Brigham Young University
BYU ScholarsArchive

6th International Congress on Environmental Modelling and Software - Leipzig, Germany - July 2012

Jul 1st, 12:00 AM

Safe Operating Spaces for Human Water Use: Applying Exploratory Modeling and Patient Rule Induction to ANEMI

Jan Kwakkel

J. S. Timmermans

Follow this and additional works at: https://scholarsarchive.byu.edu/iemssconference

Kwakkel, Jan and Timmermans, J. S., "Safe Operating Spaces for Human Water Use: Applying Exploratory Modeling and Patient Rule Induction to ANEMI" (2012). *International Congress on Environmental Modelling and Software*. 82.
https://scholarsarchive.byu.edu/iemssconference/2012/Stream-B/82

This Event is brought to you for free and open access by the Civil and Environmental Engineering at BYU ScholarsArchive. It has been accepted for inclusion in International Congress on Environmental Modelling and Software by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

Safe Operating Spaces for Human Water Use: Applying Exploratory Modeling and Patient Rule Induction to ANEMI

J.H. Kwakkel and J.S. Timmermans
Delft University of Technology, Faculty of Technology, Policy and Management.
j.h.kwakkel@tudelft.nl, j.s.timmermans@tudelft.nl

Abstract: Safe operating space for human activities that will not push the planet out of the 'Holocene state' that has seen human civilizations arise, develop, and thrive can be defined with respect to among others global freshwater use. Establishing such limits is a methodological challenge because they are critically depended on local conditions, the role of management, and financial and institutional capacity in magnifying or ameliorating problems. Moreover estimates of these limits are plagued by uncertainty arising out of conflicting models, regional variations, limitation of expansion of water use through financial and institutional capacity, and uncertainty about the realization and efficiency of trans-boundary water transfers. This paper aims at investigating the limits to global freshwater use through exploratory modelling and analysis. To this end, the behaviour of a dynamic world water model that also included the socio-economic system is explored across a wide variety of uncertainties. The resulting dynamics are analysed and dynamics indicative of water shortage are identified. In order to identify the conditions for occurring of these dynamics, we use the Patient Rule Induction Method (PRIM). PRIM can be used for data analytic questions where the analyst tries to find simultaneous combinations of values for input variables that result in similar characteristic values for the outcome variables. Specifically, one seeks a set of subspaces of the input variable space within which the values of output variables are considerably different from the average value over the entire input domain. In as far as these output sub-spaces are indicative for unsustainable water conditions, the boundaries of their congruent input parameter spaces constitute limits to global fresh water use.

Keywords: global limits, world water models, PRIM, exploratory modelling

1 INTRODUCTION

Rockström et al. [2009] introduce the concept of a safe operating space for humanity that will not push the planet out of the 'Holocene state' that has seen human civilizations arise, develop, and thrive. Rockström et al. have identified nine earth-system processes, including climate change, biodiversity loss and associated preliminary thresholds which, if crossed, are expected to generate unacceptable environmental change. These include climate change, rate of biodiversity loss, interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, chemical pollution, and atmospheric aerosol loading. However, for only three of them, notably, climate change, rate of biodiversity loss, and the nitrogen cycle, are these thresholds substantiated theoretically and methodologically. The other thresholds including the global fresh water cycle, are tentative 'best guesses' (Rockström et al. 2009). For water Rockström et al maintain that the boundary must be set to safely sustain enough green water for moisture feedback while allowing for terrestrial and aquatic ecosystem functioning and as a first attempt propose runoff depletion in the form of consumptive blue water use as a proxy. Based on global fresh water cycle assessment studies, Rockström et al set the threshold for global fresh water use at a range of 4000 to 6000 cubic kilometers per year.

There are several problems associated with the safe operating space approach. A first problem is the ambiguous treatment of reductionism versus holism. While Rockström at al. clearly recognize thresholds and threshold behavior as a systemic and emergent property, they embark on a reductionist approach by reducing the earth system to nine biophysical processes and define planetary boundaries internal to these subsystems. Such an approach is bound to overlook the impacts of the dynamic interactions between the subsystems. These dynamic interactions, in turn, are characterized by structural uncertainties, as for example in case of the relation between climate change and renewable fresh water resources [Oki et al., 2006].To this, Molden [2009] add that the concept of a global limit overlooks the importance of local conditions, regional variations, the role of management, and financial and institutional capacity in magnifying or ameliorating problems. Moreover, the estimated global limit for blue water use is based on a limited number of studies extrapolated beyond their original intentions [Molden, 2009].

