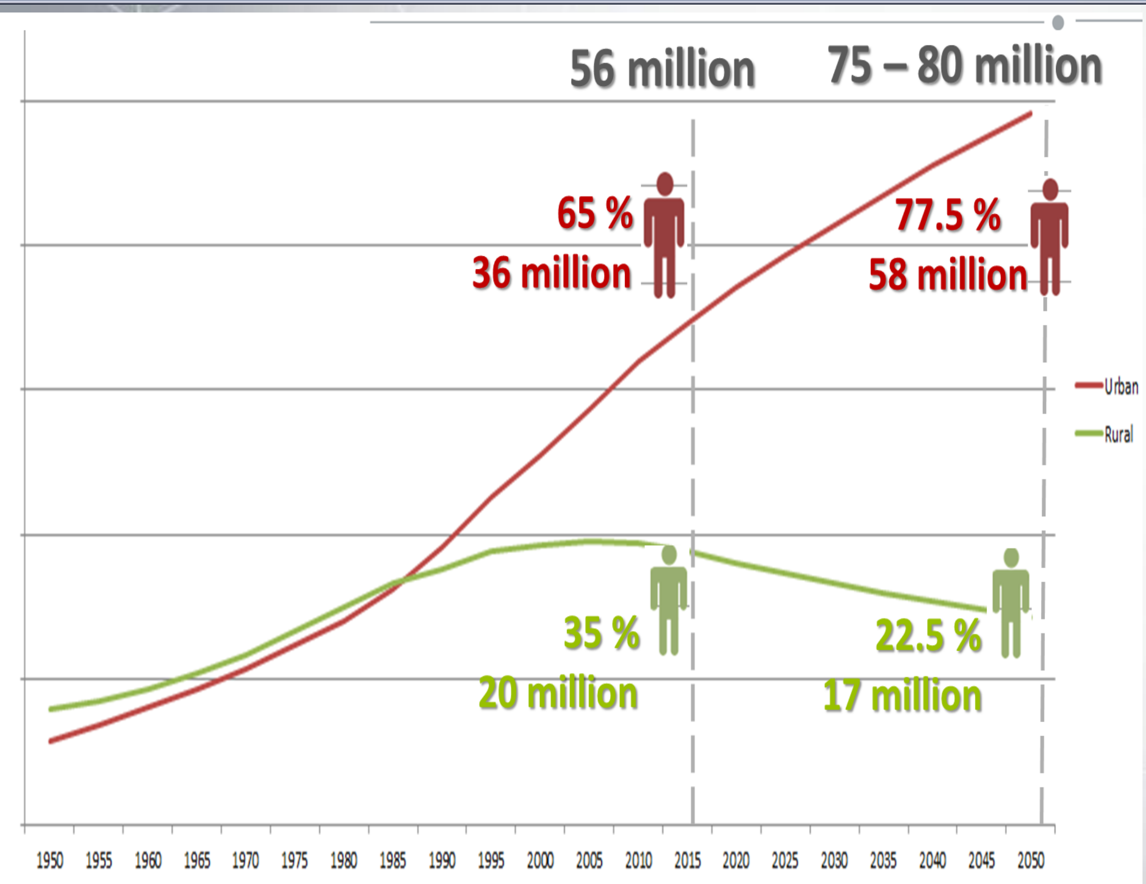
Adapting the Dyna-CLUE model for simulating LULC change in the Western Cape Province

Presenter: Alize le Roux

Petronella Tizora, Alize le Roux, Dr Antony Cooper & Gerbrand Mans

The spatial planning challenge



Western Cape

4.5 million (2001) - 6 million (2014)
Estimated 8.5 million (2050)

Growth will trigger changes in LULC

Incite issues such as urban sprawl, land degradation, informality, unsustainable land use practices, pressure on bulk services

WC – 5 Strategic Goals aligned with NDP 2030

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The spatial planning challenge

- Policies can have unintended consequences
- Consequences that can irreversible change the landscape
- 1990 – 2013 **decrease** in forest plantations, grasslands, waterbodies, bare land & **increase** in urban/built-up areas, mines & quarries, woodlands & scrublands and fynbos
- 2001 the cabinet decommissioned 45 000ha forest plantations for agriculture, human settlements
- 2008 decision partially reversed

Drivers of LULC change

- **Political Factors:** Play a significant role in land use change in South Africa – Past & Current
  - Legislations that control land use: Constitution of South Africa No 108 of 1996, Municipal Systems Act No 32 of 2000, Development Facilitation Act No 67 of 1995, National Environment Management Act No 107 of 1998, Spatial Planning and Land Use Management Act no 16 of 2013 (SPLUMA)

- **Economic Factors:** land markets, access to capital, investments, subsidies and cost of production and transportation. Economic developments in the Western Cape Province have strong links with agri-processing, tourism and gas sectors.

