCENARIO, NORTH EAST CORNER, 2% GROWTH

8. IMPACTS OF ALTERNATIVE FUTURES ON LULC

8.1 *Methods*

This chapter assesses the impact of population growth and the likely impacts of alternative urban development patterns on the socioeconomic and biophysical resources of the region. In order to do this the changes in various types of LULC due to urban conversion were quantified to provide a measure of the impacts and a method of comparison between scenarios of the changes that this growth will have on the landscape. This was conducted by taking the urban growth model outputs (future urban footprints) and combining them with the current LULC dataset. We examined the loss of LULC at three time steps, 2030, 2070 and 2100, to remain consistent with other impact analyses.

8.2 *Results*

LULC impacts varied by alternative urban growth future both in terms of total hectares and percent of total for the study area. Land cover impacts show potentially substantial loss of forest cover and coastal complex (Table 8.1). Coastal complex (Figure 8.1) shows losses from 66 ha (2.1% of total, High Climate Adapted Future-low growth variant) to over 10,000 ha (32.2%, Deregulated Future-high growth variant). In general the Climate Adapted Futures had the least impact to coastal complex, while the Deregulated Futures had the most impact. On the other hand, the largest losses to forest land cover would come under the Food Security Future, the Climate Adapted Futures, and the Regional Plan Futures under the high growth variant (Figure 8.2). Impacts to forest land cover range from 4,100 ha (1.4% of total, Deregulated Future-low growth variant) up to just over 25,000 ha (10.1% of total, Low Climate Adapted Future-high growth variant).

Impacts to land use were equally as varied, with pasture land showing the largest losses due to urban growth (Table 8.1). Impacts to pasture land (Figure 8.3) ranged from 15,700 ha (5.8% of total, Deregulated Future-low growth) to 48,000 ha (17.7% of total, Regional Plan Future-high growth). Orchard impacts were significantly smaller (56 ha to 1,100 ha) and reflected well the protections in the Food Security Future (Figure 8.4). Impacts to sugar cane production areas followed the general pattern seen in the other impact models with the Deregulated Futures showing the largest impact (up to 13,000 ha, 33% of total) and High Climate Change Adapted Future showing the least (92 ha) (Figure 8.5).

TABLE 8.1: POTENTIAL LOSS OF LULC TYPES UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW (HECTARES).

Scenario		Coastal Complex	Forest	Pasture	Orchards	Sugar Cane
Deregulated Low Growth	2030	571	522	2193	38	448
	2070	2,060	2,018	7,812	169	1,797
	2100	4,101	4,124	15,749	366	3,819
Deregulated Medium Growth	2030	872	808	3358	60	695
	2070	3,433	3,482	13,115	314	3,243
	2100	7,081	7,628	27,905	801	7,605
Deregulated High Growth	2030	1188	1130	4530	86	969
	2070	5,056	5,325	19,546	531	5,213
	2100	10,328	13,197	44,339	1,647	13,108
Energy Development	2030	669	1032	4071	22	211
	2070	2,053	5,391	15,159	142	724
	2100	3,784	12,553	30,786	250	1,569
Food Security Low Growth	2030	489	610	2520	-	153
	2070	1,512	2,760	9,093		492
	2100	2,712	6,527	17,981		941
Food Security Medium Growth	2030	718	983	3869	-	223
	2070	2,188	5,639	14,990		770
	2100	4,081	13,734	31,421		1,784
Food Security High Growth	2030	940	1388	5275	-	301
	2070	2,911	9,414	22,152		1,195
	2100	5,222	26,695	48,064		2,639
Compact Growth	2030	496	753	2995	14	161
	2070	1,569	3,443	11,290	80	539
	2100	2,865	8,176	22,948	196	1,044
Low Climate Adapted Low Growth	2030	341	734	2539	10	147
	2070	1,079	3,262	9,031	55	429
	2100	1,972	7,511	17,809	116	752
Low Climate Adapted Medium Growth	2030	509	1168	3881	20	215
	2070	1,589	6,470	14,798	116	612
	2100	2,905	15,418	31,201	245	1,249
Low Climate Adapted High Growth	2030	668	1653	5266	30	286
	2070	2,127	10,646	21,861	194	843
	2100	3,760	29,417	47,037	374	2,030
High Climate Adapted Low Growth	2030	127	995	2580	13	57
	2070	397	4,505	8,765	58	131
	2100	662	9,445	17,706	123	223

TABLE 8.1 (CONT'D): POTENTIAL LOSS OF LULC TYPES UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW (HECTARES).

Scenario		Coastal Complex	Forest	Pasture	Orchards	Sugar Cane
High Climate Adapted Medium Growth	2030	199	1598	3901	20	75
	2070	532	8,086	14,681	120	168
	2100	850	18,635	30,995	270	270
High Climate Adapted High Growth	2030	271	2269	5247	30	87
	2070	612	12,947	21,725	202	187
	2100	1,066	26,565	38,622	364	558
Regional Plan Low Growth	2030	487	609	2516	9	150
	2070	1,510	2,772	9,039	46	490
	2100	2,712	6,546	17,868	102	933
Regional Plan Medium Growth	2030	717	980	3861	15	220
	2070	2,188	5,661	14,878	93	767
	2100	4,056	13,795	31,169	222	1,778
Regional Plan High Growth	2030	936	1392	5255	23	299

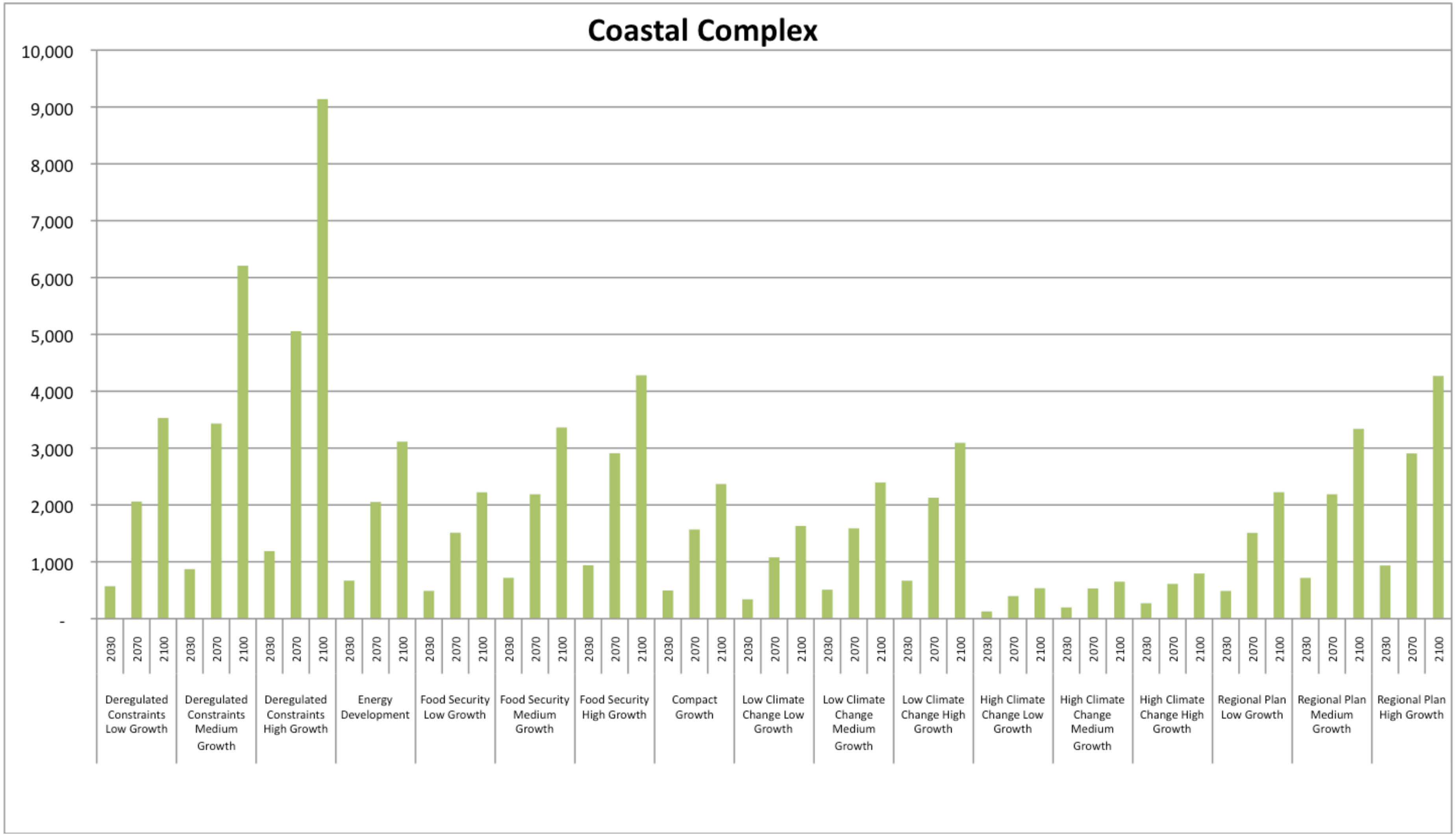


FIGURE 8.1: POTENTIAL LOSS OF COASTAL COMPLEX LAND COVER UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW. IMPACTS ARE NOT PRESENTED CUMULATIVELY, SO FINAL IMPACTS IN 2100 WOULD BE THE SUM OF THE PREVIOUS TWO TIME STEPS (HECTARES).

