Forrest Local Systems Model (FLSM) documentation

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Contents

Introduction

Forrest Local Systems Model (FLSM)

This document is the complete model documentation for the Forrest Local Systems Model, designed by Katrina Szetey, Enayat A. Moallemi, Brett A. Bryan, and the people of Forrest, Victoria, Australia. The model describes the system of Forrest in the context of sustainability achievement and the Sustainable Development Goals.

The model contains twelve *model sectors*, and this document is arranged with one chapter for each of those sectors. There is an overview of the sector, a stating of *problem definitions*, and *dynamic hypotheses* that explain how each problem has emerged. There is a description of the system conceptualisation for each sector, and a diagram of a conceptual model (excepting for the Climate Change sector). Data sources are listed and links to code and data in Github are provided. The final section of each chapter is a listing of every variable in the model sector, stating variable type, formula, units, and any assumptions and data that were used in formulating the variable. References are listed at the end of the document.

Chapter 1

Demographic sector

Forrest has been a regional Victorian township since 1890 and developed around the railway built to transport Otway timber and produce. The population has waxed and waned with its timber and forestry activities, at a peak in the 1960s. With tourism having replaced forestry as the primary economic activity in Forrest, this too may result in volatility in population (especially with the impact on tourism from the Covid-19 pandemic).

1.1 *Problem definition*

1. Between 2006 and 2016, Forrest experienced a 35% increase in population. Over that time, the number of children aged 0-14 decreased by 14% and people over 55 increased by 26%. The median age of a person living in Forrest has increased from 41 to 52. Forrest has a slowly increasing and ageing population, which will influence the needs of residents in the future.

Dynamic hypothesis: The population in Forrest is ageing due to in-migration of couples without children, and out-migration of young people for school and work after they finish high school. It is limited by housing availability and a lack of diversity in job opportunities.

2. With Forrest Primary School being the central school, pre-school, and childcare service for the community and neighbouring townships, it creates traffic for local businesses in town. It also works with many of the community groups in Forrest. If Forrest were to lose its primary school, there would be many negative knock-on effects causing harm to Forrest's future, such as out-migration of families seeking access to closer schools.

Dynamic hypothesis: The location of the primary school in Forrest makes it a central hub for the neighbouring communities. This brings in regular visitation from people outside of the township who may then go and patronise local businesses. If the school were to close, this regular visitation would likely slow down or cease, and have effects upon those businesses.

```
##         [,1] [,2] [,3] [,4]
## X2006   170   45  106   20
## X2011   238   40  165   35
## X2016   230   28  158   45
```

Population change in Forrest 2006–2016
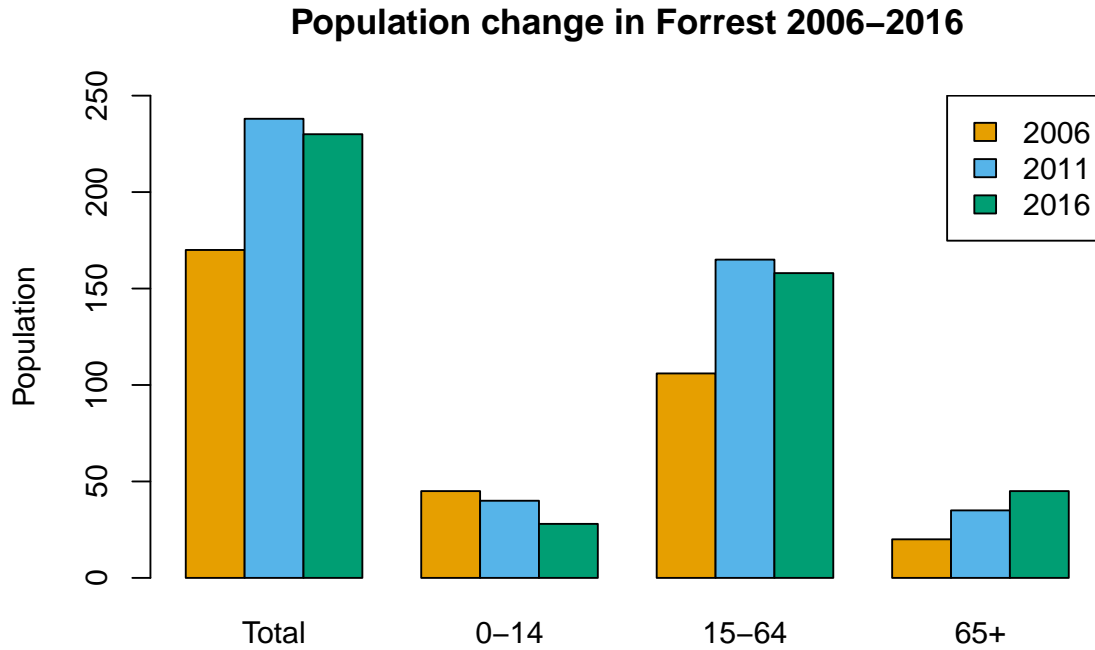
1.2 *System conceptualisation*

The population of Forrest is not large (230 at the 2016 Census) and is easiest to split into three main cohorts: children (0-15), adults (16-64), and retirees (65+).

Each of these cohorts has a migration and death rate specific to that cohort. There are ageing (maturation) rates between the 0-14 and 15-64 cohorts.

Migration rates for each cohort are influenced by different characteristics, some of which are modelled (e.g. job availability and housing) and some which are not but are captured within a reference (i.e. initial) migration rate.

School enrolments are made up of local children aged 4-10 (half of the 0-14 cohort) and from 'district' children (i.e., from surrounding townships that make up "Forrest and District").

Conceptual model

1.3 *Model formulation*

The structure of this model sector was based upon the model by Navarro and Tapiador (2019). Additional structure was added to incorporate the local school model within this sector, and for the different effects on migration rate.
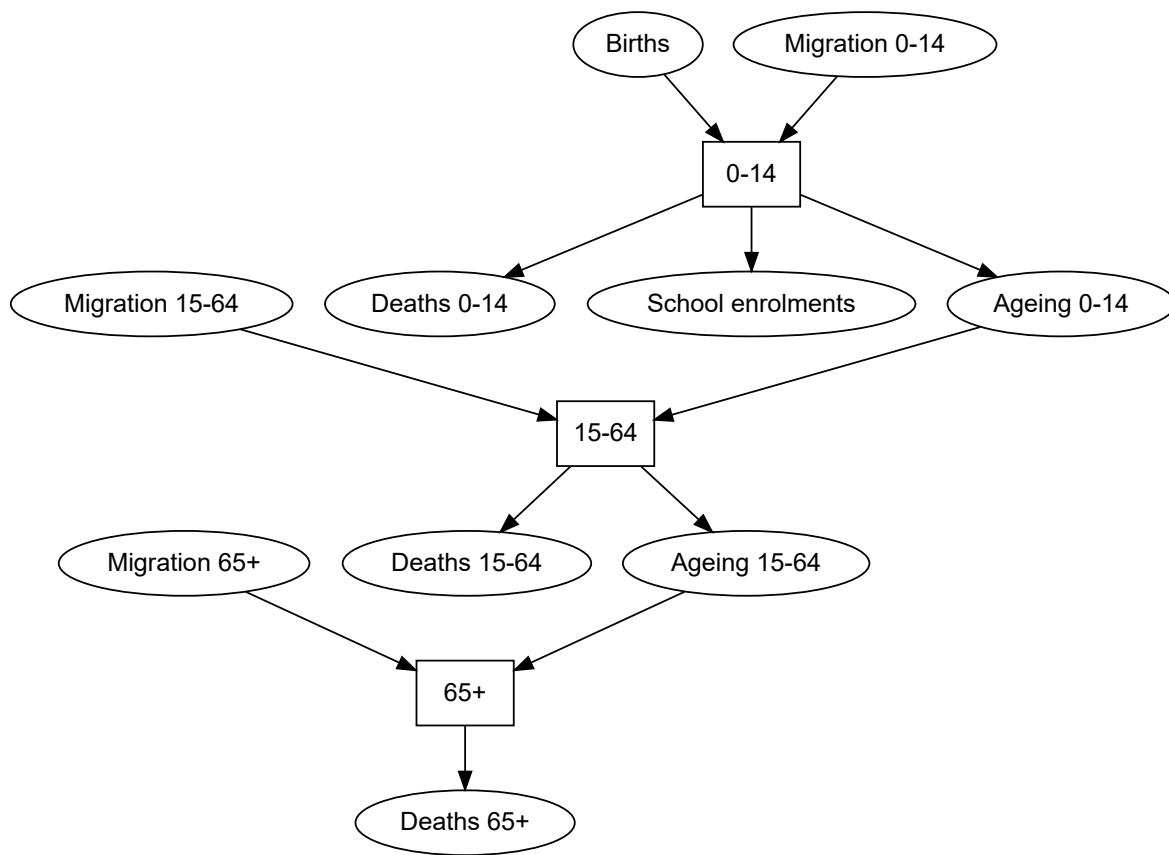
Figure 1.1: Population sector conceptual model

1.4   Data sources

Data for births. We used data for the Colac Otway LGA.

Census data for Forrest available here. Data for Forrest as a distinct location is only available for 2006, 2011 and 2016 censuses.

Data for deaths was obtained from ABS.stat, which has now been decommissioned and replaced by ABS Data Explorer. For death rates we used state-level data as this was the only way to get age-disaggregated death data.

1.5   *Equations*

0-14

Type: Stock
Formula: INTEG(Births + "In-out migration 0-14" - "Ageing 0-14" - "Deaths 0-14"), INITIAL = 45
Units: people
Assumptions/data: Intial value from 2006 census (earliest township-specific census data available)

Births

Type: Auxiliary (rate)
Formula: ("15-64" * fertility rate) / 2
Units: people/Year
Assumptions/data: Number of births per year. Assume half of the 15-64 cohort are able to bear children

fertility rate

Type: Constant
Formula: 0.07
Units: 1/Year
Assumptions/data: The number of live births per woman aged 15-64 each year. Derived from calibration of the model against data.

In-out migration 0-14

Type: Auxiliary (rate)
Formula: "migration rate 0-14" * "0-14"
Units: people/Year
Assumptions/data: net migration per year for 0-14 cohort

migration rate 0-14

Type: Auxiliary
Formula: "migration rate 15-64" 8 "reference migration rate 0-14"
Units: 1/Year
Assumptions/data: Migration rate of 0-14 cohort will be strongly influenced by the migration rate of their parents' cohort.

reference migration rate 0-14

Type: Constant
Formula: -4
Units: Dmnl
Assumptions/data: Derived from calibration of the model against data.

Deaths 0-14

Type: Auxiliary (rate)
Formula: "mortality rate 0-14" * "0-14"
Units: people/Year
Assumptions/data: Number of deaths per year of the 0-14 cohort

mortality rate 0-14

Type: Constant
Formula: 0.00031
Units: 1/Year
Assumptions/data: Derived from data aggregated at state level

Ageing 0-14

Type: Auxiliary (rate)
Formula: "0-14" / "maturation factor 0-14"
Units: people/Year
Assumptions/data: Number of population 0-14 moving to next age group

maturation factor 0-14

Type: Constant
Formula: 14
Units: Year
Assumptions/data: The length of time a person can spend in the cohort before maturing into the next (max age - min age)

15-64

Type: Stock
Formula: INTEG("Ageing 0-14" + "In-out migration 15-64" - "Ageing 15-64" - "Deaths 15-64"), INITIAL = 106
Units: people
Assumptions/data: Intial value from 2006 census (earliest township-specific census data available)

In-out migration 15-64

Type: Auxiliary (rate)
Formula: "migration rate 15-64" * "15-64"
Units: people/Year
Assumptions/data: Net migration per year for the 15-64 cohort

migration rate 15-64

Type: Auxiliary
Formula: "reference 15-64 migration rate" * effect of job availability on migration * effect of housing on migration * job availability unit conversion factor
Units: 1/Year
Assumptions/data: Potentially problematic if the reference rate is negative

reference 15-64 migration rate

Type: Constant
Formula: 0.011
Units: 1/Year
Assumptions/data: Migration rates calibrated against from Otway SA2 data: the average rate for 2017-2019

job availability unit conversion factor

Type: Constant
Formula: 1
Units: people * Year/job
Assumptions/data: This is a unit correction variable

effect of job availability on migration

Type: Auxiliary
Formula: ("job vacancies (agriculture) filled externally"+"job vacancies (other) filled externally"+"job vacancies (tourism) filled externally") / "working-age population"
Units: job/(people * Year)
Assumptions/data: The job to labour force ratio

effect of housing on migration

Type: Auxiliary
Formula: IF THEN ELSE(housing supply demand ratio > 1, (IF THEN ELSE("social housing supply/demand ratio" = 0, (average house price/reference average house price) * housing supply demand ratio, (average house price/reference average house price) * housing supply demand ratio * "social housing supply/demand ratio")), 1)
Units: Dmnl
Assumptions/data: As demand goes up, supply goes down and the ratio also goes down, and the prices go up. Additionally, if the housing supply/demand ratio is less than 1, then there aren't enough houses available for new families to move in unless existing families move out, so the effect of housing on net migration is zero (this also affects all other effect variables on migration).

Deaths 15-64

Type: Auxiliary (rate)
Formula: "15-64" * "mortality rate 15-64"
Units: people/Year
Assumptions/data: Number of deaths in a year for the 15-64 cohort

mortality rate 15-64

Type: Constant
Formula: 0.00156
Units: 1/Year
Assumptions/data: Constant derived from data aggregated at state level

Ageing 15-64

Type: Auxiliary (rate)
Formula: "15-64" / "maturation factor 15-64"
Units: people/Year
Assumptions/data: Number of population 15-64 moving to next age group

maturation factor 15-64

Type: Constant
Formula: 49
Units: Year
Assumptions/data: Cohort residence time max age - min age

65+

Type: Stock
Formula: INTEG("Ageing 15-64" + "In-out migration 65+" - "Deaths 65+"), INITAL = 20

Units: people
Assumptions/data: Inital value taken from 2006 Census data (earliest township-specific census data available)

Deaths 65+

Type: Auxiliary (rate)
Formula: "65+" * "mortality rate 65+"
Units: people/Year
Assumptions/data:

mortality rate 65+

Type: Constant
Formula: 0.03694
Units: 1/Year
Assumptions/data: Derived from data aggregated at state level

In-out migration 65+

Type: Auxiliary (rate)
Formula: "migration rate 65+" * "65+"
Units: people/Year
Assumptions/data: Net migration per year

migration rate 65+

Type: Auxiliary
Formula: "reference 65+ migration rate" * effect of housing on migration
Units: 1/Year
Assumptions/data:

reference migration rate 65+

Type: Constant
Formula: -0.022
Units: 1/Year
Assumptions/data: Derived from calibration of the model against data.

total population

Type: Auxiliary
Formula: "0-14" + "15-64" + "65+"
Units: people
Assumptions/data: sum of all population cohorts

School Enrolments

Type: Stock
Formula: INTEG(New enrolments - Outgoing school cohort), INITIAL = 31
Units: people
Assumptions/data: Inital data 31 students enrolled in 2019

New enrolments

Type: Auxiliary (rate)
Formula: ((district 0 to 14 cohort + "0-14")/cohort time * enrolment ratio)
Units: people/Year
Assumptions/data: To prevent 're-enrolment' of the same student each year, divide the cohort values by 'cohort time' so each enrolment is new.

cohort time

Type: Constant
Formula: 7
Units: Dmnl
Assumptions/data: To prevent 're-enrolment' of the same student each year, divide the cohort values by 7 so each enrolment is new.

enrolment ratio

Type: Constant
Formula: 0.5
Units: 1/Year
Assumptions/data: Only half of the 0-14 cohort will enrol at the local primary school (age 4-10)

district 0-14 cohort

Type: Auxiliary
Formula: INTEGER (RANDOM NORMAL (0, 76, 38, 1, 0))
Units: people
Assumptions/data: Selecting from a normal distrbution to obtain values for enrolments external to Forrest's population. The parameters are min = 0, max = 76, mean = 38, SD = 1, based on populations from the townships in the district.

number of childcare enrolments

Type: Auxiliary
Formula: INTEGER ((district 0 to 14 cohort + "0-14") * 0.25)
Units: people
Assumptions/data: Arbitrary value of one quarter of 0-14 cohort (have no data for this)

district kids' parents cohort

Type: Auxiliary
Formula: INTEGER ((district 0 to 14 cohort * 0.75) * 1.5)
Units: people
Assumptions/data: Multiply by 1.5 to capture both parents with some wiggle room for single parents etc Multiply by 0.75 to take into account 0.5 enrolment ratio (ie, only half of cohort are of primary school age) and 0.25 for childcare

Outgoing school cohort

Type: Auxiliary (rate)
Formula: School Enrolments / maturation of school students
Units: people/Year
Assumptions/data:

maturation of school students

Type: Constant
Formula: 7
Units: people
Assumptions/data: School age cohort tenure time (max age - min age)

Chapter 2

Land Use sector

There are four major types of land use in Forrest: Agriculture (incorporating crop farming and livestock farming), Housing, Forest, and Protected (national park). As an initial condition, we assume that agricultural land which is >40 hectares in size is classified as Farming Zone, and is thus protected from land use change (although the Forrest community would like this zoning modified so that Farming Zone land within the township could have more than one residence built on it). Housing land is primarily within the township. This link discusses the different rural planning zones.

