Lake Anderson Revisited II

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This document describes the second replication of Anderson's model (Anderson, 1973; Möhring & Troitzsch, 2001) along the lines of ODD+D (Grimm et al., 2006, 2010; Müller et al., 2013).

A. Overview

I. *Purpose*

I.i. *What is the purpose of the study?* The purpose of this study is another agent-based replication of a System Dynamics model (Anderson, 1973) where he analysed the dynamics of nutrient, biomass, oxygen and detritus in a model lake under conditions of artificial fertilising and policies to deal with the consequences of artificial fertilising.. A first replication (Möhring & Troitzsch, 2001) added those agents to the original model that were necessary to move the role of the experimenter into the model, whereas this replication replaces the original lake with a collection of small elements between which biomass, nurtients and oxygen are exchanged, adds rivers upstream and downstream as well as adjacent land divided into villages and populated with farms and industrial plants run by individual persons.

I.ii. *For whom is the model designed?* For researchers and students of complex systems as well as for social scientists at large.

II. *Entities, state variables and scales*

II.i. *What kinds of entities are in the model?* The model contains the following kinds of entities:

II.i.1 `patches` represent parcels of land and lake or river, respectively, which are assumed to be shallow, hence there are no vertically different concentrations modelled. They hold the information about what can happen in the patch, namely

II.i.1.a `is-lake?` all solved components are dissipated in all directions,

II.i.1.b `is-river?` all solved components are dissipated only downstream (i.e. from north to south),

II.i.1.c `is-groundwater?` only fertiliser is dissipated, and only in the direction of the nearest lake or river patch (within a cone of 30 degrees) — `is-agro?`, `is-industry?`, `is-residential?` and `is-wood?` are subcategories of `land` patches, it is only on `is-agro?` patches that farms can spread manure which is then slowly transported to the nearest `rivers-and-lake` patches;

II.i.1.d `categroy` is an auxiliary variable with the same meaning as the boolean variables just mentioned,

II.i.1.e `this-village` contains the information to which village a patch belongs;

and about the local state and dynamics of water and, eventually, groundwater, namely

II.i.1.f `nutrient` the concentration of natural or artificial fertilizer, initialised to 40 mg ℓ^{-1} for `rivers-and-lake`, 0 mg ℓ^{-1} for land parcels,

II.i.1.g `biomass` the concentration of biomass in water, initialised to 0.2 mg ℓ^{-1},

II.i.1.h `oxygen-hyp` the concentration of oxygen in the hypolimnion, initialised to 9 mg ℓ^{-1},

II.i.1.i `oxygen-epi` the concentration of oxygen in the epilimnion, assume dto be constant, initialised to 10 mg ℓ^{-1},

II.i.1.j `detritus` the concentration of detritus at the bottom of the lake or river, initialised to 2.0 mg ℓ^{-1}.

II.i.1.k `growth-rate` the growth rate of biomass in water, in mg ℓ^{-1} yr^{-1},

II.i.1.l `death-rate` the death rate of biomass in water, in mg ℓ^{-1} yr^{-1},

II.i.1.m `decay-rate` the rate with which dead biomass in water decays to detritus, in mg ℓ^{-1} yr^{-1},

II.i.1.n `respiration-rate` the rate at which biomass in water consumes oxygen, in mg ℓ^{-1} yr^{-1},

II.i.1.o `consumption-rate` the rate at which biomass consumes nutrient in water, in mg ℓ^{-1} yr^{-1},

II.i.1.p `solution-rate` the rate at which oxygen in the epilimnion is dissolved in water, in mg ℓ^{-1} yr^{-1},

II.i.1.q `aeration-rate` the rate at which air is biubbled artificially inti water, in mg ℓ^{-1} yr^{-1},

- II.i.1.r `feeding-rate` the rate at which nutrient is artificially brought into water, in mg ℓ^{-1} yr^{-1} (only relevant for the Anderson scenarios),
- II.i.1.s `algae-harvested` the rate at which biomass is artificially harvested from water, in mg ℓ^{-1} yr^{-1},
- II.i.1.t `detritus-dredged` the rate at which detritus is removed from the ground of rivers and lake, in mg ℓ^{-1} yr^{-1}.

II.i.2 `villages` are colllections of `land` patches which are separated by rivers. Besides constants containing information about `my-inhabitants`, `my-farms`, `my-industrial-plants`, `my-patches` B.VII.iv.6.a and `nearest-water` they have instance variables such as

- II.i.2.a `farm-algae` the farming rate currently applied by this village, in mg ℓ^{-1} yr^{-1},
- II.i.2.b `dredge` the dredgin rate currently applied by this village, in mg ℓ^{-1} yr^{-1},
- II.i.2.c `ka` the aeration rate currently applied by this village, in mg ℓ^{-1} yr^{-1},
- II.i.2.d `TAX` the tax levied on farmers for spreading manure currently applied by this village, in mg ℓ^{-1} yr^{-1},

II.i.3 `persons` do not do anything in the current version, except that about one half of them belong to either a `farm` or an `industrial-plant`, and one per village has the state of being `mayor`,

II.i.4 `farms` spread manure on one of their patches. Besides constants such as `my-village` and `my-employees`, they have one instance variable:

- II.i.4.a `TAXthres` a threshold which determines whether they spread manure after considering the tax load.

