How to "Geoscope" Transitions to Sustainable Water Use

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1. Challenges in understanding transitions to sustainability

In the process of finding paths to sustainable development, humankind faces the challenge of better understanding the interactions between human society and the natural environment. Although the definition and ultimate goal of sustainable development is still not generally agreed upon, in many cases we are able to determine what is clearly *not* sustainable: The extent of global energy consumption, the current degree of biodiversity loss, or the consumption of freshwater beyond natural recharge levels.

In order to define possible paths to sustainability, a structured analysis of the related transition processes is required. This analysis deals specifically with the time dimension, that is, the connections and switching points between different phases of transition. Even if sustainable development is a long-term process, starting points of the required transitions can already be identified and should be studied, as the path dependence of our current actions indicates significant impacts in the medium and long run.

The future remains uncertain and even the most sophisticated computer models will never provide exact predictions of future developments. Therefore, in order to decide on appropriate future steps, the human society has to continuously observe the present and learn from the past. This iterative learning-by-doing approach requires well-founded observation systems and adequate analysis tools, through which transition processes can be identified as early as possible. A systematic approach to this kind of analysis may address the following issues, which were raised during a recent workshop on the emergence of a "sustainability science" [1]:

■ Where and how do transitions start? Are there triggers to be observed which should not be ignored?
■ Do transitions follow underlying rules and patterns which can be identified and which recur over time or under different circumstances?
■ Are there typical barriers to transitions preventing or delaying required changes?
■ What kind of actions and interventions can be taken to direct, accelerate or slow down transitional changes in order to achieve social objectives?

The observation and analysis of transitions is of special importance in the case of creeping environmental problems which emerge only slowly but with a strong long-term im-

pact. There are a number of critical areas in which transitions to more sustainable nature-society interactions are required, like global water use, food security, the global energy system, biodiversity loss, public health, and human lifestyles. Martens and Rotmans provide a conceptual framework for describing and analysing transitions by distinguishing phases of pre-development, take-off, acceleration, and stabilisation [2].

2. The water transition

One of the most important transitions to sustainability lying ahead is concerned with human consumption of freshwater. Water is becoming scarce in many regions due to population growth combined with growth in average water use per capita [3]. Assuming that current consumption patterns will continue, at least 3.5 billion people, corresponding to 48 percent of the world's projected population, will live in water-stressed river basins in 2025 [4, 5].

Agriculture has a disproportionate impact on water flow, water quality, and the integrity of freshwater habitats. About 70 percent of all water is withdrawn for agriculture, and irrigation agriculture supplies about 40 percent of the world's food crops. However, more than half of the water entering irrigation distribution systems is lost because of leakage and evaporation [4]. There are natural constraints to an ever increasing water supply and it is questionable whether new sources can be made operational soon at acceptable prices (desalination, for example, provides freshwater only at very high costs). Therefore, the reduction of agricultural water use can significantly increase the availability of freshwater for industry and private households.
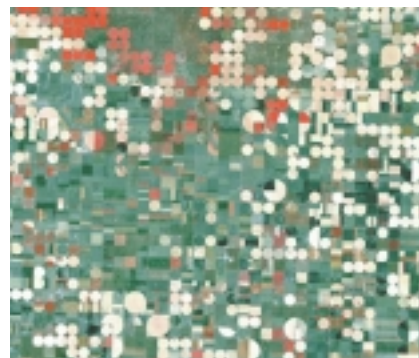

Figure 1. **Patterns of intensive agricultural land use: Pivot irrigation systems near Garden City, Kansas. Red circles show healthy vegetation.** (© NASA Goddard Space Flight Center, 2000. http:// landsat.gsfc.nasa.gov/ earthasart/garden.html)

Water is not only becoming scarce because of increasing demand, but also because of higher pollution levels and habitat degradation. Water logging and salinisation are additional widespread problems [6]. Thus, a decreasing share of global freshwater resources remains available for ecosystem functions. The challenge ahead is to manage freshwater resources in such a way that they are able to provide sufficient water for people *and* for nature [4].

The major reason for growing water scarcity and freshwater ecosystem deterioration is that, globally, water is undervalued. The price for irrigation water usually represents only a small fraction of total irrigation costs, partly due to government

subsidies aiming at providing cheap food. In urban areas the price of water often does not cover the cost of delivery. Moreover, usually the costs of watershed management are being neglected and water polluters are not being charged for the damages they cause [4, 7].