2.1 *Problem definition*

1. Agricultural land fertility is a driver of agricultural business profits. In general, the world needs to use less additional fertilisers to improve the health of ecosystems. Forrest is a hub for regenerative agriculture – where the land is improved as a result of agriculture, rather than stripped of nutrients as in traditional farming.

Dynamic hypothesis: Regenerative agriculture limits the use of fertilisers, which reduces agricultural runoff into waterways, improving local water quality and the environment generally. It also boosts agricultural profits.

2. There is not currently a great deal of land use change in Forrest. Agricultural businesses and housing demand are the greatest pressures on land use.

Dynamic hypothesis: Residents have suggested petitioning Council to change the laws restricting multiple buildings on agricultural land (the '40ha' rule), which may increase land transfer between ag and housing, and an increase in agricultural business may increase land transfer between bush and agriculture.

2.2 *System conceptualisation*

The stock of land in Forrest is fixed (approx 12,000 hectares). We assume four land use types - Agriculture, Forest, Housing and Protected. Protected land can only be increased from

Forest land, and once it is there it remains there. Housing can be increased from Agriculture or Farming but once land is Housing land, it remains there. Agriculture and Forest land can cycle between the two.

Housing land has pressures from housing demand.   Agriculture land has pressure from agricultural businesses.

Fertilisation intensity and consumption does not affect the rest of the model.

Conceptual model
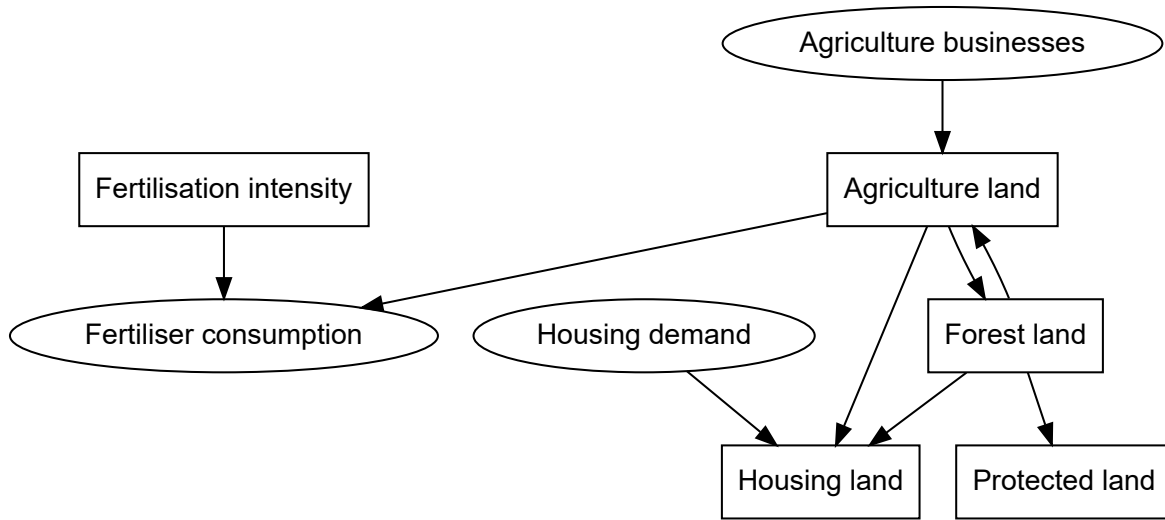
Figure 2.1: Land use sector conceptual model

2.3   *Model formulation*

The land use sector was inspired by the FeliX model Rydzak et al. (2013).   There are four stocks, one for each of the land use types, and a small structure to model fertiliser consumption. Another small structure is present to set maximum values for each land use stock. Each transfer rate between land stocks is affected by two variables: a 'change' variable (FeliX characterises this as a value which measures the 'need' for change between land use types, so we represent this as a pressure for change); and an 'allocation time' variable, which represents the amount of time it takes to change from one land use to another.

2.4 Data sources

Data and code are available at https://github.com/pelagikat/Local-SDGs-systems-model

Land use data was obtained from the Victorian Land Use Information System (VLUIS). This is a series of seven spatial datasets with land use classes which we clipped to the extent of the Forrest township. The land use classes were categorised into the model variables as follows:

Housing:
Detached Home
Residential Rural / Rural Lifestyle (0.4 to 20 Ha)
Vacant Residential Home Site / Surveyed Lot
Vacant Residential Rural / Rural Lifestyle (0.4 to 20ha)

Forest:
Creek Reserve (Fresh Water)
Forest Reserves - Public
Reserved Land
Softwood Plantation
Nature Reserve Area Water Supply
Unclassified Private Land
Native Hardwood (standing timber)

Agriculture:
Mixed farming and grazing (generally more than 20ha)
Livestock Production (Dairy Cattle)
Livestock Production (Beef Cattle)
Market Garden - Vegetables (generally less than 20ha plantings)

Protected:
National Park - Land
Conservation Area - Public

2.5 *Equations*

Agricultural to Housing transfer rate

Type: Rate
Formula: MAX(0, MIN (max land housing, agriculture to housing change * (Agriculture Land - agriculture protected land) / agriculture to housing land allocation time))
Units: ha/Year
Assumptions: The amount of agriculture land will not drop below the value of the agriculture protected land variable

Agriculture Land

Type: Stock
Formula: INTEG (Forest to Agriculture transfer rate - Agricultural to Housing transfer rate

- Agriculture to Forest transfer rate), INITIAL = INIT agricultural land
Units: hectare
Assumptions:

agriculture protected land

Type: Constant
Formula: 1533.8
Units: hectare
Assumptions: LU 2008 data: all farming and livestock land use >40ha as equivalent to
Farming Zone (see here)

agriculture to forest change

Type: Auxiliary
Formula: ("number of businesses (agriculture)" * average land per agricultural business) /
Agriculture Land
Units: Dmnl
Assumptions:

agriculture to forest land allocation time

Type: Constant
Formula: 2.5
Units: Year
Assumptions: Calibrated against data

Agriculture to Forest transfer rate

Type: Rate
Formula: MAX(0, MIN (max land forest, agriculture to forest change * (Agriculture Land
- agriculture protected land) / agriculture to forest land allocation time))
Units: ha/Year
Assumptions:

agriculture to housing change

Type: Auxiliary
Formula: (average land per house * housing demand) / Housing Land
Units: Dmnl
Assumptions:

agriculture to housing land allocation time

Type: Constant
Formula: 500
Units: Year
Assumptions: Calibrated against data

average land per agricultural business

Type: Constant
Formula: 17.3
Units: hectare/structure
Assumptions: Value derived from Land Use spatial dataset

average land per house

Type: Auxiliary
Formula: (land per house LDRZ + land per house RLZ) / 2
Units: hectares/structure
Assumptions: Mean value of Low Density Residential Zone and Rural Living Zone

Fertilisation Intensity

Type: Stock
Formula: INTEG (Fertilisation intensity change rate), INITIAL = INIT Fertilisation Intensity
Units: TonNutrient/(ha*Year)
Assumptions: Intensity of fertilisation practices per ha per year.

fertilisation intensity change

Type: Constant
Formula: -0.1
Units: Dmnl
Assumptions: Calibrated against data

Fertilisation intensity change rate

Type: Stock
Formula: Fertilisation Intensity * fertilisation intensity change / time to adjust fertilisation intensity
Units: TonNutrient/(Year * Year * ha)
Assumptions:

fertiliser consumption

Type: Auxiliary
Formula: (Fertilisation Intensity * Agriculture Land)
Units: TonNutrient/Year
Assumptions:

Forest Land

Type: Stock
Formula: INTEG (Agriculture to Forest transfer rate - Forest to Agriculture transfer rate - Forest to Housing transfer rate - Forest to Protected transfer rate), INITIAL = INIT forest land
Units: hectare
Assumptions:

forest to agriculture change

Type: Constant
Formula: 0.4
Units: Dmnl
Assumptions: Calibrated against data

forest to agriculture land allocation time

Type: Constant
Formula: 19
Units: Year
Assumptions: Calibrated against data

Forest to Agriculture transfer rate

Type: Auxiliary
Formula: MAX (0, MIN (max land ag, forest to agriculture change * (Forest Land) / (forest to agriculture land allocation time)))
Units: ha/Year
Assumptions:

forest to housing change

Type: Auxiliary
Formula: (average land per house * housing demand) / Housing Land
Units: Dmnl
Assumptions:

forest to housing land allocation time

Type: Constant
Formula: 500
Units: Year
Assumptions: Calibrated against data

Forest to Housing transfer rate

Type: Auxiliary
Formula: MAX(0, MIN (max land housing, forest to housing change * (Forest Land) / forest to housing land allocation time))
Units: ha/Year
Assumptions:

forest to protected allocation time

Type: Constant
Formula: 542
Units: Year
Assumptions: Calibrated against data

forest to protected change

Type: Constant
Formula: 25
Units: Dmnl
Assumptions: Calibrated against data

Forest to Protected transfer rate

Type: Auxiliary
Formula: MAX(0, MIN (max land protected, forest to protected change * (Forest Land / forest to protected allocation time)))
Units: hectare/Year
Assumptions:

Housing Land

Type: Stock
Formula: INTEG(Agricultural to Housing transfer rate + Forest to Housing transfer rate), INITIAL = INIT housing land
Units: hectare
Assumptions:

INIT agricultural land

Type: Constant
Formula: 3549.5
Units: hectare
Assumptions: Land area in year 2006 (earliest data available).

INIT Fertilisation Intensity

Type: Constant
Formula: 0.254
Units: TonNutrient/(ha*Year)
Assumptions: In 2008, farming in Cogangamite used 0.254 tons/ha/year

INIT forest land

Type: Constant
Formula: 4436
Units: hectare
Assumptions: Land area in year 2008 (earliest data available).

INIT housing land

Type: Constant
Formula: 57.3
Units: hectare
Assumptions: Land area in year 2008 (earliest data available).

INIT protected land

Type: Constant
Formula: 1283.7
Units: hectare
Assumptions: Land area in year 2006 (earliest data available).

land per house LDRZ

Type: Constant
Formula: 0.82
Units: hectares/structure
Assumptions: Low Density Residential Zone with a lot size of a minimum of 0.4 ha in areas
with no reticulated sewerage. See here. Mean value of LDRZ lot size is 0.82 hectares

land per house RLZ

Type: Constant
Formula: 7.3
Units: hectares/structure
Assumptions: Rural Living Zone specifies a lot size of at least 2 hectares and provides opportunities for some rural uses to occur. See here. Mean value of RLZ lot size is 7.3 hectares

max land

Type: Constant
Formula: 12041
Units: hectares/Year
Assumptions: Limiting factor for land stock expansion

max land ag

Type: Auxiliary
Formula: max land-Forest Land-Housing Land-Protected Land
Units: hectares
Assumptions:

max land forest

Type: Auxiliary
Formula: max land-Agriculture Land-Housing Land-Protected Land
Units: hectares
Assumptions:

max land housing

Type: Auxiliary
Formula: max land-Agriculture Land-Forest Land-Protected Land
Units: hectares
Assumptions:

max land protected

Type: Auxiliary
Formula: max land-Agriculture Land-Forest Land-Housing Land
Units: hectares
Assumptions:

Protected Land

Type: Stock
Formula: INTEG (Forest to Protected transfer rate), INITIAL = INIT protected land
Units: hectare
Assumptions:

time to adjust fertilisation intensity

Type: Constant
Formula: 4
Units: Year
Assumptions: Calibrated against data

total land

Type: Auxiliary
Formula: Agriculture Land + Forest Land + Housing Land + Protected Land
Units: hectares
Assumptions: Mean total land area 2008-2017 = 12427 hectares

Chapter 3

Housing sector

There are multiple intertwined issues to do with housing in Forrest. Supply cannot meet demand; tourism is reducing the available residential housing stock; development is hamstrung by existing waste management requirements. The supply issue is driving up house prices, and residents on lower incomes are being driven out because of cost.

3.1 *Problem definition*

1. Colac Otway Shire have designated that Forrest remain a low growth community and estimated a release of 3.5 permits per year for residential land development. There has only been one permit issued per year since 2011, so development has been below expected levels. There is scope for greater development in the future.

Dynamic hypothesis: Building permits are not being granted by Council because potential developments cannot meet septic tank regulations. New wastewater infrastructure is required before any significant development may occur.

2. Cost and availability of housing is an issue. Tourism businesses purchase properties for accommodation, removing them from the pool of available residential housing. This in turn drives up prices due to scarcity of supply. Other potential new residents also struggle to find housing, and anecdotally must wait until existing residents move away or travel.

Dynamic hypothesis: Lack of housing development due to wastewater issues is constraining the housing and tourism accommodation supply.

3. Median house prices have increased 188% since 2009, while median rents have increased by 30%. This puts a number of residents into mortgage or rent stress.

Dynamic hypothesis: House prices are artificially high in much of Victoria (property market bubble), and the housing supply issue additionally inflates prices. Social housing (hypothetical) may relieve rent stress.

3.2   *System conceptualisation and formulation*

There are two uses for housing in Forrest; residential and tourism. The central housing stock structure is built with Housing Supply, which has construction and demolition as flows. The Housing Supply stock drains into Tourism Housing and Residential Housing stocks. Housing demand is influenced by total population and Number of Tourists. Separate from this structure is the Social Housing Supply structure, which is a scenario variable and not active in the BAU scenario as there is currently no social housing in Forrest.

Leading off the Residential Housing stock is the housing stress structures, split into mortgage stress and rent stress, defined as when housing costs (rent or mortgage payments) exceed 30% of household income. The income and housing costs were split into three levels; low, medium and high.
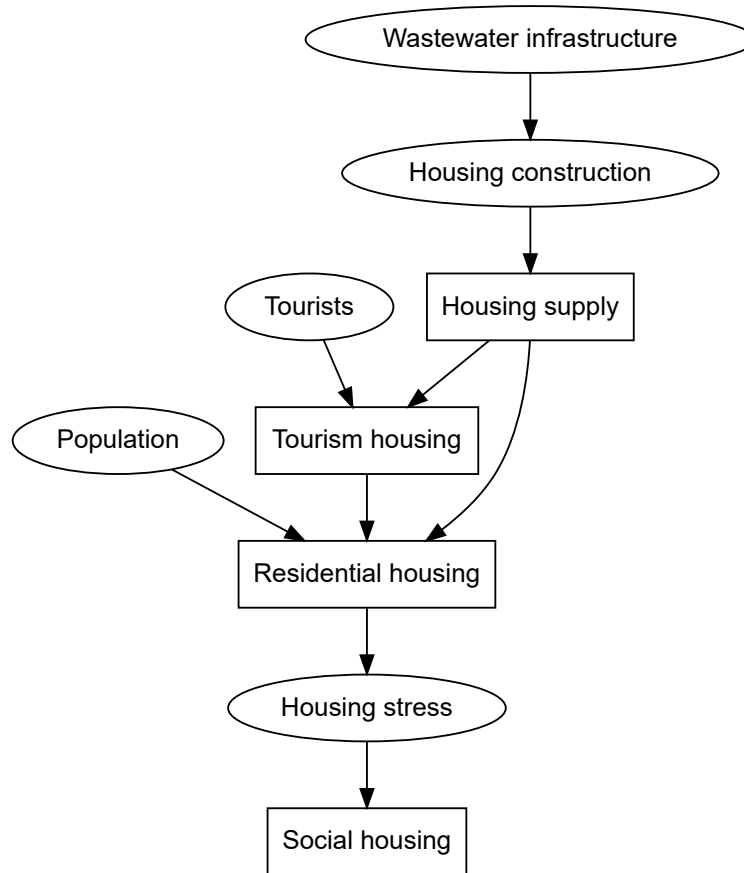
Conceptual model

Figure 3.1: Housing sector conceptual model

3.3   Data sources

Data is available at https://github.com/pelagikat/Local-SDGs-systems-model

Data was obtained from ABS Table Builder for housing tenure, Victorian Land Use Information System (VLUIS) for numbers of properties, and Aus Property Report for house sale and rental prices.

3.4 *Equations*

"30 percent"

Type: Constant
Formula: 0.3
Units: fraction
Assumptions: Housing stress is defined as housing costs that exceed 30% of household income.

