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Watershed systems science – a new paradigm to understand and govern the impact of human activities on the earth's surface in the Anthropocene

Ray Ison[1*] & Yongping Wei[2]

[1] Professor of Systems, Applied Systems Thinking in Practice Group, School of Engineering & Innovation, The Open University, UK. [2] ARC Future Fellow (River Basin Managmeent), Associate Professor, School of Earth and Environmental Sciences, Faculty of Science, University of Queensland, St Lucia, Queensland, Australia; *Corresponding author ray.ison@open.ac.uk

Recent scholars' work in Vol 58 Issue 1 (2015) and Cheng & Li's paper in Vol 58 Issue 7 (2015) in *Science China Earth Sciences* propose development of "*Watershed science"* by *"Bridging new advances in hydrological science with good management of river basins*". An analysis of the language and key concepts used in the abstracts, titles and keywords of this set of 8 papers and an editorial reveals that 'Watershed', 'River', 'Science' and 'System' are the main terms employed by authors (Figure 1). It is not surprising that 'Watershed', 'River', and 'Science' are used most frequently, given the nature of this special issue in a science-driven journal. That the concept 'system' features highly is somewhat surprising but understandable as this journal is devoted to the concept 'earth system'. So, our first interest is how employing the concept *system* in particular ways can assist in developing watershed systems science.

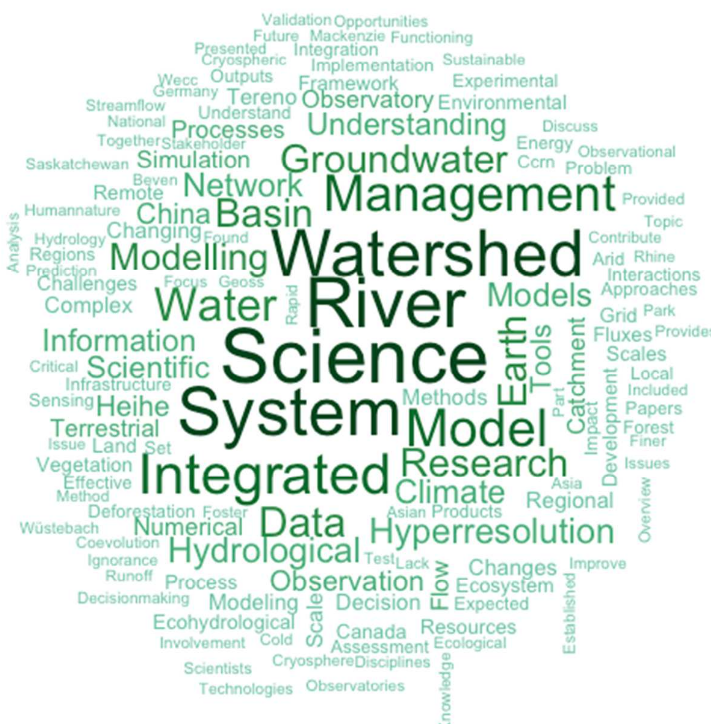

Figure 1. Words clouds included in titles, key words and abstracts of 7 papers in China Science Vol 58 Issue 1 (2015) and Cheng & Li's paper in Vol 58 Issue 7 (2015)