- **Demographic factors:** Pressure on land use is caused by aspects of population composition and distribution e.g Migration, Urbanization, Household size

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Drivers of LULC change

- **Cultural Factors:** Encompass people's beliefs, values and attitudes towards lands use

- **Biophysical Factors:** Climate, Soils, Topography, Relief, Vegetation
  - Effects of climate changes are evident in the study area - extreme weather conditions e.g Droughts, Heatwaves & Floods
  - Water availability is a serious issue in the province - leading to reduced crop production, low profits & farm conversions to other land uses
  - Very hot and dry conditions trigger fires - Loss of plantations & Biodiversity loss

- **Technological**
  - Decrease in number of farms & farm consolidations
  - Increased mechanization

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Complex spatial systems

- Lots of interaction between elements in the system
- Changes continuously
- Current condition of the system depends on its past
- Cross-scale connections (vertical/horisontal)
- Elements adapt and change to stimuli from their environment
- Self-organization
- Emergence ‘more than sum of its parts’

Why? & How

Why?

- We want to Engage in our future!!
- Better understand/explore the impacts of future policies on land use
- To predict behaviour under specific scenarios, inputs & pressures
- Estimate land use change impacts on bulk service requirements
- To study, understand & explore links & phenomena's (get a better understanding of reality)

How

- Create models
- Simplifications of reality
- Abstract of the real world
- Contained controllable version of the real world

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Land use change models

- Not a new concept! **Academia 50's, Internationally 80's**
- **Underpinned by various theories (**urban and regional economic theory, sociological and political economy theory, human-nature theories.)
- **Build on 3 key building blocks** Space, time and human choice
- **Classes of models** statistical and economic models, spatial interaction models, optimisation models, integrated models
- **Modelling techniques**
  - Equations, Statistics, Expert knowledge, CA, Hybrid, ABM

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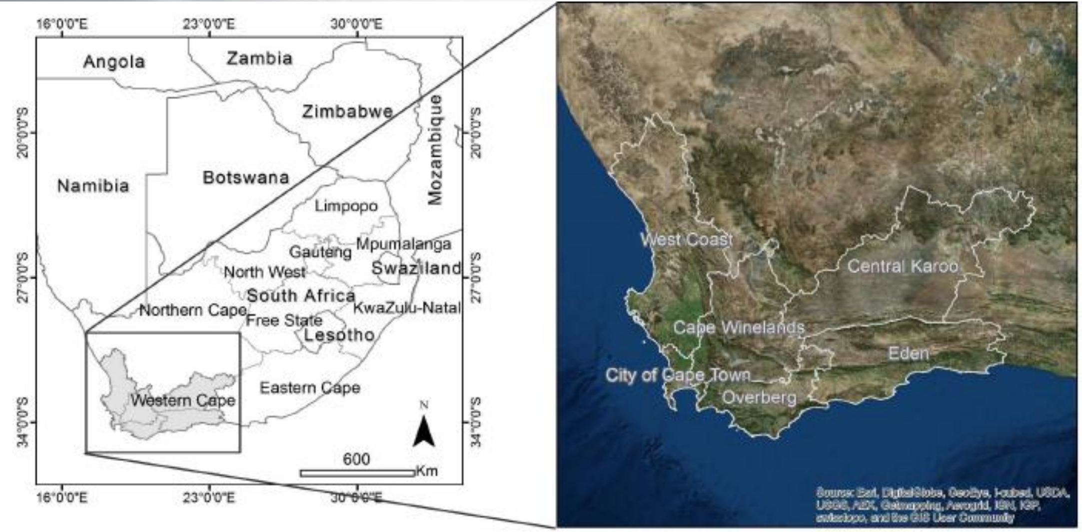
Western Cape as case study

What we decide today will inherently shape our land use/land cover patterns years from now