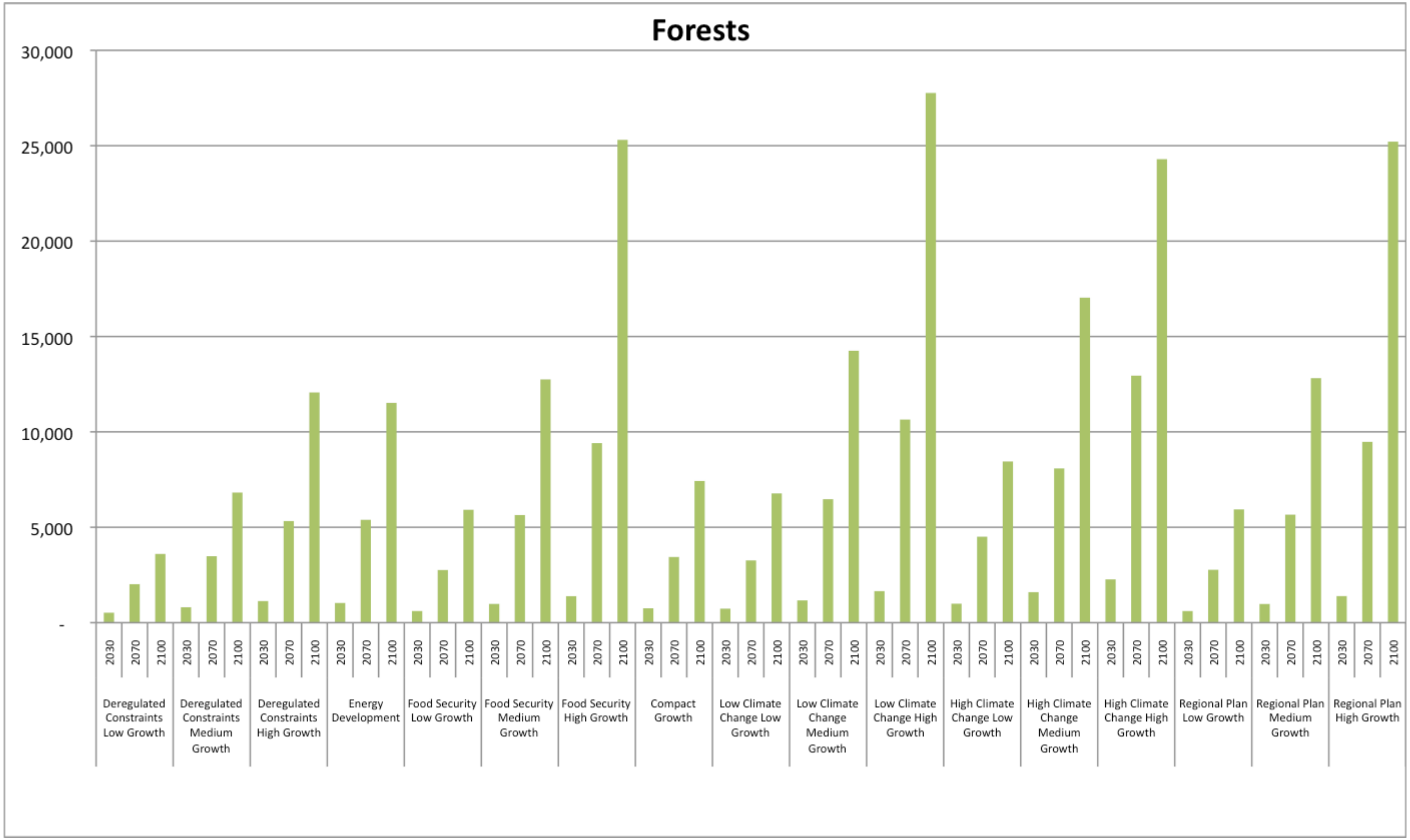


FIGURE 8.2: POTENTIAL LOSS OF FOREST LAND COVER UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW. IMPACTS ARE NOT PRESENTED CUMULATIVELY, SO FINAL IMPACTS IN 2100 WOULD BE THE SUM OF THE PREVIOUS TWO TIME STEPS (HECTARES).

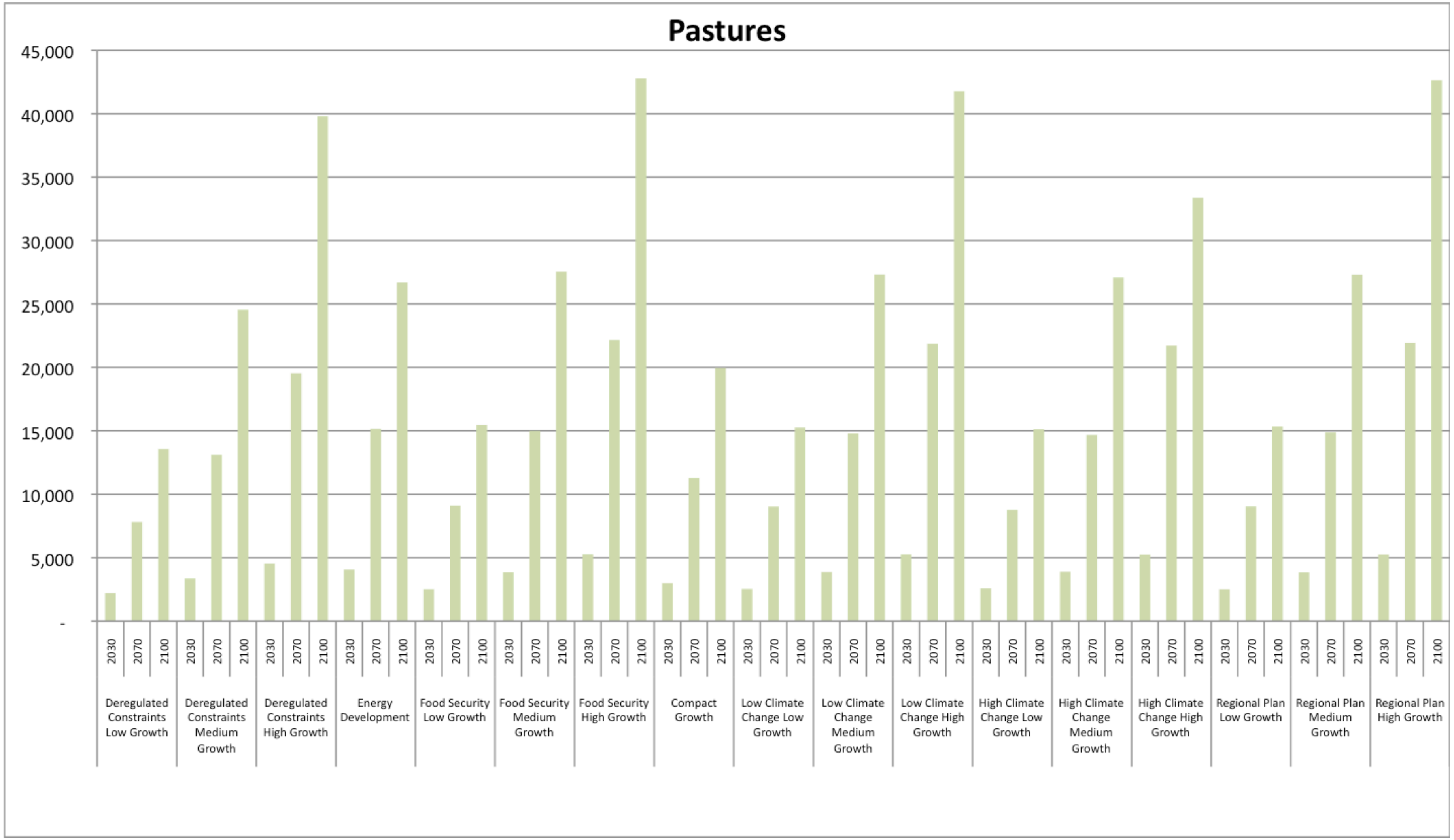


FIGURE 8.3: POTENTIAL LOSS OF PASTURE LAND USE UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW. IMPACTS ARE NOT PRESENTED CUMULATIVELY, SO FINAL IMPACTS IN 2100 WOULD BE THE SUM OF THE PREVIOUS TWO TIME STEPS (HECTARES).

