Eco-Complexity and Sustainability in China's Water Management*

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Abstract

China's severe water challenges as a result of rapid social and economic development, has led to significant impacts on regional eco-security, ecosystem service and human health. Grounded in ancient Chinese human ecological philosophy, a social-economic-natural complex ecosystem-based approach 'China Water Vision' is briefing to help people understand and simplify the complicated ecological dynamics and cybernetics of water. To transform the complexity vision into a sustainability mission, an integrative and adaptive management approach is being enhanced through capacity building including philosophical rethinking, institutional reform and technological renovation so as to transform reductionism to holism, fragmented to integrated management, and physical to ecological engineering.

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Rapid industrialization and urbanization have taken place in China since its opening up to the world and transition from planned to market economy. In the past 28 years, China's average annual economic growth rate (GDP) was about 9.67%. The pace, depth, and magnitude of this transition, while bringing prosperity to citizens, have exerted severe ecological stresses on local human living conditions and regional water sustainability. Water shortage, contamination, flooding and drought are only the surface symptoms of the water issue. Its indirect and long term impacts on regional and global eco-security are far-reaching. Water sustainability can only be assured with a human-ecological understanding of the complex interaction among environmental, economic, and social/cultural factors.

In dealing with this complexity, the key issue is to allow more people to understand China's comprehensive water vision, its ecological dynamics and cybernetics, and search for effective technological instruments including integrative planning, engineering, management and capacity building to promote water sustainability (Fig. 1).

Key words: ecological, complexity, sustainability, China, integrative water management

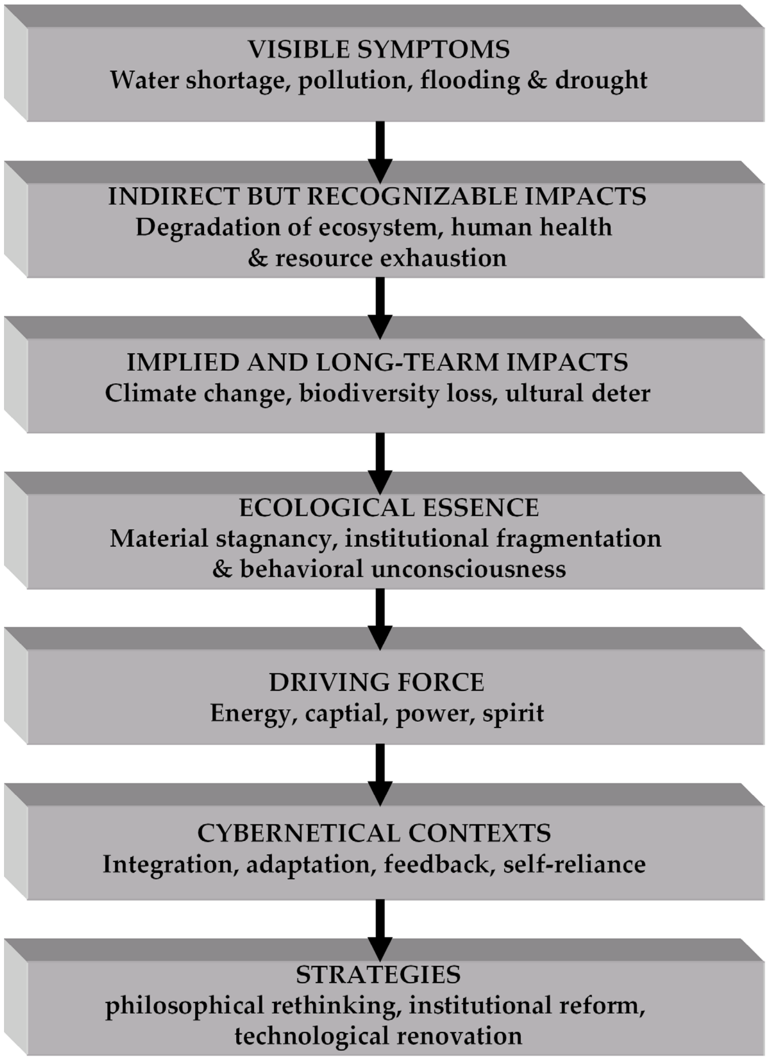

Fig. 1 Comprehensive ecological vision of water in China.

