Total	Count	Including Array Elements		Stella Architect	
Variables	58	103			
Modules	1				
Stocks	7	16			
Flows	16	37			
Converters	35	50			
Constants	10	10			
Equations	41	77			
Graphicals	10	13			

	Equation	Properties	Units	Documentation	Annotation
Top-Level Model:					
Population_in_Outer_Islands(t)	Population_in_Outer_Islands(t - dt) + (outer_islands_births - "internal_in-migration" - outer_islands_deaths) * dt	INIT Population_in_Outer_Islands = 46995	people	Calculated from the 'Total' population (72,335) minus the population of South Tarawa (25,380) for the year 1990 = 46,955 people Source: Kiribati Census Atlas 2022	NON-NEGATIVE
Population_in_Tarawa(t)	Population_in_Tarawa(t - dt) + (births + "internal_in-migration" - deaths - "out-migration") * dt	INIT Population_in_Tarawa = 25380	people	The census count for 1990 = 25380 people Source: Kiribati Census Atlas 2022	NON-NEGATIVE
births	Population_in_Tarawa*birthrate*Tarawa.EFFECT_OF		people/Years		
deaths	Population_in_Tarawa*deathrate*Tarawa.EFFECT_O	OUTFLOW PRIORITY: 2	people/ years		
"internal_in-migration"	Population_in_Outer_Islands*internal_migration_rate	OUTFLOW PRIORITY: 1	people/Years		
"out-migration"	Population_in_Tarawa*"OUT-MIGRATION_RATE"/1000	OUTFLOW PRIORITY: 4	people/ years		
outer_islands_births	Population_in_Outer_Islands*birthrate		people/Years		
outer_islands_deaths	Population_in_Outer_Islands*deathrate	OUTFLOW PRIORITY: 3	people/Years		
birthrate	(LOOKUP(HISTORICAL_BIRTHRATE, TIME))/1000		1/years	Birthrate is divided by 1000 to account for the historical crude birthrate of 1 birth per 1000 people.	
deathrate	(LOOKUP(HISTORICAL_DEATHRATE, TIME))/1000		1/years	Deathrate is divided by 1000 to account for the historical crude deathrate of 1 death per 1000 people.	
HISTORICAL_BIRTHRATE	GRAPH(TIME) Points: (1990.00, 36.577), (1991.00, 36.276), (1992.00, 35.559), (1993.00, 34.784), (1994.00, 34.216), (1995.00, 33.658), (1996.00, 33.519), (1997.00, 32.878), (1998.00, 32.239), (1999.00, 31.46), (2000.00, 30.702), (2001.00, 29.87), (2002.00, 29.025), (2003.00, 28.272), (2004.00, 28.583), (2005.00, 28.821), (2006.00, 29.26), (2007.00, 29.88), (2008.00, 30.398), (2009.00, 30.578), (2010.00, 30.783), (2011.00, 30.995), (2012.00, 30.544), (2013.00, 30.075), (2014.00, 29.547), (2015.00, 29.188), (2016.00, 28.86), (2017.00, 28.616), (2018.00, 28.46), (2019.00, 28.064), (2020.00, 27.645), (2021.00, 27.207)		people/(people)	Crude birth rate per 1000 people Source: (1) United Nations Population Division. World Population Prospects: 2022 Revision. (2) Census reports and other statistical publications from national statistical offices, (3) Eurostat: Demographic Statistics, (4) United Nations Statistical Division. Population and Vital Statistics Reprot (various years), (5) U.S. Census Bureau: International Database, and (6) Secretariat of the Pacific Community: Statistics and Demography Programme. [https://data.worldbank.org/indicator/SP.DYN.CBRT.IN?locations=KI] Accessed: Jan 22, 2024	
HISTORICAL_DEATHRATE	GRAPH(TIME) Points: (1990.00, 9.229), (1991.00, 8.912), (1992.00, 8.633), (1993.00, 8.369), (1994.00, 8.142), (1995.00, 7.952), (1996.00, 7.801), (1997.00, 7.613), (1998.00, 7.433), (1999.00, 7.255), (2000.00, 7.090), (2001.00, 6.950), (2002.00, 6.875), (2003.00, 6.829), (2004.00, 6.857), (2005.00, 6.917), (2006.00, 7.004), (2007.00, 7.064), (2008.00, 7.102), (2009.00, 7.102), (2010.00, 7.071), (2011.00, 7.007), (2012.00, 6.928), (2013.00, 6.831), (2014.00, 6.727), (2015.00, 6.623), (2016.00, 6.519), (2017.00, 6.426), (2018.00, 6.345), (2019.00, 6.252), (2020.00, 6.242), (2021.00, 6.236)		people/ (people)	Crude death rate per 1000 people Source: (1) United Nations Population Division. World Population Prospects: 2022 Revision. (2) Census reports and other statistical publications from national statistical offices, (3) Eurostat: Demographic Statistics, (4) United Nations Statistical Division. Population and Vital Statistics Reprot (various years), (5) U.S. Census Bureau: International Database, and (6) Secretariat of the Pacific Community: Statistics and Demography Programme. [https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?locations=KI] Accessed: Jan 22, 2024	