As outlined by Ison (2016) the use of the concept 'system' is widespread but all too often is employed without adequate theoretical insight. As Lakoff (2010) would say it has become a common framing choice: "And since frames come in systems, a single word typically activates not only its defining frame, but also much of the system its defining frame is in" (Lakoff 2010 pp. 71-72).[1] The issue of boundary choice is critical to the deployment of the concept 'system' (Midgely 2003). Understood metaphorically the concept *Earth System* implies a boundary associated with the whole Earth. For example, IGBP say that 'the term "Earth system" refers to Earth´s interacting physical, chemical, and biological processes. The system consists of the land, oceans, atmosphere and poles. It includes the planet's natural cycles — the carbon, water, nitrogen, phosphorus, sulphur and other cycles — and deep Earth processes (http://www.igbp.net/globalchange/earthsystemdefinitions.4.d8b4c3c12bf3be638a80001040.html). In this use of the concept people and human action do not feature or only implicitly. In contrast the Wikipedia description of Earth system science claims it 'is the application of systems science to the Earth sciences. In particular, it considers interactions between the Earth's "spheres"—atmosphere, hydrosphere, cryosphere, geosphere, pedosphere, biosphere, and, even, the magnetosphere—as well as the impact of human societies on these components. At its broadest scale, Earth systems science brings together researchers across both the natural and social sciences (https://en.wikipedia.org/wiki/Earth_system_science). The *system* concept is of utility when one is concerned with elements and their relations e.g., within the Earth System at system, sub-system or sub-sub-system levels e.g. watershed system, social system, farming system etc. At every systemic level the question of boundary judgment applies – it is we humans who must take responsibility for boundary choices as means to engage with the biophysical world whether to understand or transform it (Ison 2017).

However, there is a systemic trap in the use of the concept *system*, a noun in the English language (Ison 2016). Whilst the concept draws attention to the elements and relationships that might exist and operate in a system of interest, what is concealed by the use of the term are (i) the act of making a boundary judgment by an observer or observers; (ii) an appreciation that making a boundary judgement realises another relational dynamic – the act of making a distinction between a system and its environment and (iii) awareness that using the term system is always a shorthand for a system-environment relationship mediated by a boundary judgement. Cheng & Li (2015) frame the watershed as a basic unit of the Earth system. They argue that watershed science shares the characteristics of fundamental research in Earth system science and ground their arguments in six intellectual platforms: (i) systems science; (ii) complex systems; (iii) scale problems and (iv) Newtonism vs. Darwinism (v) hydro and eco-economics and (vi) meta-synthesis. Consistent with their claim that watershed science 'should be integrated with philosophical conceptualization, theorization, methodological exploration, infrastructure construction and field experimentation' (p. 1167) it is necessary to explore how the concept 'system' is employed by authors and how their conceptions relate to, or shape, research practice in a new field of watershed science. We believe that philosophical clarification of the concept 'system' could facilitate the systemic integration of all six intellectual platforms of Cheng & Li (2015) and

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the overall aspiration for a new 'watershed science'.

The aim of this special issue was to develop watershed science by bridging new advances in hydrological science with good management of river basins. Six papers from leading scientists on watershed science in China, the USA, Japan, the United Kingdom and Germany make significant contributions to understanding the impact of human activities on the earth's surface in the Anthropocene through modelling work (e.g., Beven et ai. 2015) and improvements in observational technologies and infrastructure (e.g. Koike et al. 2015). Unfortunately, this issue fails to link *hydrological science* with *good management of river basins* challenges as only Cai et al. (2015) call for drawing together disparate disciplines into an integrated scientific framework for a new generation of Decision Support System (DSS) for river basin management. Notably few key words are relevant to river basin management or governance (Figure 1). In a later issue, Cheng & Li (2015) ask: "*How can we better integrate the achievements of social sciences so that the large role of humans in Earth systems is fully understood*? (p. 1159) arguing this is one of most significant challenges for developing watershed systems science**.** Therefore, our second interest is how to employ social sciences for governing the impact of human activities on the earth's surface in the Anthropocene**.**

Cheng & Li (2015) argue that watershed systems are highly co-evolved, complex human-nature systems. They thus set the groundwork for how co-evolutionary processes function. However, this co-evolution is based on long term and complex 'negotiations' between culture and nature. The negotiation is a result of human decision-making, which is the primary driver of earth system change. We argue that any human decision is determined by the interactions between social values (willingness to change), technology progress (capacity to change) and institutional arrangements (change regulated formally by government or through self-organising informal institutions) at different system levels (Wei and Zhang, 2017 and Wei et al. 2017). Therefore, while we agree with Cheng & Li (2015) that hydro-economics is important for understanding interdependence between economic activities and natural systems, three sub-disciplinary fields from hydrology: socio-hydrology, techno-hydrology and institutional-hydrology are needed for the development of watershed systems science. Developments in these sub-disciplines can provide understanding of the mechanisms for governing the impact of human activities on the earth's surface in the Anthropocene.