1 Water Crisis in China: Risks and Opportunities of the Fast Development

The word *crisis* (Wei Ji) in Chinese means both *risk* (Wei) and *opportunity* (Ji). With a long tradition of sustainable water management and human ecological philosophy, the water vision in China has both optimistic and pessimistic aspects.

1.1 Risks

Water resource shortage: Though China is ranked 6th in the world in terms of the total water availability, the availability of water resources per capita in China is only 33% and 75% of the world and Asia average level respectively, and the extremely uneven spatial and temporal distribution makes the situation even worse. With 7% of the world's total freshwater resources, China supports more than 21% of the world's population. Over 400 Chinese cities are facing water shortage (with 136 experiencing severe shortages). The average annual duration that the Yellow River runs dry, for example, was 21 days in the 1970s, 36 days in the 1980s, 122 days in 1995, 133 days in 1996, and 226 days in 1997. In North China, per capita water availability reaches only 750 m^3 per year. The groundwater supply in North China in 2004 accounted for 81% of the total groundwater supply in China (State Environmental Protection Administration of China, 2005).

Reduction of water for nature: During the past 50 years, the population of China has doubled, while the amount of water used to fulfill basic human needs multiplied by 5.5 times. Around $450x10^9m^3$ water originally used by nature has been taken over by human use. As a result, natural ecosystem services have dramatically declined, causing severe ecosystem degradation, depletion of the water table and biodiversity loss. Since 2000, groundwater has accounted for about 30% of China‘s total urban water supply. However, it is estimated that only 63% of the groundwater provided to urban areas can be regarded as 'potable without treatment'. In the North, there is scarcely enough water to fulfill ecosystem requirements (Lestor 2006).

Water bodies contamination: Over 70 percent of China's rivers and lakes are polluted (Chinese Ministry of Water Resources 2006). Only 20% of lakes and river basins reached Class III or better (Qian and Zhang 2005). In 2005, China‘s rivers and lakes received about 52 billion tons of wastewater. Industrial pollutants accounted for 46% and untreated urban sewage accounted for 48% of the total discharged wastewater. Furthermore, 32 of 49 lakes (65%) in China in 2004 were found to be eutrophied. In December 2006, the Yangtze Baiji river dolphin was declared "effectively extinct" (The Washington Post 2005). Between 50 and 90 percent of urban underground water is contaminated by agricultural runoff, industrial and municipal waste water, and, in some municipalities, even toxic mine tailings (Turner 2006).

Flooding and related geo-disasters loss: Every year China records around 1,500 casualties to floods (Qiao 2006). One tenth of China's territory, populated by two thirds of the population and producing approximately 70% of all agricultural and industrial output, lies within the floodplains of major rivers (World Bank 2001). The 1998 flooding of the Yangtze River basin claimed more than 3,000 people, devastated 5 million homes, and engulfed 52 million acres of land. The economic losses are estimated at over US$20 billion, and the main causes were deforestation and the destruction of wetlands for unplanned local development along the river (World Bank 2001). The area susceptible to erosion by water account for 37% of the total area of China in 2006 (State Environmental Protection Administration of China 2006).

Drought loss: Lack of water can lead to droughts, crop failures, famine and loss of life. The worst drought in 50 years is hitting China's western, central and northeastern regions, causing drinking water shortages for at least 18 million people and economic loss of 11.74 billion yuan (1.24 billion US dollars). About 10 million people in the southwestern Sichuan Province, 7.65 million in Sichuan's neighbor Chongqing Municipality and 600,000 in northeastern Liaoning Province do not have adequate access to drinking water (http://www.china-embassy.org/eng/gyzg/t268197.htm).

Wetland loss: Dongting Lake originally extended over four hundred kilometers. But the area of Dongting Lake has shrunk by almost two thirds since the Ming Dynasty. The quality of its water has been deteriorating, and the variety and quantity of fish have been decreasing. The diminishing of lake areas might become an element triggering floods. Dongting Lake was the largest lake along the Yangtze River as well as in the whole of China. It is a precious gift endowed by nature (Wang and Ouyang 2001).

