The challenge of managing water and nutrient cycles in a mini-world – the lessons from Biosphere 2

globalwaterforum.org/2020/08/06/the-challenge-of-managing-water-and-nutrient-cycles-in-a-mini-world-the-lessons-from-biosphere-2

Mark Nelson, Institute of Ecotechnics, US/UK

Launching earlier this year, the film Spaceship Earth introduced a new generation of people to the bold and daring experiment called Biosphere 2. The project kicked off over 30 years ago with the construction of an entirely enclosed ecosystem in the Sonoran desert of southern Arizona. The first eight person crew, known as biospherians, were 'sealed in' for two years in the experimental facility. Mark Nelson, a member of this first closure crew, reflects here on the role of water in Biosphere 2, how it was recycled, and what they learnt from the experience.

Biosphere 2 pioneered a new kind of experimental laboratory for studying basic biospheric processes. The 1.27 hectare Arizona facility included natural biome areas (rainforest, savannah, desert, marsh/mangrove wetlands and coral reef ocean), a farm, human living and working areas (Figure 1). Designed for a hundred-year experiment, the first closure experiment 1991-1993 included eight 'biospherian' crew. Privately funded, the daring experiment caught the world's imagination with its optimistic premise that humans could learn to live in harmony with natural systems. Biosphere 2 built on the Institute of Ecotechnics' innovative attempts to develop better solutions to restore and enhance ecologically damaged ecosystems.