Annual Mortgage Cost By Income Group[low income]

Type: Stock
Formula: INTEG (Mortgage rate change[low income]), INITIAL = 16176
Units: dollars
Assumptions: Initial value 2017 loan repayment value annualised (see data in Github)

Annual Mortgage Cost By Income Group[mid income]

Type: Stock
Formula: INTEG (Mortgage rate change[mid income]), INITIAL = 18876)
Units: dollars
Assumptions: Initial value 2017 loan repayment value annualised (see data in Github)

Annual Mortgage Cost By Income Group[high income]

Type: Stock
Formula: INTEG (Mortgage rate change[high income]), INITIAL = 48288
Units: dollars
Assumptions: Initial value 2017 loan repayment value annualised (see data in Github)

Annual Rent Cost By Income Group[low income]

Type: Stock
Formula: INTEG (Rent rate change[low income]), INITIAL = 11964
Units: dollars
Assumptions: Initial value 2017 rent payment value annualised (see data in Github)

Annual Rent Cost By Income Group[mid income]

Type: Stock
Formula: INTEG (Rent rate change[mid income]), INITIAL = 13524
Units: dollars
Assumptions: Initial value 2017 rent payment value annualised (see data in Github)

Annual Rent Cost By Income Group[high income]

Type: Stock
Formula: = INTEG (Rent rate change[high income]), INITIAL = 13776
Units: dollar
Assumptions: Initial value 2017 rent payment value annualised (see data in Github)

average house price

Type: Auxiliary
Formula: effect of supply demand ratio on house prices * reference average house price
Units: dollars
Assumptions:

average size of household

Type: Constant
Formula: 2
Units: people/structure
Assumptions: From ABS census data (consistent for 2011 and 2016)

consumer price index

Type: Constant
Formula: 1.009
Units: Dmnl
Assumptions: CPI is the standard Australian inflationary measure. CPI rose 0.9% in 2020, data from Australian Bureau of Statistics.

Current time

Type: Constant
Formula: 2021
Units: Year
Assumptions: This variable is present to induce a delay to the model run year (2021).

effect of supply demand ratio on house prices

Type: Auxiliary
Formula: table for effect of supply demand ratio on house prices (housing supply demand ratio)
Units: Dmnl
Assumptions: Idea derived from Özbaş et al. (2014)

fraction of mortgaged houses

Type: Constant
Formula: 0.19
Units: fraction
Assumptions: From ABS Census data (see data in Github)

fraction of rented houses

Type: Constant
Formula: 0.09
Units: fraction
Assumptions: From ABS Census data (see data in Github)

housing build delay

Type: Constant
Formula: 2
Units: Year
Assumptions: it takes 2 years from approval to build completion

Housing construction

Type: Auxiliary
Formula: IF THEN ELSE (Wastewater availability > 0 :AND: Housing Land > housing land occupied, housing discrepancy delay, 0)
Units: structure/Year
Assumptions: New construction will not occur until wastewater infrastructure has been built. Additionally, the amount of housing land must be greater than the amount of land occupied already by houses.

housing demand

Type: Auxiliary
Formula: (number of desired residential households + number of desired tourist houses)
Units: structure
Assumptions:

Housing demolition

Type: Auxiliary
Formula: housing demolition rate * Housing Supply
Units: structure/Year
Assumptions:

housing demolition rate

Type: Constant
Formula: 0
Units: fraction/Year
Assumptions: For a BAU scenario, no houses are being constructed or demolished.

housing discrepancy

Type: Auxiliary
Formula: MIN(housing demand-(Residential Housing + Tourism Housing + Social Housing Supply), 140)
Units: structure
Assumptions: The formula assumes the number of houses will not go below the number recorded in the 2016 census (140)

housing discrepancy delay

Type: Auxiliary
Formula: -(DELAY3(housing discrepancy/housing transfer delay, housing build delay + Current time))
Units: structure/Year
Assumptions: This variable introduces a delay between the housing discrepancy occurring and the construction occurring in response.

housing land occupied

Type: Auxiliary
Formula: minimum average land per house * (Residential Housing + Tourism Housing + Social Housing Supply)
Units: hectares
Assumptions: Housing will not achieve a density less than *minimum average land per house*

Housing Supply

Type: Stock
Formula: INTEG (Housing construction - Housing demolition - Residential housing allocation rate - Tourism housing allocation rate), INITIAL = 100)

Units: structure
Assumptions: Initial value from 2006 census data

housing supply demand ratio

Type: Auxiliary
Formula: (Residential Housing + Tourism Housing + Social Housing Supply) / housing demand
Units: Dmnl
Assumptions:

housing transfer delay

Type: Constant
Formula: 2
Units: Year
Assumptions: This variable is the delay time for transfer between *Housing Supply* and one of the other housing stock variables.

INIT annual mortgage cost[low income]

Type: Constant
Formula: 29588
Units: dollars
Assumptions: Using data from 2020 house prices and ATO industry benchmark interest (see data in Github)

INIT annual mortgage cost[mid income]

Type: Constant
Formula: 49972
Units: dollars
Assumptions: Using data from 2020 house prices and ATO industry benchmark interest (see data in Github)

INIT annual mortgage cost[high income]

Type: Constant
Formula: 57252
Units: dollars
Assumptions: Using data from 2020 house prices and ATO industry benchmark interest (see data in Github)

INIT annual rent cost[low income]

Type: Constant
Formula: 13520
Units: dollars
Assumptions: Using data from 2020 rent prices (see data in Github)

INIT annual rent cost[mid income]

Type: Constant
Formula: 18720
Units: dollars
Assumptions: Using data from 2020 rent prices (see data in Github)

INIT annual rent cost[high income]

Type: Constant
Formula: 23400
Units: dollars
Assumptions: Using data from 2020 rent prices (see data in Github)

land per house LDRZ

Type: Constant
Formula: 0.82
Units: hectares/structure
Assumptions: Low Density Residential Zone with a lot size of a minimum of 0.4ha in areas
with no reticulated sewerage link. Mean value of LDRZ mean lot size is 0.82 hectares

land per house RLZ

Type: Constant
Formula: 7.3
Units: hectares/structure
Assumptions: Rural Living Zone specifies a lot size of at least 2 hectares and provides
opportunities for some rural uses to occur link. Mean value of RLZ mean lot size is 7.3
hectares

minimum average land per house

Type: Constant
Formula: 1.2
Units: ha
Assumptions: Rural Living Zone has minimum 2ha and Low Density Residential Zone has
minimum 0.4ha; 1.2ha is the average min of the two.

Mortgage rate change[low income]

Type: Auxiliary
Formula: consumer price index * INIT annual mortgage cost[low income] / Time
Units: dollar/Year
Assumptions: mortgage repayments will increase each year in line with CPI

Mortgage rate change[mid income]

Type: Auxiliary
Formula: consumer price index * INIT annual mortgage cost[mid income] / Time
Units: dollar/Year
Assumptions: mortgage repayments will increase each year in line with CPI

Mortgage rate change[high income]

Type: Auxiliary
Formula: consumer price index * INIT annual mortgage cost[high income] / Time
Units: dollar/Year
Assumptions: mortgage repayments will increase each year in line with CPI

mortgage stress

Type: Auxiliary
Formula: IF THEN ELSE(Annual Mortgage Cost By Income Group > "30 percent" * income
values, number of mortgaged households by income cohort, 0)
Units: structure
Assumptions: This variable is split (subscripted) across 15 income cohorts (negative, nil,
$1-$149, $150-$299, $300-$399, $400-$499, $500-$649, $650-$799, $800-$999, $1,000-$1,249,
$1,250-$1,499, $1,250-$1,499, $1,750-$1,999, $2,000-$2,999, $3,000 or more)

number of desired residential households

Type: Auxiliary
Formula: total population / average size of household
Units: structure
Assumptions:

number of desired tourist houses

Type: Auxiliary
Formula: Number Of Tourists / (average size of household * number of times each tourist
house occupied per year)
Units: structure
Assumptions: Assuming that tourist occupancy is even across the year

number of households under mortgage stress

Type: Auxiliary
Formula: sum(mortgage stress[Income!])
Units: structure
Assumptions: This variable sums up all of the households experiencing mortgage stress from the 15 income cohorts

number of households under rent stress

Type: Auxiliary
Formula: sum(rent stress[Income!])
Units: structure
Assumptions: This variable sums up all of the households experiencing mortgage stress from the 15 income cohorts

number of mortgaged households

Type: Auxiliary
Formula: fraction of mortgaged houses * Residential Housing
Units: structure
Assumptions: the fraction of mortgaged houses remains constant

number of mortgaged households by income cohort

Type: Auxiliary
Formula: INTEGER (number of mortgaged households * income distribution by income cohort)
Units: structure
Assumptions: This variable is split (subscripted) across 15 income cohorts (negative, nil, $1-$149, $150-$299, $300-$399, $400-$499, $500-$649, $650-$799, $800-$999, $1,000-$1,249, $1,250-$1,499, $1,250-$1,499, $1,750-$1,999, $2,000-$2,999, $3,000 or more)

number of rented households

Type: Auxiliary
Formula: (fraction of rented houses * Residential Housing) - Social Housing Supply
Units: structure
Assumptions: the fraction of rented houses remains constant; assume that social housing will withdraw households from the rental market

number of rented households by income cohort

Type: Auxiliary
Formula: number of rented households * income distribution by income cohort

Units: structure
Assumptions: This variable is split (subscripted) across 15 income cohorts (negative, nil, $1-$149, $150-$299, $300-$399, $400-$499, $500-$649, $650-$799, $800-$999, $1,000-$1,249, $1,250-$1,499, $1,250-$1,499, $1,750-$1,999, $2,000-$2,999, $3,000 or more)

number of times each tourist house occupied per year

Type: Constant
Formula: 52
Units: 1/Year
Assumptions: Assume each tourist house is occupied all weekends of the year

reference average house price

Type: Constant
Formula: 685000
Units: dollar
Assumptions: data from https://www.aupropertyreport.com/suburb-report/forrest-3236-vic/ (see data in Github)

Rent rate change[low income]

Type: Auxiliary
Formula: consumer price index * INIT annual rent cost[low income] / Time
Units: dollar/Year
Assumptions: rent will increase each year in line with CPI

Rent rate change[mid income]

Type: Auxiliary
Formula:=consumer price index * INIT annual rent cost[mid income] / Time
Units: dollar/Year
Assumptions: rent will increase each year in line with CPI

Rent rate change[high income]

Type: Auxiliary
Formula: consumer price index * INIT annual rent cost[high income] / Time
Units: dollar/Year
Assumptions: rent will increase each year in line with CPI

rent stress

Type: Auxiliary
Formula: IF THEN ELSE (Annual Rent Cost By Income Group > "30 percent" * income

values, number of rented households by income cohort, 0)
Units: structure
Assumptions: This variable is split (subscripted) across 15 income cohorts (negative, nil,
$1-$149, $150-$299, $300-$399, $400-$499, $500-$649, $650-$799, $800-$999, $1,000-$1,249,
$1,250-$1,499, $1,250-$1,499, $1,750-$1,999, $2,000-$2,999, $3,000 or more)

Residential Housing

Type: Stock
Formula: INTEG (Residential housing allocation rate), INITIAL $= 67$
Units: structure
Assumptions: Initial value from 2006 census data

Residential housing allocation rate

Type: Auxiliary
Formula: MIN((total population / average size of household) / housing transfer delay,
Housing Supply / housing transfer delay)
Units: structure/Year
Assumptions: This is the rate variable which transfers the housing supply stock to the
residential housing stock

social housing build delay

Type: Constant
Formula: 2
Units: Year
Assumptions: it takes two years to build a new social house

Social housing construction

Type: Auxiliary
Formula: IF THEN ELSE (Wastewater availability > 0, social housing discrepancy * social
housing scenario switch /social housing build delay, 0)
Units: structure/Year
Assumptions: this is a scenario variable that is switched off depending on the social housing
scenario switch variable

social housing demand

Type: Auxiliary
Formula: number of households under rent stress + (sum of people below poverty line /
average size of household)
Units: structure
Assumptions:

social housing discrepancy

Type: Auxiliary
Formula: social housing demand - Social Housing Supply
Units: structure
Assumptions:

social housing scenario switch

Type: Auxiliary
Formula: 0
Units: Dmnl
Assumptions: variable which switches social housing on or off

Social Housing Supply

Type: Stock
Formula: INTEG (Social housing construction), INITIAL = 0
Units: structure
Assumptions: no social housing in Forrest at start

"social housing supply/demand ratio"

Type: Auxiliary
Formula: Social Housing Supply/social housing demand
Units: Dmnl
Assumptions:

table for effect of supply demand ratio on house prices

Type: Lookup
Formula: ([(0,0.8)-(2,1.4)],(0,1.34),(0.25,1.31),(0.5,1.27),(0.75,1.17),(1,1),(1.25,0.94),(1.5,0.89),(1.75,0.87),(2,0.8
Units: Dmnl
Assumptions: data from Özbaş et al. (2014)

Tourism Housing

Type: Stock
Formula: INTEG (Tourism housing allocation rate), INITIAL = 33)
Units: structure
Assumptions: Difference between initial values for Housing Supply and Residential Housing

Tourism housing allocation rate

Type: Auxiliary
Formula: MIN ((Number Of Tourists / (average size of household * number of times each tourist house occupied per year)) / housing transfer delay, Housing Supply / housing transfer delay)
Units: structure/Year
Assumptions:

Chapter 4

Economy sector

4.1 *Problem definition*

1. The development of the Mountain Bike Trail system began the transition to a primarily tourism-based economy. This transition was enhanced with private investment in local small businesses catering to both tourists and local residents. The expansion of the tourism industry is hampered by limited housing supply for both accommodation and employees, and by ageing and failing infrastructure.

Dynamic hypothesis: There is a tension between tourism, housing and the economy, especially while new housing development is stymied. Residents resent tourism for its impact on housing and housing prices, while also benefitting from its positive economic impact. New wastewater, enabling housing development, would ease this tension.

2. Agriculture is still a major part of Forrest and District. There are local dairy and beef farms, mushroom growers. Community members have noted the future viability of these as an uncertainty.

Dynamic hypothesis: Climate change will have a diminishing effect on agricultural profit in the long term. Land fertility may be able to combat this effect, especially through the impact of regenerative agriculture.

3. The local community are happy to have tourism in Forrest, except where there is conflict with housing availability, but have expressed a desire for diversification of the economy so there are other options for employment growth within the town

Dynamic hypothesis: Local small businesses are dominated by tourism/ hospitality and farming. Other sectors (e.g. accountants, hairdressers, tradespeople etc) are constrained by a lack of housing and office space, and poor internet.

4.2 *System conceptualisation and model formulation*

The economy sector is separated into three economic sub-sectors: agriculture, tourism and other. 'Other' encompasses all other economic activity in Forrest that is not agriculture or tourism. Each sub-sector is modelled by an identical structure which represents the Cobb-Douglas production function (Angulo et al. (2015)):

$$Y = AL^{\beta}K^{\alpha}$$

where Y = total production (value of goods produced) each year, A = productivity factor, L = labour input, K = capital input, and α and β are output elasticities of capital and labour, respectively.

Additionally, a multiplier structure was added to each sub-sector which measured the effect of sub-sector specific impacts, e.g., climate change on agriculture, internet service on 'other'.

Conceptual model
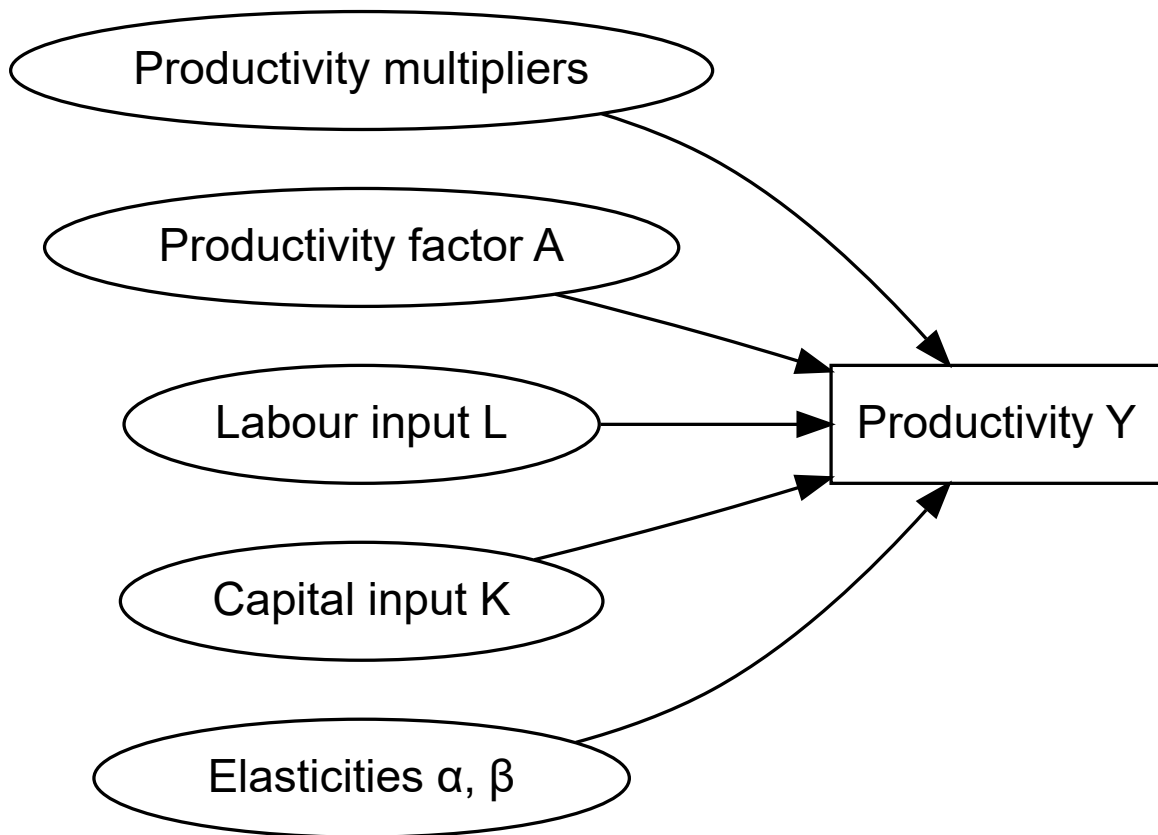
Figure 4.1: Economy sector conceptual model

4.3 Data sources

Data are available at https://github.com/pelagikat/Local-SDGs-systems-model

Data was obtained from Australian Bureau of Statistics Counts of Australian Businesses and Census Table Builder

For purposes of modelling, when data refers to bin sizes (e.g., income ranges), the median value is used to represent the whole bin (e.g., for an income range of $0 - $50,000, the value of $25,000 is used for all members of that data bin).