Coastal ecosystem deterioration: According to marine water environmental monitoring sources, water quality in 53.4% of offshore areas was worse than class III in 1998, while only 18.7% of offshore areas meet the class I water standard. The concentration of all twelve monitored substances (including activated phosphate, inorganic nitrogen, lead, petroleum, mercury, BOD, and COD) was higher than the lowest standard. Copper, mercury, cadmium, hexachlorocyclohexane, and dichlorodiphenyl-trichloroethane pollution occurred mainly in the sea area near the Pearl River estuary. Between 2001 and 2005, there were 453 reported cases of red tides, contaminating over nine million hectares of sea area, making the water uninhabitable for coastal species and organisms (http://news.xinhuanet.com). 93 cases of red tides took place in the sea of China in 2006, and accounted for an area of 19840 km^2, among which 31 cases were larger than 100 km^2 accounting for 18540 km^2 (State Environmental Protection Administration of China 2006).

Water-bone diseases threaten：Nearly a quarter of China's total population, including more than 300 million rural residents, lacks access to clean drinking water (Liu 2006). They are susceptible to over 50 kinds of disease generated or spread through drinking water in China (Zhai 2004), including diarrhea, which alone is responsible for 11.8 percent of under-five child mortality. As reported in a 2004 national conference on rural water issues, the rural prevalence rate for diarrhea-related diseases could be reduced by half if residents had access to clean water (http://news.sohu.com). Agricultural production has been severely affected as polluted waters poison crop output. Each year, about 12 million tons of crops have to be destroyed because of heavy metal contamination, costing farmers 20 billion RMB Yuan a year (Chow 2006).

1.2 Opportunities

Fortunately, there are also positive developments in China which could alleviate ecosystem risks and provide opportunities for integrated water management

3000 year tradition of human ecology philosophy China has a well established human ecology philosophy of "man and nature be in one", such as Yin and Yang theory (negative and positive forces play upon each other and formulate all ecological relationships), Wuxing theory (five fundamental eco-elements and movements promoted and restrained by each other), and Feng-Shui (Wind-Water theory expressing the geographical and ecological relationship between human settlements and the natural environment). One example is Chinese 7000 years of eco-agriculture, which has nourished 21% of the world population with only seven percent of the world's arable land and fresh water, while maintaining sustainable production and soil fertility. Its secret is to design and maintain a sustainable agricultural ecosystem by enhancing the mechanisms of material regeneration and recycling, while maintaining ecological integrity and self-reliance. Another example of the holistic ecological view can be found in traditional Chinese medicine, where the human body is considered a functional system closely connected with its environment (Wang et al. 2001).

Growing environmental awareness among the public Environmental awareness amoong the public is highly significanct in making human activities suitable for natural ecological processes. According to an investigation of environmental awareness among the urban public in China in 2005, an increasing number of people pay attention to environmental protection. They believe the most serious environmental problems in China are the destruction of vegetation, farmland reduction and water pollution, followed by air pollution, greenhouse effect and solid waste pollution (State Environmental Protection Administration of China and Chinese Academy of Social Sciences 2005).

Technological innovation for alternative water resources The desalination of seawater is a basic and scientific way of developing new water sources and solving the global crisis of water supply. China started studying seawater desalination technology in 1960s. China has taken great breakthroughs in key technology of seawater desalination. Seawater desalination project of 3 000 m^3 per day has been completed. The cost of seawater desalination is gradually decreased and it was nearly five RMB Yuan per m^3 water (http://gb.cri.cn/14714/2007/08/07/107@1707143.htm).

Institutional integration The Ministry of Water Resources (MWR) is the leading ministry overseeing general water management issues in China and collaborates with other water-related ministries under the State Council. These relevant ministries are integrated in order to gain consensus on the implementation of water policies. This integration can help avoid incoherent policy-making and implementation, and overlapping of investment in water management.