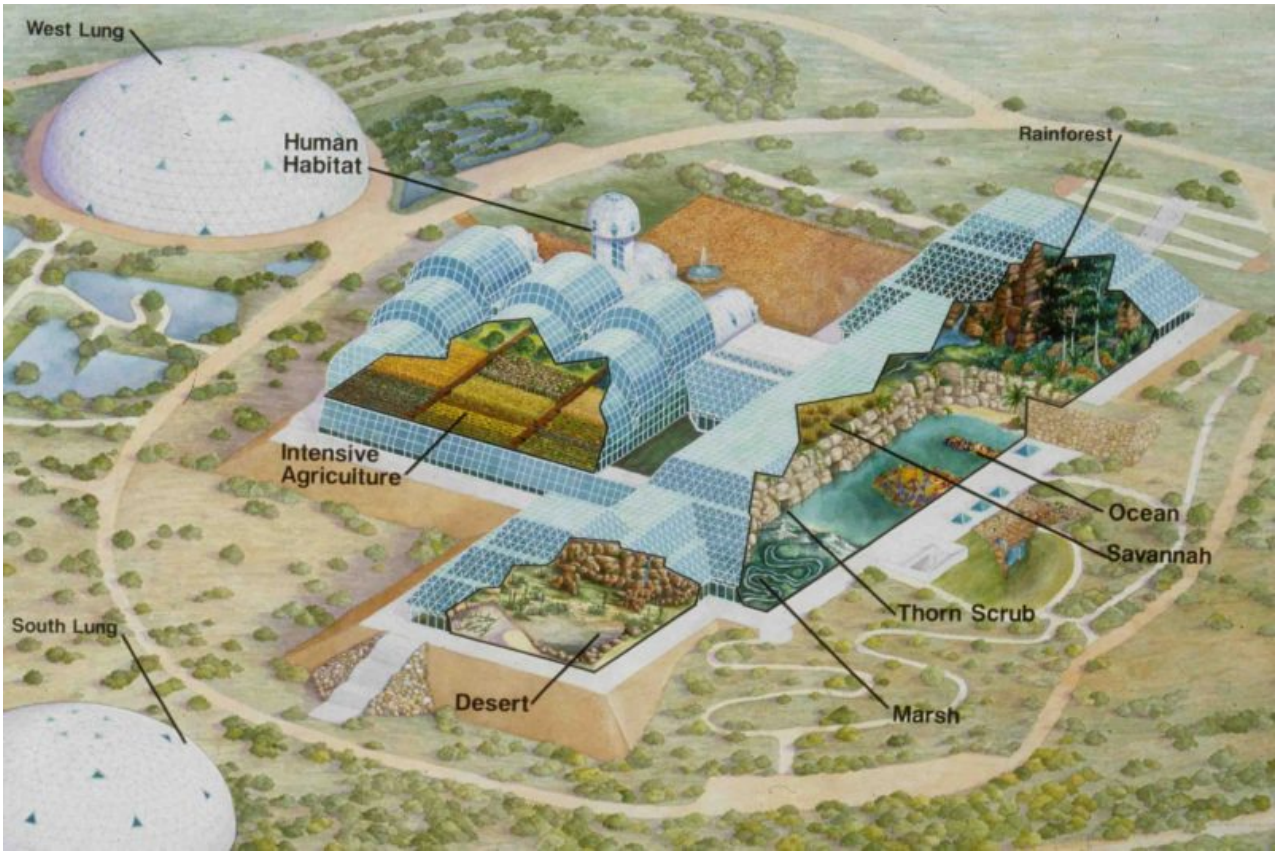

Figure 1: Schematic showing the configuration of wilderness biomes, agricultural area and human living areas of Biosphere 2.

A second experiment commencing in 1994 was terminated with a take-over of the project after disputes among the owner/managers. The facility supported scientific research by Columbia University and now University of Arizona. Though the facility is no longer operated as an airtight closed system with humans, the early closed-system experiments continued to yield a wealth of scientific research.

This article focuses on the water and nutrient cycles incorporated into Biosphere 2. Understanding these cycles was essential for creating an enclosed mini-world. What has been learnt will help us address environmental challenges relating to limited water resources and the treatment and recycling of human wastewater to maintain soil fertility while preventing water contamination.

The biospheres

Biosphere 2 was so named to emphasize that 'Biosphere 1' is the Earth's biosphere, the only one currently known. Containing all the life of our planet and the non-living resources from which nutrients and energy are obtained, Biosphere 1 is literally our life-support system. Biosphere 2 was intended to create a new kind of biospheric laboratory to discover how biospheres function. It was to serve as an ongoing experiment to see how human activities and technologies can be better designed to reinforce rather than degrade natural 'wilderness' areas.

Biosphere 2 was envisioned as the first of many experimental biospheric systems, so we can study comparative biospheres[1]. Mini-biospheres are also necessary for long-term human habitation off this planet. If you'd like to read more about the science behind the project, see *Pushing our Limits: Insights from Biosphere 2*[2]. For insights on what it was like to live inside the facility, see *Life Under Glass: Crucial Lessons in Planetary Stewardship from 2 Years in Biosphere 2*[3].

Water and nutrient cycle challenges

Amongst Biosphere 2's big challenges was the cycling of water and nutrients.

With a relatively small total water volume of 6,500 kiloliters, the necessity of recycling all of the waters of Biosphere 2 necessitated creative engineering. The lives of the biospherian crew and the health of our mini-biomes depended on it.

Each biome had different requirements so wastewater and irrigation water applied to agricultural and terrestrial biome soils was collected, treated and mixed with appropriate amounts of condensate water to supply the required amount and quality of water.

How we re-created a water cycle

We managed this artificial water cycle by harnessing nature's processes where possible. Condensate was collected from air handlers and space frames. Constructed wetlands were used to treat and recycle human and domestic animal wastewater.

Biophere 2 was the first closed ecological system to treat all wastewater. A leachate system allowed water draining through soils to be collected for reapplication. Potable water was supplied from condensate after 2-stage physical filtration and UV sterilization (Figure 2).