4.4 *Equations*

agriculture productivity multiplier

Type: Auxiliary
Formula: regenerative agriculture multiplier * net climate change impact on economy
Units: Dmnl
Assumptions:

"average jobs per business (agriculture)"

Type: Constant
Formula: 1.45
Units: jobs/structure/Year
Assumptions: Data from ABS (see data in Github)

"average jobs per business (other)"

Type: Constant
Formula: 3.66
Units: job/structure/Year
Assumptions: Data from ABS (see data in Github)

"average jobs per business (tourism)"

Type: Constant
Formula: 3.71
Units: job/structure/Year
Assumptions: Data from ABS (see data in Github)

"business income distribution (agriculture)"

Type: Constant
Formula: 0-$50k = 0.3
$50k-$100k = 0.1
$100k-$200k = 0.1
$200k-$500k = 0.3
$500k-$2m = 0.1
$2m-$5m = 0
Units: structure*Year/dollars
Assumptions: This variable is split (subscripted) across 6 income cohorts. See data in Github.

"business income distribution (other)

Type: Constant
Formula: 0-$50k = 0.4
$50k-$100k = 0.2
$100k-$200k = 0.2
$200k-$500k = 0.2
$500k-$2m = 0.1
$2m-$5m = 0
Units: structure*Year/dollars
Assumptions: This variable is split (subscripted) across 6 income cohorts. See data in Github.

"business income distribution (tourism)

Type: Constant
Formula: 0-$50k = 0.1
$50k-$100k = 0.1
$100k-$200k = 0.1
$200k-$500k = 0.3
$500k-$2m = 0.3
$2m-$5m = 0.1
Units: structure*Year/dollars
Assumptions: This variable is split (subscripted) across 6 income cohorts. See data in Github.

capital input ag

Type: Constant
Formula: 2767.84
Units: dollars/Year
Assumptions: This value was calibrated against data. See data in Github.

capital input other

Type: Constant
Formula: 138131
Units: dollars/Year
Assumptions: This value was calibrated against data. See data in Github.

capital input tourism

Type: Constant
Formula: 928124
Units: dollars/Year
Assumptions: This value was calibrated against data. See data in Github.

effect of internet on other sector business

Type: Auxiliary
Formula: internet service performance / (maximum speed per connection / Fixed Wireless Towers)
Units: Dmnl
Assumptions: That poor internet performance has a negative impact on other sector businesses (which are principally home-based businesses in professional industries)

effect of non-local school parents participating in Forrest's economy

Type: Auxiliary
Formula: ((district kids' parents cohort / "15-64") + 1) * "non-local retail demand"
Units: Dmnl
Assumptions: A multiplier which quantifies the additional traffic in Forrest as a result of transporting children to school and the effect it may have on e.g., retail business.

elasticity q1 ag

Type: Constant
Formula: 0.45
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

elasticity q1 other

Type: Constant
Formula: 0.2
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

elasticity q1 tourism

Type: Constant
Formula: 0.26
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

elasticity q2 ag

Type: Constant
Formula: 0.01
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

elasticity q2 other

Type: Constant
Formula: 0.74
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

elasticity q2 tourism

Type: Constant
Formula: 0.73
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

fraction of land under regenerative agriculture

Type: Constant
Formula: 0.05
Units: fraction
Assumptions: Actual value unknown; can be a scenario variable

fraction of residents in paid work

Type: Constant
Formula: Male = 0.344
Female = 0.424
Units: fraction
Assumptions: Data from ABS, this variable is disaggregated by gender. ABS only collects
data on male/female gender so is not truly representative of gender. See data in Github.

fraction of residents not in paid work

Type: Constant
Formula: Male = 0.072
Female = 0.08
Units: fraction
Assumptions: Data from ABS, this variable is disaggregated by gender. ABS only collects data on male/female gender so is not truly representative of gender. See data in Github.

fraction of unemployed residents

Type: Constant
Formula: Male = 0.024
Female = 0.056
Units: fraction
Assumptions: Data from ABS, this variable is disaggregated by gender. ABS only collects data on male/female gender so is not truly representative of gender. See data in Github.

INIT ag productivity

Type: Constant
Formula: 1.875e+06
Units: dollars/Year
Assumptions: Data from ABS, see data in Github

INIT other productivity

Type: Constant
Formula: 1.175e+06
Units: dollars/Year
Assumptions: Data from ABS, see data in Github

INIT tourism productivity

Type: Constant
Formula: 25000
Units: dollars/Year
Assumptions: Data from ABS, see data in Github

"job vacancies (agriculture) filled externally"

Type: Auxiliary
Formula: IF THEN ELSE("labour demand (agriculture)" > labour input ag, "labour demand (agriculture)" - labour input ag, 0)
Units: job/Year

Assumptions: This variable represents the number of jobs within Forrest that require non-local employees

"job vacancies (other) filled externally"

Type: Auxiliary
Formula: IF THEN ELSE("labour demand (other)" > labour input other, "labour demand (other)" - labour input other, 0)
Units: job/Year
Assumptions: This variable represents the number of jobs within Forrest that require non-local employees

"job vacancies (tourism) filled externally"

Type: Auxiliary
Formula: IF THEN ELSE("labour demand (tourism)" > labour input tourism, "labour demand (tourism)" - labour input tourism, 0)
Units: job/Year
Assumptions: This variable represents the number of jobs within Forrest that require non-local employees

"labour demand (agriculture)"

Type: Auxiliary
Formula: "number of businesses (agriculture)" * "average jobs per business (agriculture)"
Units: job/Year
Assumptions:

"labour demand (other)"

Type: Auxiliary
Formula: "average jobs per business (other)"*"number of businesses (other)"
Units: job/Year
Assumptions:

"labour demand (tourism)"

Type: Auxiliary
Formula: "number of businesses (tourism)" * "average jobs per business (tourism)"
Units: job/Year
Assumptions:

labour force

Type: Auxiliary
Formula: Male = residents in paid work[Male] + unemployed residents[Male]
Female = residents in paid work[Female] + unemployed residents[Female]
Units: people
Assumptions: This variable is disaggregated by gender. ABS only collects data on male/female gender so is not truly representative of gender.

labour input ag

Type: Auxiliary
Formula: sum(labour force [Gender!]) * "reference jobs fraction (agriculture)"
Units: job/Year
Assumption: This variable re-aggregates the gender disaggregated variables

labour input other

Type: Auxiliary
Formula: sum(labour force [Gender!]) * "reference jobs fraction (other)"
Units: job/Year
Assumption: This variable re-aggregates the gender disaggregated variables

labour input tourism

Type: Auxiliary
Formula: sum(labour force [Gender!]) * "reference jobs fraction (tourism)"
Units: job/Year
Assumption: This variable re-aggregates the gender disaggregated variables

"non-local retail demand"

Type: Constant
Formula: 1.2
Units: Dmnl
Assumptions: Actual value unknown; can be a scenario variable

"number of businesses (agriculture)"

Type: Auxiliary
Formula: INTEGER(sum ("number of businesses in income bracket (agriculture)"[Business Income!]))
Units: structure
Assumptions: this variable sums the agriculture businesses in all income brackets to arrive at an integer value

"number of businesses (other)"

Type: Auxiliary
Formula: INTEGER(sum ("number of businesses in income bracket (other)"[Business Income!]))
Units: structure
Assumptions: this variable sums the other businesses in all income brackets to arrive at an integer value

"number of businesses (tourism)"

Type: Auxiliary
Formula: INTEGER(sum ("number of businesses in income bracket (tourism)"[Business Income!]))
Units: structure Assumptions: this variable sums the tourism businesses in all income brackets to arrive at an integer value

"number of businesses in income bracket (agriculture)"

Type: Auxiliary
Formula: 0-$50k = ("business income distribution (agriculture)"["0-$50k"] * Total Agricultural Productivity) / 25000
$50k-$100k = ("business income distribution (agriculture)"["$50k-$100k"] * Total Agricultural Productivity) / 75000
$100k-$200k = ("business income distribution (agriculture)"["$100k-$200k"] * Total Agricultural Productivity) / 150000
$200k-$500k = ("business income distribution (agriculture)"["$200k-$500k"] * Total Agricultural Productivity) / 350000
$500k-$2m = ("business income distribution (agriculture)"["$500k-$2m"] * Total Agricultural Productivity) / 1.25e+06
$2m-$5m = ("business income distribution (agriculture)"["$2m-$5m"] * Total Agricultural Productivity) / 3.5e+06
Units: structure
Assumptions: This variable is split (subscripted) across 6 income cohorts. Median values used for each for income bracket divisor.

"number of businesses in income bracket (other)"

Type: Auxiliary
Formula: 0-$50k = ("business income distribution (other)"["0-$50k"] * Total Agricultural Productivity) / 25000
$50k-$100k = ("business income distribution (other)"["$50k-$100k"] * Total Agricultural Productivity) / 75000
$100k-$200k = ("business income distribution (other)"["$100k-$200k"] * Total Agricultural Productivity) / 150000
$200k-$500k = ("business income distribution (other)"["$200k-$500k"] * Total Agricultural

Productivity) / 350000
$500k-$2m = ("business income distribution (other)"["$500k-$2m"] * Total Agricultural Productivity) / 1.25e+06
$2m-$5m = ("business income distribution (other)"["$2m-$5m"] * Total Agricultural Productivity) / 3.5e+06
Units: structure
Assumptions: This variable is split (subscripted) across 6 income cohorts. Median values used for each for income bracket divisor.

"number of businesses in income bracket (tourism)"

Type: Auxiliary
Formula: 0-$50k = ("business income distribution (tourism)"["0-$50k"] * Total Agricultural Productivity) / 25000
$50k-$100k = ("business income distribution (tourism)"["$50k-$100k"] * Total Agricultural Productivity) / 75000
$100k-$200k = ("business income distribution (tourism)"["$100k-$200k"] * Total Agricultural Productivity) / 150000
$200k-$500k = ("business income distribution (tourism)"["$200k-$500k"] * Total Agricultural Productivity) / 350000
$500k-$2m = ("business income distribution (tourism)"["$500k-$2m"] * Total Agricultural Productivity) / 1.25e+06
$2m-$5m = ("business income distribution (tourism)"["$2m-$5m"] * Total Agricultural Productivity) / 3.5e+06
Units: structure
Assumptions: This variable is split (subscripted) across 6 income cohorts. Median values used for each for income bracket divisor.

other productivity multiplier

Type: Auxiliary
Formula: effect of internet on other sector business * "effect of non-local school parents participating in Forrest's economy"
Units: Dmnl
Assumptions:

productivity factor ag

Type: Constant
Formula: 145.7
Units: 1/job
Assumptions: calibrated against data. See data in Github.

productivity factor other

Type: Constant
Formula: 700
Units: 1/job
Assumptions: calibrated against data. See data in Github.

productivity factor tourism

Type: Constant
Formula: 421.7
Units: 1/job
Assumptions: calibrated against data. See data in Github.

profitability increase from regenerative agriculture

Type: Auxiliary
Formula: RA coefficient*Time +RA intercept
Units: Dmnl
Assumptions: Linear model from NSW data - Ogilvy et al. (2018)

RA coefficient

Type: Constant
Formula: -0.034
Units: Dmnl
Assumptions: Calculated from data. See Github for data and derivation of linear model.

RA intercept

Type: Constant
Formula: 69.8
Units: Dmnl
Assumptions: Calculated from data. See Github for data and derivation of linear model.

Rate of productivity change ag

Type: Auxiliary
Formula: agriculture productivity multiplier * productivity factor ag * (capital input ag ^ elasticity q1 ag) * (labour input ag ^ elasticity q2 ag)
Units: dollars/(Year*Year)
Assumptions: the Cobb-Douglas production function

Rate of productivity change other

Type: Auxiliary
Formula: other productivity multiplier * productivity factor other * (capital input other ^ elasticity q1 other) * (labour input other ^ elasticity q2 other)
Units: dollars/(Year*Year)
Assumptions: the Cobb-Douglas production function

Rate of productivity change tourism

Type: Auxiliary
Formula: tourism productivity multiplier * productivity factor tourism * (capital input tourism ^ elasticity q1 tourism) * (labour input tourism ^ elasticity q2 tourism)
Units: dollars/(Year*Year)
Assumptions: the Cobb-Douglas production function

"reference jobs fraction (agriculture)"

Type: Constant
Formula: 0.18
Units: job/people/Year
Assumptions: calibrated against data. See data in Github.

"reference jobs fraction (other)"

Type: Constant
Formula: 0.22
Units: job/people/Year
Assumptions: calibrated against data. See data in Github.

"reference jobs fraction (tourism)"

Type: Constant
Formula: 0.279638
Units: job/people/Year
Assumptions: calibrated against data. See data in Github.

regenerative agriculture multiplier

Type: Auxiliary
Formula: 1 + (fraction of land under regenerative agriculture * profitability increase from regenerative agriculture)
Units: Dmnl
Assumptions: calibrated against data. See data in Github.

residents in paid work

Type: Auxiliary
Formula: Male = fraction of residents in paid work[Male] * "working-age population"
Female = fraction of residents in paid work[Female] * "working-age population"
Units: people Assumptions: Data from ABS, disaggregated by gender (only two categories),
"Employed, worked x-time" categories. See data in Github.

residents not in paid work

Type: Auxiliary
Formula: Male = fraction of residents not in paid work[Male] * "working-age population"
Female = fraction of residents not in paid work[Female] * "working-age population"
Units: people Assumptions: Data from ABS, disaggregated by gender (only two categories),
ABS "Away From Work" category. See data in Github.

Total Agricultural Productivity

Type: Stock
Formula: INTEG (Rate of productivity change ag), INITIAL = INIT ag productivity
Units: dollars/Year
Assumptions:

Total Other Productivity

Type: Stock
Formula: INTEG (Rate of productivity change other), INITIAL = INIT other productivity
Units: dollars/Year
Assumptions:

total productivity

Type: Auxiliary
Formula: Total Agricultural Productivity + Total Other Productivity + Total Tourism
Productivity
Units: dollar/Year
Assumptions: Sum of all total productivity stocks

Total Tourism Productivity

Type: Stock
Formula: INTEG (Rate of productivity change tourism), INITAL = INIT tourism
productivity)
Units: dollars/Year
Assumptions:

tourism productivity multiplier

Type: Auxiliary
Formula: Number Of Tourists / normal tourist numbers
Units: Dmnl
Assumptions:

unemployed residents

Type: Auxiliary
Formula: Male = fraction of unemployed residents[Male] * "working-age population"
Female = fraction of unemployed residents[Female] * "working-age population"
Units: people
Assumptions: Data from ABS, disaggregated by gender (only two categories), looking for x-time work" categories. See data in Github.

"unemployment (agriculture)"

Type: Auxiliary
Formula: IF THEN ELSE("labour demand (agriculture)" < labour input ag, labour input ag - "labour demand (agriculture)", 0)
Units: job/Year
Assumptions:

"unemployment (other)"

Type: Auxiliary
Formula: IF THEN ELSE("labour demand (other)" < labour input other, labour input other - "labour demand (other)", 0)
Units: job/Year
Assumptions:

"unemployment (tourism)"

Type: Auxiliary
Formula: IF THEN ELSE("labour demand (tourism)" < labour input tourism, labour input tourism - "labour demand (tourism)", 0)
Units: job/Year
Assumptions

"working-age population"

Type: Auxiliary
Formula: "15-64"
Units: people

Assumptions: this is a renaming of the "15-64" age cohort to make clear it is explicitly the population of Forrest who are of working age.

Chapter 5

Tourism sector

5.1 *Problem definition*

1. Forrest's major tourism drawcards are its beautiful natural environment and the Mountain Bike Trails. It follows that these are also its vulnerabilities.

Dynamic hypothesis: Tourist numbers are affected by the incidence of bushfire either locally or elsewhere in Victoria, by flooding, and by the quality of local infrastructure (including the MTB trails and wastewater).

2. Because tourism accommodation is primarily sourced from residential housing stock, neither residential housing nor dedicated tourism accommodation is able to be built because of the wastewater problem.

Dynamic hypothesis: The current state of wastewater in Forrest impacts the development of housing and tourism accommodation, thus impacting growth in tourist numbers.

3. Forrest is virtually inaccessible unless you have a car, thus is excluded from tourists who do not drive.

Dynamic hypothesis: The frequency of bus services in Forrest is inadequate for residents, let alone to support tourist movement. An increase in bus frequency would enable growth in tourist numbers.