Unfortunately, very limited research on a single watershed has been conducted from the perspective of different sub-disciplines of watershed systems science. Such studies could cross-fertilise the development of individual sub-disciplines and generate systemic knowledge for watershed managing and governing. The Heihe River basin (HRB) in China is perhaps the one exception; it is the second longest inland river in China, with a length of 948 km and an area of approximately 143, 000 km^2. HRB covers typical ecosystems and catchment processes in an arid and semi-arid region; it sits within an important part of the ancient Silk Road established in the Han Dynasty (206 BC–AD 220) and thus within the new Belt and Road initiative being undertaken by China . The HRB 'story' is of a typical watershed involving many catchment processes related to hydrology and experiencing several management phases in early civilization, rapid economic development, serious environmental degradation and rebalance between humans and environment. The Heihe

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The arguments made by Cheng & Li (2015) for the 'atomic' nature of a watershed, and thus its utility as a locus of study and of governance are conceptually sound. They also allow consideration of co-evolutionary dynamics between a social and a biophysical system but unfortunately many watersheds are no longer purely 'natural systems'; when inter-basin water transfers are made, or human wellbeing is linked to economic activity that spans watersheds then the question of system boundary choice, aligned to human purpose must be addressed. A holistic science that begins with systemic sensibilities and does not privilege linear or systematic causality is needed in all situations, including an earth system, characterized by interdependency, uncertainty, complexity, and controversy. These are the features of an Anthropocene world in which human action is effecting whole earth dynamics and in which traditional understandings and practices such as commitments to stationarity in hydrological modelling are no longer adequate. Achievements from the 'Heihe Plan' constitute a unique opportunity and significant investment to further build on multi-disciplinary achievements. To transform further towards a mature watershed systems science we urge the systemic use of the concept 'system' and bringing in new social-oriented subdisciplines of hydrology. The HRB could be developed as an iconic watershed for watershed systems science – a new paradigm to understand and govern the impact of human activities on the earth's surface in the Anthropocene.

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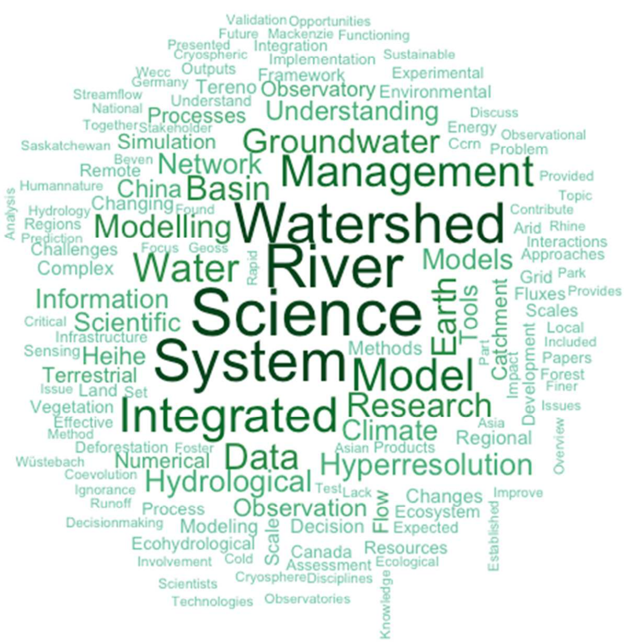