Planners need to understand their 'unintended' consequences

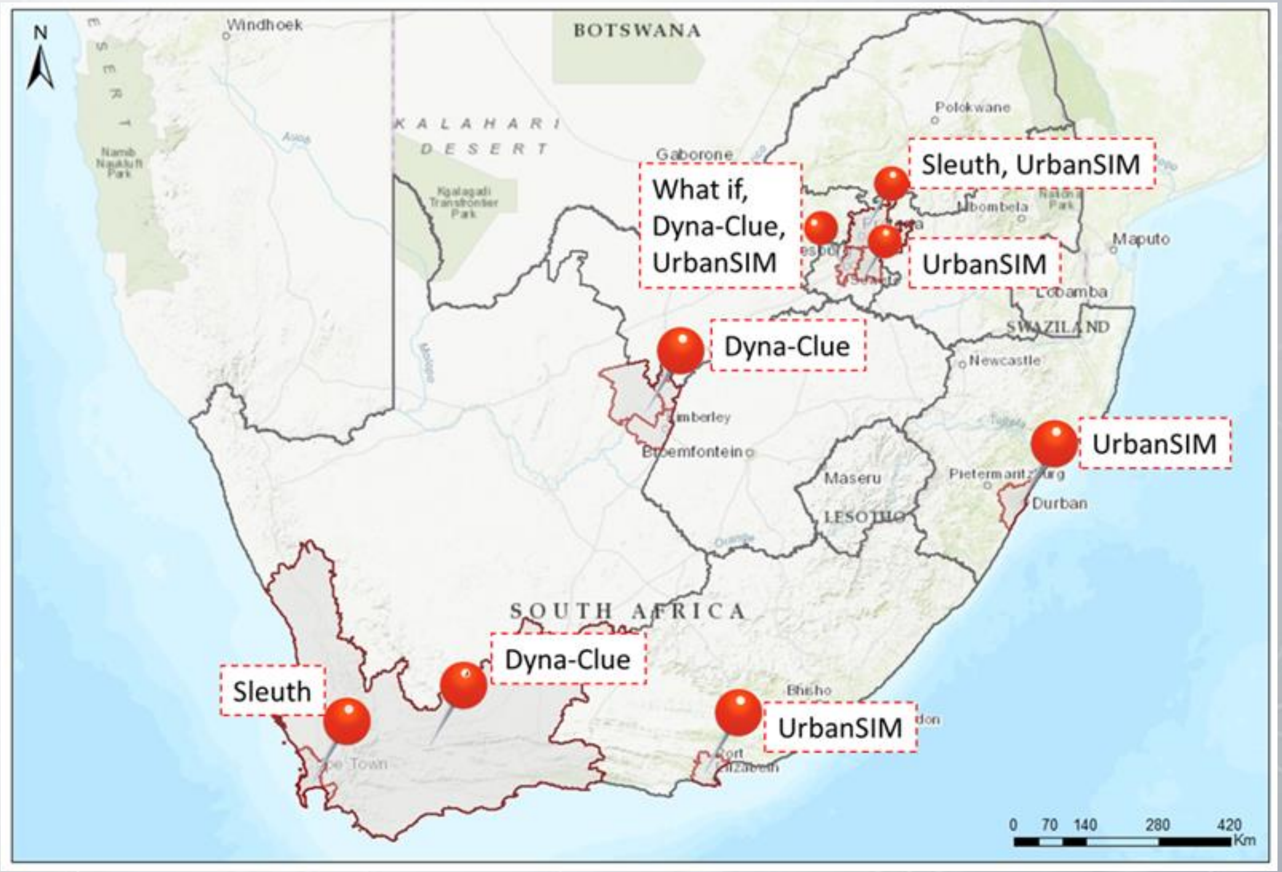
Spatial tools advise planners as to the possible best route of action to take

- Developed urban land use change model to *investigate*, *quantify* and *compare* long-term (spatial) consequences of planning policies in SA
- Monitors and evaluates policy scenarios (what-if)
- Urban land use change models simplify reality and provide unique opportunities to study the system
- Quantify impacts of future land use policies

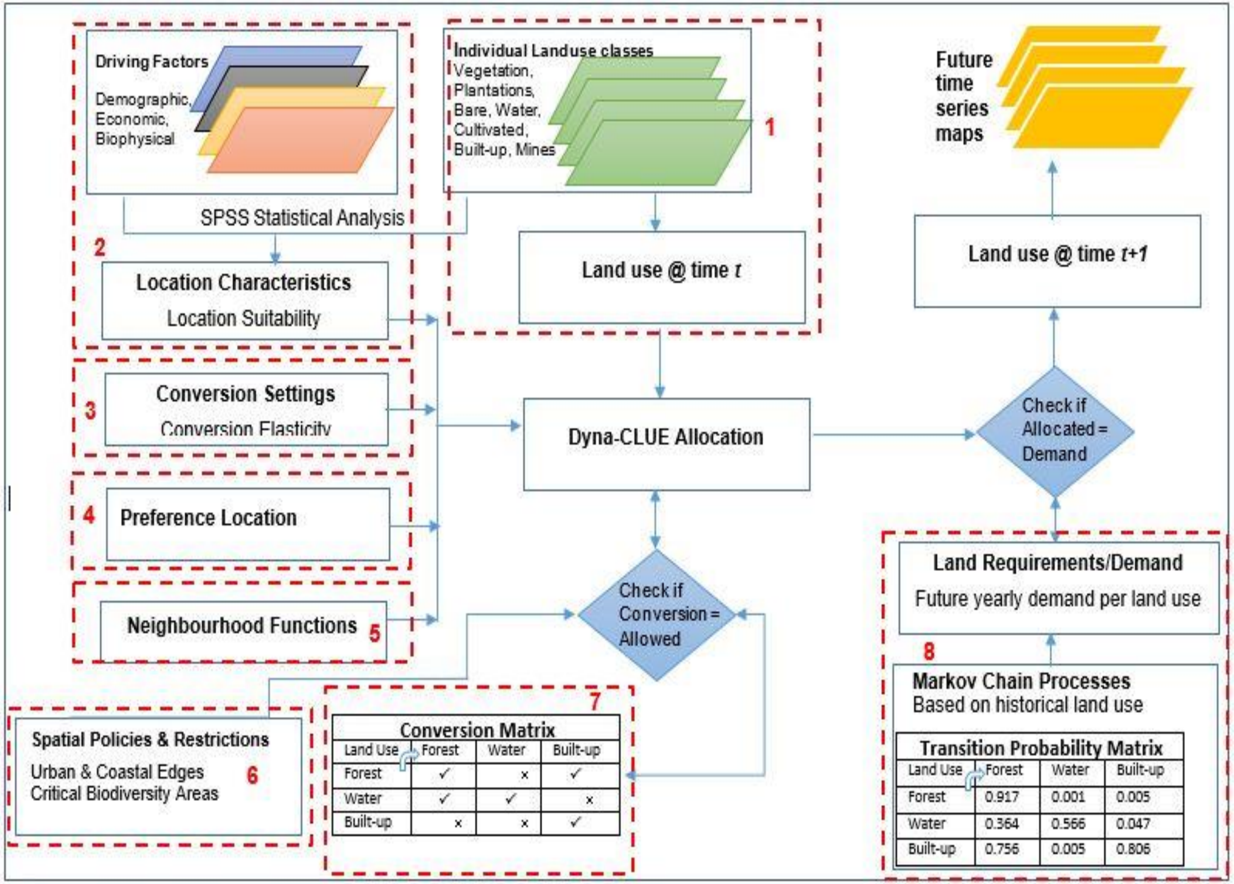
Previous land use model applications in SA