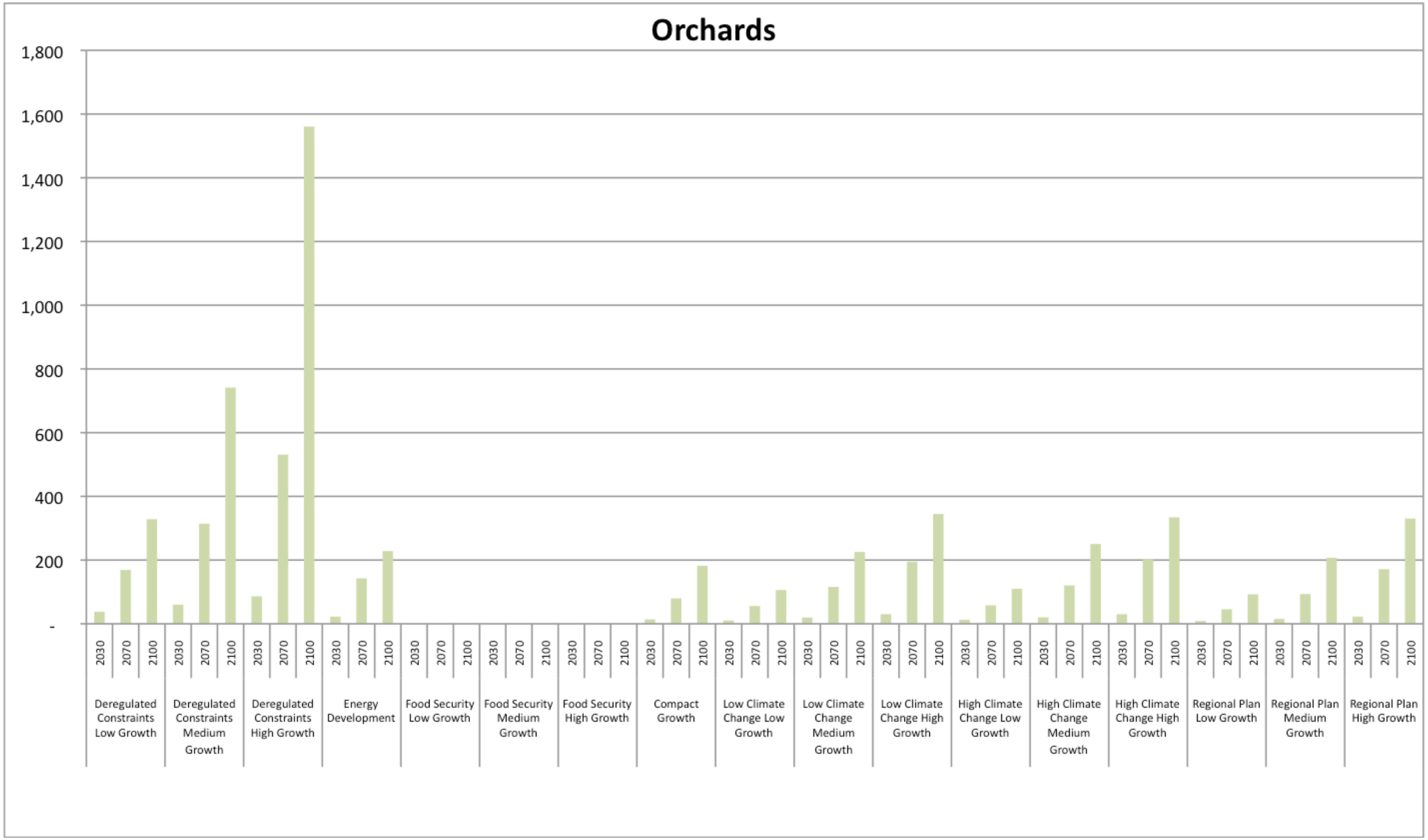


FIGURE 8.4: POTENTIAL LOSS OF ORCHARDS UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW. IMPACTS ARE NOT PRESENTED CUMULATIVELY, SO FINAL IMPACTS IN 2100 WOULD BE THE SUM OF THE PREVIOUS TWO TIME STEPS (HECTARES).

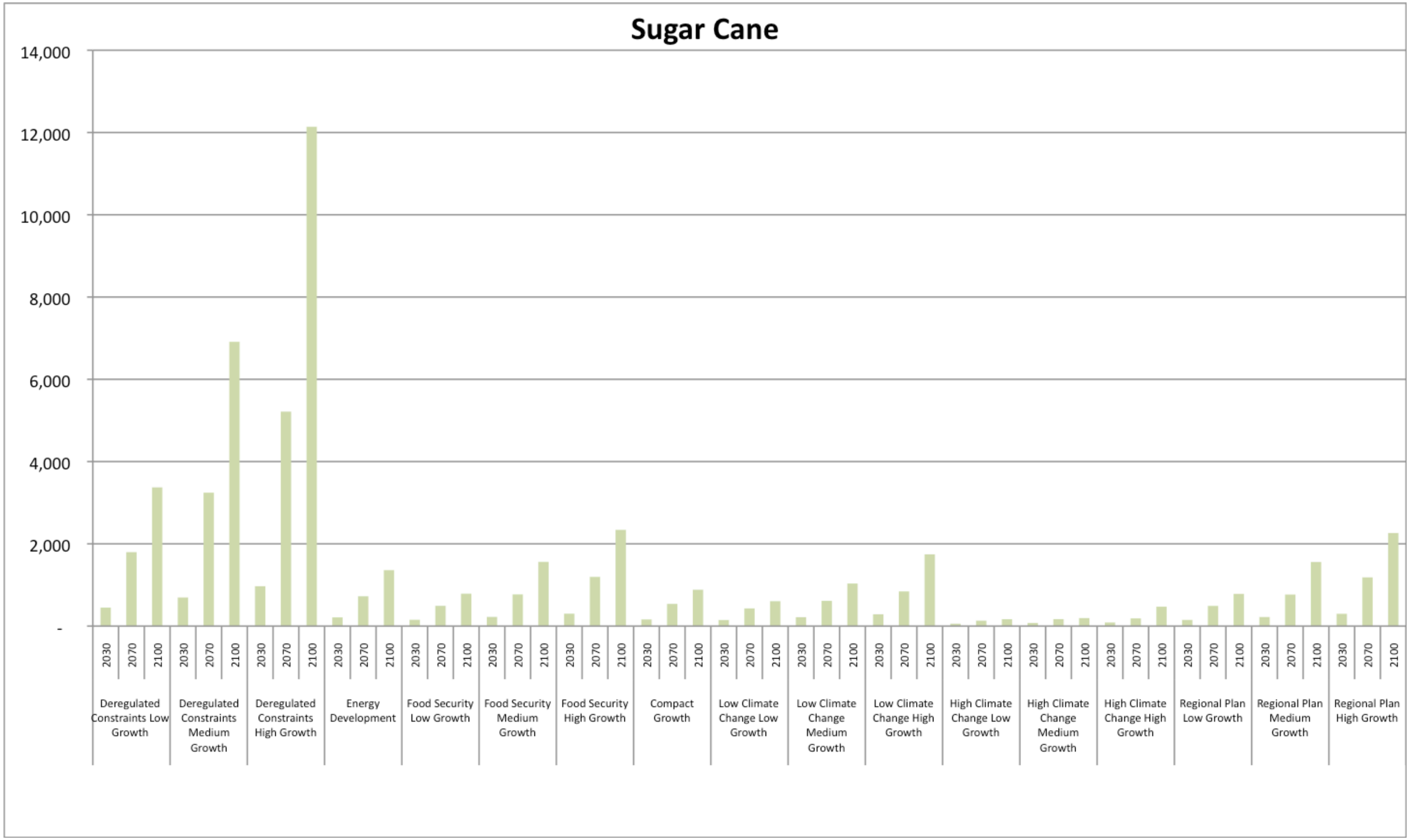


FIGURE 8.5: POTENTIAL LOSS OF SUGAR CANE LAND USE UNDER ALTERNATIVE URBAN GROWTH SCENARIOS FOR THE NORTH COAST, NSW. IMPACTS ARE NOT PRESENTED CUMULATIVELY, SO FINAL IMPACTS IN 2100 WOULD BE THE SUM OF THE PREVIOUS TWO TIME STEPS (HECTARES).