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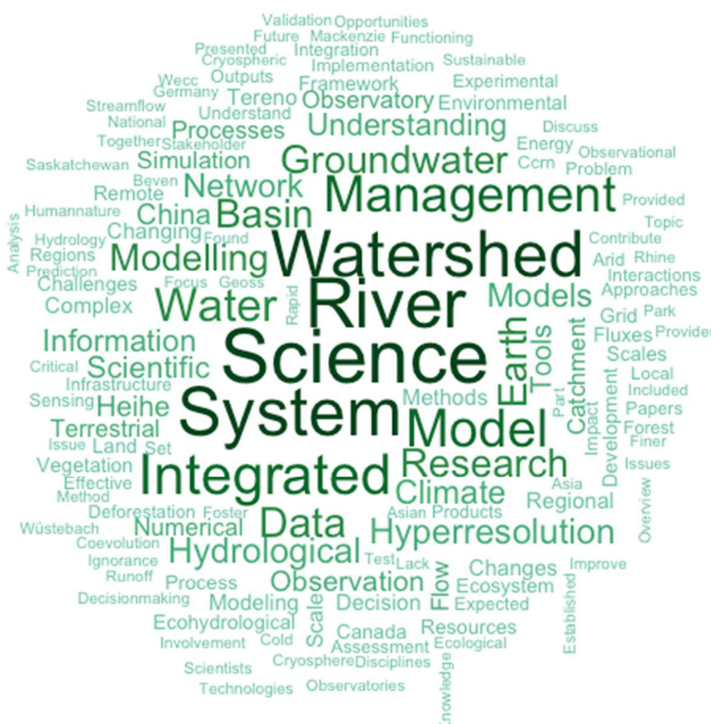

Figure 1. Words clouds included in titles, key words and abstracts of 7 papers in China Science Vol 58 Issue 1 (2015) and Cheng & Li's paper in Vol 58 Issue 7 (2015).

As outlined by Ison (2016) the use of the concept ‘system’ is widespread but all too often is employed without adequate theoretical insight. As Lakoff (2010) would say it has become a common framing choice: “And since frames come in systems, a single word typically activates not only its defining frame, but also much of the system its defining frame is in” (Lakoff 2010 pp. 71-72).[1] The issue of boundary choice is critical to the deployment of the concept ‘system’ (Midgely 2003). Understood metaphorically the concept *Earth System* implies a boundary associated with the whole Earth. For example, IGBP say that ‘the term “Earth system" refers to Earth´s interacting physical, chemical, and biological processes. The system consists of the land, oceans, atmosphere and poles. It includes the planet's natural cycles — the carbon, water, nitrogen, phosphorus, sulphur and other cycles — and deep Earth processes (http://www.igbp.net/globalchange/earthsystemdefinitions.4.d8b4c3c12bf3be638a80001040.html). In this use of the concept people and human action do not feature or only implicitly. In contrast the Wikipedia description of Earth system science claims it ‘is the application of systems science to the Earth sciences. In particular, it considers interactions between the Earth's "spheres"—atmosphere, hydrosphere, cryosphere, geosphere, pedosphere, biosphere, and, even, the magnetosphere—as well as the impact of human societies on these components. At its broadest scale, Earth systems science brings together researchers across both the natural and social sciences (https://en.wikipedia.org/wiki/Earth_system_science). The *system* concept is of utility when one is concerned with elements and their relations e.g., within the Earth System at system, sub-system or sub-sub-system levels e.g. watershed system, social system, farming system etc. At every systemic level the question of boundary judgment applies – it is we humans who must take responsibility for boundary choices as means to engage with the biophysical world whether to understand or transform it (Ison 2017).

