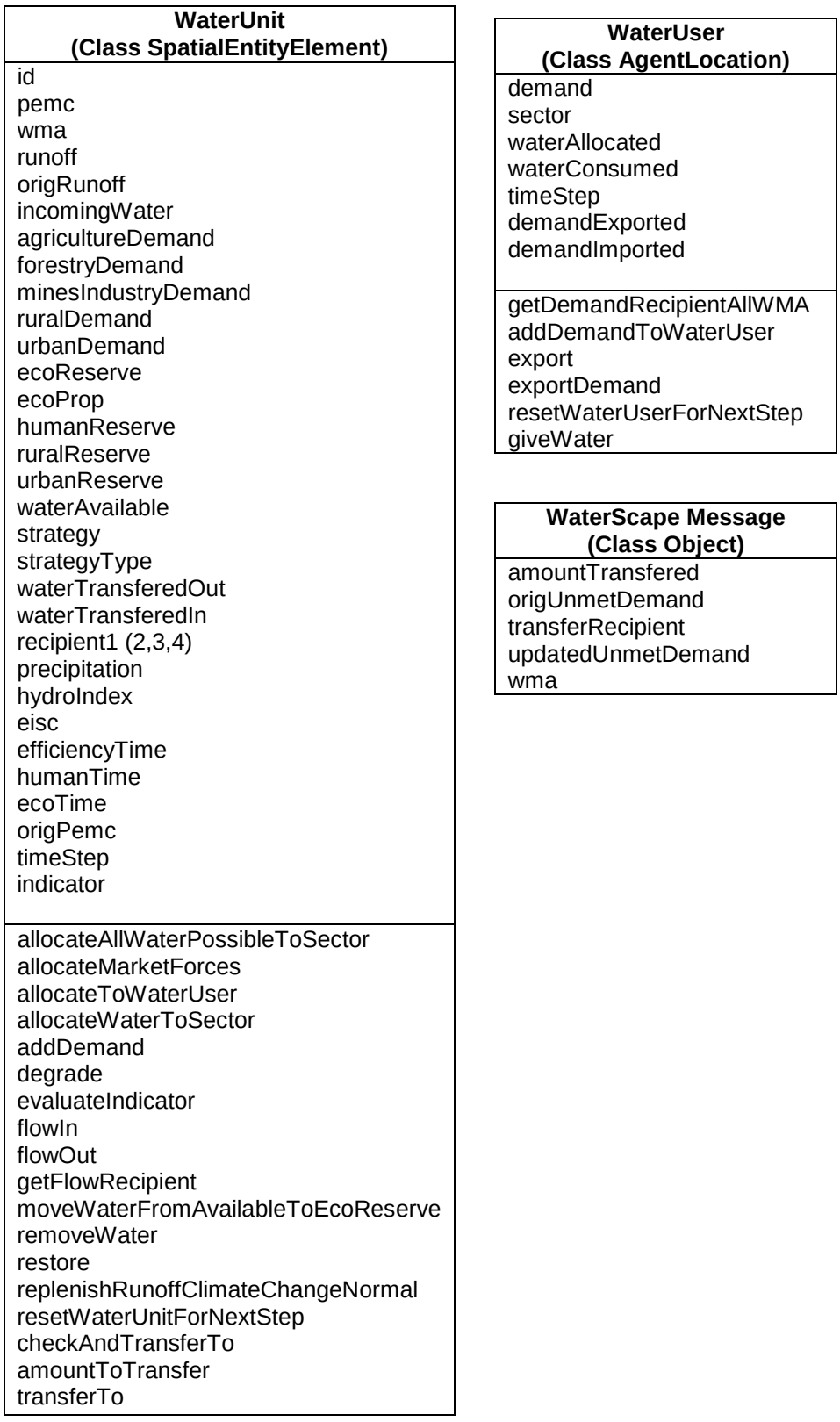
Appendix A.

van Jaarsveld, A. S., R. Biggs, R. J. Scholes, E. Bohensky, B Reyers, T. Lynam, C. Musvuto and C. Fabricius. 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SA*f*MA) experience. Philosophical Transactions of the Royal Society B: Biological Sciences. 360(1454): 425- 441.

Appendix B. Class diagram depicting agent classes of the WaterScape model, with attributes in top box and methods in bottom box.