From the foregoing, we conclude that the hypothesis of Rockström et al. that humanity may soon be approaching the boundaries for global freshwater use is disputed. Much of this dispute relates to uncertainties in the interaction between socio-economic and physical factors in the approach used for establishing the safe operation space with respect to water use and the consequences of climate change. That is, the limits on fresh water use cannot be established without considering related subsystems and the wide variety of uncertainties. In this contribution, the reductionist and complex dynamics issues are tackled by utilizing an integrated dynamic model of the planetary fresh water cycle that takes into consideration the non-linear and dynamic feedback relationships between physical characteristics of water balance and population growth; development of agriculture and industry; technological development, use of other resources; and climate change. The issue of uncertainty is addressed by applying Exploratory Modeling and Analysis (EMA), a research methodology that uses computational experiments to analyse complex and uncertain systems [Agusdinata, 2008, Bankes, 1993]. The overall objective of this paper is to investigate the limits to the planetary fresh water cycle trough exploring and analysing the dynamics of an integrated dynamic model over a wide range of uncertainties.

2 METHOD

2.1 Exploratory Modelling and Analysis

One modeling approach that fits with this suggested systemic approach is System Dynamics [Forrester, 1968, Sterman, 2000]. At present, several integrated dynamic water cycle models exist at the global scale. AQUA (Hoekstra 1998) and WorldWater (Simonovic 2002) are the most relevant and best known models. ANEMI is a more recent model in this same tradition [Davies et al., 2010, 2011]. In this paper, we use ANEMI. It is the most recent integrated world water model and was kindly made available for our use by its maker [Davies, 2007]. Future work will consider the other models, allowing for a cross model comparison.

EMA is being used to handle the various uncertainties intrinsic to assessing planetary limits. EMA can be contrasted with the use of models to predict system behavior, where models are built by consolidating known facts into a single package [Hodges et al., 1992]. When experimentally validated, this single model can be used for analysis as a surrogate for the actual system. Unfortunately, for many systems of interest, the construction of a model that may be validly used as surrogate is simply not a possibility. [Cambell et al., 1985, Hodges et al., 1992]. For such systems, a methodology based on consolidating all known information into a single model and using it to make best estimate predictions can be highly misleading. However, models can be constructed that are consistent with the available information, but such models are not unique. Rather than specifying a single model and falsely treating it as a reliable image of the system of interest, the available information is consistent with a set of models, whose implications for potential decisions may be quite diverse. A single model run drawn from this potentially infinite set of plausible models is not a “prediction”; rather, it provides a computational experiment that reveals how the world would behave if the various guesses any particular model makes about the various unresolvable uncertainties were correct. By conducting many such computational experiments, one can explore the implications of the various guesses. EMA is the explicit representation of the set of plausible models, the process of exploiting the information contained in such a set through a large number of computational experiments, and the analysis of the results of these experiments Many well established techniques, such as Monte Carlo sampling, factorial methods, and optimization techniques, can be usefully and successfully employed in the context of EMA [Agusdinata, 2008, Kwakkel, 2010, Lempert et al., 2003, Miller, 1998].

In order to analyze the results of the series of computational experiments, we utilize a modified version of the Patient Rule Induction Method (PRIM) [Chong et al., 2008, Friedman et al., 1999]. PRIM can be used for data analytic questions where the analyst tries to find combinations of values for input variables that result in similar characteristic values for the outcome variables. Specifically, one seeks a set of subspaces of the input variable space within which the values of output variables are considerably different from the average value over the entire domain. This results in a very concise representation, for typically only a limited set of dimensions of the input variable space is restricted. That is, a subspace is characterized by upper and/or lower limits on only a few of the input dimensions.

2.2 ANEMI

ANEMI, an ancient Greek term for the four winds, heralds of the four seasons, links physical systems such as climate, the hydrological cycle and the carbon cycle with socio-economic systems, including economy, land use, population change and water use. It was designed as an integrated assessment model that would permit the assessment both of socio-economic policies and uncertainties about the overall system [Davies et al., 2010].