Legislation enforcement The Chinese government has established a set of laws and regulations including the Water Law (1988 and revised 2002), the Environmental Protection Law (1979 and revised 1989), the Water Pollution Prevention Law (1984 and amended 1996) , the Water and Soil Conservation Law (1991) and the Environmental Impact Assessment Law (2002), which has significantly enhanced water governance in China. In particular, EIA has paved the way for better public access to environmental policy-making and implementation.

Increasing investment Since 1998, China started to experiment and carry out the ‘Six Forest Key Engineering’, including natural forest resources protection project, reafforestation of cultivated land, controlling the wind and sand fountain around Beijng and Tianjin, shelter forest project in East China, North China, West China, the mid and downstream area of the Yangtse River, wildlife protection and nature reserves construction, and development of a rapid fertile forest base in key zones. The six projects initiatives above involved 97% of the national country and city, the area of planned afforestation is 7.6 million hm^2 with an investment of 700 billion RMB. From 1998 to 2006, the cumulative reforested area of 20 million hm^2 with a cumulative investment of 94.5 billion RMB was accomplished. It is also contributed to China’s water management (http://www.forestry.gov.cn/old/SHTGC/).

Participation activation Now an increasing number people take part in environmental protection in China. According to the investigation of environmental awareness among the urban public in 2005 in China, 50% of the urban population have actively participated in various environmental protection activities. Television, newspaper, internet, books and magazines are important medium. In addition, school education, NGOs, broadcasting, family education and influence of friends are also useful in activating people to participate in environmental protection and management (State Environmental Protection Administration of China and Chinese Academy of Social Sciences 2005).

2 From Symptom to System: A SENCE approach-based China water vision

The above mentioned complex environmental problems can be simplified by tracing back their origins to three major causes: ecosystem exhaustion due to resource over-exploitation and unused materials remaining in the environment (mass); fragmentation and agglomeration in landscape management (matter); and short-sighted behavior and lack of feedback in dealing with the relationship between parts and the whole (man). Integrated water management needs to deal appropriately with the relationship between mass/matter and man.

The water eco-sphere is a kind of artificial ecosystem dominated by human behavior, sustained by natural life support systems, and vitalized by ecological processes. We call it a Social-Economic-Natural Complex Ecosystem (SENCE) (Ma and Wang, 1984). Its natural subsystem consists of the Chinese traditional five elements: water, fire (energy), metal (minerals), wood (living organism) and soil (nutrients and land). Its economic subsystem includes the components that play the roles of production, consumption, reduction, transportation and regulation respectively. While its social subsystem includes technological, institutional and cultural networks (Fig.2). Its structure is expressed as an ecological complex between/among human beings and their working and living settlement (including geographical, biological and artificial environs), their regional environment (including sources for material and energy, sinks for products and wastes, pools for buffering and maintaining) and their social networks (including culture, organization, technology and so on) which play a key role in sustaining the complicated human ecological relationships such as that of exploitation and adaptation, of competition, symbiosis and self-reliance. Its function includes production, consumption, supply, assimilation, steering and buffering. These fundamental interactions bring about five fundamental flows of material metabolism, energy transformation, information accumulation, currency exchange and population migration in the eco-scape, and result in its cybernetic behavior and formulate specific urban/rural forms. The goal of science and management is to understand and coordinate the temporal, spatial, quantitative, structural, and functional relationships among and within these three subsystems (Wang and Ouyang 1996).