CMA **(Class AgentComm)**
wma waterUnits allocationStrategy firstTimeStep timeStep status
adjustDemandAgricultureBase adjustDemandForestryBase adjustDemandMinesIndustryBase adjustDemandRuralBase adjustDemandUrbanBase adjustDemandAgricultureHigh adjustDemandForestryHigh adjustDemandMinesIndustryHigh adjustDemandRuralHigh adjustDemandUrbanHigh allocateCollectiveLearningEfficiency allocateCollectiveLearningEfficiencyIndicator allocateCollectiveLearningEquity allocateCollectiveLearningEquityIndicator allocateCollectiveLearningSustainability allocateCollectiveLearningSustainabilityIndicator allocateCollectiveLearningIndicator allocateFortressWorld allocateMarketForces allocateToWaterUser allWaterUnitsGetFortressWorldAllocation allWaterUnitsGetMarketForcesAllocation allWaterUnitsUsePolicyReform waterUnitsGetRandomStrategy getTransferDonor getTransferDonorNearest getTransferRecipientMaxDemand getTransferRecipientMaxUnmetDemand resetCMAForNextStep applyStrategy fortressWorldStrategy getStrategy learningStrategy marketForcesStrategy policyReformStrategy deficitAlertFortressWorld deficitAlertMarketForces deficitAlertPolicyReform recipientsSendMessageFortressWorld recipientsSendMessageLearning recipientsSendMessageMarketForces recipientsSendMessagePolicyReform transferMaxAvailable transferToNearest transferToNearestMaxAvailable

APPENDIX C. Description of attributes of entities in the WaterScape model.

Entity	Attribute	Method	Description
WaterUnit	id		Unique value for each water unit
	pemc		Present ecological management class
	wma		Identification number of Water Management Area (WMA)
	runoff		Natural mean annual runoff
	origRunoff		Runoff value at initialisation
	incomingWater		Water from upstream water units
	agricultureDemand		Water requirement of agricultural sector
	forestryDemand		Water requirement of forestry sector
	minesIndustryDemand		Water requirement of mining and industrial sector
	ruralDemand		Water requirement of rural sector
	urbanDemand		Water requirement of urban sector
	ecoReserve		Ecological reserve requirement
	ecoProp		Proportion of total runoff designated for ecological reserve requirement
	humanReserve		Human reserve requirement
	ruralReserve		Human reserve requirement of rural population
	urbanReserve		Human reserve requirement of urban population
	waterAvailable		Component of runoff that is available for use
	strategy		Water management strategy (i.e. scenario)
	strategyType		Strategy type (i.e. previous or most successful strategy)
	waterTransferedOut		Water transferred out of water unit
	waterTransferedIn		Water transferred into water unit
	recipient1 (2,3,4)		Downstream water unit that receives water from this water unit
	precipitation		Mean annual precipitation
	hydroIndex		Hydrological index value
	eisc		Ecological importance and sensitivity value
	efficiencyTime		Consecutive number of times water unit exceeds efficiency indicator threshold value
	humanTime		Consecutive number of times water unit exceeds human indicator threshold value
	ecoTime		Consecutive number of times water unit exceeds ecological indicator threshold value

	origPemc		PEMC value at initialisation
	timeStep		Number of time steps (years) since initialisation
	indicator		Indicator by which success of strategy is measured
		allocateAllPossibleWaterToSector	Gives all water needed to satisfy demand; if demand is more than water available, gives all water available.
		allocateMarketForces	Allocates water to each of the sectors in turn according to 'Market Forces' rule (i.e. in order of average economic productivity).
		allocateToWaterUser	Allocates an amount to water user proportional to its demand.
		allocateWaterToSector	Gives water to the WaterUser of the specified sector; if not enough water is available, gives all available.
		addDemand	Increases demand of a WaterUser.
		degrade	Adjusts ecological management class (PEMC) for degradation, based on withdrawal-to-availability ratio and ecological importance and sensitivity index, for water unit and recipient (downstream) water units.
		evaluateIndicator	Evaluates success of indicator and changes if it fails for 5 successive timesteps.
		flowIn	Releases water into water unit from donor (upstream) water units.
		flowOut	Releases water out of this water unit into recipient water units.
		getFlowRecipient	Finds recipient to which water flows downstream from this water unit. If there is more than one, selects the nearest of these.
		moveWaterFromAvailableToEcoReserve	Sets aside water for ecological reserve. If the amount required is greater than the actual water available, moves all available.
		removeWater	Takes an amount of water away from the available water pool. If the requested amount is more than the amount available, takes it all.
		restore	Adjusts ecological management class (PEMC) for restoration, based on withdrawal-to-availability ratio and ecological importance and sensitivity index, for water unit and recipient (downstream) water units.
		replenishRunoffClimateChangeNormal	Sets runoff equal to the greater of 0 and the change projected to occur due to climate change, multiplied by a random positive number drawn from a normal distribution around the mean.
		resetWaterUnitForNextStep	Resets variables at the beginning of the timestep.
		checkAndTransferTo	Before water is transferred to water unit, checks unmet demand of transfer recipient to see if it has changed since requesting transfer. Compares the updated unmet demand to the amount designated for transfer and transfers the lesser of the two.
		transferTo	Transfers requested amount of water to transfer recipient.
WaterUser	demand		Water requirement of water user