Dyna-Clue model

- **The CLUE model is a dynamic, spatially explicit, land use and land cover change model**
- **Hybrid model**
- **Land use model used frequently globally**
- **Developed by P. Verburg @ VU Amsterdam, NL**
- **Previously applied in City of Johannesburg & Frances Baard District Municipality**



Dyna-Clue model building & implementation

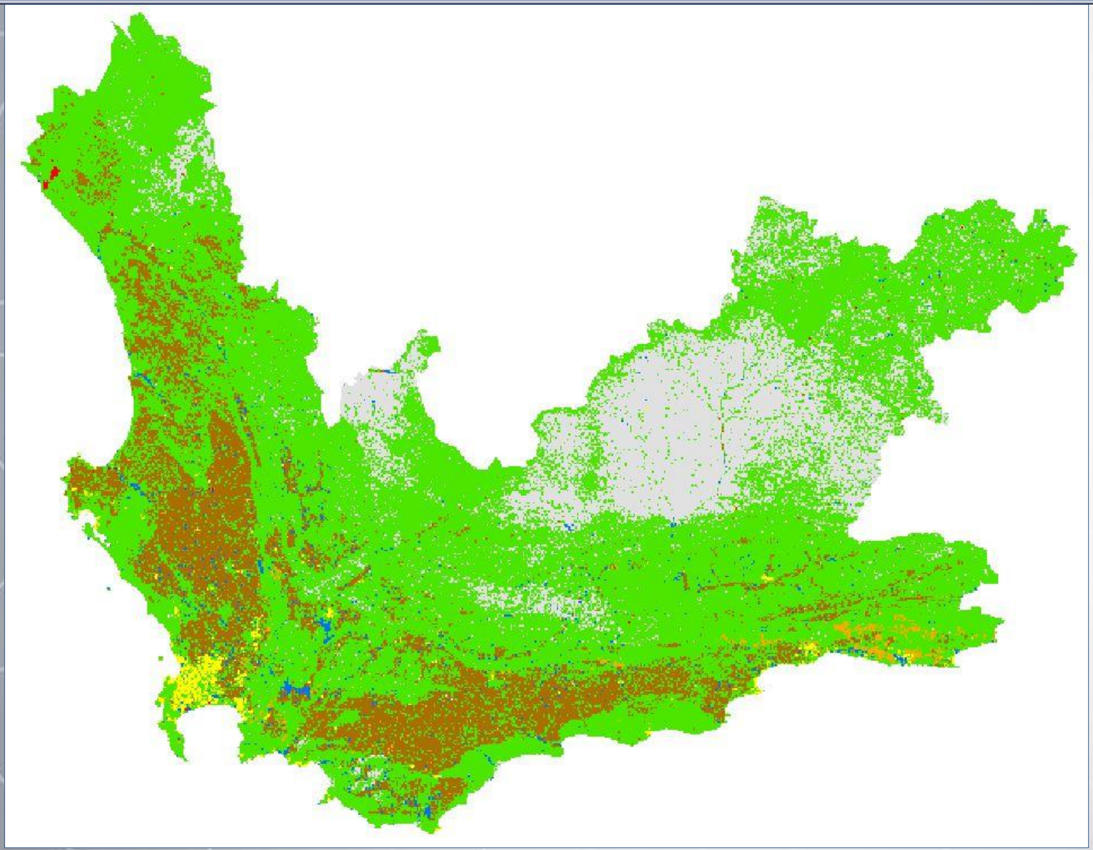


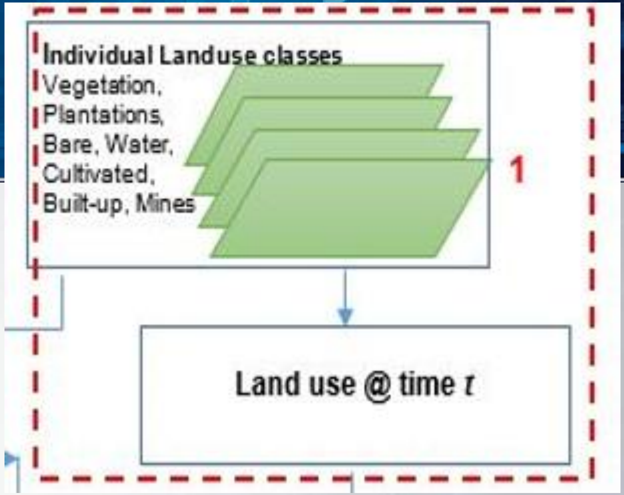
Dynamic Conversation of Land Use and its Effects (DYNA CLUE)

Dyna-Clue data inputs:

- Historical land use maps
- Driving factors of land use change
- Spatial policies and restrictions
- Land use requirements/ demands

1. Input LULC data





Input Maps

- 1990 LULC map – base map (derived from multi-seasonal Landsat 5 imagery acquired between 1989 & 1991)
- 2014 LULC map – validation map

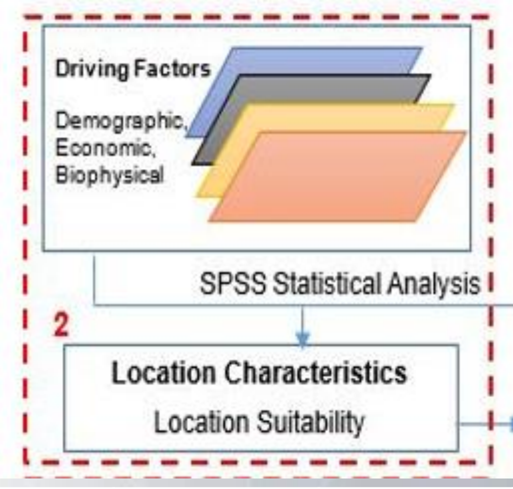
Modelling resolution

- Source data – 30x30m resolution
- Resampling – 1x1km

Maps of individual land use classes

- Individual land use class types are required as input data

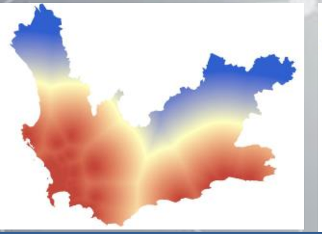
2. Driving factors of LULC change

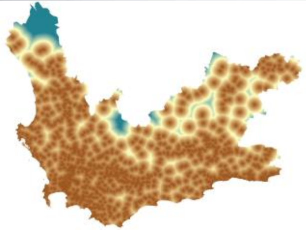