Different phases of a water transition have been conceptualised by Hoekstra and Huynan [3]. In a *first phase*, increasing water withdrawals and rates of pollution disturb the original near-equilibrium of the water system. This disturbance is self-reinforcing: the utilisation of water resources supports socio-economic development, which in turn prompts further exploitation of, and thus pressure on, the water system. In a *second phase*, increasing water scarcity and rising water supply costs induce competition between water users. Water supplies may become less reliable, which leads to temporary shortfalls. Yields in irrigated agriculture may be affected, pollution may harm aquatic life, and fisheries may be threatened. Growth rates of water use slow down. In a *third phase*, water consumption reaches a level at which people are forced to increase water-use efficiency and reduce pollution. Under favourable economic conditions this phase may conclude with a stabilisation of water demand and a recovery of the quality of the natural water system.

In theory, the required steps towards more sustainable water management are clear. Key elements for reforming water wasting policies include the establishment of secure water rights related to different water uses, decentralisation and privatisation of water management functions, introduction of incentives such as markets for tradable property rights, pricing reform and reduction in subsidies, and pollution charges. Water prices should also reflect watershed management efforts. Additionally, non-market instruments such as licensing, regulation, and conservation programmes can play an important role [4, 7, 8].

Apart from institutional reform, a transition to more sustainable water use also involves transitions in human lifestyles, especially in food consumption. A typical diet with meat consumption at American levels requires about 5 400 litres of water per capita per day, if all physiological requirements of food crops in terms of evapo-transpiration are accounted for. A comparable vegetarian diet requires only about half this amount. In comparison, the daily amount of water required for drinking and sanitary purposes, less than 60 litres, is negligible [8, 9].

Although the necessary steps and policy changes are clear in theory, the implementation and success of reforms is case-specific. Measures that work in one region might not be appropriate in others. A better understanding of how a sustainability transition works in practice may require systematic regional case studies. Here, the basic instruments and suggested steps can be tested against real constraints and adaptive capacities, which differ among regions.

3. Failures and successes in irrigation management

Aral Sea: an example of a failed transition

The Aral Sea region in Central Asia is a prime example for the conflicting uses between irrigation agriculture and environmental protection. Irrigation has been rapidly extended on a large-scale with a primary focus on water-intensive crops like cotton and rice. Poor water distribution and drainage together with inefficient irrigation techniques resulted in enormous losses of irrigation water. Moreover, fertilisers and pesticides have been applied excessively (Figure 2) [6].

Continuously high water abstraction has lead to a decline in average annual inflow to the Aral Sea by more than 85 per-

cent between 1981 and 1990. In 1960, the Aral Sea was the world's fourth largest inland lake; by the early 1990s the lake had shrunk to about half its size, was 16 metres below its former level, and three times as salty. Thirty-five million people have lost access to the lake's water, fish stocks, and transport functions. Dust storms, erosion, and poor drinking water quality have negatively affected human health and economic development in the region. About 80 percent of fish species have disappeared and there has been a drastic reduction in terrestrial biodiversity on the floodplains. These are "creeping" environmental changes that have emerged slowly but cumulating over time. First problems were identified in the 1960s, widespread recognition of a crisis only started in the mid-1980s and first actions to solve the problems were not taken before 1990. An important indicator of the increasing environmental deterioration in the basin was the reduction in crop yields in the 1980s, because irrigation induced water and soil quality problems [3, 6].

All these factors have been strongly influenced by the political situation in the region, that is, the general political and management deficiencies during the Soviet era and the huge economic and institutional restructuring process in the Central Asian republics after their independence. Strong population growth and increased food demand together with urban development will further draw heavily on water resources. Economic reliance on few water-intensive crops provides little flexibility in reducing water demand for irrigation. Structural and managerial changes, like improvements in water distribution, drainage and irrigation, replacement of rice and cotton with wheat and maize, and water pricing have been introduced
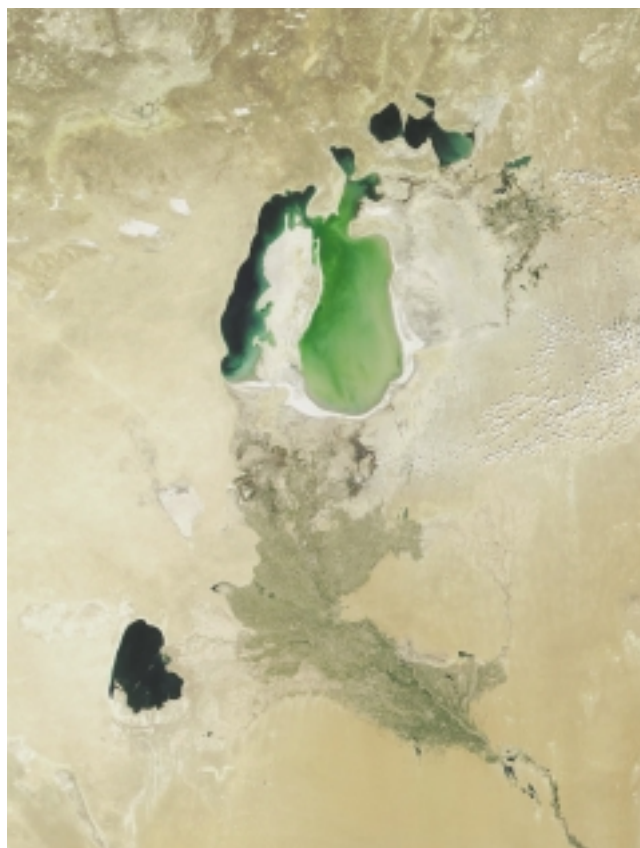