8.3 *Discussion*

The modelled impacts to LULC highlight the trade-offs between alternative patterns of urban development. As with many of the environmentally-focused impact models, the Deregulated Futures showed the largest impacts to coastal complex, suggesting that the Deregulated Futures scenarios represents the most harmful option for maintaining ecosystem services. Conversely, forest land cover had varied impacts and highlights the trade-offs that exist with protecting one environmental service versus another. For example, while the Climate Adapted Futures had the least impact to the coastal complex, they showed the largest impacts to forest cover. Additionally, extensive protection of agriculturally productive lands shifted urban growth more into forested landscapes in the Food Security Futures, showing the trade-off between agricultural protection and natural landscape protection.

Impacts to the different land uses also provided insight into the repercussions of alternative land development patterns. Impacts to pasture land were relatively consistent between the futures, but impacts to orchards and sugar cane definitely highlight the need for coordinated protection of agricultural resources, if desired by the stakeholders in the region. Although the Deregulated Futures may represent a relatively extreme policy direction, it is good to consider the implications of reduced planning regulations as a point of comparison. Too often planning policies are enacted but never evaluated against alternatives. Modelling a Deregulated Future allows a look at what such a future might be like. This Deregulated Future (high growth variant) demonstrates impacts to orchards and sugar cane that are an order of magnitude higher than most of the other futures. Thus, according to this analysis, the current regional planning regulations are doing a good job at protecting agricultural resources important to the region, even under future urban growth pressures.

9. CLIMATE CHANGE IMPACT ANALYSIS

In this chapter the alternative landscape future scenarios are assessed against the impact of the modelled climatic changes. Focussing on the impact on future settlements this process again quantifies the impacts to provide a standardised measure across scenarios at a regional scale.

9.1 *Sea-level Rise and Storm Surge*

As would be expected, impacts of sea-level rise vary between the alternative futures. Sea-level rise will be particularly damaging to urban environments under the Deregulated Future. Under the other scenarios, sea-level rise has a smaller impact. The climate change adapted futures do the best job of minimizing sea-level rise impacts, particularly the high variant of the Climate Adapted Future Scenario, where there is no forecasted impact of SLR. Focusing just on a mean SLR between 0.5 and 1m (the current accepted SLR estimates for most municipalities), the pattern remains similar. For most futures, 0.5m of SLR would inundate between 42 and 56 ha of urban development by 2100 (Table 9.1). Under the High Growth Deregulated Future the impact rises to 804 ha. Under 1.0m of SLR, the impact increases for most of the futures to totals between 104 ha and 143 ha. The worst case Deregulated Future scenarios increase to 570 ha (low growth) and 1285 ha (high growth).

Taking into considering the varying density of urban development within the region, this means that between 621 and 832 people could be displaced under a 0.5m SLR in most futures and 5,155 – 11,932 people in the Deregulated Future (Table 9.2). With a SLR of 1.0m this would rise to between 1551 and 2122 people. The Deregulated Future Scenarios also increase significantly with up to 19069 people potentially facing displacement from inundation.

When we consider SLR of 1.5m and 2.0m, we see a large increase in the possible inundated urban area, particularly under the Deregulated Future. Additionally, at 2.0m of SLR we see substantial (>500 ha) inundation of houses by 2100 in most futures (Table 9.1). This level of inundation will likely displace between 7,860 and 11,037 people, using modelled urban densities (Table 9.2). Again, the Deregulated Future leads to a much greater loss of urban area, showing up to 3601 ha of lost development (Table 9.1; Figure 9.1). When considering extreme SLR and/or storm surges at 2.0m and 2.5m there is a continual increase in inundated land, before it levels off at elevations above 3.5m. Thus, a combination of moderate SLR of 1.0m and a storm surge of 1.5m could lead to a greater number of impacted people, than currently exists.

TABLE 9.1: POTENTIAL SLR AND STORM SURGE IMPACTS UNDER ALTERNATIVE FUTURES FOR THE NORTH COAST, NSW. IMPACTS ARE PRESENTED AS HECTARES OF URBAN DEVELOPMENT LIKELY TO BE INUNDATED AT VARIOUS LEVELS OF SLR AND/OR STORM SURGES. (HECTARES)

Alternative Futures		SLR 0.5m	SLR 1.0m	SLR 1.5m	SLR 2.0m	SLR 2.5m	SLR 3.0m	SLR 3.5m
Deregulated Low Growth	2030	47	81	136	266	387	440	491
	2070	174	294	467	868	1259	1433	1591
	2100	347	570	902	1675	2401	2718	3014
Deregulated Medium Growth	2030	71	123	206	399	582	661	740
	2070	294	477	748	1377	1971	2227	2462
	2100	581	936	1472	2681	3773	4251	4717
Deregulated High Growth	2030	98	170	281	535	778	886	986
	2070	434	689	1067	1937	2727	3068	3395
	2100	804	1285	1984	3601	5058	5727	6353
Energy Development	2030	17	40	85	192	296	336	380
	2070	26	68	146	361	614	705	794
	2100	51	130	269	642	1058	1221	1384
Food Security Low Growth	2030	15	35	69	158	244	276	311
	2070	24	60	128	304	499	574	651
	2100	42	105	218	530	879	1004	1131
Food Security Medium Growth	2030	17	41	88	201	311	353	401
	2070	26	69	149	371	633	725	817
	2100	51	133	276	656	1098	1280	1453
Food Security High Growth	2030	21	49	105	246	384	435	493
	2070	34	90	184	446	749	864	977
	2100	56	143	301	744	1252	1488	1718
Compact Growth	2030	15	35	69	158	244	276	311
	2070	24	61	131	313	517	593	671
	2100	44	107	222	541	894	1020	1150
Low Climate Adapted Low Growth	2030	-	-	-	-	42	61	84
	2070	-	-	-	-	75	112	159
	2100	-	-	-	-	125	187	265
Low Climate Adapted Medium Growth	2030	-	-	-	-	54	77	109
	2070	-	-	-	-	83	124	177
	2100	-	-	-	-	159	241	347
Low Climate Adapted High Growth	2030	-	-	-	-	65	94	132
	2070	-	-	-	-	92	146	213
	2100	-	-	-	-	195	308	460
High Climate Adapted Low Growth	2030	-	-	-	-	-	-	-
	2070	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-
High Climate Adapted Medium Growth	2030	-	-	-	-	-	-	-
	2070	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-
	2070	34	90	184	447	750	865	978

TABLE 9.1 (CONT'D): POTENTIAL SLR AND STORM SURGE IMPACTS UNDER ALTERNATIVE FUTURES FOR THE NORTH COAST, NSW. IMPACTS ARE PRESENTED AS HECTARES OF URBAN DEVELOPMENT LIKELY TO BE INUNDATED AT VARIOUS LEVELS OF SLR AND/OR STORM SURGES. (HECTARES)

Alternative Futures		SLR 0.5m	SLR 1.0m	SLR 1.5m	SLR 2.0m	SLR 2.5m	SLR 3.0m	SLR 3.5m
High Climate Adapted High Growth	2030	-	-	-	-	-	-	-
	2070	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-
Regional Plan Low Growth	2030	15	34	68	156	241	273	308
	2070	23	58	126	301	497	572	649
	2100	42	104	217	528	876	1001	1127
Regional Plan Medium Growth	2030	17	40	87	200	309	351	398
	2070	25	67	147	368	629	722	814
	2100	51	131	274	655	1096	1279	1451
Regional Plan High Growth	2030	21	49	105	245	382	433	491

TABLE 9.2: POTENTIAL NUMBER OF PEOPLE DISPLACED BY SLR AND/OR STORM SURGES UNDER ALTERNATIVE GROWTH SCENARIOS FOR THE NORTH COAST, NSW. ESTIMATED USING CURRENT AND MODELLED DENSITIES OF PEOPLE PER HOUSEHOLD IN THE REGION.