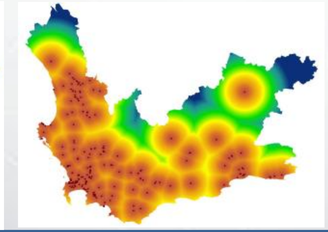
- Regional (influence land demand)
  - Demographics
  - Economy
  - Technology
  - Policies and strategies

- Local (influence spatial distribution)
- Driving factors are explanatory factors
- Create various hypothesis
- Conduct logistic regression models in SPSS
- Indicate the preference of a specific land use based on its relationship with explanatory factors.

Driving Factors	(1) Plantations	(3) Bare	(4) Cultivated	(5) Built-Up
	β-values	β-values	β-values	β-values
(0) Agri-Processing	-	-	0.00015	0.0001
(1) Economic Nodes	0.0001	0.0001	-	-
(2) Population	-	-	-	0.0016
(3) land Capability	-	-	0.0001	-
ROC Values	0.864	0.817	0.644	0.92







3. Conversion settings

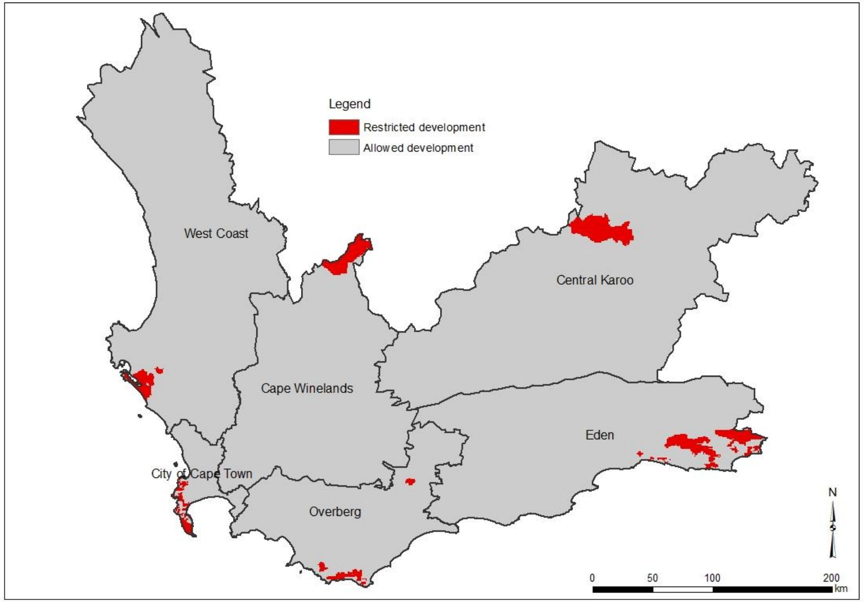
- Conversion elasticity gives an indication of conversion costs from one land use type to another & is assigned a value between 0 and 1
- A high elasticity value (close to 1) indicates a high cost of conversion and a consequently higher probability of the land use type to remain at the same location
- Conversion elasticities were based on analysis of land use history data.