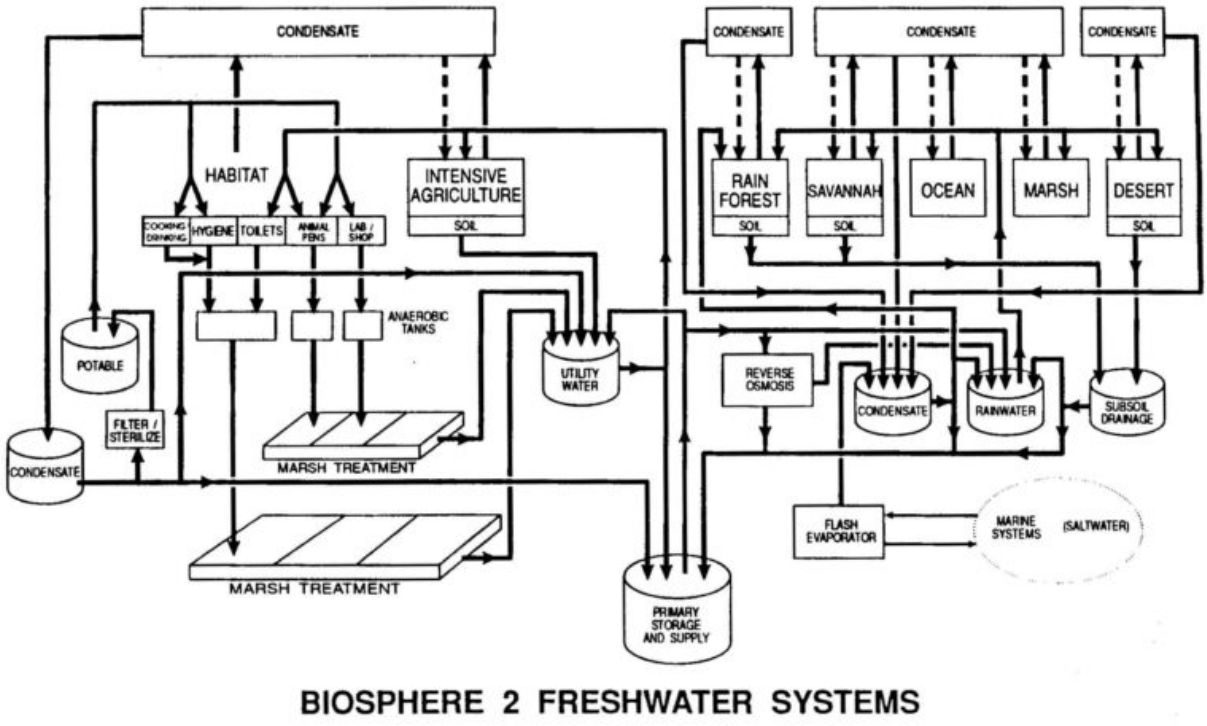

Figure 2: Schematic of the Biosphere 2 freshwater systems. Marsh treatment were constructed wetlands to treat and recycle human, domestic animal and laboratory/workshop wastewater.

The two constructed wetland systems handled all domestic human wastewater and also water from our farm animal area, laboratories and workshops. Designed with Bill Wolverton, NASA Stennis Center, the constructed wetlands were housed in fibreglass tanks with recirculating pumps after primary treatment in anaerobic settling tanks.

Daily wastewater averaged 1-1.1 m^3, since we used water-efficient showerheads, toilets and shared one kitchen. Pruning the wetland plants provided extra fodder for the domestic animals (chickens and dwarf varieties of goats and pigs) .The treated wastewater and remaining nutrients were mixed with leachate and condensate water and irrigated farm soils (Figure 3).[4,5]

Figure 3: Author managing the Biosphere 2 constructed wetlands which contained 14 species of emergent and floating wetland plants.

Marine water and nutrient cycling

The aquatic and marine biomes included an estuary modelled on the Everglades in Florida. This biome included five salinity/vegetation zones and ajoined a mini-ocean with coral reef. Recirculating pumps and vacuum pumps produced marsh and ocean waves.

To prevent a buildup of nutrient levels, an ‘algal scrubber’ was first used. This system, a design of the Smithsonian Marine Systems Laboratory, removed nutrients from the marsh and ocean water. The algae were periodically harvested to promote new growth. The scrubber was replaced during the first 2-year Biosphere 2 experiment with ‘protein skimmers’ (foam fractionation or absorptive foam separation) which helped the ocean maintain low concentrations of nutrients which was vital for this biome.[2,3]

What we learned

A striking feature of Biosphere 2’s water cycle was the acceleration of cycling times compared to Earth. Atmospheric water residence was around 4 hours, 50-200 times

faster than the 9 days in Earth's atmosphere; ocean/marsh water residence was 1200 days, a thousand times faster than Earth's 3000 years (Table 1).[6]