However, there is a systemic trap in the use of the concept *system*, a noun in the English language (Ison 2016). Whilst the concept draws attention to the elements and relationships that might exist and operate in a system of interest, what is concealed by the use of the term are (i) the act of making a boundary judgment by an observer or observers; (ii) an appreciation that making a boundary judgement realises another relational dynamic – the act of making a distinction between a system and its environment and (iii) awareness that using the term system is always a shorthand for a system-environment relationship mediated by a boundary judgement. Cheng & Li (2015) frame the watershed as a basic unit of the Earth system. They argue that watershed science shares the characteristics of fundamental research in Earth system science and ground their arguments in six intellectual platforms: (i) systems science; (ii) complex systems; (iii) scale problems and (iv) Newtonism vs. Darwinism (v) hydro and eco-economics and (vi) meta-synthesis. Consistent with their claim that watershed science ‘should be integrated with philosophical conceptualization, theorization, methodological exploration, infrastructure construction and field experimentation’ (p. 1167) it is necessary to explore how the concept ‘system’ is employed by authors and how their conceptions relate to, or shape, research practice in a new field of watershed science. We believe that philosophical clarification of the concept ‘system’ could facilitate the systemic integration of all six intellectual platforms of Cheng & Li (2015) and

[1] It should not escape notice that Lakoff employs the concept system to make his points; whether this is an adequate use of the concept system is a question worth asking.

the overall aspiration for a new 'watershed science'.

The aim of this special issue was to develop watershed science by bridging new advances in hydrological science with good management of river basins. Six papers from leading scientists on watershed science in China, the USA, Japan, the United Kingdom and Germany make significant contributions to understanding the impact of human activities on the earth's surface in the Anthropocene through modelling work (e.g., Beven et al. 2015) and improvements in observational technologies and infrastructure (e.g. Koike et al. 2015). Unfortunately, this issue fails to link *hydrological science* with *good management of river basins* challenges as only Cai et al. (2015) call for drawing together disparate disciplines into an integrated scientific framework for a new generation of Decision Support System (DSS) for river basin management. Notably few key words relevant to river basin management or governance dominate (Figure 1). In a later issue, Cheng & Li (2015) ask: "*How can we better integrate the achievements of social sciences so that the large role of humans in Earth systems is fully understood*? arguing this is one of most significant challenges for developing watershed systems science**.** Therefore, our second interest is how to employ social sciences for governing the impact of human activities on the earth's surface in the Anthropocene**.**

Cheng & Li (2015) argue that watershed systems are highly co-evolved, complex human-nature systems. They thus set the groundwork for how co-evolutionary processes function. However, this co-evolution is based on long term and complex 'negotiations' between culture and nature. The negotiation is a result of human decision-making, which is the primary driver of earth system change. We argue that any human decision is determined by the interactions between social values (willingness to change), technology progress (capacity to change) and institutional arrangements (change regulated formally by government or through self-organising informal institutions) at different system levels (Wei and Zhang, 2017 and Wei et al. 2017). Therefore, while we agree with Cheng & Li (2015) that hydro-economics is important for understanding interdependence between economic activities and natural systems, three sub-disciplinary fields from hydrology: socio-hydrology, techno-hydrology and institutional-hydrology are needed for the development of watershed systems science. Developments in these sub-disciplines can provide understanding of the mechanisms for governing the impact of human activities on the earth's surface in the Anthropocene.

Unfortunately, very limited research on a single watershed has been conducted from the perspective of different sub-disciplines of watershed systems science. Such studies could cross-fertilise the development of individual sub-disciplines and generate systemic knowledge for watershed managing and governing. The Heihe River basin (HRB) in China is perhaps the one exception; it is the second longest inland river in China, with a length of 948 km and an area of approximately 143, 000 km^2. HRB covers typical ecosystems and catchment processes in an arid and semi-arid region; it sits within an important part of the ancient Silk Road established in the Han Dynasty (206 BC–AD 220) and thus within the new Belt and Road initiative being undertaken by China. The HRB 'story' is of a typical watershed involving many catchment processes related to hydrology and experiencing several management phases in early civilization, rapid economic development, serious environmental degradation and rebalance between humans and environment. The Heihe River Basin and the resources committed to understand and manage it constitute an ideal watershed 'laboratory' for inter-disciplinary research on watershed co-evolutionary dynamics. In 2010, the National Natural Science Foundation of China launched a major research plan titled "Integrated Study of the Eco-hydrological Processes of the Heihe River Basin" (referred to as the "Heihe Plan") which aimed to understand the water-ecosystem-economy system for sustainable river basin management. Since then over 500 papers have been published covering traditional hydrology, remote-sensing hydrology, eco-hydrology, hydro-economics and socio-hydrology. The challenge remains that identified by Cheng & Li (2015) when they ask: how can the innovations in Earth system science and technology be used to support a sustainable future Earth?".