Land Use	Elasticity Value
Vegetation	0.1
Plantations	0.1
Water	0.7
Bare	0.1
Cultivated	0.4
Built-Up	0.7
Mines	0.6

6. Spatial policies and restrictions

Spatial Policies & Restrictions
Urban & Coastal Edges
Critical Biodiversity Areas
6

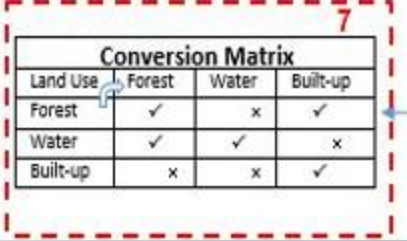
- Spatial policies and restrictions are defined by specific pixels that are not allowed to convert to any other land use type
- These restrictions aim to support biodiversity and ecosystem functioning and are in the form of political factors i.e. legislations, policies and plans at national and provincial levels
    - National Environmental Management Act 107 of 1998 (NEMA)
    - Biodiversity Act 10 of 2004 (NEMBA)
    - Western Cape Nature Conservation Board Act 15 of 1998
    - Spatial Development Frameworks



7. Conversion matrix

- The conversion matrix used in the Western Cape Province model was determined using previous trends.

  - Analysis of changes between 1990 & 2014 using land change modeller for ArcMap
  - Time elements e.g 12th year (year 2002) since this was the year when the forest exit policy was implemented and major changes in plantations began.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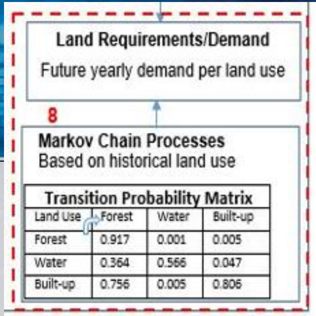
Conversion Matrix			
Land Use	Forest	Water	Built-up
Forest	✓	×	✓
Water	✓	✓	×
Built-up	×	×	✓

	Vegetation	Plantations	Water	Bare	Cultivated	Built-Up	Mines
Vegetation	1	0	0	0	1	1	1
Plantations	112	1	0	0	112	112	112
Water	1	0	1	0	1	0	0
Bare	1	0	0	1	1	1	1
Cultivated	0	0	0	1	1	1	1
Built-Up	0	0	0	0	0	1	0
Mines	0	0	0	1	0	0	1