Alternative Futures		SLR 0.5m	SLR 1.0m	SLR 1.5m	SLR 2.0m	SLR 2.5m	SLR 3.0m	SLR 3.5m
Deregulated Low Growth	2030	692	1201	2012	3,937	5,740	6521	7279
	2070	2,583	4,364	6,920	12,871	18,684	21,258	23,605
	2100	5,155	8,458	13,380	24,861	35,650	40,342	44,741
Deregulated Medium Growth	2030	1,054	1831	3,067	5,927	8,643	9,811	10,983
	2070	4,370	7,091	11,120	20,456	29,271	33,072	36,567
	2100	8,634	13,911	21,873	39,822	56,035	63,126	70,049
Deregulated High Growth	2030	1,452	2,514	4,159	7,926	11,530	13,132	14,619
	2070	6,439	10,219	15,827	28,748	40,474	45,534	50,397
	2100	11,932	19,069	29,437	53,454	75,092	85,021	94,322
Energy Development	2030	246	585	1254	2,848	4,397	4991	5650
	2070	379	1006	2171	5,365	9,125	10480	11805
	2100	744	1915	3984	9,529	15,712	18,130	20,556
Food Security Low Growth	2030	224	516	1017	2,339	3,613	4086	4609
	2070	350	876	1889	4,508	7,403	8516	9658
	2100	621	1552	3232	7,865	13,043	14892	16770
Food Security Medium Growth	2030	253	607	1311	2,988	4,618	5243	5952
	2070	389	1029	2218	5,517	9,401	10773	12138
	2100	763	1976	4097	9,748	16,309	19,022	21,585
Food Security High Growth	2030	311	728	1559	3,656	5,699	6463	7319
	2070	498	1333	2725	6,625	11,122	12841	14515
	2100	832	2122	4457	11,037	18,578	22,096	25,511
	2070	497	1330	2722	6,618	11,110	12828	14500
	2100	831	2122	4459	11,019	18,542	22,051	25,456

TABLE 9.2 (CONT'D): POTENTIAL NUMBER OF PEOPLE DISPLACED BY SLR AND/OR STORM SURGES UNDER ALTERNATIVE GROWTH SCENARIOS FOR THE NORTH COAST, NSW. ESTIMATED USING CURRENT AND MODELLED DENSITIES OF PEOPLE PER HOUSEHOLD IN THE REGION.

Alternative Futures		SLR 0.5m	SLR 1.0m	SLR 1.5m	SLR 2.0m	SLR 2.5m	SLR 3.0m	SLR 3.5m
Compact Growth	2030	222	512	1020	2,342	3,623	4099	4624
	2070	355	899	1942	4,645	7,680	8813	9970
	2100	652	1582	3289	8,023	13,273	15147	17070
Low Climate Adapted Low Growth	2030	-	-	-	-	623	899	1239
	2070	-	-	-	-	1113	1654	2344
	2100	-	-	-	-	1857	2765	3915
Low Climate Adapted Medium Growth	2030	-	-	-	-	797	1143	1620
	2070	-	-	-	-	1231	1845	2635
	2100	-	-	-	-	2,360	3581	5153
Low Climate Adapted High Growth	2030	-	-	-	-	961	1388	1949
	2070	-	-	-	-	1358	2155	3142
	2100	-	-	-	-	2,890	4569	6,814
High Climate Adapted Low Growth	2030	-	-	-	-	-	-	-
	2070	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-
High Climate Adapted Medium Growth	2030	-	-	-	-	-	-	-
	2070	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-
High Climate Adapted High Growth	2030	-	-	-	-	-	-	-
	2070	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-
Regional Plan Low Growth	2030	224	510	1013	2,325	3,592	4064	4585
	2070	349	874	1884	4,493	7,409	8519	9662
	2100	626	1551	3234	7,860	13,040	14887	16763
Regional Plan Medium Growth	2030	258	606	1309	2,991	4,616	5240	5944
	2070	383	1020	2207	5,495	9,382	10759	12128
	2100	768	1975	4095	9,752	16,309	19,024	21,582
Regional Plan High Growth	2030	310	728	1561	3,638	5,667	6427	7285

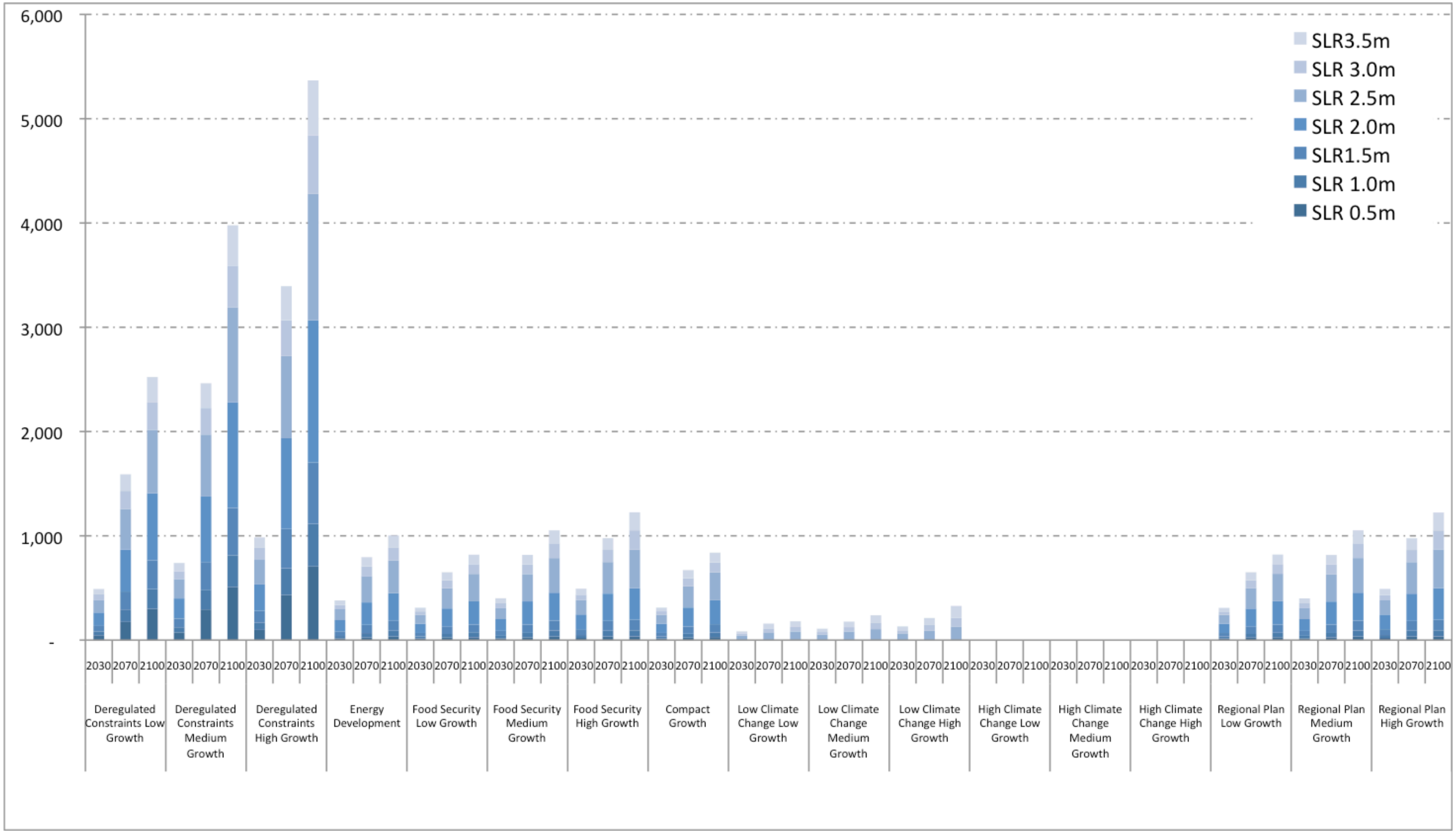


FIGURE 9.1: FORECASTED LOSS OF URBAN AREA DUE TO SEA-LEVEL RISE AND/OR STORM SURGES UNDER ALTERNATIVE URBAN GROWTH FUTURES FOR THE NORTH COAST, NSW. IMPACTS ARE NOT CUMULATIVE OVER TIME, SO ACTUAL IMPACTS IN 2100 ARE THE SUM OF THE IMPACTS IN 2030 AND 2070 (HECTARES).

9.2 *Flooding*

Flooding in the north coast of New South Wales appears to be a likely impact of climate change, although the magnitude and timing varies depending upon the GCM and scenario assessed. Several planning jurisdictions have acknowledged this risk and modelled future flood events given climate change (Table 9.3).

TABLE 9.3: FLOOD LEVELS (IN METRES) FOR MAJOR RIVERS NEAR URBAN SETTLEMENTS IN THE NORTH COAST OF NSW. CURRENT AND FUTURE 100-YR FLOOD LEVELS ARE PRESENTED. ITALISIZED CLIMATE CHANGE 100-YR LEVELS ARE CARRIED OVER IN THE ABSENSE OF DOCUMENTED FLOOD MODELS.