"INITIAL_OUT-MIGRATION_RATE"	5.759		1/years	Source: Regional population dynamics and mobility trends in the Pacific (Table 9, pg 31) [https://www.auckland.ac.nz/assets/news-and-opinion/2024/01/report-pacific-population-dynamics-and-mobility-trends.pdf] Accessed: Jan 22, 2024	
internal_migration_rate	IF TIME < 2024 THEN 0.01 ELSE 0.01		1/Years	Internal migration rate is estimated at 0.01. During scenario 2, value is set to 0.001	
"OUT-MIGRATION_RATE"	Tarawa."EFFECT_OF_HOUSEHOLD_DENSITY_ON_OUT-MIGRATION"*"INITIAL_OUT-MIGRATION_RATE"		1/years		
Tarawa:					
Floating_Land(t)	Floating_Land(t - dt) + (development_rate) * dt	INIT Floating_Land = 0	sq km	Initial value for floating land = 0. This is not currently a strategy used in Kiribati.	
Housing_Units(t)	Housing_Units(t - dt) + (housing_development - houses_lost) * dt	INIT Housing_Units = 3905	house	Initial housing units was calculated from initial population in 1990 (25,380 people) / average household size (6.5 people per household) = 3,905 houses	
Land_Area[RCP](t)	Land_Area[RCP](t - dt) + (accretion[RCP] - land_loss[RCP]) * dt	INIT Land_Area[RCP] = 15.76	sq km	Land Area from ADB Report, 'Kiribati: South Tarawa Sanitation Improvement Sector Project (formerly Tarawa Sanitation Improvement Project)' File: 'ADB_South Tarawa Sanitation Improvement Project.pdf'	
Residential_Land_Area[RCP](t)	Residential_Land_Area[RCP](t - dt) + (developing_residential_land[RCP] - residential_land_loss[RCP]) * dt	INIT Residential_Land_Area[RCP] = 5.17	sq km	Measured from national Government Land Use Plan 2017 File: 'General Land Use Plan 2017_measurements'	
Undeveloped_Land_Area[RCP](t)	Undeveloped_Land_Area[RCP](t - dt) + (gaining_undeveloped_land[RCP] - loss_of_open_land[RCP] -	INIT Undeveloped_Land_Area[RCP] = 0.2	sq km	Measured from national Government Land Use Plan 2017 File: 'General Land Use Plan 2017_measurements'	
accretion[RCP]	RECLAMATION_RATE+development_rate		sq km/Years	Total new land from both reclaimed land and floating islands.	
developing_open_land[RCP]	(housing_development *(HOUSE_FOOTPRINT/ SQ_M_TO_SQ_KM_CONVERSION) / HOUSING_LEVELS)		sq km/year		
developing_residential_land[RCP]	developing_open_land		sq km/year		

Name	Equation/Value		Units	Notes	
development_rate	IF TIME < 2024 THEN 0 ELSE FLOATING_LAND_RATE		sq km / year	An IF THEN statement was used to reflect that up to 2024, floating islands have not been used.	
gaining_undeveloped_land[RCP]	accretion[Baseline]		sq km/year	All new land is undeveloped.	
houses_lost	5 + (residential_land_loss[Baseline]*SQ_M_TO_SQ_KM_CONVERSION/HOUSE_FOOTPRINT*HOUSING_LEVELS)		house/Years	Five houses are estimated to be lost per year from damage. Additional house loss from from loss of land.	
housing_development	(new_people_to_Tarawa*rate_of_development_for_new_people)*(1-PERCENT_OF_NEW_PEOPLE_MOVING_IN_WITH_FAMILY)/household_density_for_new_migrants		house/Years		
land_loss[RCP]	RATE_OF_LAND_LOSS		sq km/Years		
loss_of_open_land[RCP]	land_loss*percent_of_land_area_undeveloped		sq km/year	Assuming that all land use areas are affected by land loss proportionally.	
residential_land_loss[RCP]	land_loss*percent_of_residential_land_area		sq km/year	Assuming that all land use areas are affected by land loss proportionally.	