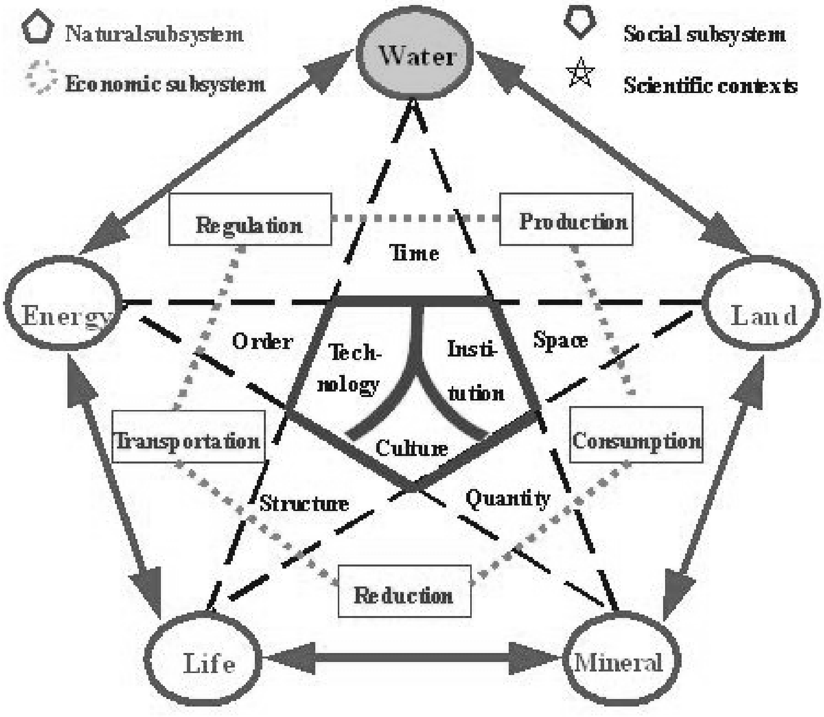

Fig. 2 The eco-sphere of water, environment, life, economy & society.

2.1 Water and Nature: Physical Interconnection

Among all ecological factors, water is the most important for promoting or limiting the survival and development of man and nature. It interacts with other four elements and causes the following changes:

1. Water and Soil (soil and land): soil cultivation and erosion, contamination and degradation, land gain and loss, landscape fragmentation and geo-disaster.
2. Water and Fire (energy, light, atmosphere and climate): hydropower, power generation by fossil fuel, waste heat, climate change, flood and drought.
3. Water and Wood (plant, animal, microbe and biodiversity): rain-fed and irrigation agriculture, biomass production, habitat creation, water-bone disease and pest break-out, and biodiversity conservation.

4. Water and Metal (mineral metabolism and geo-chemical process): eutrophication, contamination and material metabolism.

2.2 Water and economy: the ecology of human activities

The second subsystem in the waterscape is the MATTER-sphere driven by the human activities of production, transportation, consumption, reduction and regulation, which form the economic subsystem contexts including:

1. Water and agricultural production: food, fodder, fiber, fish, and forest productivity.
2. Water and industrial production: material, energy, medium, goods, and capital.
3. Water and human consumption: supply, infrastructure, service, origination, and prosperity/ruin.
4. Water and transportation: waterworks, canals, recreation and trade.
5. Water and regional development: watershed management, regional development, landscape planning, and watershed management.

2.3 Water and economy: the ecology of human activities

The third sub-system of ecosphere is social relationships including:

1. Water and technology: alternative water resources, water saving, purification and exploitation, and hydraulics efficiency.
2. Water and institution: governance, plans, policy, and legislation.
3. Water and culture: attitudes, ethics, morals, and consciousness.

These three physical, economic and social layers promote and restrain each other, playing roles of production, consumption and service, causing the complicated water problems of too much or too little and too dirty or too clean, and supporting the survival and development of life, environment, and human society (Wang et al. 1989; Wang and Qi. 1991).

2.4 Eco-dynamics and cybernetics of water ecosphere

The water-ecosphere is driven by four fundamental forces: energy (physical agent), money (economic agent), power (governance), and spirit (cultural agent). Energy drives material cycling and water flowing. Money promotes or prohibits the improvement of water use efficiency. Power speeds or restricts the development and management of water resource.

Spirit induces or impedes people's behavior. Any of these forces alone cannot work appropriately and leads to unsustainable development. On the other hand, water can in turn generate or stimulate energy, money/wealth, power/governance, and spirit/culture, as well as put on big impacts on their interwoven products of human society (Fig. 2).

The Cybernetic Principles fall into four categories: ***integration*** in recognition, institution and technology; ***adaptation*** to co-evolve with natural, economic and social development, ***feedback*** of material and information; and ***self-reliance*** to sustain structural, functional and procedural stability.