Figure 2. Aral Sea after decades of decline and environmental degradation. (© Jacques Descloitres, MODIS Land Rapid Response-Team, NASA/GSFC, August 2001, http://visibleearth.nasa.gov/cgi-bin/vie wrecord?9625)

only to a very limited extent. Moreover, an integrated natural resource management is rarely implemented in the region.

The Central Asian republics currently lack the economic capacity to deal with environmental costs resulting from irrigation agriculture. The example of the Aral Sea shows that the second phase of a water transition, as sketched above, may be marked by serious problems. As a result, the third transition phase may not even take place. So here we have a water transition that shows no sign of stabilisation or even trend reversal [3].

Murray-Darling Basin: first steps towards sustainable agricultural water use

The Murray-Darling-Basin (MDB), which stretches across four states in Australia, contains more than 75 percent of the country's irrigated area and produces more than 40 percent of Australia's total agricultural output value. About 95 percent of MDB water diverted for human use goes to agriculture.

Starting three decades ago, water-related environmental issues have become a key factor in motivating change in Australia's water institutions. The water issue has moved to the forefront of national policy debates aimed at meeting social, economic and environmental objectives. A bloom of toxic blue-green algae in 1991–1992, mainly caused by fertiliser used in MDB, became an environmental crisis that was impossible to ignore and triggered substantial political reform. Water logging and salinisation are still diminishing the productivity of irrigated lands and decreasing water flows are reducing pollution assimilation as well as fish and wildlife habitat [10].

Going back as far as the 1880s, regulatory approaches have dominated Australia's policy response to environmental issues and resource mismanagement. Only in the mid-1970s an interest in tradable abstraction rights (TAR) emerged, which offered a new flexibility to the existing allocation arrangement, with clear economic and environmental advantages. The overall policy goal of "minimum effective regulation" led to a water policy reform strategy with the following components: Water prices which reflect social costs and benefits; removal of subsidies and cross subsidies; establishment of tradable abstraction rights; introduction of market mechanisms to encourage more efficient management and use. Furthermore, recommendations were given for institutional reforms, water-related research, taxation, consultations and public education [10]. In 1997 a cap on total water diversions was imposed. This, together with an allocation mechanism for TARs, has started to improve water supply reallocation both regarding agricultural and non-agricultural uses. In 1998–1999 about 11 percent of total abstraction entitlements for that year have been traded, starting from zero in 1990, which shows that water trading has become a significant component of water allocation in MDB [11–13]. Thus the overall efficiency of the system was improved, while at the same time achieving a significant reduction in agricultural water use.

Although it is too early to call the MDB case a success story on sustainable water management, first positive results can be observed. Overall, the cap has restricted water supply and prices for water licences have risen substantially. From 1995–2000, water prices in South Australia's horticultural areas with access to Murray River water have increased from AUD 500 to AUD 1200 per million litres. Irrigators are required to present farm management plans, pay environmental levies on water use, establish salinity prevention plans and pay salinity fees when purchasing water. Nevertheless, total water-related expenses frequently dropped, mainly because farmers invested in new water-saving technologies. Water entitlement transfers between irrigators occurred mostly from lower- to higher-valued commodities, above all grapes, which are low-volume water users compared with other crops. Despite these positive developments future challenges will arise due to uncertainties related to climate change, an aspect currently often neglected by water managers [10, 14].