ANEMI is a System Dynamics model, focusing in particular on the importance of the feedback relations between the various physical and socio-economic subsystems, and the dynamics arising out of these feedbacks. Central to System Dynamics models is the endogenous point of view [Richardson, 2011]. According to this view, the dynamic behavior of a system arises within the internal structure of a model. This view implies a closed system boundary, where the behavioral dynamics of the system arise out of interacting feedback loops. Thus, in system dynamics, a system is viewed as an ongoing interdepended, self-sustaining, dynamic process. The observed behavior of a system is to be understood as arising out of the internal structure of the system which is conceptualized using stocks and flows, and relations between them. System Dynamics is a modeling method for understanding the behaviors of nonlinear, dynamic and complex systems and for policy analysis and design [Sterman, 2000]. ANEMI is implemented in Vensim, a System Dynamics software package.

ANEMI is composed of nine subsystems: climate, carbon cycle, economy, land-use, population, agricultural production, natural hydrological cycle, water use, and water quality [Davies, 2007, Davies et al., 2008, 2011]. Figure 1 shows the main feedback structure of the model. The positive or negative sign associated with each arrow indicates the direction of change one model component has on the other model component. The names next to each arrow indicate which aspect of the model component causes a change in the other model component. The closed loop structure of the model implies that model behavior emerges from the interaction of model components, rather than from being driven by external inputs.

That is, the dynamic behavior of the model is the result of endogenous feedbacks. The model has been validated through comparison with government statistics, scientific data, results from other models, and socio economic data [Davies, 2007, Davies et al., 2008, 2010, 2011].

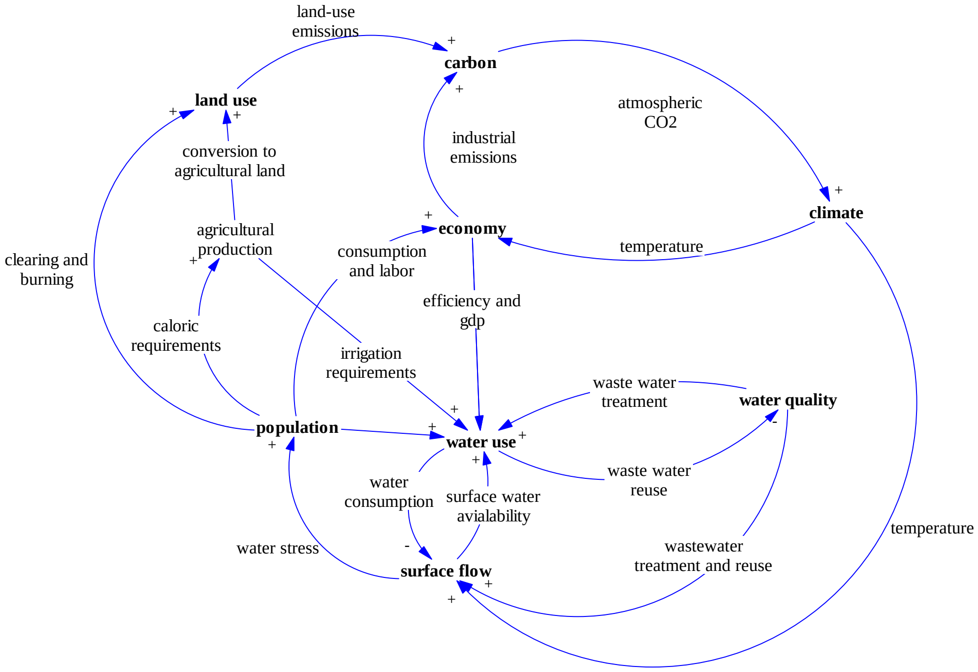

Figure 1: Model components and their feedbacks [Davies et al., 2011]

The climate sector is an upwelling diffusion energy balance model based on the box advection diffusion model of Harvey and Schneider [1985]. The carbon cycle is based on Goudriaan and Ketner [1984], where the oceanic sector is modified based on Fiddaman [1997]. The land use system is based on Goudriaan and Ketner [1984]. The population component is based on Nordhause and Boyer [2000] and Fiddaman [1997]. However, the dynamics are endogenous by including water stress [Davies et al., 2010]. The economic components is inspired by the updated DICE model [Nordhaus, 1992, 2008, Nordhaus et al., 2000]. The three water parts and the agricultural production are unique to ANEMI, but build on earlier work [e.g. Shiklomanov, 2000, Simonovic, 2002]. The water use model is similar to WaterGAP 2 [Alcomo et al., 2003]. Water quality is comparable to how it is handled in WorldWater [Simonovic, 2002]. Surface flow, and the hydrological cycle are influenced by Chanine [1992], Shiklomanov [2000], and Simonovic [2002]. The agricultural component is the latest addition to ANEMI and is based on Bouwman et al. [2005], Siebert and Döll [2010], and FAO data [Davies et al., 2011].