5.2 *System conceptualisation*

Tourism already exists as part of the Economy sector, so here we are not modelling the finances of tourism, but instead we want to explore what effect external factors may have on tourist numbers.
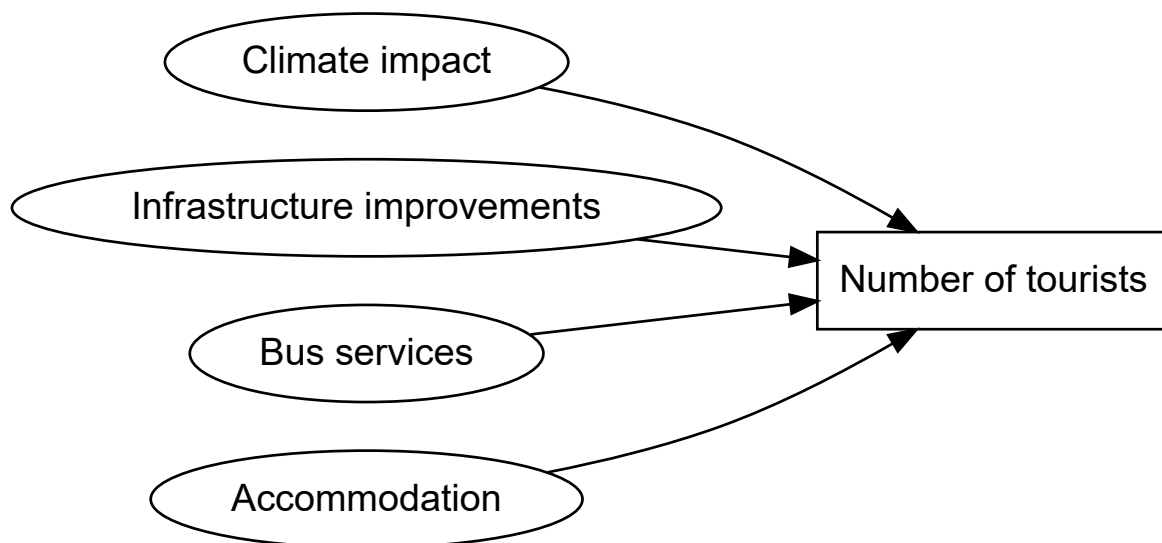
Figure 5.1: Tourism sector conceptual model

Conceptual model

5.3 *Model formulation*

Here our stock variable is the Number of Tourists, with a flow of Rate of tourist increase. Affecting that flow rate are climate disasters, tourism accommodation, infrastructure improvement, and bus frequency.

5.4 *Equations*

effect of future improvements to infrastructure

Type: Constant
Formula: 1
Units: Dmnl
Assumptions: Scenario variable to model unknown changes

effect of MTB Trails improvements

Type: Auxiliary
Formula: IF THEN ELSE(MTB trails improvements availability > 0, 1.5, 1)
Units: Dmnl
Assumptions: Cost benefit analysis of mountain bike trail improvements: increase of 25,000 cycling tourists per annum from 24,000 (doubling). Assume that only half of these stay in Forrest.

effect of wastewater

Type: Auxiliary
Formula: IF THEN ELSE(Wastewater availability > 0, 2, 1)
Units: Dmnl
Assumptions: Assume a doubling of tourists from improved wastewater infrastructure

impact of bus frequency on tourist numbers

Type: Auxiliary
Formula: IF THEN ELSE(tourist bus frequency > 1 :AND: Time > 2006, (1 + ((tourist bus frequency * tourist bus capacity) / Number Of Tourists)) , 1)
Units: Dmnl
Assumptions: modelling for tourist buses that do not currently exist.

impact of climate on tourism

Type: Auxiliary
Formula: 1- ((1 - bushfire risk fraction) + probability of catastrophic bushfire elsewhere in Victoria - annual probability of flood)
Units: Dmnl
Assumptions: local bushfire risk and flooding is a negative impact, bushfire elsewhere is a positive impact

impact of tourism infrastructure improvements on tourist numbers

Type: Auxiliary
Formula: effect of MTB Trails improvements * effect of wastewater * effect of future improvements to infrastructure
Units: Dmnl
Assumptions: that infrastructure improvements will each have an independent effect on tourist numbers

initial tourist increase

Type: Auxiliary
Formula: RAMP(100, 2000, 2006)
Units: people/Year
Assumptions: tourism did not commence in Forrest in earnest until 2006, so this is a value to show a small increase in tourist numbers over the period 2000 - 2006.

normal tourist numbers

Type: Constant
Formula: 3432
Units: people/Year
Assuming 33 houses in Forrest used for tourism (2006 census unoccupied dwellings), at an average of 3 night stays, this means Forrest's houses can support a max of 6000 tourists per year. Make an assumption that houses will only be occupied on weekends (for "normal" numbers), multiplied by two for two-people-per-house stays: 33 * 52 * 2 approx = 3232 people per year

Number Of Tourists

Type: Stock
Formula: INTEG (Rate of tourist increase), INITIAL = 0)
Units: people/Year
Assumptions:

probability of catastrophic bushfire elsewhere in Victoria

Type: Constant
Formula: 0.1
Units: Dmnl
Assumptions: Assume 1 catastrophic bushfire every ten years elsewhere in Victoria (prior data: 1983, 1998, 2009, 2020)

Rate of tourist increase

Type: Auxiliary
Formula: IF THEN ELSE (Time > 2006 :AND: tourist house discrepancy > 0, tourist house discrepancy * average size of household * tourist numbers multiplier, initial tourist increase)
Units: people/Year
Assumptions: An if-then-else formula to represent the pre- and post-2006 states of tourism in Forrest

tourist bus capacity

Type: Constant
Formula: 25
Units: people/bus
Assumptions: Assume same size bus as public transport

tourist bus frequency

Type: Constant
Formula: 0
Units: bus/Year
Assumptions: Currently no buses run; this can be a scenario variable

tourist house discrepancy

Type: Auxiliary
Formula: (Tourism Housing * number of times each tourist house occupied per year - (Number Of Tourists / average size of household))
Units: structure/Year
Assumptions: a supply vs demand variable

tourist numbers multiplier

Type: Auxiliary
Formula: SMOOTH3 (impact of tourism infrastructure improvements on tourist numbers * impact of climate on tourism * impact of bus frequency on tourist numbers , 10)
Units: Dmnl

Assumptions: A smoothing function to show a gradual impact change over time from various impact inputs

Chapter 6

Biodiversity sector

6.1 *Problem definition*

Forrest is located in a biodiversity hotspot, and the Great Otway National Park provides protection for some of that biodiversity. The local residents are proud of their pristine surroundings and dedicated to ensuring they remain so. Climate change and potential bushfire impact are both threats to the local environment, as well as any land use change which reduces the amount of bushland. Fertiliser runoff from agriculture is also a potential danger.

Dynamic hypothesis: Climate change and land use change are the fundamental drivers for biodiversity risk. They both increases bushfire risk and land use change reduces habitat. Indigenous cultural burning may be a way to mitigate biodiversity loss (by healing Country) but has a significant lead-in/preparation time.

6.2 *System conceptualisation and model formulation*

Species richness is the critical variable in the biodiversity sector. Species richness can be affected by cultural burning, land use change, invasive species and climate change. Land use change is modelled using a species area curve,

$$S = cA^z$$

where Z = 0.86 (derived from data), A = land area, c = constant, and S = number of species.

Land use for biodiversity purposes is modelled as a stock and flow structure to accurately represent the impact of climate damage on land area for biodiversity. We assume that agricultural land does not support biodiversity for simplicity.

6.3 Data sources

Data are available at https://github.com/pelagikat/Local-SDGs-systems-model

These data represent only those species that have data on the Atlas of Living Australia and have passed a data cleaning process. It likely represents about 40-50% of terrestrial vertebrate
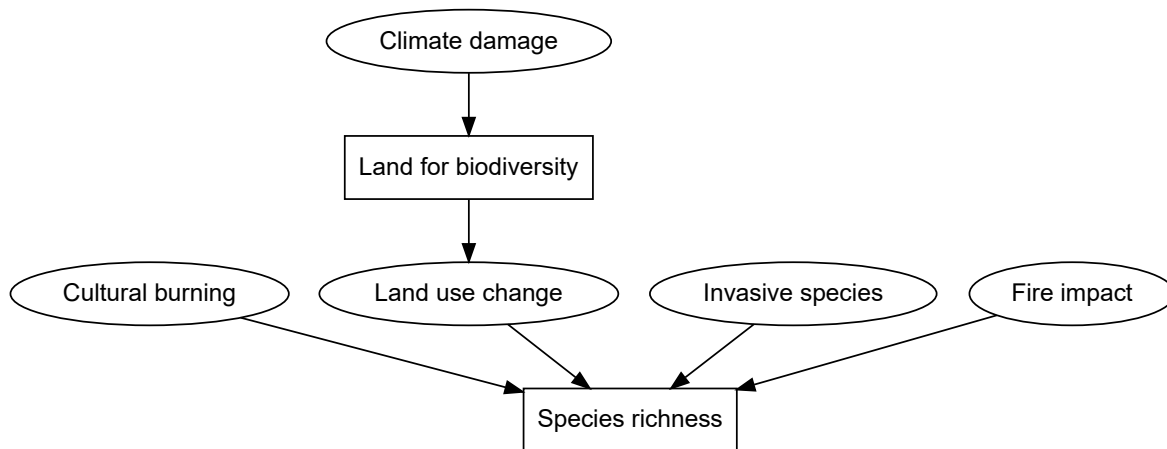
Figure 6.1: Biodiversity sector conceptual model

and vascular plant species (Graham et al. (2019)). The underlying information that these data represent is climate suitability. For each species, climate variables were used to project suitability of cells across Australia for species based on current climate ranges (cells receive a value between 0-1). To create the species richness map, cells that were projected with values greater than 0.5 were classified into a binary value of 1. All species rasters were then spatially added within each taxonomic group. See https://github.com/CarlaBirdy/MaxEnt-climate-models for the code for this analysis.

Thanks to Carla Archibald for assisting with data for this model sector.

6.4 *Equations*

baseline invasive species impact

Type: Auxiliary
Formula: INIT species richness - (0.21*INIT species richness)
Units: species
Assumptions: 21% species richnesss decline compared to natural systems; Crystal-Ornelas and Lockwood (2020)

fire impact on biodiversity

Type: Auxiliary
Formula: $1 + (1 - (1/\text{FFDI model}))$
Units: Dmnl
Assumptions:

impact of climate damage on biodiversity

Type: Auxiliary
Formula: 0.00091
Units: Dmnl
Assumptions: Climate damage for Forrest area from LUTO model. Land suitable for biodiversity reduces by 10% between 1990 and 2100, therefore annualised reduction is 9.1e-4 %

impact of cultural burning on biodiversity

Type: Auxiliary
Formula: 1+Cultural Burning
Units: Dmnl
Assumptions: In personal discussions with an Australian fire researcher, they suggested that cultural burning would have a positive impact on biodiversity compared with a fire suppression regime (business as usual). Some evidence provided by Bowman et al. (2011), Trauernicht et al. (2015).

INIT species richness

Type: Constant
Formula: 4637
Units: species
Assumptions: Baseline 1990 data for species richness in the Colac Otway LGA area. Includes amphibians, birds, mammals, plants and reptiles. See Github for spatial data.

invasive species impact discrepancy

Type: Auxiliary
Formula: Species richness-baseline invasive species impact
Units: species
Assumptions:

Land for Biodiversity Impact

Type: Stock
Formula: INTEG(Land use change over time - Land reduction from climate damage), INITIAL = 0
Units: hectares
Assumptions:

land use change impact on biodiversity

Type: Auxiliary
Formula: (species area curve coefficient * Land for Biodiversity Impact ^ species area curve exponent) / simulation time
Units: species/Year
Assumptions: Species area curve S = cA^z , z = 0.86 (derived from data). Assume that species richness initial variable is 50% of total c = 2 Area = 8375 S = 4637

Land use change over time

Type: Auxiliary
Formula: (Forest Land + Protected Land) / simulation time
Units: hectares/Year
Assumptions: Agricultural land has no biodiversity impact

Land reduction from climate damage

Type: Auxiliary
Formula: Land for Biodiversity Impact * impact of climate on biodiversity
Units: hectares/Year
Assumptions:

species area curve coefficient

Type: Constant
Formula: 2
Units: species/hectares
Assumptions: as derived in *land use change impact on biodiversity*

species area curve exponent

Type: Constant
Formula: 0.86
Units: Dmnl
Assumptions: derived from data

Species richness

Type: Stock
Formula: INTEG (Species richness increase rate - Species richness decrease rate), INITIAL = INIT species richness)
Units: species
Assumptions:

Species richness decrease rate

Type: Auxiliary
Formula: (invasive species impact discrepancy / simulation time) * fire impact on biodiversity
Units: species/Year
Assumptions:

Species richness increase rate

Type: Auxiliary
Formula: impact of cultural burning on biodiversity * land use change impact on biodiversity
Units: species/Year
Assumptions:

Chapter 7

Climate change sector

7.1 *Problem definition*

1. Human-induced climate change is a problem that will require a united, global effort to combat. However, the effects of climate change do and will continue to affect Forrest at a community level. Such affects include increasing temperatures, drying climates, increased and more serious bushfires, droughts, and more extreme weather. To remain safe and stay resilient in the face of climate change, Forrest must anticipate more frequent bushfires, flooding and drought, and develop plans for sustainable recovery.

Dynamic hypothesis:

Forrest is vulnerable to bushfires and drought, and the effect of climate change on biodiversity may begin to affect Forrest's eco-tourism economy. Increasing temperatures will also affect Forrest's residents, especially as the community is ageing. More frequent heatwaves will put older people, more susceptible to heat-induced illness, at risk. Forrest is occasionally subject to flooding (e.g. the spillover of Barwon Dam in 2012), and with the increase in extreme weather events this could become more frequent.

7.2 *System conceptualisation*

There are four climate-related models that make up the climate change sector, with a separate structure for cultural burning. These four models are for carbon dioxide, temperature, rainfall, and bushfire.

7.3 *Model formulation*

For each of the four climate models, we generated linear models based on past data. The rainfall model is for annual rainfall; the temperature model is for annual mean maximum temperature; the CO_2 model is for monthly CO_2 measurements; and for bushfire we modelled the annual mean Forest Fire Danger Index (Matthews (2009)) for the Forrest area. The linear models were created using data from 1990-2020.

The climate damage structure was adapted from FeliX (Rydzak et al. (2010)).

The cultural burning structure represents the percentage of land that is managed by cultural burning. The initial value is 0 and the model is 'switched' on or off depending on scenario. The cultural burning goal is set as 100%.

7.4   Data sources

Data and code are available at https://github.com/pelagikat/Local-SDGs-systems-model

CO_2 data was obtained from the Cape Grim monitoring station

Temperature and rainfall data was obtained from the Bureau of Meteorology. Temperature data was from the Cape Otway weather station, and rainfall data was from the Pennyroyal weather station. These stations were selected as they were both the most complete and spatially nearest datasets available.

Forest Fire Danger Index historical data was provided from the Victorian Government Department of Land, Water and Planning ViCClim dataset. Data was extracted from the spatial VicClim dataset using the centre of Forrest township. We do not have permission to share this data.

7.5   Abbreviations

FFDI = Forest Fire Danger Index

7.6   *Equations*

annual probability of flood

Type: Constant
Formula: 0.01
Units: Dmnl
Assumptions: Corangamite Catchment Management Authority flood mapping portal shows 1 in 100 year riverine flood extent (limited data)

bushfire risk fraction

Type: Auxiliary
Formula: reference FFDI/FFDI model
Units: Dmnl
Assumptions: Modelled FFDI at time of simulation as proportion of reference FFDI

climate damage fraction

Type: Auxiliary
Formula: 1 / (1 + climate damage scale * (temperature change since 1865 / reference temperature for climate damages) ^ climate damage nonlinearity)
Units: Dmnl
Assumptions: Variable and formula taken from FeliX (Rydzak et al. (2010)). Fraction of Output lost to combating Climate Change.

climate damage nonlinearity

Type: Constant
Formula: 2
Units: Dmnl
Assumptions: Variable and formula taken from FeliX (Rydzak et al. (2010)). Nonlinearity (exponent) of Climate Damage Cost Fraction.

climate damage scale

Type: Constant
Formula: 0.013
Units: Dmnl
Assumptions: Variable and formula taken from FeliX (Rydzak et al. (2010)). Coefficient for climate damage fraction at Reference Temperature.

CO2 change

Type: Auxiliary
Formula: CO2 linear model - reference CO2
Units: ppm
Assumptions: Change from reference CO2 value

CO2 linear model

Type: Auxiliary
Formula: CO2 model coefficient * Time - 3177.44
Units: ppm
Assumptions: Model derived from data. See code and data in Github.

CO2 model coefficient

Type: Constant
Formula: 1.77
Units: ppm/Year
Assumptions: Model derived from data. See code and data in Github.