The two cases of the Aral Sea and the Murray-Darling-Basin indicate that – mainly due to specific regional circumstances, above all differences in institutional design and policy measures – a general assessment of successful strategies for a water transition requires a broader sample of world regions investigated as well as long time series of observations.

4. The concept of a Sustainability Geoscope

The study of transition processes with respect to water use and other society-nature interactions will be a key challenge and research task for an emerging sustainability science. This will have to be a science of design, which means that instead of providing precise blueprints for sustainability, it will build on successful examples and learn from instructive failures in the past. By pursuing a learning-by-doing approach it will continuously observe human actions and try to identify, document and analyse patterns of sustainable development. Recent research efforts on syndromes of global change as well as on vulnerability and adaptation provide first examples of such an approach [16].

The prerequisite for analysing and understanding long-term transition processes is an appropriate empirical base, that is, a long time series of key variables covering all relevant aspects of society-nature interactions. Currently available observation and monitoring systems often reflect specific disciplinary methods and their demand for information. While natural scientists use spatially explicit global information collected by weather stations and remote sensing satellites, the social sciences are often confined to official statistical data on the level of nation states or other administrative units. Moreover, key indicators for an integrated analysis are either not yet defined or only available with insufficient coverage over time or space. This holds especially true for global data on water use, which are often spotty or based on rough estimates, in rich and poor countries alike [17]. For the analysis of transitions to sustainability the existing gaps have to be filled and integrated observation procedures have to be developed.

Such a global monitoring and observation system has been proposed as a "Sustainability Geoscope" [18]. The Geoscope vision aims at an instrument for systematic collection of congruent natural-scientific and socio-economic data that enable a validation of integrated views of society-nature dynamics. In brief, the Geoscope shall *continuously* investigate *selected regions on a global scale* with regard to *actions related to sustainable development* by using *remote sensing* as well as *observations on the ground* (Figure 4).

The process of "geoscoping" a transition to sustainable water use involves a number of steps and actions. In order to facilitate a well-structured learning process, a sufficient set of comparative regional case studies covering the global hot spots of water-related problems has to be chosen. Within these sample regions a common protocol for empirical research has to be established with a focus on key actors – who are they, what are their intentions and constraints, what are the consequences of their actions – and on the mechanisms and patterns of sustainable development that can be identified among different regions.

Figure 4. The Geoscope website is being developed as a central communication node on global monitoring and observation for sustainability science.

In an initial phase, investigations may be restricted to certain topics, like the relationship between regional water availability, land use and public health problems. In the long run, possible water-related parameters to be continuously observed may include human lifestyles and preferences, general education and especially "water literacy" (the awareness and understanding of water-related problems) [3], perception of water shortages and risks, access to water-saving technology, technology adoption and diffusion, allocation of water abstraction rights, demographic changes and other early warning signs, specific agricultural production and market conditions, and management of irrigation and water distribution.

In addition to these ground-based observations, large-area monitoring of water use, especially agricultural irrigation, has to be intensified. Currently, the extent of irrigated areas on a global scale is predominantly assessed based on rough estimates. However, newly available remote sensing satellites provide the opportunity for continuous regional and global mapping of irrigated areas [4, 15]. By combining ground-based and remotely sensed observations, water-related social and economic activities can be linked to the spatial dimension of specific environmental changes and the adaptive capacities of societies in view of these changes can be determined.

If the envisaged comparative regional case studies are carefully chosen and investigated for a sufficiently long time, it should be possible to identify certain patterns of sustainable water use. In a next step, these results will have to be linked to simulation models on different scales, so as to allow for generalisation and comparison. This will in turn create the demand for even more advanced, operational methods of monitoring and observation with global coverage over extended time periods.

A Sustainability Geoscope cannot be developed in isolation, it rather has to be established as an open process with broad participation. An international community around the Geoscpe idea is already emerging from a series of workshops over the last two years. For stimulating the process, a competition for ideas and research contributions has been initiated through the Geoscope website [18]. The Geoscope concept has been presented and discussed at various international con-ferences and workshops, and it contributes to the Initiative on Science and Technology for Sustainability [1, 16]. In order to raise financial support, an expression of interest for a Geo-scope project has been submitted to the EU Sixth Framework Programme.

With respect to water-related questions the Geoscope will have to be linked with other international activities and organisations, including the Joint Water Project (JWP), the Dialogue on Water and Climate (DWC), the Dialogue on Water, Food, and the Environment (DWFE), the UNESCO project on Hydrology for Environment, Life and Policy (HELP), the Global Assessment, Integration and Modelling Task Force (GAIM), and various IHDP-endorsed projects.

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