2.3 Experimental set up

Appendix A contains an overview of the parameters and their ranges that are to be explored. For this paper, we concentrated on parameters related directly to water use. The documentation of the model was reviewed and parameters that were either explicitly denoted as a guess or assumption, or for which divergent possible values were given were included in the analysis. The parameters include various time series that describe developments over the full runtime, such as the changing demand for food per person per year. These time series were replaced with sigmoid functions:

$$f(t) = \alpha \frac{1}{1 + e^{\frac{t-\gamma}{k}}} + \beta$$

Here, α, β, γ, δ, are uncertain parameters that can be explored; α and β respectively control the upper and lower limit of the sigmoid, γ controls when the sigmoid is half way between the two limits, and δ controls the slope.

In order to explore the behavior of the model over the listed uncertainties, a shell written in Python is utilized. This ‘EMA workbench’ controls Vensim through its Dynamic Link Library (DLL). The workbench is responsible for generating input values for the various uncertainties, setting these values on the model, executing the model, and storing its results. The workbench supports parallel processing to reduce computational time. We used a Latin hypercube to generate 10.000 experiments. These were run on an workstation with an Intel Xeon processer with six cores. Computational time was roughly 12 hours with 6 parallel processes.

3 RESULTS

Figure 2 shows a performance envelope for three key performance indicators and a Gaussian kernel density estimate of the terminal values. We observe that over the 10.000 experiments, the water stress first rises and then either stabilizes or comes back down again. With respect to population, we observe that the population in 2100 can be somewhere between 10.000 and 16.0000 million. We also see that the blue water consumption in some of the runs exceeds the 4000 km^3 per year threshold suggested by Röckstrom et al. [2009]. Dynamics indicative of water shortage are dynamics resulting in a high water stress. Another indicator of water shortage is low values for population, since we do not sample over population related parameters, the only factor affecting population growth is water stress.

In order to identify the combinations of uncertain parameters that are responsible for the water shortage dynamics, we focus on the population dynamics. Runs resulting in a population lower than 12.500 million in 2100 are classified as being cases of interest. Next, we use PRIM to identify regions in the input space that produce these outcomes. Figure 3 and Appendix B show the results of this analysis. From this, we conclude that low population is driven mainly by a combination of a relatively low yield off rain fed agriculture and a high demand for food (beta food controls the upper limit for food demand). The extent to which domestic water needs to be diluted also has some influence.