Cultural Burning

Type: Stock
Formula: INTEG (Cultural burning rate), INITIAL = 0
Units: Dmnl
Assumptions:

cultural burning adjustment time

Type: Constant
Formula: 15
Units: Year
Assumptions: Victorian Cultural Fire Strategy (The Victorian Traditional Owner Cultural Fire Knowledge Group (2021)) states a 10 year transition time to properly implement cultural burning, as Country is currently too sick to immediately begin cultural burns. We assume an additional 5 years to implement the strategy.

cultural burning discrepancy

Type: Auxiliary
Formula: cultural burning goal - Cultural Burning
Units: Dmnl
Assumptions: The difference between the goal and the current state

cultural burning goal

Type: Constant
Formula: 1
Units: Dmnl
Assumptions: The goal is to have 100% of land managed by cultural burning

Cultural burning rate

Type: Auxiliary
Formula: IF THEN ELSE (Time < 2025, 0, (cultural burning discrepancy / cultural burning adjustment time) * cultural burning scenario switch)
Units: 1/Year
Assumptions: Assume that cultural burning won't commence until 2025

cultural burning scenario switch

Type: Constant
Formula: 0
Units: Dmnl
Assumptions: The scenario switch variable. 0 = off, 1 = on.

FFDI model

Type: Auxiliary
Formula: (FFDI model coefficient * Time) - 51.7397
Units: Dmnl
Assumptions: linear model of FFDI dataset from 1990-2020. Model derived from data. See code and data in Github.

FFDI model coefficient

Type: Constant
Formula: 0.02662
Units: 1/Year
Assumptions: Coefficient of linear model of FFDI dataset 1990-2020

net climate change impact on economy

Type: Auxiliary
Formula: climate damage fraction
Units: Dmnl
Assumptions: Variable and formula taken from FeliX (Rydzak et al. (2010)). The fraction of ecomomy output loss due to climate change.

rainfall change

Type: Auxiliary
Formula: rainfall linear model - reference rainfall
Units: mm
Assumptions: Change from reference rainfall value.

rainfall linear model

Type: Auxiliary
Formula: (rainfall model coefficient * Time) + 6182.65
Units: mm
Assumptions: linear model for data 1990-2020 for Pennyroyal weather station. Model derived from data. See code and data in Github.

rainfall model coefficient

Type: Constant
Formula: -2.711
Units: mm/Year
Assumptions: Coefficient of linear model of annual rainfall 1990-2020 using Pennyroyal weather station data

reference CO2

Type: Constant
Formula: 348.33
Units: ppm
Assumptions: CO2 mean Cape Grim data for 1976-2000. See code and data in Github.

reference FFDI

Type: Constant
Formula: 1.4
Units: Dmnl
Assumptions: 1973 annual mean FFDI.

reference rainfall

Type: Constant
Formula: 776
Units: mm
Assumptions: Pennyroyal rainfall measuring station; mean of annual rainfall 1960-2020. See code and data in Github.

reference temperature 1865

Type: Constant
Formula: 16.6
Units: DegreesC
Assumptions: Annual mean max temperature. Earliest available full year dataset for Cape Otway climate station. See data in Github.

reference temperature for climate damages

Type: Constant
Formula: 3
Units: DegreesC
Assumptions: Reference Temperature change for Calculation of Climate Damages. Variable and formula taken from FeliX (Rydzak et al. (2010)).

temperature change since 1865

Type: Auxiliary
Formula: temperature linear model - reference temperature 1865
Units: DegreesC
Assumptions:

temperature linear model

Type: Auxiliary
Formula: (temperature model coefficient * Time) - 47.88
Units: DegreesC
Assumptions: linear model for Annual mean max temp 1990-2020 for Cape Otway weather station. Model derived from data. See code and data in Github.

temperature model coefficient

Type: Constant
Formula: 0.03241
Units: DegreesC/Year
Coefficient of linear model of Cape Otway annual mean max temperatures from 1990-2020. Model derived from data. See code and data in Github.

Chapter 8

Inequality sector

8.1 *Problem definition*

In the greater Otway region, 19% of people live in poverty and the median family income in Forrest is 55% lower than for the rest of Victoria (2016). Twenty percent of all families in Forrest are single-parent families (and all single parents are women). The SEIFA score (a measure of socio-economic conditions) puts Forrest in the 30% most disadvantaged areas in the country, and the 20% most disadvantaged in Victoria.

Dynamic hypothesis: Intergenerational inequality is only one factor. Other contributing factors are income inequality, employment, the social gradient of health, housing stress, travel inequality, and internet access.

8.2 *System conceptualisation and model formulation*

The inequality system is by nature both difficult to measure and multifaceted. To gauge the level of inequality in the Forrest system, we identified a range of contributing factors and normalised them, then took the arithmetic mean to arrive an an indicator value.

Conceptual model

Data are available at https://github.com/pelagikat/Local-SDGs-systems-model

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8.3 *Equations*

disability fraction

Type: Constant
Formula: 0.177
Units: Dmnl
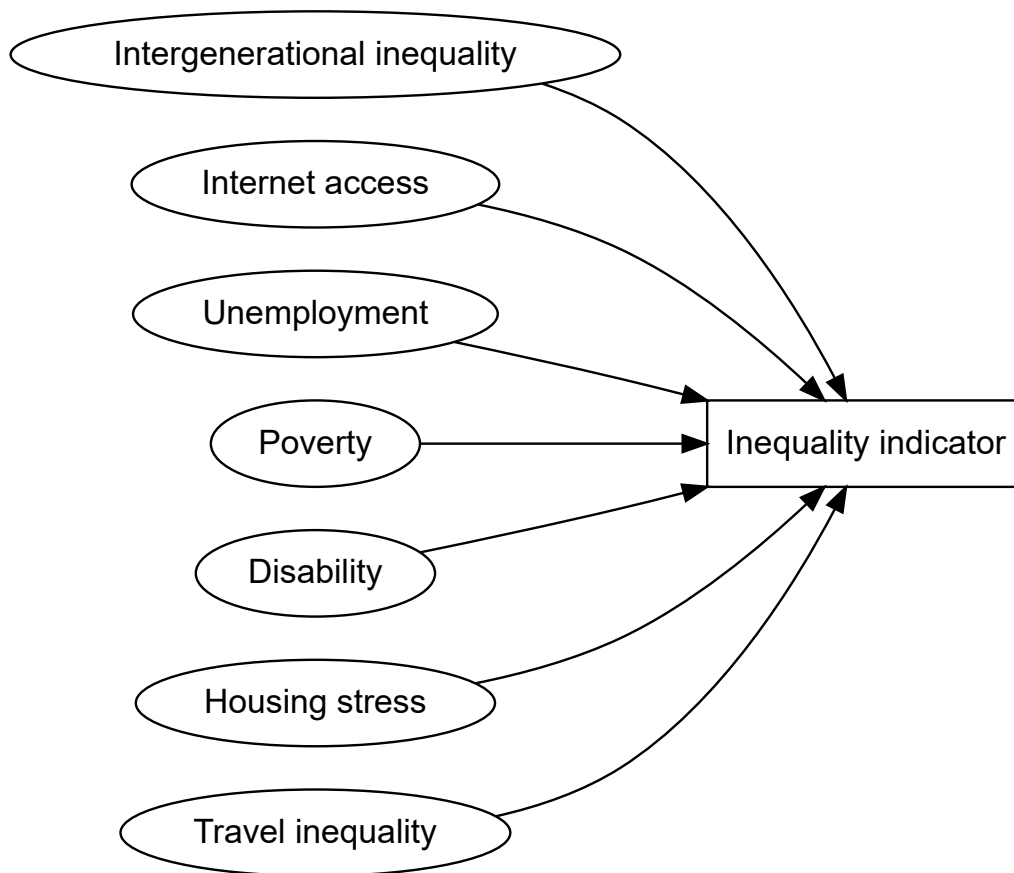Assumptions: Data obtained from ABS: Percentage of population who have a disability

Figure 8.1: Inequality sector conceptual model

households without internet access fraction

Type: Auxiliary
Formula: 1-households with internet access fraction
Units: Dmnl
Assumptions: 1 minus the fraction of those with internet access (from Telecommunications)

income distribution by income cohort

Type: Auxiliary Formula: sum(income distribution fractions by income cohort and gender)
Units: Dmnl
Assumptions: This variable is split (subscripted) across 15 income cohorts (negative, nil, $1-$149, $150-$299, $300-$399, $400-$499, $500-$649, $650-$799, $800-$999, $1,000-$1,249, $1,250-$1,499, $1,250-$1,499, $1,750-$1,999, $2,000-$2,999, $3,000 or more) and summed over the two gender categories

income distribution fractions by income cohort and gender

Type: Constant
Formula: [Negative; M,F] = 0.006, 0.0022
[Nil; M,F] = 0.0105, 0.009
["$1-$149"; M,F] = 0.0224, 0.0269
["$150-$299"; M,F] = 0.0284, 0.0396
["$300-$399"; M,F] = 0.0366, 0.0403
["$400-$499"; M,F] = 0.0448, 0.0612
["$500-$649"; M,F] = 0.0523, 0.0717
["$650-$799"; M,F] = 0.0605, 0.0695
["$800-$999"; M,F] = 0.0859, 0.0471
["$1,000-$1,249"; M,F] = 0.0799, 0.0381
["$1,250-$1,499"; M,F] = 0.0276, 0.0224
["$1,500-$1,749"; M,F] = 0.0246, 0.0261
["$1,750-$1,999"; M,F] = 0.0202, 0.003
["$2,000-$2,999"; M,F] = 0.0194, 0.0105
["$3,000 or more"; M,F] = 0.0112, 0.0075
Units: Dmnl
Assumptions: Data from 2016 census, for weekly income. Disaggregated by gender - ABS only uses male and female for gender so is not comprehensive. Formulas above list [male, female]. See Github for data.

inequality indicator

Type: Auxiliary
Formula: (disability fraction + households without internet access fraction + normalised intergenerational inequality youth at risk +normalised poverty line + normalised travel inequality + normalised unemployed + normalised housing stress) / 7
Units: Dmnl
Assumptions: Arithmetic mean of normalised input variables

intergenerational risk factor

Type: Constant
Formula: 1.8
Units: structure/people
Assumptions: Cobb-Clarke et al. (2017) estimate it is 1.8 times more likely for children of parents receiving long-term welfare to receive welfare themselves

normalised housing stress

Type: Auxiliary
Formula: (number of households under mortgage stress + number of households under rent stress) / Residential Housing
Units: Dmnl
Assumptions: Normalisation by number of residential households

normalised intergenerational inequality youth at risk

Type: Auxiliary
Formula: number of young people at risk for intergenerational inequality / "0-14"
Units: Dmnl
Assumptions: Normalisation by 0-14 age cohort population

normalised poverty line

Type: Auxiliary
Formula: sum of people below poverty line / total population
Units: Dmnl
Assumptions: Normalisation by total population

normalised travel inequality

Type: Auxiliary
Formula: 1- (bus frequency / bus frequency required for travel equity)
Units: Dmnl
Assumptions: Normalisation by bus frequency and subtract result from 1 to obtain inequality instead of equity.

normalised unemployed

Type: Auxiliary
Formula: (number of unemployed people / total population) * normalised unemployed unit conversion
Units: Dmnl
Assumptions: normalisation by total population

normalised unemployed unit conversion

Type: Auxiliary
Formula: 1
Units: Year*people/job
Assumptions: Unit conversion to force all input units to dimensionless

number labour force in income bracket

Type: Auxiliary
Formula: INTEGER (income distribution fractions by income cohort and gender * labour force)
Units: people
Assumptions: Summed over all income cohorts and genders

number of unemployed people

Type: Auxiliary
Formula: "unemployment (agriculture)" + "unemployment (other)" + "unemployment (tourism)"
Units: job/Year
Assumptions:

number of young people at risk for intergenerational inequality

Type: Auxiliary
Formula: intergenerational risk factor * "0-14" * (sum of people below poverty line / Residential Housing)
Units: people
Assumptions: Multiply risk factor by proportion of total households below poverty line by youth cohort

number people below poverty line

Type: Auxiliary
Formula: number labour force in income bracket
Units: people
Assumptions: Poverty line is below first quartile ($0 - $399). This is in line with the ACOSS figure of $457 (ACOSS (2020)). Excludes income cohorts above $300-$399.

sum of people below poverty line

Type: Auxiliary
Formula: sum (number people below poverty line [poverty line ss!,Gender!])
Units: people
Assumptions: Summed over income cohorts from Negative to $300-$399 and genders

Chapter 9

Health and Wellbeing sector

9.1 *Problem definition*

1. Being in a regional area, Forrest does not have local access to healthcare services (closest hospital is Colac).

Dynamic hypothesis: Living in regional areas impacts life expectancy.

2. Potential disease burden in Forrest has been estimated to be approximately 80-90,000 times greater than the WHO target because of failing septic systems in Forrest.

Dynamic hypothesis: Building new wastewater infrastructure will reduce disease burden

3. Climate change and bushfire are risks to the local environment and population.

Dynamic hypothesis: People like to live in Forrest because the local bush has a positive effect on wellbeing but there is a trade-off from bushfire risk

4. There is a wide income distribution in Forrest, with a larger proportion of people in lower income brackets compared to the state.

Dynamic hypothesis: People experiencing income inequality have poorer health outcomes (social gradient of health)

9.2 *System conceptualisation*

This sector was inspired by the work of Homer and Hirsch (2006), and seeks to model local scale population health contributors. The community clearly identified positive and negative impacts on health and wellbeing, many of which are modelled in other sectors in the Forrest Local Systems Model.
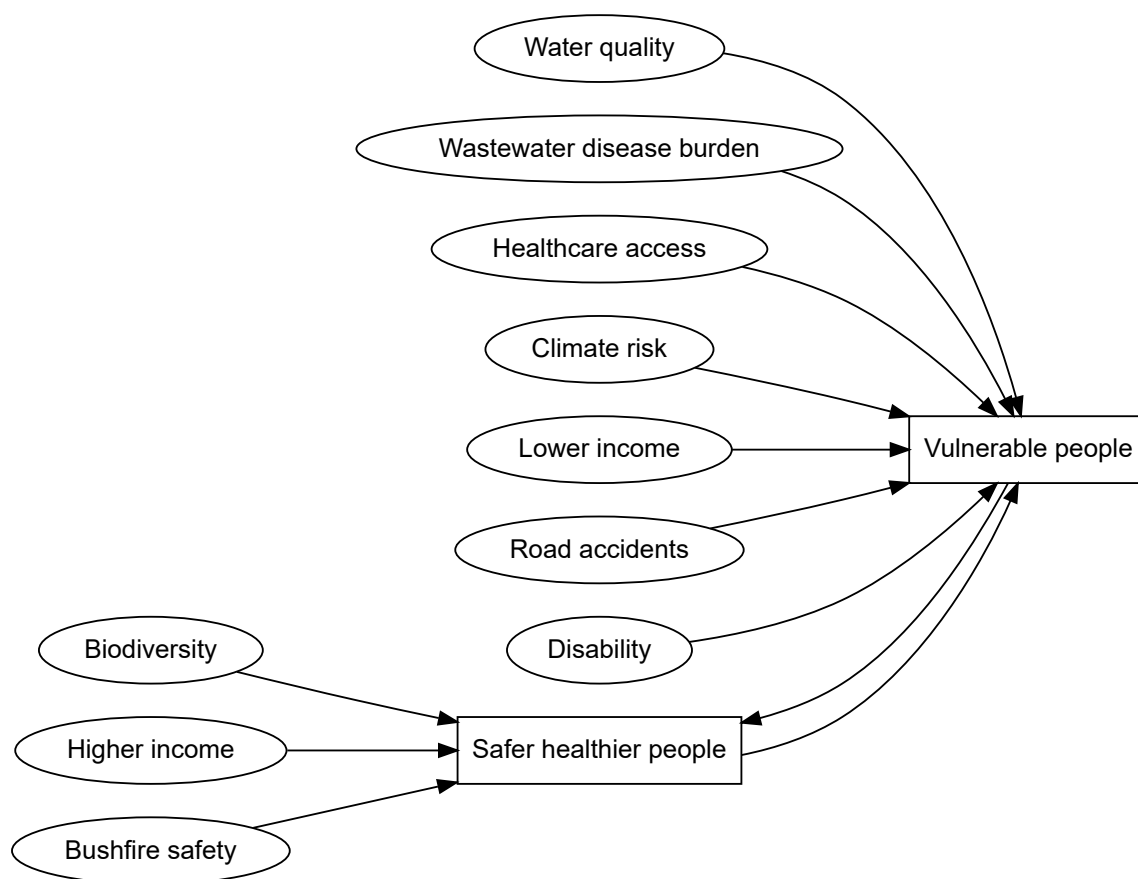
Figure 9.1: Health and wellbeing sector conceptual model

Conceptual model

9.3 *Model formulation*

Following the model in Figure 3 of Homer and Hirsch (2006), this sector models "Safer healthier people" and "Vulnerable people" as stocks, and these form a cycle with flow variables. The various different health impacts (normalised where required) are multiplied together in the flow variables and this creates the dynamics of the model sector.

9.4 Data sources

Data are available at https://github.com/pelagikat/Local-SDGs-systems-model

Data was obtained from the Victorian Government DATA VIC for road accident statistics.