Reservoir	*Earth residence time*	*Biosphere 2 estimated residence time*	*Acceleration of Cycle Compared to Earth*
Atmosphere	**9 days**	**~ 4 hours**	**50-200 times**
Ocean/marsh	**3000-3200 years**	**~ 1200 days (3.2 years)**	**1000 times**
Soil water	**30-60 days**	**~ 60 days**	**Similar**

Table 1: Water fluxes and residence times compared between the Earth's biosphere and Biosphere 2. (Refs 14, 15 & 16)

This meant that as a scientific laboratory there was a much greater yield of data. The accelerated cycles reinforced our understanding that every action altering these cycles had consequences. Any pollution of our water would wind up in our cooking pots or teas in a matter of weeks. These rapid cycling times are replicated with other accelerated cycles, such as carbon dioxide residence in the atmosphere, making such systems a virtual ecological cyclotron for study.[7]

Managing salinity to prevent the buildup of salts in agricultural and wilderness biome soils were some of the greatest challenges. Some of the farm subplots and rice paddies had salinity buildup as well as the primary water storage tanks.[8] Salinity buildup is a widespread and serious issue in world agriculture dependent on groundwater irrigation.

Improvements in crop selection and greater experience with Biosphere 2's farm led the second crew to produce 100% of its diet and compared to 81% achieved by the first crew. Methods for alleviating salt buildup in several farm plots and in the rice paddies helped mitigate these problems.[9,10]

The wetlands constructed for Biosphere 2 inspired me to develop 'Wastewater Gardens' with Professor H.T. Odum, the father of ecological engineering. Wastewater gardens differ from the usual monoculture or limited species 'reed-bed' approach. They reuse water and nutrients to grow high biodiversity subsurface flow wetlands including flowers, decorative plants and harvestable ones. Wastewater Gardens have now been installed in 14 countries (www.wastewatergardens.com).[11,12]

There is no 'away'

It was surprising how well Biosphere 2 operated, given the level of unknowns in designing and operating the first biospheric laboratory. Challenges remained and if the facility had continued operation as a materially closed system for its intended 100-year duration much greater insight would have been gained about long-term dynamics of its water and nutrient systems and cycle.

Biosphere 2 vastly expanded the field of closed ecological systems which were mainly used to research bio-regenerative life support systems for space to cut supply chains and internally regenerate air, water and produce food. Those systems used hydroponics for crops and had simple water cycles. To be more relevant for Earth applications, Biosphere 2's farm and wilderness system were soil-based, which aided in air purification and also made recycling of nutrients and water easier and relatively low-tech.

Biosphere 2 was the first facility to include more than food crops with its wilderness biomes. Afterwards, the Japanese built a mini-biospheric system and the Chinese are the current leaders in long-term life support for space. Biosphere 2 also inspired other educational facilities such as the Eden Project in Cornwall, UK, and botanical exhibits such as large rainforests.

Nutrient cycling is also a major issue in Earth's biosphere, given the enormous demands for water and the problems of nutrient runoff contaminating ground and surface water resources.

The reality of Biosphere 2's rapid cycling and small reservoirs hit home in the recognition that "there is no 'away'" (ie, nowhere to dispose 'throw away' wastes).

'There is no away.' Maybe this realization is one of the most profound revelations emerging from Biosphere 2 for the inhabitants of Biosphere 1 – Planet Earth.[2,13,7]

Main image: Biosphere 2 at night (all images courtesy of Mark Nelson)

References:

1. Nelson M, T Burgess, A Alling, N Alvarez-Romo, W Dempster, R Walford & JP Allen (1993). Using a closed ecological system to study Earth's biosphere: Initial results from Biosphere 2. *BioScience* 43: 225-236.
2. Nelson M (2018). *Pushing Our Limits: Insights from Biosphere 2*, University of Arizona Press, Tucson.
3. Alling A, M Nelson & S Silverstone (2020). *Life Under Glass: Crucial Lessons in Planetary Stewardship from 2 years inside Biosphere 2*, 2nd edition, Synergetic Press, Santa Fe, NM.
4. Nelson M & BC Wolverton (2011). Plants + Soil/Wetland Microbes and Food Crop Systems that also Clean Air and Water. *Advances in Space Research* 47:582-590. http://dx.doi.org/10.1016/j.asr.2010.10.007
5. Nelson M, M Finn, C Wilson, B Zabel, M van Thillo, P Hawes & R Fernandez (1999). Bioregenerative recycle of wastewater in Biosphere 2 using a created wetland: two year results. *Ecological Engineering* 13:189-197.
6. Tubiello FN, JW Druitt, & BDV Marino (1999). Dynamics of the global water cycle of Biosphere 2. *Ecological Engineering* 13:287-300.
7. Nelson M, J Allen, A Alling, WF Dempster & S Silverstone (2003). Earth applications of closed ecological systems: relevance to the development of sustainability in our global biosphere. *Advances in Space Research* 31:1649-1656.

8. Silverstone, S., Harwood, R., Franco-Vizcaino, E., Allen, J., and M. Nelson (1999). Soil in the agricultural area of Biosphere 2 (1991–1993). *Ecological Engineering* (13): 179–188.
9. Silverstone SE & M Nelson (1996). Food production and nutrition in Biosphere 2: results from the first mission, September 1991 to September 1993. *Advances in Space Research* 18:49-61.
10. Marino B D, TR Mahato, JW Druitt, L Leigh, G Lin, RM Russell & FN Tubiello (1999). The agricultural biome of Biosphere 2: Structure, composition and function. *Ecological Engineering* 13:199-234.
11. Nelson, M. (2014). *The Wastewater Gardener: Preserving the Planet One Flush at a Time*, Synergetic Press, Santa Fe, NM.
12. Nelson, M., R. Tredwell, A. Czech, G. Depuy, M. Suraja and F. Cattin (2008). Worldwide Applications of Wastewater Gardens and Ecoscaping: Decentralised Systems which Transform Sewage from Problem to Productive, Sustainable Resource. Decentralised Water and Wastewater Systems : International Conference, Fremantle, Western Australia, 10-12 July 2006, pp. 63-73, edited by Kuruvilla Mathew, Stewart Dallas, Goen Ho, IWA Publications, London.
13. Allen JP, M Nelson, AK Alling (2003). The legacy of Biosphere 2 for the study of biospherics and closed ecological systems. *Advances in Space Research* 31: 1629-1640.
14. Nelson M, WF Dempster & J Allen (2009). The Water Cycle in Closed Ecological Systems: Perspectives from the Biosphere 2 and Laboratory Biosphere Systems. *Advances in Space Research* 44:1404-1412.
15. Dempster WF (1994). *Water Systems of Biosphere 2*, presented at the International Conference on Life Support and Biospherics at the University of Alabama, Huntsville, 1992 and published by Space Biospheres Ventures, Oracle, AZ, 1994.
16. Dempster WF (1993). Biosphere 2: System Dynamics and Observations During the Initial Two-Year Closure Trial. Society of Automotive Engineers Technical Paper No. 932290, *Society of Automotive Engineers 23rd International Conference on Environmental Systems,* Colorado Springs, CO, July 1993.

Dr Mark Nelson is a founding director of the Institute of Ecotechnics and has worked for several decades in closed ecological system research, ecological engineering, the restoration of damaged ecosystems, desert agriculture and orchardry and wastewater recycling. He is Chairman and CEO of the Institute of Ecotechnics (www.ecotechnics.edu), a U.K. and U.S. non-profit organization, which consults to several demonstration projects working in challenging biomes around the world. Mark was a member of the eight person biospherian crew for the first two year closure experiment in Biosphere 2, 1991-1993. Mark has helped pioneer a new ecological approach to sewage treatment named Wastewater Gardens® which are constructed subsurface flow wetlands with high biodiversity. Over 150 such systems have been created in over a dozen countries (www.wastewatergardens.com)

The views expressed in this article belong to the individual authors and do not represent the views of the Global Water Forum, the UNESCO Chair in Water Economics and Transboundary Water Governance, UNESCO, the Australian National University, or any of the institutions to which the authors are associated. Please see the Global Water Forum terms and conditions here.