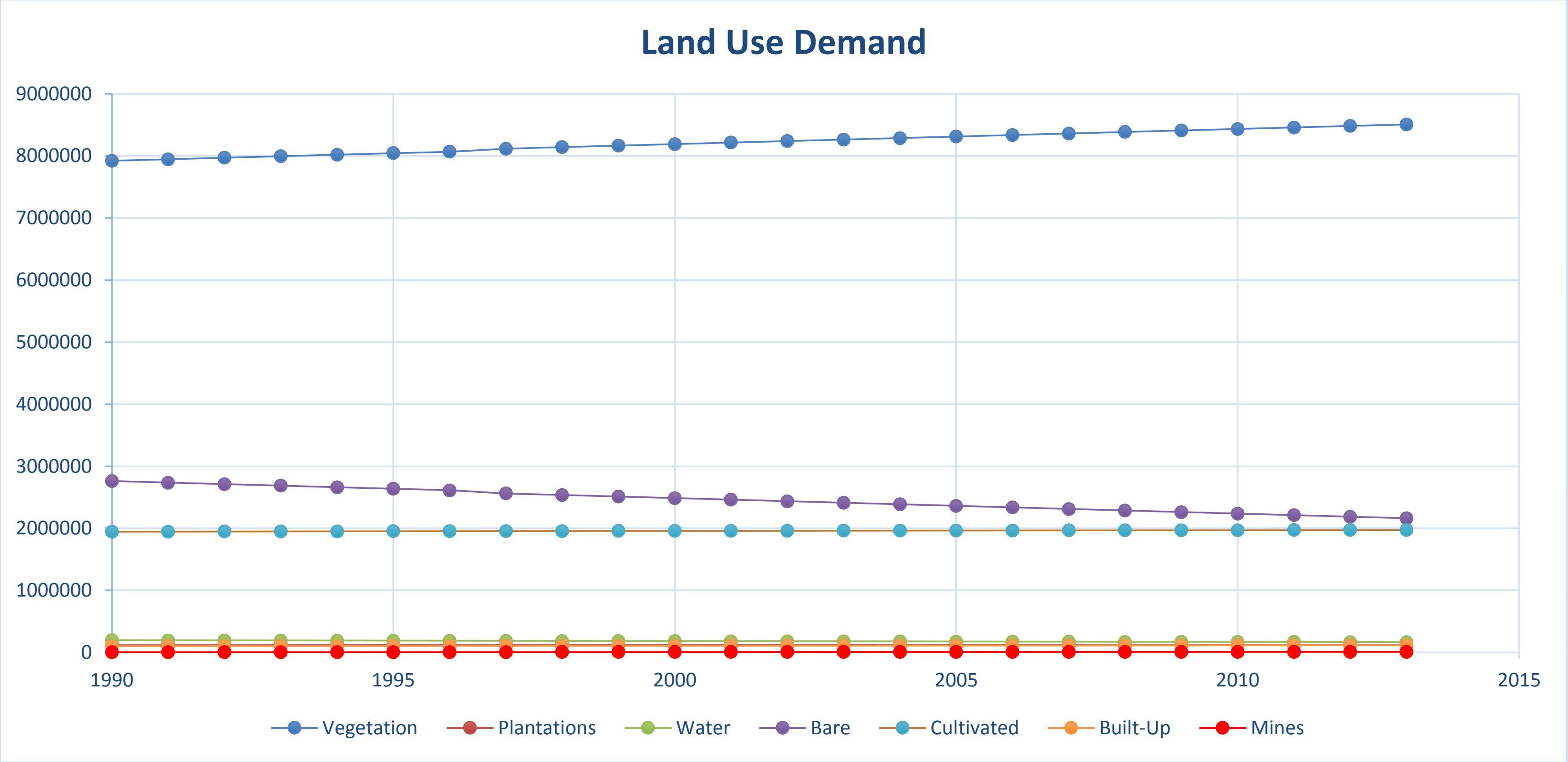
8. Land requirements/demand



Transition Probability Matrix			
Land Use	Forest	Water	Built-up
Forest	0.917	0.001	0.005
Water	0.364	0.566	0.047
Built-up	0.756	0.005	0.806

- Dyna CLUE requires a set of demand values per land use class
- Land use demands were determined based on the concept of Markov Chain Models.
- The Markov property in land use is when future use of land at time (t+1) can be predicted solely based on the immediately preceding state of land at time(t) and not the sequence
  - $P(X_{t+1} | X_0, \cdots, X_t) = P(X_{t+1} | X_t)$
- Calculation of future land use involved cross tabulation of land use for 1990 with 2014 using IDRISI analysis tools (in TerrSet).
- The result of the cross tabulation was a transition probability matrix
  - Each column of the probability matrix was multiplied by the number of cells corresponding land use in the 2014 image as shown in the equation below.
  - $X_{t+1} = P_{ij} \times X_t$, where $P_{ij} = \begin{pmatrix} P_{11} & P_{12} & P_{1n} \\ P_{22} & P_{22} & P_{2n} \\ P_{n1} & P_{n2} & P_{nn} \end{pmatrix}$

8. Land use demand



Putting it all together

- Land use allocation was based on the equation

$$Ptot_{i,t,lu} = Ploci_{,t,lu} + Pnbhi_{,t,lu} + Compt_{,lu} + ELASlu$$

- Where

Where $Ptot_{i,t,lu}$= the highest total probability calculated for every land use (*lu*) for every grid cell or location (*i*) at time (*t*) by summation of:

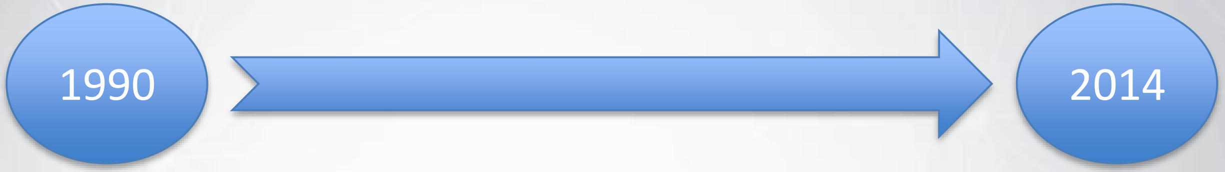
$Ploc_{i,t,lu}$ - Location suitability

$Pnbh_{i,t,lu}$- Neighbourhood functions

$Elas_{i,t,lu}$- Conversion settings

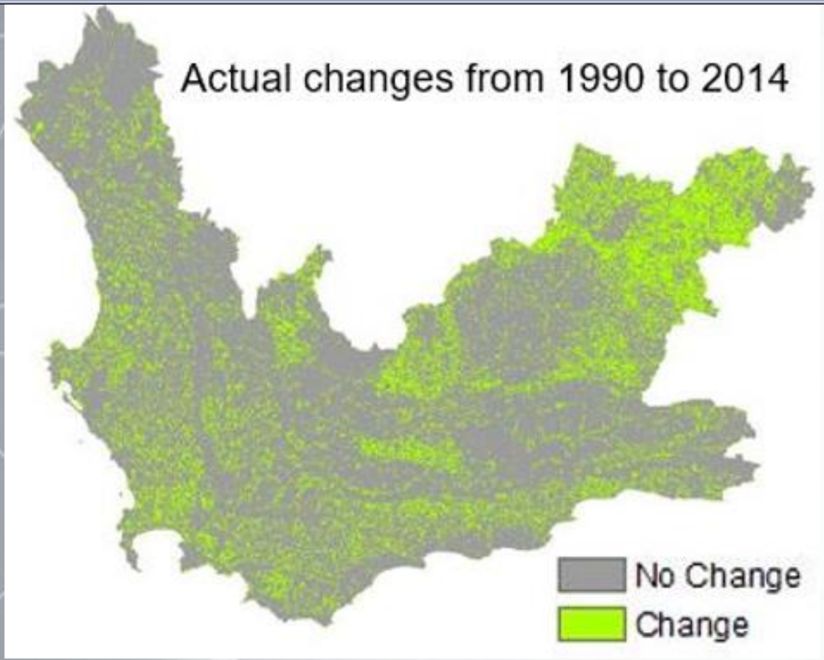
$Comp_{t,lu}$- Preference location

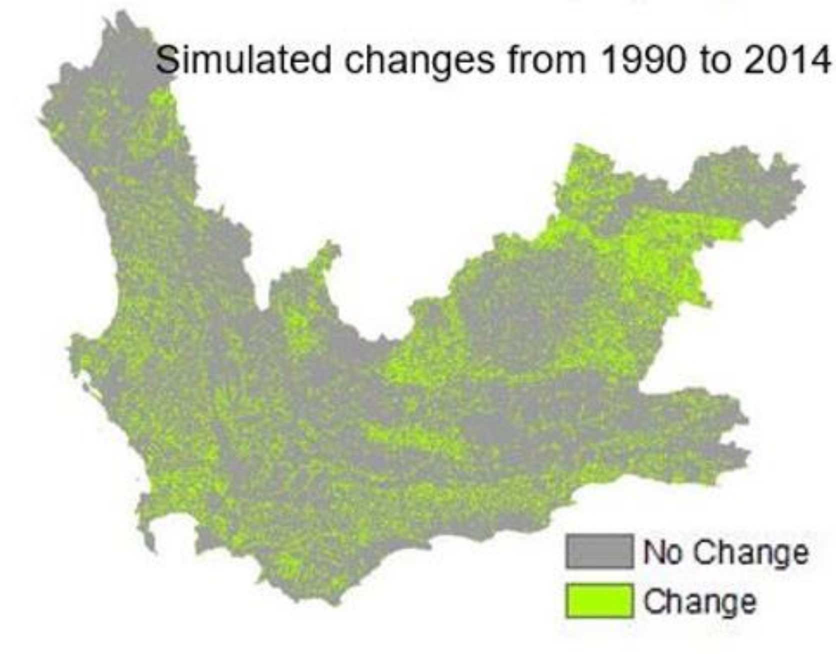
Dyna-Clue validation



- Validation of simulated map of the year 2014 was both Visually & Statistically
- Visual examination provides a quick way to examine spatial patterns &
- Statistical Validation to find out
  - How well the simulated map agrees with the reference map in terms of quantity of cells in each category?
  - How well the simulated map agrees with the reference map in terms of location of cells in each category.
- IDRISI Validation Statistics module was used to address these questions & examine the agreements between the simulated map created using Dyna-CLUE and reference map of 2014

Dyna-Clue validation





Visual analysis was done using IDRISI cross-tabulation with hard classification analysis

Dyna-Clue validation

- Kno, Klocation & Kstandard were used to examine the accuracy of the model.
- Kno indicates overall agreement and is used to evaluate success of the simulation.
- Klocation indicates agreement of the simulation and reference map in terms of location of each land use category.
- Kstandard represents Kappa Index of Agreement (KIA).
- For all Kappa statistics, 0% indicates that the level of agreement is due to chance and 100% indicates perfect agreement

Parameter	Value
Kno	0.9001
Klocation	0.8623
Kstandard	0.8528

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Value – Planning Support tool advising planners

- The simulation maps produced by Dyna-CLUE were in good agreement with the reference maps
- The validation results indicated that the Dyna-CLUE model can simulate LULC changes in the study area effectively
- The model can therefore be used to support future land use planning by incorporating policies which influence future land use, e.g. The Western Cape Urban and Coastal Edge Policy.
- LULC change models can be used to guide planners in making informed decisions
- Used to create a balance between growth pressures & preservation of the natural environment
- Quantify the effect of policies on land use patterns
- Offer a unique opportunity to study the system
- Produces scientific evidence to support policy debates
- Doesn't predict land use change but monitors and evaluates **'What-if'** scenarios

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Q&A
Thank you

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