Census data for Forrest available here. Data for Forrest as a distinct location is only available for 2006, 2011 and 2016 censuses.

9.5 Abbreviations

GTOC = Gateway to the Otways Centre, a Bushfire Safer Place
WHO = World Health Organisation
WW = Wastewater, new local wastewater infrastructure

————————————————————

9.6 *Equations*

accident coefficient

Type: Constant
Formula: -19.25
Units: people
Assumptions: Calibrated against road accident data. See Github for data.

Becoming safer and healthier

Type: Auxiliary
Formula: (increasing bushfire safety from GTOC * (biodiversity impact on health (middle and high income population / total population) * total population) / Time)
Units: people/Year
Assumptions:

Becoming vulnerable

Type: Auxiliary
Formula: ((climate risk * disability fraction * water quality * disease from wastewater * excess disease burden from lowered healthcare access * (low income population / total population) * (road accidents / total population)) * total population) / Time
Units: people/Year
Assumptions:

biodiversity impact on health

Type: Auxiliary
Formula: Species richness / INIT species richness
Units: Dmnl
Assumptions: Current species richness as a proportion of the baseline species richness

climate risk

Type: Auxiliary
Formula: risk to health from bushfire * risk to health from increasing temperatures
Units: Dmnl
Assumptions: the main risks to health as a result of climate are bushfire and high temperature

disease burden before WW

Type: Constant
Formula: 0.1
Units: Year/person
Assumptions: Wastewater investigation report in Forrest (Decentralised Water Consulting (2019), p. 28) found that the existing disease burden was approximately 1×10^{-1} (or 0.1) Disability Adjusted Life Years (DALYs). Note the Decentralised Water Consulting (2019) report calls this "Level of Disease Protection" instead of disease burden, and appears to incorrectly interpret Figure 12 in the text.

disease from wastewater

Type: Auxiliary
Formula: (IF THEN ELSE (Wastewater availability > 0, WHO target disease burden / WHO target disease burden, disease burden before WW / WHO target disease burden))
Units: Dmnl
Assumptions: Effect of installing new wastewater infrastructure as a proportion of the WHO target.

excess disease burden from lowered healthcare access

Type: Constant
Formula: 1.103
Units: fraction
Assumptions: Forrest is classified as inner regional by the RRMA classification. Inner regional areas have 10.3% excess disease burden compared to major cities (percentage of total observed burden for the area) (Australian Institute of Health and Welfare (2019), Table 8.5)

high income population

Type: Auxiliary
Formula: sum (number labour force in income bracket[high income!,Gender!])
Units: people
Assumptions: Summed over income cohorts $1,500 and above, and summed over gender

increasing bushfire safety from GTOC

Type: Auxiliary
Formula: IF THEN ELSE (GTOC availability > 0, 1-bushfire risk fraction, 1)
Units: Dmnl
Assumptions: If GTOC has been built, its presence negates the risk from bushfire as it is a Bushfire Safer Place

low income population

Type: Auxiliary
Formula: sum (number labour force in income bracket[low income!, Gender!])
Units: people
Assumptions: Summed over income cohorts from Negative to $649, and summed over gender.

middle and high income population

Type: Auxiliary
Formula: high income population + middle income population
Units: people
Assumptions:

middle income population

Type: Auxiliary
Formula: sum (number labour force in income bracket[mid income!,Gender!])
Units: people
Assumptions: Summed over income cohorts from $650 - $1,499, and summed over gender.

population initial

Type: Constant
Formula: 171
Units: people
Assumptions: From 2006 census data, population at start of simulation.

risk to health from bushfire

Type: Auxiliary
Formula: bushfire risk fraction
Units: Dmnl
Assumptions: A one-to-one mapping of bushfire risk fraction

risk to health from increasing temperatures

Type: Auxiliary
Formula: climate damage fraction
Units: Dmnl
Assumptions: A one-to-one mapping of climate damage fraction

road accidents

Type: Auxiliary
Formula: Road Quality * accident coefficient + 9.6
Units: people
Assumptions: Linear model calibrated in Vensim. Intercept is dataset mean.

Safer Healthier People

Type: Stock
Formula: INTEG (Becoming safer and healthier - Becoming vulnerable), INITIAL = population initial
Units: people
Assumptions: There are only two states of being in this model: Safer & Healthier, or Vulnerable.

Vulnerable People

Type: Stock
Formula: INTEG (Becoming vulnerable - Becoming safer and healthier), INITIAL = 0)
Units: people
Assumptions: There are only two states of being in this model: Safer & Healthier, or Vulnerable. Assume that all the population begin as Safer & Healthier and as the simulation runs, may move to Vulnerable.

water quality

Type: Constant
Formula: 1
Units: Dmnl
Assumptions: This is a scenario variable. The baseline is zero (no effect).

WHO target disease burden

Type: Constant
Formula: 1e-05
Units: Year/person
Assumptions: Wastewater investigation report in Forrest (Decentralised Water Consulting (2019), p. 28) states that the World Health Organisation target disease burden from wastewater was approximately 1×10^{-5} Disability Adjusted Life Years (DALYs). Note the Decentralised Water Consulting (2019) report calls this "Level of Disease Protection" instead of disease burden, and appears to incorrectly interpret Figure 12 in the text. The new wastewater infrastructure will meet this disease burden target.

Chapter 10

Telecommunications sector

10.1 *Problem definition*

The NBN has been rolled out in Forrest, but the service can be poor. NBN Fixed Wireless is known to suffer from congestion issues, and the distance to the fixed wireless tower can also affect internet speeds. The nearest tower to Forrest is in Barwon Downs, and towers have an effective range of 14kms, which can be disrupted by terrain (trees, mountains, etc.), and precipitation. There is also limited mobile reception throughout Forrest.

Dynamic hypothesis: Poor internet and mobile phone service impacts establishment of new businesses and growth of existing ones. Improved internet access (fixed and mobile) would encourage new businesses which rely on connectivity, and better support the existing residents and businesses. It is also necessary for education and better health outcomes.

10.2 *System conceptualisation*

We are only considering Fixed Wireless NBN in our model. We wish to explore how internet demand, infrastructure (in the form of Fixed Wireless towers) and internet capacity interact in Forrest. There are a number of assumptions made on limited data for some of these variables as much of the information underlying the NBN is commercial-in-confidence.

Conceptual model

10.3 *Model formulation*

There are three stocks with inflow rates forming the basis of the model: Internet Service Demand, Fixed Wireless Towers, and Internet Service Capacity. Demand is influenced by business and residential internet demand. Capacity is influenced by demand, user limits and speeds per connection. Fixed wireless towers is influenced by oversubscription of the existing infrastructure (i.e. how far the capacity exceeds the user limit). We have not modelled infrastructure funding in this case, as NBN Co is supposed to roll out upgrades according to need (although this is intermittent currently), and it is funded by the Federal Government.
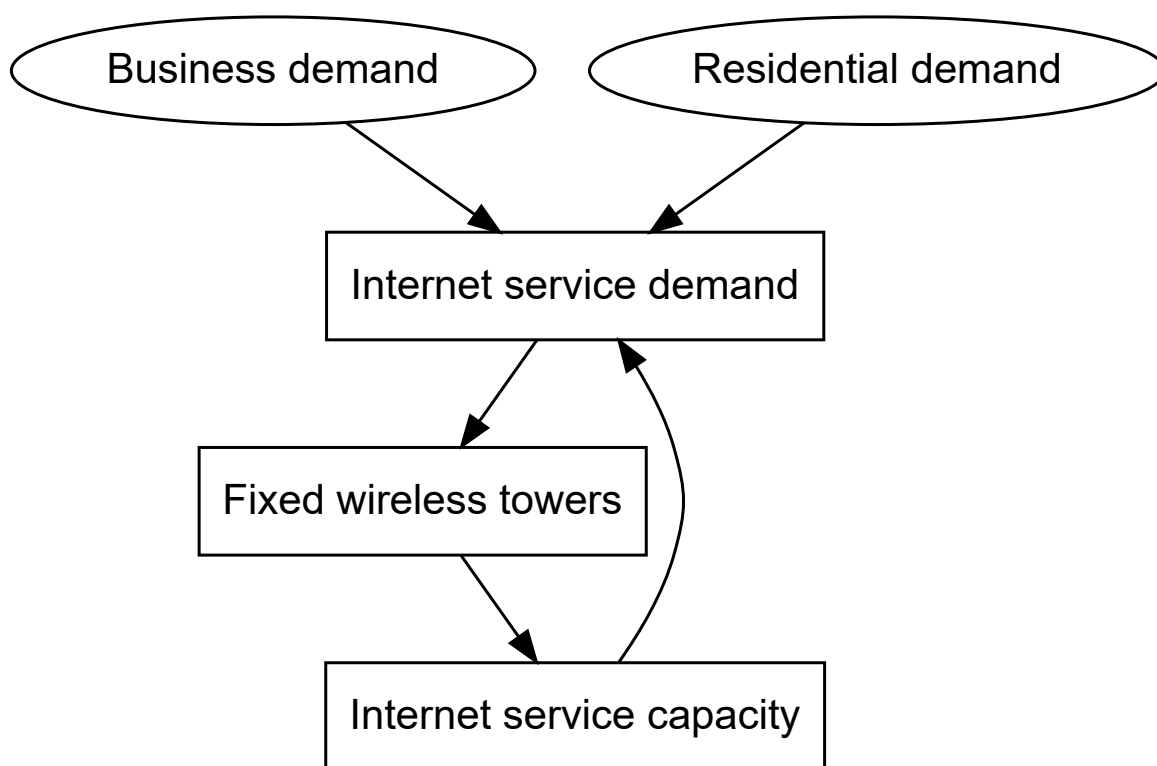
Figure 10.1: Teleconmmunications sector conceptual model

10.4   Data sources

Data are available at https://github.com/pelagikat/Local-SDGs-systems-model (Economic data is used in this sector)

Census data for Forrest available here. Data for Forrest as a distinct location is only available for 2006, 2011 and 2016 censuses.

Data was obtained from Australian Bureau of Statistics Counts of Australian Businesses and Census Table Builder

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10.5   *Equations*

business internet demand

Type: Auxiliary
Formula: "number of businesses (agriculture)" + "number of businesses (other)" + "number of businesses (tourism)"
Units: structure
Assumptions: Assume that all businesses require a connection to the internet

demand per location

Type: Constant
Formula: 1
Units: connections/structure
Assumptions: 1 connections per location

Fixed wireless tower investment rate

Type: Auxiliary (rate)
Formula: tower oversubscription factor / Time
Units: tower/Year
Assumptions:

Fixed Wireless Towers

Type: Stock
Formula: INTEG (INTEGER(Fixed wireless tower investment rate)), INITIAL = INIT number of towers
Units: tower
Assumptions:

fixed wireless user limit

Type: Constant
Formula: 60
Units: connections/tower
Assumptions: This value was difficult to ascertain, however this article quoted NBN Co saying they had reduced users from historical levels of 60 per cell to an average of 19. Based upon that, we assume 60 connections is higher than acceptable and have set that as the maximum value.

households with internet access fraction

Type: Constant
Formula: 0.77
Units: fraction
Assumptions: From ABS 2016 census data: 77% of households accessed the internet from their home

INIT NBN connections

Type: Constant
Formula: 114 + 27
Units: connections
Assumptions: 77% of 148 dwellings (from 2016 ABS Census data) plus 27 businesses (from 2020 ABS counts of businesses). See Github for data.

INIT number of towers

Type: Constant
Formula: 1
Units: tower
Assumptions: There is one fixed wireless tower in Forrest

internet capacity demand

Type: Auxiliary
Formula: Internet Service Demand * maximum speed per connection / Fixed Wireless Towers
Units: Mbps * connection/tower
Assumptions: This is a variable which represents the total amount of traffic demand as a proportion of number of towers.

internet capacity discrepancy

Type: Auxiliary
Formula: internet capacity demand-Internet Service Capacity

Units: Mbps*connection/tower
Assumptions: This is the discrepancy between capacity demand and capacity actual.

Internet Service Capacity

Type: Stock
Formula: INTEG (Internet service capacity rate), INITIAL = maximum speed per connection * fixed wireless user limit
Units: Mbps * connections/tower
Assumptions: The initial value is the maximum available capacity

Internet service capacity rate

Type: Auxiliary
Formula: IF THEN ELSE (tower oversubscription factor <= Fixed Wireless Towers, internet capacity discrepancy / Time, (fixed wireless user limit * maximum speed per connection) / Time)
Units: Mbps * connection /(Year * tower)
Assumptions: If the tower oversubscription factor is less than the number of towers (i.e., there are enough towers), then the discrepancy structure will be valid. However, if there are not enough towers to meet demand, then the capacity rate will stay at its max level, which is the user limit * max speed per connection.

Internet Service Demand

Type: Stock
Formula: INTEG (Internet service demand rate), INITIAL = INIT NBN connections
Units: connections
Assumptions:

Internet service demand rate

Type: Auxiliary (rate)
Formula: (business internet demand + residential internet demand) * demand per location / Time
Units: connections/Year
Assumptions: Assume that all businesses require a connection to the internet

internet service performance

Type: Auxiliary
Formula: Internet Service Capacity / Internet Service Demand
Units: Mbps/tower
Assumptions: This is the equivalent of a supply/demand ratio

max number of premises to connect to the internet

Type: Constant
Formula: Residential Housing + Tourism Housing
Units: structure
Assumptions:

maximum speed per connection

Type: Constant
Formula: 75
Units: Mbps
Assumptions: Fixed wireless has a maximum plan speed of 75Mbps

residential internet demand

Type: Auxiliary
Formula: max number of premises to connect to the internet * households with internet access fraction
Units: structure
Assumptions:

tower build delay time

Type: Constant
Formula: 2
Units: Year
Assumptions: Assume it takes two years to build

tower investment responsiveness

Type: Constant
Formula: 0
Units: Dmnl
Assumptions: This variable represents whether or not a new tower is built when it is oversubscribed. Currently a binary (yes/no; 0/1) but can be modified to be an investment delay

tower oversubscription factor

Type: Auxiliary
Formula: INIT number of towers + (Internet Service Demand / fixed wireless user limit) - Fixed Wireless Towers
Units: tower
Assumptions: Desired state of system (Initial number of towers plus the number mandated by the demand)

Chapter 11

Infrastructure sector

The Forrest community have four major infrastructure projects currently in train which they have identified as being important for the future development and growth of Forrest. There is one additional project which is as important for the community but not reliant on outside intervention.

11.1 *Problem definition*

1. In the past, on-site septic systems were adequate for a town the size of Forrest, which did not have many visitors. With the change to a tourism economy, there are many more people that come to town, particularly for events, and the now ageing septic infrastructure requires upgrading. The limits of septic infrastructure for waste are hindering attempts to increase housing in the town. Studies have been undertaken by Barwon Water to upgrade wastewater infrastructure but there has been no progress, partly due to funding issues. The current option on the table expects the community to contribute, which may delay or entirely derail the development.

Dynamic hypothesis: Ageing septic systems that don't meet current safety standards are no longer adequate and new infrastructure is urgently needed. This affects the local environment and biodiversity, the local economy (by limiting tourism), health of local residents, and additional development in the town.

2. The Forrest MTB Trails were first opened in 2005, encompassing over 60km of trails. A proposal was released in December 2019 to increase the MTB trail network by approximately 38kms, including restructuring the existing trails and creating a new Trail Head. This plan is aimed to revitalise mountain bike tourism and re-establish Forrest as a nationally significant mountain bike destination.

Dynamic hypothesis: Mountain bike trails in Forrest are already a major tourism drawcard but upgrades to the trail network would encourage more visitation to the town. This is a benefit to the tourism economy but issues still remain around accommodation (i.e. housing supply) and wastewater.

3. The Forrest Common is a piece of public land which could be put to better use for the community. After several years of consultation with Colac Otway Shire, a plan has been approved but it is beyond the ability of Council to fund.

Dynamic hypothesis: A revamped Forrest Common would benefit tourism and in-migration of families (due to new play equipment).

4. The community identified that a bushfire safer place is necessary for the community, and that one of the DELWP parcels of land could be used to achieve this. A feasibility study and preliminary plans have been completed, but funding needs to be found to build it.

Dynamic hypothesis: If funding can be obtained for the Gateway to The Otways Centre, this would have a positive impact on community health and wellbeing in the event of a bushfire and potentially prevent loss of life.

11.2   *System conceptualisation*

The life cycle of an infrastructure project is focused on three stages: acquiring the funding, building the infrastructure, and completion of the project. Accordingly, we have developed our system around these three stages.

Conceptual model

11.3   *Model formulation*

We have defined the Funding, Build-in-Progress and Completion stages of infrastructure projects as stocks in the model. We have incorporated delays through the process for funding, build delay and build time. The crucial information which is required for other model sectors is the time at which the build is complete and the infrastructure is ready for use.

As there are five infrastructure projects and the process is the same for each, the five projects have been subscripted into model structure; that is, five different versions (subscripts) exist in the one model structure.