River	Urban Area	Current 100yr	Climate Change 100yr	Source
Brunswick	Mullumbimby	3	3.5	Tweed Byron Coastal Creeks Flood Study
Cudgera	Pottsville	2.5	3.5	Hastings Point Flood Study
Richmond	Broadwater	4	4.9	Richmond River Flood Mapping Study
Richmond	Casino	24.5	25.4	Richmond River Flood Mapping Study
Richmond	Woodburn	4.7	5.6	Richmond River Flood Mapping Study
Tweed	Murwillumbah	6.9	8	Tweed Valley Flood Study Update, Climate Change
Tweed	Tweed Heads	2.4	2.9	Tweed Valley Flood Study Update, Climate Change
Tweed	Uki	11.1	11.1	Tweed River Gage Readings
Wilsons	Lismore	12.2	12.2	Richmond River Flood Mapping Study

Like the SLR analysis, impacts of flooding vary substantially between the futures (Table 9.4; Figure 9.2). Similar patterns emerged as the Deregulated Future led to the largest amount of urban land lost to flooding, and the Climate Adapted Futures having the least impact. Under the high growth rate of the Deregulated Future, 12,762 ha of urban development will likely occur within the current 100-yr floodplain, which increases to over 14,456 ha with the increased precipitation expected under some climate scenarios. However, under most of the futures, the difference between the current and future 100-yr floodplain is not very large, suggesting that increasing flooding may not be a large impact on future urban growth in the region. It does suggest that current 100-yr flood plans are important to protect, as nearly every future shows substantial growth within those flood zones.

Similar to the SLR impacts, we can anticipate how many people these impacts are likely to affect using current and modelled density of urban development (Table 9.5). Under most of the futures we would expect a 10-20% increase in the number of people affected by increased levels of flood inundation. It must be noted again (see Chapter 5) that a significant consideration of increased rainfall and subsequent inundation levels is the increase in frequency of events to a specified level, in that current 1% or 1 in 100 year flood level is likely to become the 4% or 1 in 25 year level.

TABLE 9.4: HECTARES OF POTENTIALLY FLOODED URBAN AREA UNDER ALTERNATIVE GROWTH FUTURES FOR THE NORTH COAST, NSW.

Alternative Future		100-yr Flood	100-yr Flood 2100
Deregulated Low Growth	2030	582	673
	2070	2,160	2,484
	2100	4,411	5,042
Deregulated Medium Growth	2030	892	1,030
	2070	3,716	4,237
	2100	8,071	9,157
Deregulated High Growth	2030	1,225	1,411
	2070	5,656	6,415
	2100	12,762	14,456
Energy Development	2030	624	739
	2070	1,694	1,994
	2100	3,009	3,554
Food Security Low Growth	2030	391	474
	2070	1146	1349
	2100	2042	2,434
Food Security Medium Growth	2030	578	692
	2070	1,624	1,928
	2100	2,976	3,542
Food Security High Growth	2030	753	895
	2070	2,095	2,482
	2100	3,698	4,374
Compact Growth	2030	459	547
	2070	1316	1539
	2100	2,433	2,874
Low Climate Adapted Low Growth	2030	-	57
	2070	-	155
	2100	-	292
Low Climate Adapted Medium Growth	2030	-	78
	2070	-	234
	2100	-	466
Low Climate Adapted High Growth	2030	-	103
	2070	-	324
	2100	-	552
High Climate Adapted Low Growth	2030	-	10
	2070	-	34
	2100	-	60
High Climate Adapted Medium Growth	2030	-	16
	2070	-	49
	2100	-	118
High Climate Adapted High Growth	2030	-	24
	2070	-	85
	2100	-	146

TABLE 9.4 (CONT'D): HECTARES OF POTENTIALLY FLOODED URBAN AREA UNDER ALTERNATIVE GROWTH FUTURES FOR THE NORTH COAST, NSW.

Alternative Future		100-yr Flood	100-yr Flood 2100
Regional Plan Low Growth	2030	383	467
	2070	1120	1324
	2100	1990	2,382
Regional Plan Medium Growth	2030	567	679
	2070	1,582	1,884
	2100	2,902	3,460
Regional Plan High Growth	2030	737	878

TABLE 9.5: POTENTIAL NUMBER OF PEOPLE DISPLACED DUE TO A 100-YR FLOOD EVENT UNDER CURRENT AND FUTURE CLIMATES ACCORDING TO ALTERNATIVE GROWTH SCENARIOS. ESTIMATED USING CURRENT AND MODELLED DENSITIES OF PEOPLE PER HOUSEHOLD.

Alternative Future		People (est.)	
		100-yr Flood	100-yr Flood 2100
Deregulated Low Growth	2030	8649	9997
	2070	32,084	36,881
	2100	65,510	74,861
Deregulated Medium Growth	2030	13251	15298
	2070	55,188	62,920
	2100	119,856	135,974
Deregulated High Growth	2030	18184	20954
	2070	83,978	95,250
	2100	189,487	214,640
Energy Development	2030	9265	10971
	2070	25,160	29,610
	2100	44,682	52,769
Food Security Low Growth	2030	5799	7041
	2070	17,006	20,036
	2100	30,312	36,146
Food Security Medium Growth	2030	8589	10277
	2070	24,117	28,633
	2100	44,196	52,604
Food Security High Growth	2030	11175	13296
	2070	31,098	36,867
	2100	54,901	64,959
Compact Growth	2030	6808	8119
	2070	19,526	22,854
	2100	36,110	42,678
Low Climate Adapted Low Growth	2030	-	841
	2070	-	2,295
	2100	-	4,327

TABLE 9.5 (CONT'D): POTENTIAL NUMBER OF PEOPLE DISPLACED DUE TO A 100-YR FLOOD EVENT UNDER CURRENT AND FUTURE CLIMATES ACCORDING TO ALTERNATIVE GROWTH SCENARIOS. ESTIMATED USING CURRENT AND MODELLED DENSITIES OF PEOPLE PER HOUSEHOLD.

Alternative Future		People (est.)	
		100-yr Flood	100-yr Flood 2100
Low Climate Adapted Medium Growth	2030	-	1156
	2070	-	3,475
	2100	-	6,919
Low Climate Adapted High Growth	2030	-	1527
	2070	-	4,806
	2100	-	8,195
High Climate Adapted Low Growth	2030	-	142
	2070	-	493
	2100	-	875
High Climate Adapted Medium Growth	2030	-	244
	2070	-	736
	2100	-	1,764
High Climate Adapted High Growth	2030	-	360
	2070	-	1,265
	2100	-	2,175
Regional Plan Low Growth	2030	5683	6927
	2070	16,632	19,647
	2100	29,555	35,361
Regional Plan Medium Growth	2030	8423	10078
	2070	23,496	27,973
	2100	43,097	51,375
Regional Plan High Growth	2030	10939	13037