	sector		Water use sector
	waterAllocated		Water allocated to water user
	timeStep		Number of time steps (years) since initialisation
	demandExported		Demand exported by water user
	demandImported		Demand imported by water user
	waterConsumed		Water consumed by water user
		getDemandRecipientAllWMA	Finds recipient water unit within WMA to which water user can export excess demand.
		addDemandToWaterUser	Increases demand by amount that has been exported to this water user; water user immediately consumes this amount of water from the WaterUnit.
		export	WaterUser with excess demand exports demand to WaterUnit with available water.
		exportDemand	Adds amount of exported demand to recipient's demand, and subtracts same amount from donor water user's demand.
		resetWaterUserForNextStep	Resets variables at the beginning of the timestep.
		giveWater	Adds amount of exported water to water user's available water and water consumed.
WaterScape Message	amountTransfered		Amount of water transferred from donor to recipient
	origUnmetDemand		Unmet demand of recipient at time of transfer request
	transferRecipient		Water unit that receives transfer
	updatedUnmetDemand		Unmet demand of recipient at time of transfer
	wma		Identification number of water management area requesting transfer
CMA	wma		Identification number of water management area
	waterUnits		Water units within water management area of CMA's jurisdiction
	firstTimeStep		First time step (true or false)
	timeStep		Number of time steps (years) since initialisation
	status		Status of water availability (i.e. surplus or deficit)
		adjustDemandAgricultureBase	Adjusts demand of agricultural sector in each of its WaterUnits according to base growth projections.
		adjustDemandForestryBase	Adjusts demand of forestry sector in each of its WaterUnits according to base growth projections.
		adjustDemandMinesIndustryBase	Adjusts demand of mining and industry sector in each of its WaterUnits according to base growth projections.
		adjustDemandRuralBase	Adjusts demand of rural sector in each of its WaterUnits according to

			base growth projections.
		adjustDemandUrbanBase	Adjusts demand of urban sector in each of its WaterUnits according to base growth projections.
		adjustDemandAgricultureHigh	Adjusts demand of agricultural sector in each of its WaterUnits according to high growth projections.
		adjustDemandForestryHigh	Adjusts demand of forestry sector in each of its WaterUnits according to base growth projections.
		adjustDemandMinesIndustryHigh	Adjusts demand of mining and industrial sector in each of its WaterUnits according to high growth projections.
		adjustDemandRuralHigh	Adjusts demand of rural sector in each of its WaterUnits according to high growth projections.
		adjustDemandUrbanHigh	Adjusts demand of urban sector in each of its WaterUnits according to high growth projections.
		allocateCollectiveLearningEfficiency	Allocates water randomly, then allows agents to use efficiency indicator to choose allocation strategy in subsequent timesteps.
		allocateCollectiveLearningEfficiencyIndicator	Allocates water randomly, then allows agents to use efficiency indicator to choose allocation strategy in subsequent timesteps (used when all three indicators are distributed among agents).
		allocateCollectiveLearningEquity	Allocates water randomly, then allows agents to use equity indicator to choose allocation strategy in subsequent timesteps.
		allocateCollectiveLearningEquityIndicator	Allocates water randomly, then allows agents to use equity indicator to choose allocation strategy in subsequent timesteps (used when all three indicators are distributed among agents).
		allocateCollectiveLearningSustainability	Allocates water randomly, then allows agents to use sustainability indicator to choose allocation strategy in subsequent timesteps.
		allocateCollectiveLearningSustainabilityIndicator	Allocates water randomly, then allows agents to use sustainability indicator to choose allocation strategy in subsequent timesteps (used when all three indicators are distributed among agents).
		allocateCollectiveLearningIndicator	Allocates water randomly, then allows agents to use efficiency, equity, and sustainability indicators.
		allocateFortressWorld	Allocates water using Fortress World rule (proportional allocation).
		allocateMarketForces	Allocates water using Market Forces rule (preferential allocation, then to human and ecological Reserve).
		allWaterUnitsUsePolicyReform	Allocates water using Policy Reform rule (allocation to human and ecological Reserve, then preferential allocation).
		waterUnitsGetRandomStrategy	Randomly assigns allocation strategies to water units.
		getTransferDonor	Selects a surplus water unit from which to transfer water.