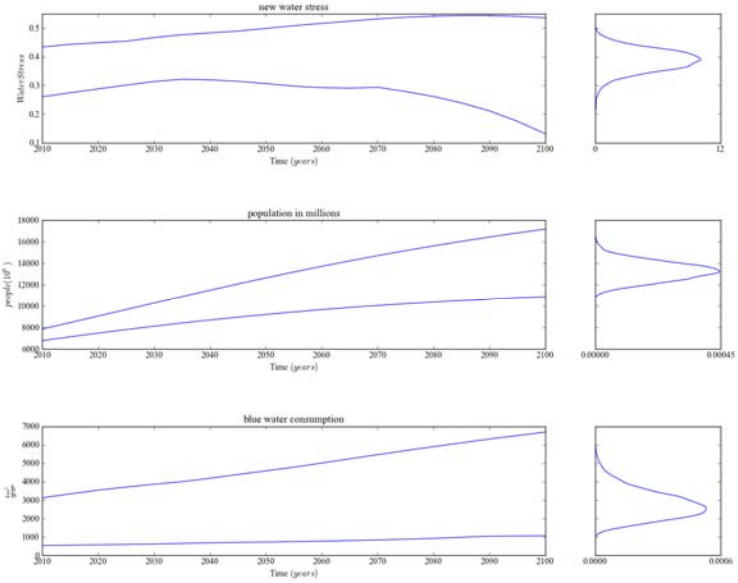

Figure 2: Performance envelopes and end state Gaussian kernel density estimates

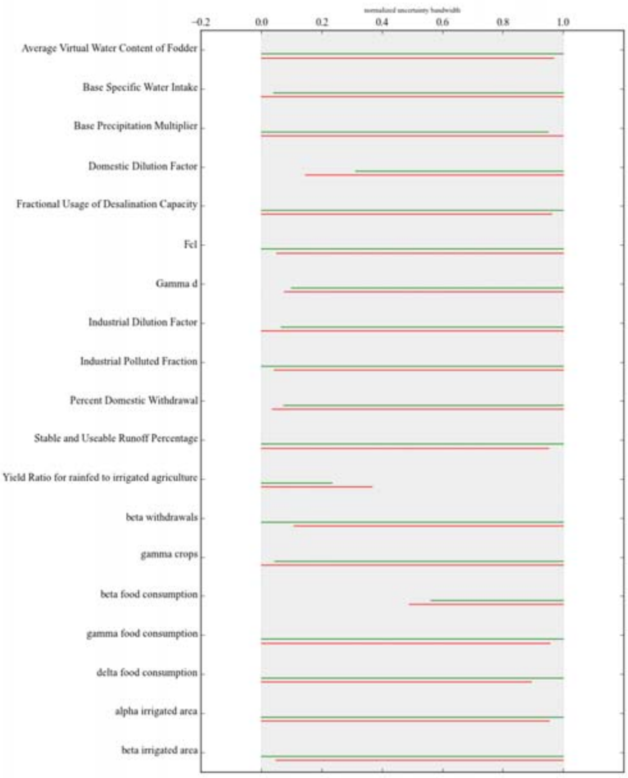

Figure 3: Results of the PRIM analysis. The light grey shaded area is the normalized range for each parameter. The green and red line correspond to box 1 and box 2 respectively and indicate the size of the box for each parameter.

4 DISCUSSION

The model considered in this paper is an integrated dynamic model of the world water cycle, taking into consideration the climate system, the population system, the economic system etc. However, this integration comes at the price of being not geographically and temporally explicit. Thus, changes in geographic precipitation patterns or shifts in the seasonal rain patterns are not included in this model. Molden's [2009] contention that it is potentially misleading to look at global limits for fresh water is corroborated by our results. For, in some of our simulations, the blue water consumptions per year passed the suggested threshold without resulting in catastrophic shifts in global dynamics. Still, given that values for water stress beyond 0.4 are seen as severe water stress [Alcomo et al., 2007], our results do indicate that water shortages are to be expected in the years to come.

The analysis of the dynamics using PRIM indicate that the main driver for water shortage, given their uncertainties, are the food demand per person per year, the yield of rain fed agriculture, and the dilution factor for domestic water use. These findings have direct policy implication. Fighting obesity in the Western world can affect the average food demand. Agricultural technology can be used to increase the yield of rain fed agriculture. Investments and innovation in sanitation can reduce pollution and in turn results in a reduction of the dilution factor. Each of these three can help in reducing water stress. Along a different dimension, the results of PRIM can help in prioritizing research into reducing the uncertainty. Our results for example suggest that the fraction of runoff withdrawal has only a small influence on water shortage dynamics. Thus, trying to estimate that parameter more precisely will yield little increase in confidence about estimates for future water shortage dynamics.

In this paper, we only looked at a single integrated dynamic model of the world water cycle. Future research needs to compare these results with other integrated dynamic models. In addition, investigating the dynamics of spatio-temporal explicit models given the various uncertainties is another highly relevant direction for research.

ACKNOWLEDGMENTS

The research is sponsored by the Dutch National Science Foundation (NWO). It is part of the research program on planetary limits to the fresh water cycle. We also would like to express our gratitude to Dr. Davies who made an extensively documented version of ANEMI available for our use.

REFERENCES

Agusdinata D.B., Exploratory Modeling and Analysis: A promising method to deal with deep uncertainty [Ph.D. thesis]. Delft: Delft University of Technology; 2008.

Alcomo J., Döll P., Henrichs T., Kaspar F., Lehner B., Rösch T., et al., Development and Testing of the WaterGAP 2 Global Model of Water Use and Availability, *Hydrological Sciences Journal*, 48(3), 317-37, 2003.

Alcomo J., Flörke M., Märker M., Future long-term changes in global water resources driven by socio-economic and climatic changes, *Hydrological Sciences Journal*, 52(2), 247-75, 2007.

Bankes S., Exploratory Modeling for Policy Analysis, *Operations Research*, 4(3), 435-49, 1993.

Bouwman A.F., van der Hoek K.W., Eickhout B., Soenario I., Exploring Changes in World Ruminant Production Systems, *Agricultural Systems*, 84(2), 121-53, 2005.