The arguments made by Cheng & Li (2015) for the 'atomic' nature of a watershed, and thus its utility as a locus of study and of governance are conceptually sound. They also allow consideration of co-evolutionary dynamics between a social and a biophysical system but unfortunately many watersheds are no longer purely 'natural systems'; when inter-basin water transfers are made, or human wellbeing is linked to economic activity that spans watersheds then the question of system boundary choice, aligned to human purpose must be addressed. A holistic science that begins with systemic sensibilities and does not privilege linear or systematic causality is needed in all situations, including an earth system, characterized by interdependency, uncertainty, complexity, and controversy. These are the features of an Anthropocene world in which human action is effecting whole earth dynamics and in which traditional understandings and practices such as commitments to stationarity in hydrological modelling are no longer adequate. Achievements from the 'Heihe Plan' constitute a unique opportunity and significant investment to further build on multi-disciplinary achievements. To transform further towards a mature watershed systems science we urge the systemic use of the concept 'system' and bringing in new social-oriented sub-disciplines of hydrology. The HRB could be developed as an iconic watershed for watershed systems science – a new paradigm to understand and govern the impact of human activities on the earth's surface in the Anthropocene.

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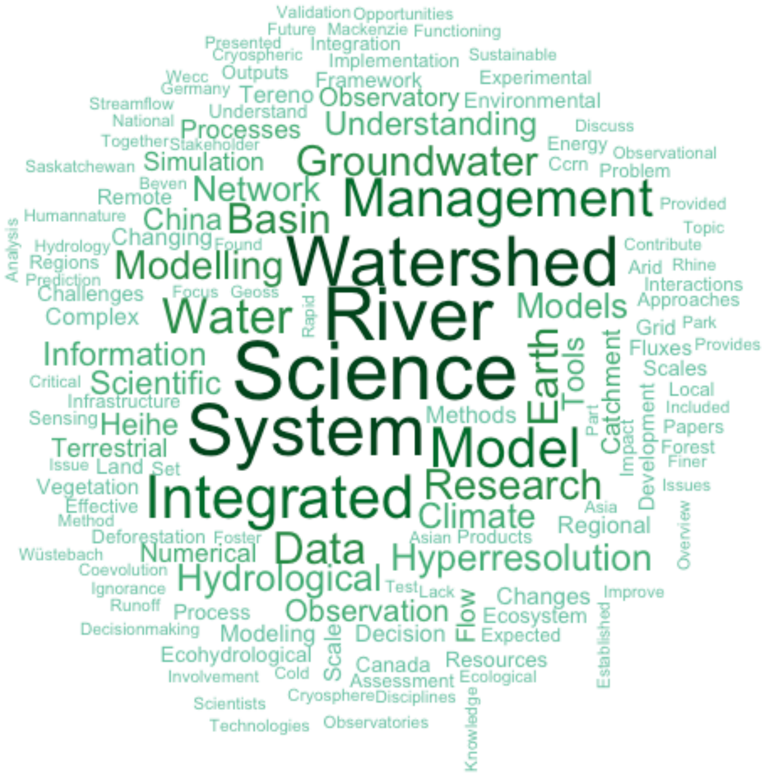

Figure 1. Words clouds included in titles, key words and abstracts of 7 papers in China