II.i.5 `sources` are simple agents which manage the spread of the manure from its origin to the nearest shore; they do not need instance variables other than the built-in variables of NetLogo turtles.

II.i.6 `sensors` are simple agents reporting the state of its `rivers-and-lake` patch to the villages they belong to; they do not need instance variables other than the built-in variables of NetLogo turtles.

II.i.7 `industrial-plants` do not do anything in the current version.

II.ii. *What are the exogenous drivers of the model?* Each model run is driven by a set of thresholds for water quality, strategy limits and taxes . These are

II.ii.1 `awareness` a number ≥ 1.0 determining that villages take measures as soon the water quality measured in nutrient, biomass and detritus concentration exceeds the respective initial value multiplied by this factor and end these measures when the concentrations fall below the initial value divided by this factor; for the oxygen concentration the algorithm is the other way round,

II.ii.2 `TAXapplied` is the tax rate levied upon farmers spreading manure during a period when measures are taken by the respective village,

II.ii.3 `manure-spread` is the volume of manure spread per patch per tick,

II.ii.4 `aeration-applied` is the rate at which air is bubbled into the rivers and the lake share belonging to the village that takes this measure,

II.ii.5 `dredging-applied` is the rate at which detritus is dredges from the ground of the rivers or lake share belonging to the village that takes this measure,

II.ii.6 `farming-applied` is the rate at which algae are harvested from the rivers and the lake share belonging to the village that takes this measure,

II.iii. *If applicable, how is space included in the model?* Space plays a prominent role in the model as the distribution of agents over the simulated world differs between different random initialisations. Patches play different roles, depending whether they represent the lake or rivers, agricultural or industrial areas and natural areas.

III. ***Process overview and scheduling***

III.i. *What entity does what, and in what order?* The model is scheduled as follows:

III.i.1 some time-dependent constants for the original Anderson version of the model are set if applicable,

III.i.2 `rivers-and-lake` patches dissipate `nutrient`, `biomass`, `oxygen-hyp` and `detritus` among their neighbours, manure spread on `land` patches flows toward the nearest shore,

III.i.3 each patch metabolises according to the rules given in (**?**) (although more recent knowledge would perhaps lead to different algorithms),

III.i.4 `villages` make their decisions and apply them,

III.i.5 `farmers` make their decisions and apply them,

III.i.6 some global variables for reporting are updated.

B. Design Concepts

I. *Theoretical and Empirical Background*

I.i. *Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) . . . ?* The model inherits the dynamics of the lake (and of the rivers) from Anderson's model with the modification that the lake and the rivers are no longer one entitiy but are modeled as adjacent cubes of water (but only one layer) which exchange their contents among themselves. Farms and villages are modelled to apply the experiments described in Anderson's paper, but the measures taken to cope with the consequences of artificial fertilising are not externalised as applied by the experimenter, but are taken by the villages and depend on what sensors communicate to them about the water quality.

I.ii. *On what assumptions are the agents' decision models based?* These assumptions are simple enough: farmers spread manure on their fields when the tax they have to pay for this (if any) are low enough, villages decide to take the measures foreseen in Anderson's model when the sensor report that the water quality at their places exceed specified limits.

I.iii. *Why are certain decision models chosen?* Just to internalise Anderson's consideration into the agents. This had already been done in (Möhring & Troitzsch, 2001), but in this replication the measures are taken by agents in the vicinity of the lake and work only locally, and their success (if any) dissipates over the whole water body.

I.iv. *If the model ... is based on empirical data, where does the data come from?* The empirical data about the dynamics of the lake are taken from **?** who gave a number of sources from which he took the values of the constants of his (and this) model.

I.v. *At which level of aggregation were the data available?* Only at the aggregate level.

II. ***Individual Decision Making***

II.i. *What are the subjects and objects of decision making? On which level of aggregation is decision making modelled?* Objects of decision making are the `land` patches where `farmers` decide to spread manure and the `rivers-and-lake` patches where the `villages` decide to dredge detritus, farm algae or bubble air into the water.

II.ii. *What is the basic rationality behind agents' decision making in the model? Do agents pursue an explicit objective or have other success criteria?* The success criterion of the villages is to keep the quality within narrow bounds, the success criterion of the farmers is to get rid of their manure in a traditional way and evade taxes posed on manure spreading.

II.iii. *How do agents make their decisions?* Currently, only comparing preset threshold values with values describing the water quality at the places where sensors measure it.

II.iv. *Do the agents adapt their behaviour to changing endogenous and exogenous state variables?* When the village tax exceeds the tax threshold of farmers, they stop spreading manure, when water quality thresholds are exceeded, villages start their measures and drop them when the quality is at least as good as in the initial situation.

II.v. *Do social norms or cultural values play a role in the decision making process?* One could think of the norms obeyed by farmers and villages as legal norms defined by the threshold values set by the modeller (see A.II.ii.7.a).