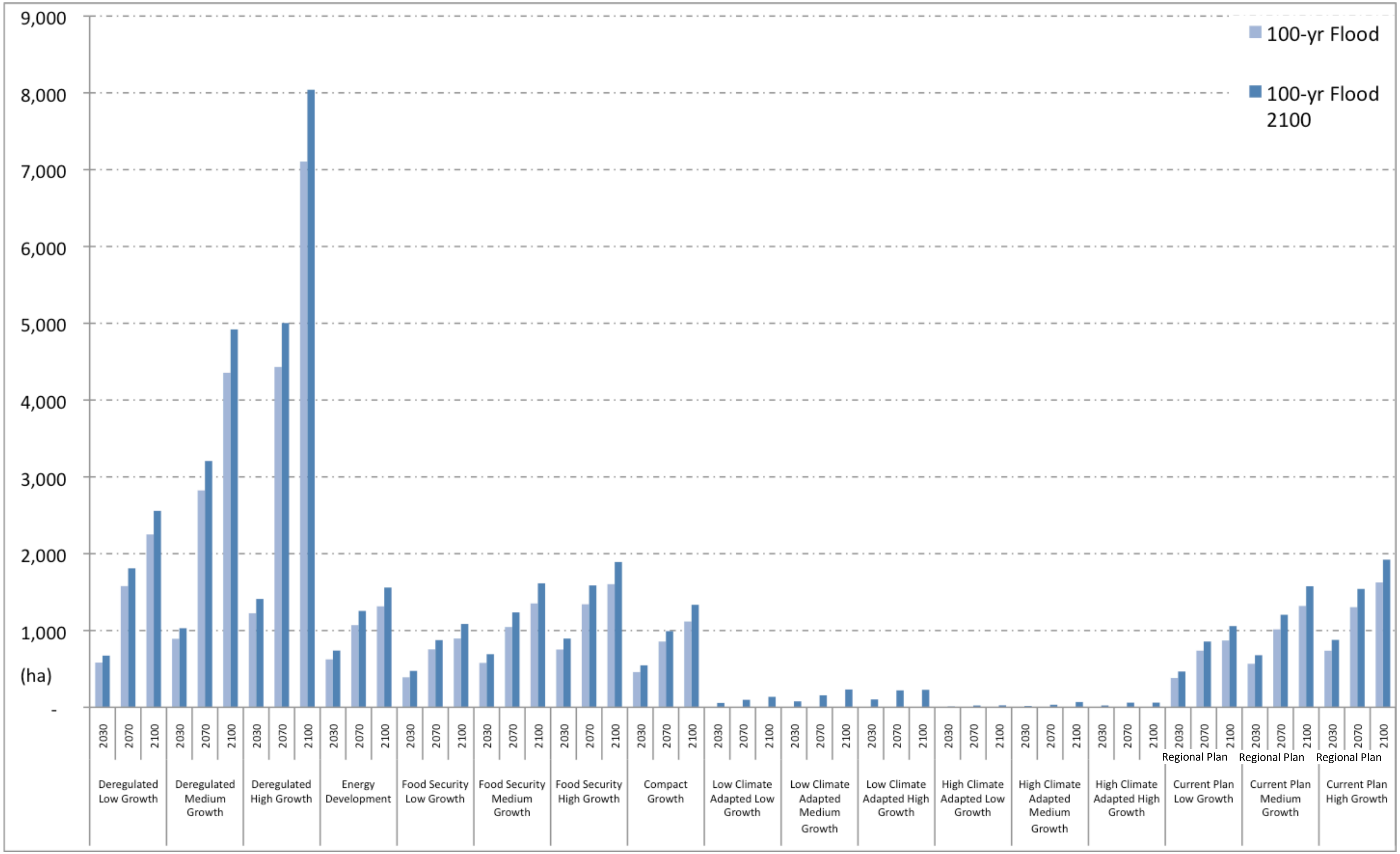


FIGURE 9.2: POTENTIAL FLOOD IMPACTS TO URBAN GROWTH UNDER ALTERNATIVE FUTURES FOR THE NORTH COAST, NSW.

9.3 *Beach Recession*

Impacts to urbanisation due to beach recession were moderate across the board (Table 9.6). As in previous impact models, the Climate Adapted Futures had the least forecasted impact to urban areas due to beach recession. However, all the other futures had similar impacts, including the Deregulated Future. If beaches in the study area only recess 23m, the impacts are almost negligible across the board. With beach recession of 53m there will be up to 95 ha of urbanisation impacted in the high growth Deregulated Future by 2100 (Figure 9.3). At a recession level of 150m the maximum impact we might expect from beach recession is the loss of 344 ha under the high growth Deregulated Future in 2100.

TABLE 9.6: POTENTIAL IMPACTS OF DIFFERENT LEVELS OF BEACH RECESSION ON URBAN DEVELOPMENT UNDER ALTERNATIVE FUTURES FOR THE NORTH COAST, NSW (HECTARES).

Alternative Future		Rec. 23m	Rec. 53m	Rec. 83m	Rec. 150m
Deregulated Low Growth	2030	2	20	37	77
	2070	4	45	82	164
	2100	6	69	127	259
Deregulated Medium Growth	2030	2	31	56	112
	2070	3	48	88	178
	2100	6	83	152	306
Deregulated High Growth	2030	3	38	68	134
	2070	4	52	95	190
	2100	8	95	172	344
Energy Development	2030	3	36	61	94
	2070	4	41	71	115
	2100	8	82	141	235
Food Security Low Growth	2030	3	33	55	85
	2070	4	39	68	109
	2100	7	73	125	201
Food Security Medium Growth	2030	3	36	61	95
	2070	4	41	71	116
	2100	8	82	142	239
Food Security High Growth	2030	3	37	63	100
	2070	4	44	77	135
	2100	8	88	154	265
Compact Growth	2030	3	33	55	85
	2070	4	40	69	110
	2100	7	74	127	205
Low Climate Adapted Low Growth	2030			3	30
	2070			4	40
	2100			7	79
Low Climate Adapted Medium Growth	2030			3	34
	2070			4	47
	2100			8	99
Low Climate Adapted High Growth	2030			3	37
	2070			4	59
	2100			8	111

TABLE 9.6 (CONT'D): POTENTIAL IMPACTS OF DIFFERENT LEVELS OF BEACH RECESSION ON URBAN DEVELOPMENT UNDER ALTERNATIVE FUTURES FOR THE NORTH COAST, NSW (HECTARES).

Alternative Future		Rec. 23m	Rec. 53m	Rec. 83m	Rec. 150m
High Climate Adapted Low Growth	2030				0
	2070				0
	2100				1
High Climate Adapted Medium Growth	2030				0
	2070				1
	2100				1
High Climate Adapted High Growth	2030				0
	2070				1
	2100				2
Regional Plan Low Growth	2030	3	33	55	85
	2070	4	40	69	110
	2100	7	74	126	202
Regional Plan Medium Growth	2030	3	36	61	95
	2070	4	41	71	117
	2100	8	82	142	239
Regional Plan High Growth	2030	3	37	63	100

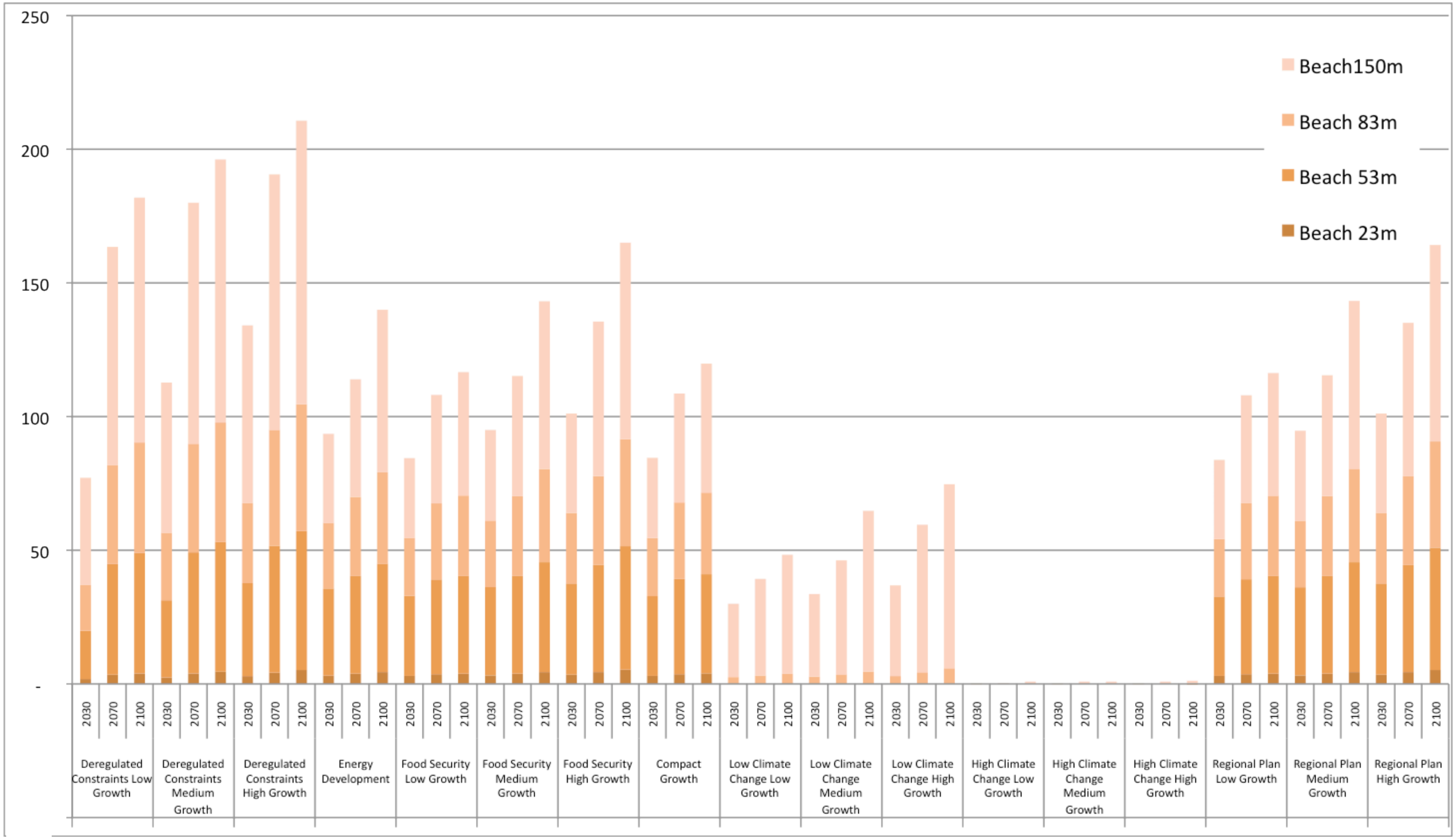


FIGURE 9.3: POTENTIAL IMPACTS OF DIFFERENT LEVELS OF BEACH RECESSION ON URBAN DEVELOPMENT UNDER ALTERNATIVE FUTURES FOR THE NORTH COAST, NSW (HECTARES).