Abbreviations used:

CFA = Country Fire Authority (regional fire service)
GTOC = Gateway to the Otways Centre (bushfire safer place)
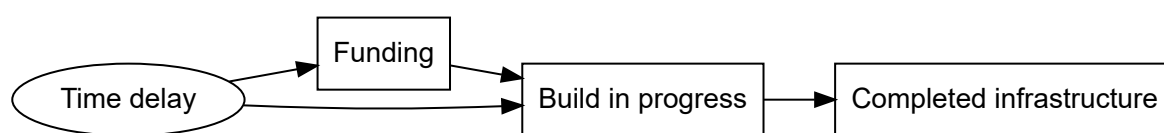MTB = Mountain Bike (e.g., MTB Trails = Mountain Bike Trails)

Figure 11.1: Infrastructure sector conceptual model

11.4 *Equations*

asset component discrepancy

Type: Auxiliary
Formula: total number of asset components - Completed Infrastructure Item
Units: asset component
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

build delay

Type: Constant
Formula: [Forrest Common] = 0.5
[GTOC] = 1
[MTB Trails] = 1
[Wastewater] = 2
[CFA Truck] = 0.5
Units: Year Assumptions: Arbitrary values; can be used for scenarios if needed.

build time

Type: Constant
Formula: [Forrest Common] = 0.5
[GTOC] = 2
[MTB Trails] = 1
[Wastewater] = 3
[CFA Truck] = 0.25
Units: Year
Assumptions: Arbitrary values; can be used for scenarios if needed.

CFA Truck availability

Type: Auxiliary
Formula: IF THEN ELSE (time at which infrastructure item is complete[CFA Truck] > 0,
STEP(1, (Current time + time at which infrastructure item is complete [CFA Truck])) , 0)
Units: Year
Assumptions: The time from which the infrastructure is complete and can begin having an
effect on other variables

Completed Infrastructure Item

Type: Stock
Formula: INTEG (Infrastructure completion rate), INITIAL = 0)
Units: asset component
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

cost per asset component

Type: Constant
Formula: [Forrest Common] = 1.7e+06 / 10
[GTOC] = (1.2e+07) / 10
[MTB Trails] = 4.55e+06 / 10
[Wastewater] = 1.01e+07 / 10
[CFA Truck] = 210000 / 10
Units: dollar/asset component
Assumptions: Total cost of project divided by 10

Current time

Type: Constant
Formula: 2021
Units: Year
Assumptions: Reference year to compare to project completion times.

Forrest Common availability

Type: Auxiliary
Formula: IF THEN ELSE (time at which infrastructure item is complete [Forrest Common] >0, STEP(1, (Current time + time at which infrastructure item is complete[Forrest Common])) , 0)
Units: Year
Assumptions: The time from which the infrastructure is complete and can begin having an effect on other variables

funding duration

Type: Constant
Formula: [Forrest Common] = 1
[GTOC] = 2
[MTB Trails] = 1
[Wastewater] = 3
[CFA Truck] = 1
Units: Year
Assumptions: Arbitrary values; can be used for scenarios if needed.

funding lag

Type: Constant
Formula: [Forrest Common] = 2
[GTOC] = 5
[MTB Trails] = 0.5
[Wastewater] = 2

[CFA Truck] = 1
Units: Year
Assumptions: Arbitrary values; can be used for scenarios if needed.

funding scenario

Type: Constant
Formula: [Forrest Common] = 0
[GTOC] = 0
[MTB Trails] = 1
[Wastewater] = 0
[CFA Truck] = 0
Units: Dmnl
Assumptions: This is a 'switch' variable (0 = off, 1 = on)

GTOC availability

Type: Auxiliary
Formula: IF THEN ELSE (time at which infrastructure item is complete[GTOC] > 0, STEP (1, (Current time + time at which infrastructure item is complete[GTOC])) , 0)
Units: Year
Assumptions: The time from which the infrastructure is complete and can begin having an effect on other variables

infrastructure approved funding

Type: Auxiliary
Formula: [Forrest Common] = IF THEN ELSE (funding scenario[Forrest Common] = 1, 1.7e+06, 0)
[GTOC] = IF THEN ELSE (funding scenario[GTOC] = 1, 1.2e+07, 0)
[MTB Trails] = IF THEN ELSE (funding scenario[MTB Trails] = 1, 4.55e+06, 0)
[Wastewater] = IF THEN ELSE (funding scenario[Wastewater] = 1, 1.01e+07, 0)
[CFA Truck] = IF THEN ELSE (funding scenario[CFA Truck] = 1, 21000, 0) Units: dollar
Assumptions: These values are the funding estimates for each project. See The Forrest and District Plan for more information (Szetey et al. (2020))

Infrastructure Build In Progress

Type: Stock
Formula: INTEG (Infrastructure start rate - Infrastructure completion rate), INITIAL = 0)
Units: asset component
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

Infrastructure completion rate

Type: Auxiliary
Formula: (asset component discrepancy) / build time
Units: asset component/Year
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

Infrastructure Funding

Type: Stock
Formula: INTEG (-Infrastructure funding allocation rate), INITIAL = infrastructure approved funding
Units: dollar
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

Infrastructure funding allocation rate

Type: Auxiliary
Formula: Infrastructure Funding / funding duration
Units: dollar/Year
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

Infrastructure start rate

Type: Auxiliary
Formula: DELAY1 (Infrastructure funding allocation rate / cost per asset component, build delay + funding lag)
Units: asset component/Year
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

MTB trails improvements availability

Type: Auxiliary
Formula: IF THEN ELSE (time at which infrastructure item is complete[MTB Trails]> 0, STEP(1, (Current time + time at which infrastructure item is complete[MTB Trails])) , 0)
Units: Year
Assumptions: The time from which the infrastructure is complete and can begin having an effect on other variables

time at which infrastructure item is complete

Type: Auxiliary
Formula: IF THEN ELSE(funding scenario > 0, build delay + build time + funding lag , 0)
Units: Year
Assumptions: This variable is split (subscripted) across the 5 infrastructure projects.

total number of asset components

Type: Constant
Formula: 10
Units: asset component
Assumptions: Have arbitrarily assumed that each infrastructure project has 10 stages. This variable is split (subscripted) across the 5 infrastructure projects.

Wastewater availability

Type: Auxiliary
Formula: IF THEN ELSE (time at which infrastructure item is complete[Wastewater] > 0, STEP(1, (Current time + time at which infrastructure item is complete[Wastewater])) , 0)
Units: Year
Assumptions: The time from which the infrastructure is complete and can begin having an effect on other variables

Chapter 12

Transport sector

12.1 *Problem definition*

1. Forrest lies on the route between Apollo Bay and Colac. It is a feeder route to tourism along the Great Ocean Road and the Great Otway National Park. Recent upgrades to the channel routes to Forrest make it easier for tourists to visit the area, and safer for residents to drive.

Dynamic hypothesis: Forrest is midway between Colac and Apollo Bay, and the road between them is a key route to the tourism of the Great Ocean Road. It is important that these roads remain in excellent condition for safety of road users. Road deaths on rural roads far exceed those in metropolitan areas.

2. There is one bus line that runs through Forrest, the Colac-Marengo route. This service runs only on Wednesdays and only once in each direction. There is a V-Line station in Birregurra, but apart from the once-weekly bus, there is no connecting service from Birregurra to Forrest, and there is no alignment of the bus timetable with the train timetable. This puts a severe limit on residents who may want to avoid driving, and for tourists who wish to visit that do not drive.

Dynamic hypothesis: There is poor public transport service from Forrest to Colac or Birregurra. One service per week does not enable general uptake of public transport. This is also an inequality issue, as people of lower incomes may not be able to afford to own or use a car, and this also restricts mobility for those unable to drive, due to age or disability. More tourists may visit if there was better public transport access.

12.2 *System conceptualisation*

There are three main structures to the model of transport in Forrest. The first is road quality, the second is car use, and the third is modelling the dynamics of public transport, for which Forrest is only served by buses. Within the bus structure, we examine the current level of service, the potential level of service, and the service that would be required for there to be

travel equity across the population. By travel equity, we mean that there are frequent enough bus services that people who are of lower income or reduced mobility would have as much mobility as someone with a car.
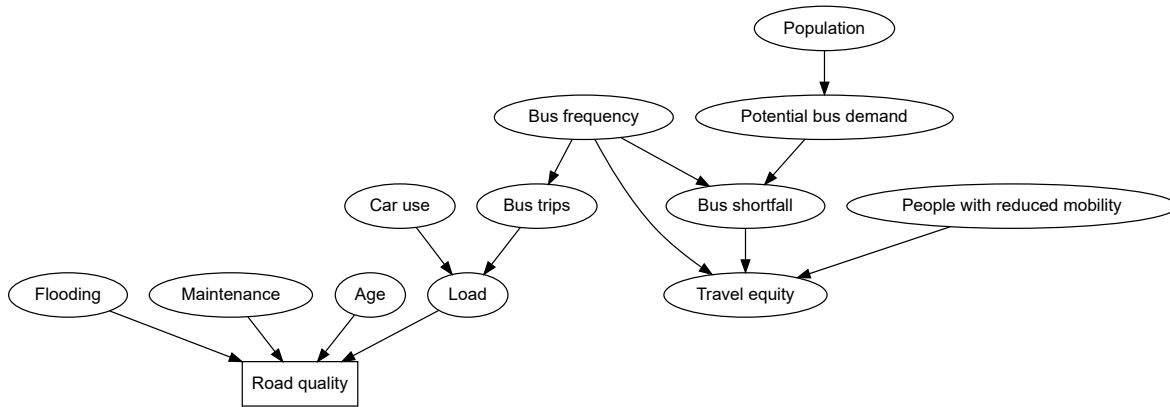
Conceptual model

Figure 12.1: Transport sector conceptual model

12.3   *Model formulation*

The road quality structure was adapted from work by Fallah-Fini et al. (2015). We added flooding as a factor in road deterioration. The car use structure was built from data on the number of cars in Forrest and the number of car trips made each year. The bus demand structure developed from understanding how the current levels of service fell short, and examining how service levels would need to increase to meet potential demand. The travel equity structure then fed into this to calculate how demand would increase to serve those of reduced mobility.

12.4 Data sources

Australian Bureau of Statistics: Car use in Australia

Travel to work - ABS Census data

12.5 *Equations*

age of pavement

Type: Constant
Formula: 10
Units: Year
Assumptions: Assume 10 year old pavements at start of simulation. From Fallah-Fini et al. (2015).

ageing nonlinearity factor

Type: Constant
Formula: 1.42
Units: Dmnl
Assumptions: Exponent of function. From Fallah-Fini et al. (2015).

allowable number of load cycles

Type: Constant
Formula: 1e+08
Units: trip/Year
Assumptions: From Fallah-Fini et al. (2015)

annual bus capacity discrepancy

Type: Auxiliary
Formula: annual potential bus demand - max annual capacity of bus route
Units: trip*people/Year
Assumptions:

annual potential bus demand

Type: Auxiliary
Formula: average number of bus trips per year * number people with ability to travel by bus
Units: trip*people/Year
Assumptions:

annual probability of flood

Type: Constant
Formula: 0.01
Units: Dmnl
Assumptions: Corangamite Catchment Management Authority flood mapping portal shows
1 in 100 year riverine flood extent (limited data)

average litres of petrol per 100km

Type: Constant
Formula: 11.1
Units: litre
Assumptions: Source

average number of bus trips per year

Type: Constant
Formula: 156
Units: trip/Year
Assumptions: 3 x return trips per week per person = 156 trips per person

average trip distance

Type: Constant
Formula: 19
Units: Km
Assumptions: Data derived from census data: *travel to work days*

bus capacity

Type: Constant
Formula: 24
Units: people
Assumptions: Confirmed with bus line running route

bus frequency

Type: Constant
Formula: 52
Units: trip/Year
Assumptions: Bus runs once a week return currently. Can be a scenario variable.

bus frequency required for travel equity

Type: Auxiliary
Formula: travel equity bus demand / bus capacity
Units: trip/Year
Assumptions:

bus frequency required for whole population

Type: Auxiliary
Formula: annual potential bus demand / bus capacity
Units: trip/Year
Assumptions:

car travel cost per year

Type: Auxiliary
Formula: ((average litres of petrol per 100km * cost of petrol) / average trip distance) * car use
Units: trip * dollar / (Year * Km)
Assumptions:

car use

Type: Auxiliary
Formula: (number of cars in Forrest * number of car trips per year per car)
Units: trip/Year
Assumptions:

corrective maintenance

Type: Auxiliary
Formula: IF THEN ELSE (critical condition index >=50 :AND: critical condition index <80, 1, 0.5)
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

cost of petrol

Type: Constant
Formula: 1.47
Units: $/litre
Assumptions: Source Global petrol prices

critical condition index

Type: Auxiliary
Formula: MAX(52, Road Quality * 100)
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

damage to road from flooding

Type: Constant
Formula: 0.5
Units: Dmnl
Assumptions: From Sultana et al. (2015) - reduction in road structure of up to 50%

deterioration multiplier

Type: Constant
Formula: 1.2
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

effect of ageing of pavement on deterioration rate

Type: Auxiliary
Formula: 1 + (age of pavement / service life of road) ^ ageing nonlinearity factor
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

effect of flooding on road quality

Type: Auxiliary
Formula: 1 - (damage to road from flooding * annual probability of flood)
Units: Dmnl
Assumptions:

effect of road quality on deterioration rate

Type: Auxiliary
Formula: 1 + (road quality multiplier * (1 - Road Quality) ^ road quality nonlinearity factor)
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

fraction of population who would choose to travel by bus

Type: Constant
Formula: 0.35
Units: Dmnl
Assumptions: Arbitrary value, can be a scenario variable

max annual capacity of bus route

Type: Auxiliary
Formula: bus capacity * bus frequency
Units: trip*people/Year
Assumptions:

number of car trips per year per car

Type: Constant
Formula: 654
Units: trip / (vehicle * Year)
Assumptions: Vic total km travelled 2020 = 63,602,000,000 km. Vic number of vehicles 2020 = 5,114,444. Avg trip distance = 19km. Total km travelled/total no cars = 12,435km travelled by each car in one year. Div by avg trip distance = 654 trips per year.

number of cars in Forrest

Type: Lookup
Formula: LOOKUP EXTRAPOLATE(table for car ownership, Time)
Units: vehicle
Assumptions:

number of people of reduced mobility

Type: Auxiliary
Formula: "0-14" + "65+" + sum of people below poverty line
Units: people
Assumptions: This is a simplification - many people 65 and over will be able to drive, but as they age this will change

number people with ability to travel by bus

Type: Auxiliary
Formula: (fraction of population who would choose to travel by bus * total population)
Units: people
Assumptions:

preventative maintenance

Type: Auxiliary
Formula: IF THEN ELSE (critical condition index $>= 80$, 1, 0.5)
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

restorative maintenance

Type: Auxiliary
Formula: IF THEN ELSE (critical condition index $>=0$, 1, 1)
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

road damage ratio

Type: Auxiliary
Formula: (car use + average number of bus trips per year + tourist trips per year) / allowable number of load cycles
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015)

Road deterioration rate

Type: Auxiliary
Formula: (deterioration multiplier * effect of ageing of pavement on deterioration rate * effect of road quality on deterioration rate * road damage ratio * effect of flooding on road quality * Road Quality) / Time
Units: 1/Year
Assumptions: From Fallah-Fini et al. (2015)

Road maintenance rate

Type: Auxiliary
Formula: (IF THEN ELSE (Road Quality $>= 0.8$, 0, IF THEN ELSE (Road Quality $>=0.6$:AND: Road Quality <0.8, preventative maintenance, IF THEN ELSE (Road Quality $>=0.4$:AND: Road Quality <0.6, corrective maintenance, IF THEN ELSE (Road Quality $>=0.2$:AND: Road Quality <0, restorative maintenance, restorative maintenance))))) / Time
Units: 1/Year
Assumptions: From Fallah-Fini et al. (2015)

Road Quality

Type: Stock
Formula: INTEG (Road maintenance rate - Road deterioration rate), INITIAL = 0)

Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015). Assume road quality at start of simulation is good.

road quality multiplier

Type: Constant
Formula: 8.6
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015).

road quality nonlinearity factor

Type: Constant
Formula: 2
Units: Dmnl
Assumptions: From Fallah-Fini et al. (2015).

service life of road

Type: Constant
Formula: 30
Units: Year
Assumptions: From Fallah-Fini et al. (2015).

table for car ownership

Type: Lookup table
Formula: ([(2000,0)-(2100,300)],(2006,266),(2011,172),(2016,167))
Units: Dmnl
Assumptions: ABS Census data: 2006 = 266; 2011 = 172; 2016 = 167

tourist trips per year

Type: Auxiliary
Formula: Number Of Tourists * trips per tourist
Units: trip/Year
Assumptions: All tourists come using cars

travel equity bus demand

Type: Auxiliary
Formula: average number of bus trips per year * number of people of reduced mobility
Units: trip*people/Year
Assumptions:

travel equity bus frequency discrepancy

Type: Auxiliary
Formula: bus frequency required for travel equity - bus frequency
Units: trip/Year
Assumptions:

trips per tourist

Type: Constant
Formula: 2
Units: trip/person
Assumptions: Tourists drive on roads at least twice while in Forrest

whole population bus frequency discrepancy

Type: Auxiliary
Formula: bus frequency required for whole population - bus frequency
Units: trip/Year
Assumptions:

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