Cambell D., Crutchfield J., Farmer D., Jen E., Experimental Mathematics"the role of computation in nonlinear science, *Communications of the ACM*, 28374-84, 1985.

Chahine M.T., The hydrological cycle and its influence on climate, *Nature*, 359(6394), 373-80, 1992.

Chong I.G., Jun C.H., Flexible patient rule induction method for optimizing process variables in discrete types, *Expert Systems with Applications*, 34(4), 3014-20, 2008.

Davies E.G.R., Modelling Feedback in the Society-Biosphere-Climate System [PhD Thesis]. London, Ontario, Canada: The University of Western Ontario; 2007.

Davies E.G.R., Simonovic S.P., *An Integrated System Dynamics Model for Analyzing Behaviour of the Social-Economic-Climatic System: Model Description and Model Use Guide*. London, Ontario, Canada: University of Western Ontario; 2008.

Davies E.G.R., Simonovic S.P., ANEMI: a new model for integrated assessment of global change, *Interdisciplinary Environmental Review*, 11(2/3), 127-61, 2010.

Davies E.G.R., Simonovic S.P., Global water resources modeling with an integrated model of the social-economic-environmental system, *Advances in Water Resources*, 34(6), 684-700, 2011.

Fiddaman T.S., Feedback Complexity in Integrated Climate-Economy Models. Cambridge, Massachusetts: Massachusetts Institute of Technology; 1997.

Forrester J., *Principles of Systems*. Cambridge, MA: Wright-Allen Press; 1968.

Friedman J.H., Fisher N.I., Bump hunting in high-dimensional data, *Statistics and Computing*, 9(2), 123-43, 1999.

Goudriaan J., Ketner P., A simulation study for the global carbon cylce, including man's impact on the biosphere, *Climatic Change*, 6167-92, 1984.

Harvey L.D., Schneider S.H., Transient Climate Response to External Forcing on 10^0-10^4 Year Time Scales Part 1' Experiments With Globally Averaged, Coupled, Atmosphere and Ocean Energy Balance Models, *Journal of Geophysical Research*, 90(1), 2191-205, 1985.

Hodges J.S., Dewar J.A., *Is it You or Your Model Talking? A Framework for Model Validation*. Santa Monica: RAND; 1992.

Kwakkel J.H., The Treatment of Uncertainty in Airport Strategic Planning. Delft: Delft University of Technology; 2010.

Lempert R.J., Popper S., Bankes S., *Shaping the Next One Hundred Years: New Methods for Quantitative, Long Term Policy Analysis*. Santa Monica: RAND; 2003.

Miller J.H., Active Nonlinear Tests (ANTs) of Complex Simulation Models, *Management Science*, 44(6), 820-30, 1998.

Molden, The devil is in the details, *Nature*, 3(october 2009), 2009.

Nordhaus W.D., *The 'DICE' model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming*. Cowles Foundation Discussion Papers. New Haven, CT: Cowles Foundation for Research in Economics, Yale University; 1992.

Nordhaus W.D., *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press; 2008.

Nordhaus W.D., Boyer J., *Warming the World: Economic Models of Global Warming*. Cambridge, Massachusetts: The MIT Press; 2000.

Oki T., Kanae S., Global Hydrological Cycles and World Water Resources, *Science*, 31310681072, 2006.

Richardson G.P., Reflections on the foundations of system dynamics, *System Dynamics Review*, 27(3), 219-43, 2011.

Rockström J., Steffen W., Noone K., Persson A., Chapin F.S., Lambin E.F., et al., A safe operating space for humanity, *Nature*, 461(7263), 472-5, 2009.

Shiklomanov I.A., Appraisal and Assessment of World Water Resources, *Water International*, 25(1), 11-32, 2000.

Siebert S., Döll P., Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation, *Journal of Hydrology*, 384(3-4), 198-217, 2010.

Simonovic S.P., World Water Dynamics: Global Modeling of Water Resources, *Journal of Environmental Management*, 66(3), 349-67, 2002.

Sterman J.D., *Business dynamics: systems thinking and modeling for a complex world*. Boston, MA: McGraw-Hill; 2000.