10. DISCUSSION

From these alternative futures assessments, we can see the value of examining different land use patterns in the context of climate change. Impacts from climate change on urban settlements ranged widely from the highly impacted Deregulated Futures, to the fully protected High Climate Adapted Futures. However, outside of those two extremes, climate impacts to urbanisation in this study area appear to be relatively minimal. Despite differing drivers of urban growth and land use change in the region, the impacts from climate change seemed to be consistent. Regardless of whether food security, energy development, or following the current regional planning guidelines was the focus, impacts of SLR/storm surge and flooding remained similar between the futures. Furthermore, under this analysis, it appears that current planning policies in this region are well equipped to handle the climate change impacts assessed here.

The impact of SLR and storm surges to urban development were less than anticipated given the current concentration of development along the coast in the study area. Even under the highest growth scenario (Deregulated Future-high growth variant), anticipated impacts from 0.5 to 1.0m of SLR are relatively small (1,200 ha, displacing up to 19,000 people). Although 19,000 people is a significant impact, the Deregulated Future represents a relatively extreme scenario, which is reflected in the results from the other futures. In most of the futures, even under the high-growth variants, SLR up to 1.0m will likely displace only 2,000 people, which, given the extent and total population of the study area, represents a very small impact. However, particular attention should be paid to the 1.5m to 2.5m threshold, where impacts to urban settlement increase rather dramatically. Average impacts double and sometimes triple between 1.5 and 2.5m SLR/storm surge. While we do not expect to see SLR of 2.5 or 3.5m, studies in Byron Bay have identified maximum SLR and storm surge estimates of 3.5m (Byron Shire Council 2009).

Similar results were seen from the flood impact analysis. Although the current land use plans exclude growth from the 100-yr floodplain, there is substantial evidence that this standard is not strongly enforced. Current urban development already exists within the 100-yr floodplain. In the future, this is likely to increase by at least 50% by 2100, and under extreme cases like the Deregulated Futures, could increase more than 200%. While the Deregulated Future scenario may seem unrealistic, it is a good benchmark to compare current policies and regulations, and it is a strong justification for strict enforcement of the existing guidelines. While increased flooding will certainly have a noticeable impact, particularly with an increase in the frequency of events, the majority of the impact comes from building within the current 100-yr floodplain.

Another key point is revealed by comparing the impacts expected from SLR versus the impacts due to flooding. While SLR potentially displaces 500-2,000 people (depending upon scenario and SLR-level) the number of people impacted by flooding is an order of magnitude higher. Granted, SLR represents a permanent displacement, while flooding is primarily temporary and may not lead to permanent displacement; it appears that most of the focus on disaster reduction and management should be placed on protecting the current floodplain from development and methods to reduce the impact of inundation events.

The impact of beach recession was quite minimal, and generally followed the impacts expected by SLR. While up to 344 ha of development could be lost due to beach recession under the most extreme scenario (Deregulated Future-high growth variant), most impacts were quite minimal. Additionally, most of the impacts to urbanisation from beach recession occur either in 2030 or 2100 (except in the Deregulated Futures). This suggests that urban development that is already near the erodible beaches will see the first and largest impact, but it will not be until 2100 that future development will again conflict with beach recession.

Although the results of these impact analyses are separate from the typical GCM outputs, important climate change risks can be identified using basic physical landscape information. When these basic models are combined with sophisticated sea-level rise, storm surge (and other weather), flood and beach recession models, planners can more efficiently develop adaptation plans for climate change. At the regional level, these first-cut models provide important baselines to compare more specific and sophisticated models. As well, when these basic models are combined with social vulnerability, we begin to understand the comprehensive impacts of climate change.

11. GAPS AND FUTURE RESEARCH DIRECTIONS

11.1 *Data limitations*

Data access and time for assembly: Despite having good working relationships with data custodians, an understanding of what data is where and what information it represents, the acquisition of data takes considerable time; generally more than allowed for in the current project. Being denied access, or having only limited access to data, did cause numerous problems and the need to assemble data bases from scratch 'in-house'.

The limited availability or difficulty in accessing data and the poor quality of the data that we were able to access in some instances, was the most serious limitation of this study. Flood data in particular is extremely variable between methods of recording and storage, and varied from gauge readings to printed maps and in one instance, a scattering of photos showing flooded locations. In two cases flood data, requested early in the project arrived after the completion of the project and despite assurances, LIDAR data expected at the beginning of the project has not yet been released by New South Wales Land and Property Information. Even quality spatial data always requires considerable preparatory work before use and in this instance often required extensive pre-processing or re-processing before being used. In studies where time is pressing, this can lead to compound errors. These issues forced a reliance on 'bath-tub' style approaches that unfortunately reduces the integrity of the results.

A review of such national database infrastructure is urgently required to adapt it to new and future requirements for timely delivery of information appropriate to scales useful in policy making such as adaptation to climate change vulnerabilities.

11.2 *Some caveats in the present study*

Forecasting: Despite some uncertainty, we still make decisions based on weather forecasts. Likewise, for climate change policy and planning, decisions still need to be made and policies are needed to help minimise vulnerability. Advancing information about what might plausibly happen can be valuable for policy considerations, even if it cannot provide probabilities on what might actually happen.

It must be kept in mind that data and models are limited in their accuracy and are intended as tools for general guidance. The greatest limitations (or caveats) in climate change analysis and studies are the combinatorial errors and variations. While there is indisputable evidence for climate change and a range of possible effects, predictions of greenhouse gas levels are forecasts with variation and error. These are used to produce sea level rise predictions with additional variation and error in predictions. These are then coupled with geographical variation and other local climate influences.

Different models can introduce further variation or error. In other words, in such studies, regardless of how predictions are made, there is one certainty – that the prediction will be wrong in some way. Often, what is poorly understood is just how far off the prediction is going to be and how acceptable the error is (Booij 2005). It becomes quite a task to describe all the necessary caveats on the combinatorial effects of variations and errors added to models (Dettinger 2005; Bürger *et al.* 2006). Any modelling process tends to complicate or hide implicit errors or natural variability. It is important therefore, not to focus so much on the details of a particular model or equation, but what can be learned generally about that which might be vulnerable at different stages of climate change and associated conditions.

Bruun Rule applications: Important caveats should be noted in respect of shoreline recession estimates. Firstly, it is possible that some areas shown as Quaternary alluvium on the 1:250,000 Geological series are thin veneers of Aeolian origin covering more resistant sediments. The Bruun Rule is likely to overestimate recession in these situations. Secondly, the Bruun Rule makes no allowance for local sediment transport dynamics, such as long-shore drift, or for cyclic erosion and accretion cycles, possibly related to decadal climatic cycles (Ranasinghe *et al*. 2007). Lastly, no shoreline recession estimates for areas of coast where Quaternary alluvium is absent have been made. These areas generally comprise cliffs, bluffs, slopes and tidal platforms and some localised recession may be triggered by sea level rise. However, estimates of recession due to undercutting by wave action, landslips and soil creep are necessarily locality specific and would be the subject of more detailed, finer scale assessments. To complement the broader scale analysis of this report, such assessments are critical.

Landscape futures analysis: Despite inaccuracies due to uncertainties in predicting future LULC, a landscape futures approach provides greater insight into the risks of adaptation to potential future exposure and vulnerability than simply examining the effects of future climate change perturbations on the present landscape.

Social-ecological systems behaviours: Finely detailed and accurate data on physical impacts or vulnerability (e.g., sea level rise) has little to do with how communities (even similar communities) will react to the effects of a “natural disaster”. Local government professionals, SES and RFB senior staff and volunteers, and members of the public often reflect on the fact that every flood or storm is different. One reason for this is the different interactions and interdependencies operating in and amongst social, ecological and economic elements at a particular time and place are often inseparable, and produce new or different emergent properties (the ‘sum’ of the parts from the ‘system’ interactions, is not a linear addition and produces something ‘different’; see (Pattee 1973, Carpenter & Gunderson 2001, Gunderson & Holling 2001).

Social vulnerability indices and indicators: Indicators of social vulnerability have been chosen with regard to the broad understanding in the literature about factors that increase or decrease vulnerability. There are, of course, many localised and culture-specific exceptions to these generalised relationships between vulnerability and explanatory factors. In addition, Census questions were not designed with these relationships in mind. This has forced the use of proxy indicators dependent on a posited relationship between the proxy and the unmeasured indicator. For these reasons, it is essential that areas identified as possibly having a high level of vulnerability be investigated in finer detail.

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