Faced with sharp contradictions between reductionism and the holistic approach, the traditional analytical and statistical approach cannot work well in modeling its dynamics and cybernetics. A methodological revolution is underway with the management target switched from tangible/physical object to intangible/ecological contexts; the measurement rule switched from numerical quantification to functional and multi-scale identification; the regulation strategies switched from mathematical optimization under some simplified conditions and subjective hypotheses to process-oriented social learning and ecological adaptation, while the research goal switched from morphological assessment and hypothesis validation to ecosystem-based sustainability management (Wang et al. 1999).

3 From Complexity to Sustainability：Integrative and Adaptive Management influence China Water Mission (Rethinking, Reform and Renovation)

The ultimate goal of understanding and simplifying of the complexity of water systems is to regulate, conserve and construct a sustainable waterscape and to transform the complex vision into sustainability mission (Fig.3).

Currently, the waterscape mapping in China involves **rethinking** the production mode, consumption behavior, development goal and life meaning; to **reform** the fragmented institution with regard to legislation, organization, governance, decision making, planning and management, and to **renovate** reductionism-based technology (cost-effective resource saving, renewable energy, environmentally friend).

Fig. 3 Transfer complexity to sustainability.

To turn the complexity into sustainability, we need a profound value change in understanding the ecological relationship between man and nature, the influence of the production mode on resource metabolism, and of consumption behavior on environmental impacts. A new ecological philosophy should be encouraged from linear, physical and reductionism thinking to systematic, ecological and holistic thinking, from wealth-only development to a combination of wealth, health and faith development.

To turn complexity into sustainability, we need institutional reform in policy making and inter-sectoral, inter-regional and interdisciplinary coordination. We need a bridge between man and nature, science and society; a scientific tie connecting survival and development, the poor and the rich, the East and West, the traditional culture and the modern technologies; a common language of communication between biology, environmental sciences, engineering and all the branches of natural disciplines and between the natural and social sciences (Wang et al. 1991).

To turn complexity into sustainability, we need technological renovations in ecological research, conservation and design.

The key to fulfill the emerging water mission is to find an appropriate way to help local people to understand, simulate and regulate complex water cybernetics.

A campaign of 'Ecopolis' development has been spread in China since the late 1980s supported by central and local governments. Ecopolis is a kind of administrative unit that has an economically productive and ecologically efficient industry, a systematically responsible and socially harmonious culture, and a biologically adaptive and functionally vivid landscape. Three so called ecopolis legs advocated by Chinese politicians are Circular Economy, Harmonious Society and Safe Ecology. There are currently 13 provinces and 525 cities/counties in China that are engaged in ecopolis development. Yangzhou is one of these demonstration metropolis. It is located in the central part of Jiangsu province, at the confluence of the Grand Canal and Yangtze River, has 4.47 million residents, 6638 km^2 land and 2500 years' history (Wang 2004).

The focus of Yangzhou ecopolis development is on ecological restoration of water resources, water environment, water landscape, aqua-habitat, and water culture. The Yangzhou integrated water management approach includes regional watershed management to ensure the water quality of Eastern water division project from Yangzhou to Beijing-Tianjin; water supply and flooding control of the Lixiahe basin agricultural irrigation, and sustaining a national watershed conservation park; rural non-point water pollution control and eco-sanitation development; and ecological engineering for human settlement sewage/garbage management and traditional water-culture conservation.

A comprehensive ecopolis plan was prepared and 148 ecological engineering projects were implemented for this "water-town of fish and rice", an integrative ecopolis administrative office has been set up to coordinate the work of the different agencies. After 8 years of development, water quality improved significantly with its comprehensive environmental index ranked second of all prefecture level cities of Jiangsu province compared with seventh in 1998 before the ecopolis campaign was initiated. The city also received several national honors such as national healthy city, national model city for environmental protection, national garden city, and received a human settlement award from UN HABITAT in 2006.

Water is both a positive and negative ecological agent. Only when the roles of government leadership, citizen participation, enterprise support, and scientific and technological guidance are carried out in harmony can sustainable development be realized. Globalization, decentralization, and ecological modernization are the main trends in today's changing world, whether west or east, north or south. Integrative water management has no choice but to follow the ecological principles of integration, adaptation, feedback and self-reliance (Fig.1). Sustainability requires a balance among social/economic wealth, human/natural ecological health and ethical and spiritual faith.

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