		getTransferDonorNearest	Selects the surplus water unit from which to transfer water with sufficient water available to meet recipient's unmet demand and that is nearest to the recipient.
		getTransferRecipientMaxDemand	Selects the water unit with the greatest demand from which to transfer water.
		getTransferRecipientMaxUnmetDemand	selects the water unit with the greatest unmet demand from which to transfer water.
		resetCMAForNextStep	Resets variables at the beginning of the timestep.
		deficitAlertFortressWorld	Sends a message to all other CMAs containing wma number and selected transfer recipient (water unit with maximum demand). The messages are delivered and processed asynchronously (as soon as received).
		deficitAlertMarketForces	Sends a message to all other CMAs containing wma number, selected transfer recipient (water unit with maximum demand), and amount requested (recipient's unmet demand). The messages are delivered and processed synchronously (at end of timestep).
		deficitAlertPolicyReform	Sends a message to all other CMAs containing wma number, selected transfer recipient (water unit with maximum unmet demand), and amount requested (recipient's unmet demand). The messages are delivered and processed synchronously (at end of timestep).
		transferMaxAvailable	Transfers all available water from the donor water unit, regardless of the requested amount, to selected recipient.
		transferToNearest	Transfers the lesser of the amount requested and the donor's available water to selected recipient.
		transferToNearestMaxAvailable	Transfers all available water from the donor water unit, regardless of the requested amount, to nearest of selected recipients.

Appendix D. Translation of scenario archetypes of Gallopín et al. (1997) to the South African water management context. Adapted from Bohensky, E. and A.S. van Jaarsveld. "Water management and conservation in a southern African river basin: A scenario planning approach to uncertainty." Poster presentation, Annual Meeting of the Society for Conservation Biology, New York, 30 July–2 August, 2004.

Scenario archetype	**WaterScape name**	**Key elements**
Market Forces	***Efficiency First***	Strong economy facilitated by national governance framework; poor wealth distribution; weak local governance; weak social and environmental policies. Economic efficiency of water allocation is achieved, with urban and industrial users in Gauteng Province paying high prices for water. This impacts the ability to fulfill ecological reserve requirements downstream. Human reserve requirements are met where spin-offs occur from economic development, but not in some rural areas.
Policy Reform	***Some, for All, Forever***	Effective democratic governance; strong, globally-linked economy in a balanced trade regime; significant poverty reduction; substantial investments in health, education, and technology sectors. Ecological reserve requirements are met through strict enforcement of both resource protection measures and demand management. Human reserve requirements are met due to large investments in service delivery to rural areas. This comes at a cost to short-term economic efficiency in some areas where this results in decreased water availability for agricultural and industrial use.
Fortress World	***Hydraulic Mission***	Weak and ineffective governance; economic collapse; weak civil society; increasing gap between wealthy and poor, who live, respectively, inside and outside the "fortress."Water management reverts to the pre-1994 system; agriculture commandeers resources and government subsidies are re-introduced. None of the economic, social, or environmental goals is met; however, a decline in industrial activity means ecological conditions are better in catchments downstream from industries than they would be under *Market Forces*.
Local Learning	Learning variants (Chapter 4: Learning by Maximum Allocation, Learning by Proportion Satisfied; Chapter 5: Learning by use of indicators)	Weak national governance; weak economy; strong civil society; community-driven resource management; strong reliance on informal sector. Overall, the situation remains the same as at present, with improvement in conditions in some catchments and increased degradation in others. However, these "varied experiments" can teach water managers about what works and what does not, and function as an adaptive management strategy if the lessons learned from these experiments can be implemented.