II.vi. *Do spatial aspects play a role in the decision process?* Yes, this is the main difference between this replication and its forerunner.

II.vii. *Do temporal aspects play a role in the decision process?* Apart from the model being a dynamic model with dissipation processes in the water body, there are no seasons (although one could think of manure only spread in late spring of every year if the tax does not prevent farmers from spreading manure).

II.viii. *To which extent and how is uncertainty included in the agents' decision rules?* Currently, there is no uncertainty.

III. ***Learning***

III.i. *Is individual learning included in the decision process?* Not yet, or at most indirectly, as villages raise taxes when the realise that the water quality deteriorates, and farmers are "taught" not to spread manure any longer.

III.ii. *Is collective learning implemented in the model?* Not yet. In a future version, mayors might be elected by the population of each village, their voting decision depending on the strategies they promise to apply.

IV. ***Individual Sensing***

IV.i. *What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?* Villages measure the water quality in their part of the lake.

IV.ii. *What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?* Water patches know the concentration of nutrient, biomass, oxygen and detritus with their neighbouring patches and exchange these components. `villages` sense the water quality at one patch at the score of the lake or river (whichever is nearer).

IV.iii. *What is the spatial scale of sensing?* Villages have exactly one land patch on the shore which is nearest to the lake or a river and know only the water quality of the adjacent water patch.

IV.iv. *Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?* Currently, `farmers`, `sensors` and `villages` do not send each other messages about taxes or the water quality, but in future versions this can easily be implemented.

IV.v. *Are costs for cognition and costs for gathering information included in the model?* No.

V. ***Individual Prediction*** There are no predictions.

VI. ***Interaction***

VI.i. *Are interactions among agents and entities assumed as direct or indirect?* Direct.

VI.ii. *On what do the interactions depend?* Interactions depend on vicinity.

VI.iii. *If the interactions involve communication, how are such communications represented?* Currently, there is no communication proper.

VI.iv. *If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?* There is no network as yet, but a conference of village mayors could be added to the model where strategies are discussed.´

VII. ***Collectives*** Currently, collectives exist (employees of farms and industrial plants, inhabitants of villages, see), but they do not play any role; future version will use facilities of collectives.

VIII. ***Heterogeneity*** Patches belong to different categories (A.II.i.1.c) with different behavior.

IX. ***Stochasticity*** Currently, there is no stochasticity, except for behaviour space experiments whose runs are initialised Monte Carlo style.

X. ***Observation*** `sensors` observe the water quality.

X.i. *What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected?* If `logging?` is switched on, a file with the histories of levels and rates is produced for further analysis. Monitors display current values of minima and maxima of water quality variables and the current rates of change of these variables; the same variables are also plotted.

X.ii. *What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)* Given appropriate global parameters, the NetLogo view shows the lake as a dissipative system in which concentration waves pulse over the lake and rivers. If the appropriate feature is chosen, the view shows the topographical distribution of the respective level variable (yellow represents the current minimum, green represents the initial value which is also taken as the optimal value, blue represents the maximum value).

C. Details

I. *Implementation Details*

I.i. *How has the model been implemented?* The model is implemented with NetLogo 6.2.0. The buttons, sliders, switches etc. with which global parameters (see below C.IV.ii.2.a) have the following meaning (from top left to bottom right, left of the view):

I.i.1 `setup` and `go` have the usual meaning. For the six sliders below the block of monitors with minima, maxima and ranges see A.II.ii.7.a.

I.i.2 `feature-to-show` and `grad-visual` determine which feature is shown in the view and how the colour coding is done (yellow is always the minimum, green is always the initial or standard value, blue is always the current maximum; for the conversion of the values in between several different functions can be used). The feature is automatically set when the ticks proceeds, when the run is interrupted, the `show-feature` button applies the currently set feature.

I.i.3 The switches and choosers below are used to switch between different version of the original **?** model.

I.ii. The monitors and plots are more or less self-explanatory:

I.ii.1 One plot shows the mean values of the water quality variables, the other shows the mean values of the rate of change of the water quality variables.

I.ii.2 Histograms show the distribution of the water quality variables.

I.iii. ...

II. ***Initialisation***

II.i. *What is the initial state of the model world, i.e. at time* $t = 0$ *of a simulation run?* For the standard and initial values of state of the water quality see A.II.i.1.e.

II.ii. *Is the initialisation always the same, or is it allowed to vary among simulations?* The initialisation is equal for equal random number generator seeds. This seed is different for each run of the model provided that the global parameter `constant-seed?` is switched off.

III. ***Input Data***

III.i. *Does the model use input from external sources such as data files or other models to represent processes that change over time?* No.

IV. ***Submodels***

IV.i. *What, in detail, are the submodels that represent processes listed in 'Process overview and scheduling'?* Already described there.

IV.ii. *What are the model parameters, their dimension and reference values?* The following list informs about all the global parameters of the model (standard values in parenthese): These are given in A.II.i.1.e.

IV.iii. *How were submodels designed or chosen, and how were they parameterised and then tested?* The dissipation submodel was tested against Anderson's experiment (in a version without any dissipation and without any farmer or village activities, and it yields exactly the same results as Anderson's baseline version.

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