EFFECT_OF_HOUSEHOLD_DENSITY_OF_BIRTH_RATE	GRAPH(overall_household_density_in_Tarawa/INITIAL_HOUSEHOLD_DENSITY) Points: (0.000, 1.467), (0.500, 1.361), (1.000, 1.090), (1.500, 0.787), (2.000, 0.623), (2.500, 0.574), (3.000, 0.492), (3.500, 0.434), (4.000, 0.344), (4.500, 0.148), (5.000, 0.057)		Dimensionless	Relationship estimated from population and fertility data. Data in "Effect of Pop Density of Fertility.xlms" Source: Rotella A, Varnum MEW, Sng O, Grossmann I. Increasing population densities predict decreasing fertility rates over time: A 174-nation investigation. Am Psychol. 2021 Sep;76(6):933-946. doi: 10.1037/amp0000862. PMID: 34914431.	
EFFECT_OF_HOUSEHOLD_DENSITY_ON_DEATHRATE	GRAPH(overall_household_density_in_Tarawa/INITIAL_HOUSEHOLD_DENSITY) Points: (0.000, 0.800), (0.500, 0.900), (1.000, 1.000), (1.500, 1.200), (2.000, 1.300), (2.500, 1.500), (3.000, 1.600), (3.500, 1.700), (4.000, 1.800), (4.500, 1.900), (5.000, 2.000)		Dimensionless	Relationship is estimated from researcher judgement.	
"EFFECT_OF_HOUSEHOLD_DENSITY_ON_OUT-MIGRATION"	GRAPH(overall_household_density_in_Tarawa/INITIAL_HOUSEHOLD_DENSITY) Points: (0.000, 0.639), (0.500, 0.754), (1.000, 1.000), (1.500, 1.164), (2.000, 1.320), (2.500, 1.500), (3.000, 1.664), (3.500, 1.811), (4.000, 1.902), (4.500, 2.000), (5.000, 2.000)		Dimensionless	Relationship is estimated from researcher judgement.	
EFFECT_OF_LAND_AVAILABILITY_ON_ABILITY_TO_BUILD	GRAPH(Undeveloped_Land_Area[Baseline]/INITIAL_OPEN_LAND) Points: (0.000, 0.000), (0.333333333333, 0.00103416666667), (0.666666666667, 0.105347), (1.000, 1.0002), (1.33333333333, 1.895), (1.66666666667, 1.99916666667), (2.000, 2.000)		Dimensionless	Relationship is estimated from researcher judgement.	
EFFECT_OF_SEA_LEVEL_RISE_ON_LAND_LOSS[RCP]	GRAPH((SEA_LEVEL_RISE + INITIAL_MEAN_SEA_LEVEL)/INITIAL_MEAN_SEA_LEVEL) Points: (1.000, 0.000), (1.297, 0.01485), (1.594, 0.05482), (1.891, 0.1566), (2.188, 0.3638), (2.485, 0.6362), (2.782, 0.8434), (3.079, 0.9452), (3.376, 0.9851), (3.673, 1.000)		1/year	Relationship is estimated from researcher judgement.	
FLOATING_LAND_RATE	0		sq km / year	Baseline rate for the development of floating island land is 0.0. In Scenario 3, the rate is set to 0.01 sq km/ yr.	
HOUSE_FOOTPRINT	70		sq m / footprint	Source: 'UNDP Pacific Housing Guide 2023'. Gives footprint of concrete (80 sq m) and timber (60 sq m) in Fiji. Average of 70 sq m is used. Fiji can be used as a proximate for Kiribati housing structure.	
household_density_for_new_migrants	6.5		people/ house	Value is estimated from historical household sizes.	
HOUSING_LEVELS	1		house / footprint	Traditional I-Kiribati houses are 1 story (level). In Scenario 1, this value is set to 5.	