APENDIX A

Table 1: The uncertain parameters and their ranges

uncertainty	description	range
Agricultural Blue Water Dilution Factor	factor for dilution of polluted agricultural blue water	5-10
Agricultural Polluted Fraction	percentage of return flow of agricultural blue water that is polluted	0.7-0.95
Average Virtual Water Content of Crops	virtual water in crops in m3/Gcal	400-500
Average Virtual Water Content of Fodder	virtual water in fodder in m3/Gcal	200-300
Base Specific Water Intake	base value for water intake in agriculture in m3/ha/year	9000-12000
Base Returnable Water	base value for water return flow from agriculture in m3/ha/year	10-50
Base Precipitation Multiplier	increase of precipitation due to increasing global temperature in %/Celsius	3-4
Domestic Dilution Factor	factor for dilution of polluted domestic water	5-10
Domestic Polluted Fraction	percentage of return flow of domestic water that is polluted	90-100
Fractional Usage of Desalination Capacity	fraction of desalinization capacity that is being used	0.3-0.7
Fcl	simple area weighted cloud fraction	0.5-0.6
Gamma d	factor affecting increase in water demand per person due to gdp/capita increase	2.2e-10-2.2e-06
Industrial Dilution Factor	factor for dilution of polluted industrial water	5-10
Industrial Polluted Fraction	percentage of return flow of industrial water that is polluted	38-46
Max Groundwater Withdrawal	maximum amount of ground water withdrawal in km3/Year	7-10
Maximum Establishment of Desalination Facilities	maximum amount of desalinization capacity in km3/year	25-40
Percent Domestic Withdrawal	percentage of domestic withdrawal that is consumed	80-90
Stable and Useable Runoff Percentage	fraction of runoff that can be used, taking pollution dilution into account	30-40
Yield Ratio for rainfed to irrigated agriculture	yield fraction of rain fed agriculture as compared to irrigated agriculture	0.4-0.8
Wastewater Dilution Requirement	multiplier for dilution of polluted water	6-10
Technological Change for Consumption in Agricultural Sector lookup	transient scenario for technological change in agriculture affecting water consumption	sigmoid function
Technological Change for Withdrawals in Agricultural Sector lookup	transient scenario for technological change in agriculture affecting water withdrawal	sigmoid function
Crop Productivity Gains lookup	transient scenario for gains in crop productivity	sigmoid function
Percentage increase in irrigated area lookup	transient scenario for increase in irrigated area	sigmoid function
Global Per Capita Food Consumption lookup	transient scenario for increase in food consumption	sigmoid function

APENDIX B

Table 2: Detailed PRIM results

	box 1		**box 2**		**Rest box**	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Average Virtual Water Content of Fodder	200.0083004	299.9921	200.0083	296.8169	200.1416	299.8984
Base Specific Water Intake	9120.570344	11999.88	9000.16	11999.88	9002.946	11996.57
Base Precipitation Multiplier	3.000051535	3.948175	3.000052	3.999922	3.00176	3.999922
Domestic Dilution Factor	6.562758038	9.999565	5.72724	9.999565	5.000258	9.998078
Fractional Usage of Desalination Capacity	0.300032757	0.699976	0.300033	0.684442	0.300228	0.699532
Fcl	0.500004983	0.6	0.505147	0.6	0.500059	0.599935
Gamma d	2.17E-07	2.20E-06	1.68E-07	2.20E-06	7.11E-10	2.20E-06
Industrial Dilution Factor	5.329750219	9.99966	5.000086	9.99966	5.004184	9.997944
Industrial Polluted Fraction	38.00059686	45.99975	38.32983	45.99975	38.00173	45.99309
Percent Domestic Withdrawal	80.72755178	89.99924	80.35444	89.99924	80.0032	89.97587
Stable and Useable Runoff Percentage	30.00058031	39.99997	30.00058	39.51254	30.01732	39.99572
Yield Ratio for rainfed to irrigated agriculture	0.400001596	0.493578	0.400002	0.546869	0.400734	0.799299
beta withdrawals	0.500002361	0.899987	0.54303	0.899987	0.500002	0.899779
gamma crops	1990.890039	2009.998	1990.001	2009.998	1990.006	2009.972
beta food consumption	3059.983118	3499.916	2990.044	3499.916	2500.009	3497.723
gamma food consumption	1940.000964	1960	1940.001	1959.109	1940.001	1959.996
delta food consumption	10.00156605	29.99891	10.00157	27.87852	10.00414	29.98531
alpha irrigated area	2.25E-05	0.4	2.25E-05	0.38116	2.25E-05	0.39986
beta irrigated area	1.500027352	2.499923	1.549019	2.499923	1.501038	2.499559