INITIAL_HOUSEHOLD_DENSITY	6.5		PEOPLE/ HOUSE	Source: Kiribati Census Atlas 2022	
INITIAL_MEAN_SEA_LEVEL	1.673		meters	This is the mean sea level for Kiribati from 1992 (when the tidal gauge was installed) to 2023. Data in Excel: 'Monthly Sea Levels for Kiribati' tab 'Historic Sea Levels' Source: http://www.bom.gov.au/ntc/IDO70060 IDO70060SLD.shtml	
INITIAL_OPEN_LAND	0.2		sq km	Measured from national Government Land Use Plan 2017 Same value as initial for 'Undeveloped Land Area'. File: 'General Land Use Plan 2017_measurements'	
new_people_to_Tarawa	.births+."internal_in-migration"		people/ years	New people to Tarawa are calculated from births and in-migration.	
overall_household_density_in_Tarawa	.Population_in_Tarawa/Housing_Units		people/ house		
percent_of_land_area_undeveloped[RCP]	Undeveloped_Land_Area/Land_Area[Baseline]		Dimensionless	Measured from national Government Land Use Plan 2017 File: 'General Land Use Plan 2017_measurements'	
PERCENT_OF_NEW_PEOPLE_MOVING_IN_WITH_FAMILY	0.7		Dimensionless	Value is estimated from researcher judgement.	
percent_of_residential_land_area[RCP]	Residential_Land_Area/Land_Area		Dimensionless		
rate_of_development_for_new_people	EFFECT_OF_LAND_AVAILABILITY_ON_ABILITY_TO_BUILD		Dimensionless		
RATE_OF_LAND_LOSS[RCP]	(Land_Area*EFFECT_OF_SEA_LEVEL_RISE_ON_LAND_LOSS)		sq km/year		
RECLAMATION_RATE	STEP(0.01, 2000, 1, 10)		sq km/ year	Based on reclamation rate of 0.09 ha/year (0.0009 sq km/year). Reclamation projects were assumed to occur once per decade with a 1 year project time. Source: Biribo, N., & Woodroffe, C. D. (2013). Historical area and shoreline change of reef islands around Tarawa Atoll, Kiribati. Sustainability Science, 8(3), 345–362. https://doi.org/10.1007/s11625-013-0210-z	
SEA_LEVEL_RISE[Baseline]	0		meters	Sea level rise 1990-2030: sea level height of 1.673m was estimated from 'Monthly sea levels for Kiribati' (http://www.bom.gov.au/ntc/IDO70060/IDO70060SLD.shtml) Ramp function slope was found from 1990=1.65m and 2030 = 1.77m (RCP4.5) for a slope of 0.003. The slope was similarly calculated for sea level rise projections for RCP4.5, RCP6.0, and RCP8.5.	

				Data for RCP sea level rise projections from https://www.adb.org/sites/default/files/publication/808926/sea-level-change-pacific-islands-region.pdf) [also in 'SLR Projections' - Monthly Sea Levels for Kiribati.xlsx]	
SEA_LEVEL_RISE[RCP45]	RAMP(0.003, 1990, 2030) +RAMP(0.005, 2030, 2050)+RAMP (0.0055, 2050, 2070) +RAMP (0.0065, 2070, 2090)				
SEA_LEVEL_RISE[RCP6]	RAMP (0.0028, 1990, 2030) + RAMP(0.005, 2030, 2050)+RAMP (0.006, 2050, 2070)+RAMP(0.007, 2070, 2090)				
SEA_LEVEL_RISE[RCP85]	RAMP(0.003, 1990, 2030)+RAMP(0.006, 2030, 2050) + RAMP(0.008, 2050, 2070)+RAMP(0.0105, 2070, 2090)				
SQ_M_TO_SQ_KM_CONVERSION	1000000		sq m / sq km	Conversion of sq m to sq km.	

Run Specs	
Start Time	1990
Stop Time	2090
DT	4-Jan
Fractional DT	TRUE
Save Interval	0.25
Sim Duration	1.5
Time Units	Years
Pause Interval	0
Integration Method	Euler
Keep all variable results	TRUE
Run By	Run
Calculate loop dominance information	TRUE
Exhaustive Search Threshold	1000

Array Dimension	Indexed by	Elements
RCP	Label (4)	Baseline RCP45 RCP6 RCP85