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Reconstructing the duty of water: a study of emergent norms in socio-hydrology

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Abstract

This paper assesses changing norms of water use known as the duty of water. It is a case study in historical socio-hydrology, a line of research useful for anticipating changing social values with respect to water. The duty of water is currently defined as the amount of water reasonably required to irrigate a substantial crop with careful management and without waste on a given tract of land. The historical section of the paper traces this concept back to late-18th century analysis of steam engine efficiencies for mine dewatering in Britain. A half-century later, British irrigation engineers fundamentally altered the concept of duty to plan large-scale canal irrigation systems in northern India at an average duty of 218 acres per cubic foot per second (cfs). They justified this extensive irrigation standard (i.e., low water application rate over large areas) with a suite of social values that linked famine prevention with revenue generation and territorial control. Several decades later irrigation engineers in the western US adapted the duty of water concept to a different socio-hydrologic system and norms, using it to establish minimum standards for water rights appropriation (e.g., only 40 to 80 acres per cfs). The final section shows that while the duty of water concept has now been eclipsed by other measures and standards of water efficiency, it may have continuing relevance for anticipating if not predicting emerging social values with respect to water.

1 Problem statement

In a doctoral qualifying exam, an older faculty member asked the candidate to discuss the duty of water concept in irrigation, to which the candidate briefly replied that while it had been an important standard for application rates in the early 20^{th} century, it had been replaced by more precise standards of water use efficiency. While accurate, my answer at that time stopped short of considering how and why these water norms have changed over time, and whether such changes can be anticipated if not predicted. Nor

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did I reflect on why the word duty was used, or what connotations it has had, past and present? This paper strives to answer these questions.

The duty of water concept is still used in some irrigated regions to establish standards of water use. An influential judicial opinion defined it as:

"... that measure of water which, by careful management and without wastage, is reasonably required to be applied to any given tract of land for such a period of time as may be adequate to produce therefrom a maximum amount of such crops as ordinarily are grown thereon" (State of Colorado Supreme Court, Farmers Highline Canal & Res Co. v. City of Golden, 272 p. 2d 629, 129 Colo. 575, 1954).

There are many interesting phrases in this definition: "careful management", "without wastage", "reasonably required", "adequate", "maximum amount", and "ordinarily grown". These terms have normative as well as analytical significance insofar as they refer to:

- ordinary practices (i.e., normal water use)
- standards (i.e., measurable expectations for normal water practices)
- values (i.e., ascription of instrumental, inherent, and intrinsic water benefits)
- justifications (i.e., reasons for water values, standards, and practices).

Collectively, these normative dimensions of water use help link observations with expectations. In addition to understanding how they operate in specific places today, it is important to reconstruct how they have developed over time, in ways that have shaped and addressed current water problems. Approached in an historical way, water challenges can be understood in dynamic terms, i.e., less in terms of established norms, and more in terms of emergent norms. The historical geography of water norms can help anticipate if not predict future norms, which can help extend prediction toward the social as well as hydrologic bases of water management.

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2 A socio-hydrologic framework for analysis

Rather than treat social and hydrologic dimensions of water management separately, this paper adopts a socio-hydrologic framework for analyzing the duty of water. Socio-hydrology is an emerging field of water inquiry analogous to the field of eco-hydrology (e.g., Eagleson, 2005). It is defined by Sivapalan et al. (2012) as the co-evolution or co-production of water-society relationships in time and space. Co-evolution is characterized by emergent properties in social and hydrologic systems, the focus of which in this paper are emergent water norms (cf. Falkenmark and Folke, 2010; Gerlak et al., 2011).

Sivapalan et al. (2012) identified three main lines of socio-hydrologic research: (1) historical; (2) comparative; and (3) process-focused. This paper pursues the first category of historical socio-hydrology, which strives to offer a longitudinal perspective on water norms, and thereby stimulate ideas about future management alternatives. When approached critically, historical socio-hydrology can complement scenario construction and water demand forecasting. Glantz (1988) referred to this as forecasting by analogy, in which societies construct analogies about possible futures and assess their preparedness to meet them (cf. Meyer et al., 1998; Wescoat, 1992).

With this brief explication of the historical socio-hydrology framework in mind, the next section retraces the origins of the duty of water concept back to steam engine performance in late-18th century Britain. The paper will then follow its evolving applications in canal irrigation in colonial India, the American West, and contemporary water ethics.

3 Origins of the duty concept

The concept of duty has an ancient history (Cicero, 1991), but as a measure of water-related efficiency, it can be traced back to late-18th century steam engine technologies in Britain. James Watt used the term duty to compare his patented steam engine performances with competing engines for mine dewatering in Cornwall (Nuvolari and Verspagen, 2007). From Roman times mines had employed chains of buckets drawn by geared water-lifting technologies, later known in Europe as whims, horse gins, horse windlasses, or horse capstans for short lifts of meters to several tens of meters (Fraenkel, 1986; Moseley and Mahan, 1866, 203–204; Oleson, 1984 and Schioler, 1973).

In 1712, Thomas Newcomen invented an early steam engine, named after himself, for draining tin and copper mines in Cornwall (Andrew and Allen, 2009). It was not the first steam device, early visions of which can be traced back to Hero of Alexandria, but 18th century Britain was the context in which steam engines competed with animal-driven water lifting machines. The relative efficiency of early steam engine pumps in Britain was not quantitatively measured until James Watt and partner Mathew Boulton developed more efficient engines and ways of comparing them with other technologies. Watt developed the concept of horsepower to compare his steam engines with the horse capstan (Cleveland, 2007, on the definition of horsepower as the physical work a horse can do by turning a 12 foot radius shaft a rate of 2.4 rotations per minute with a force of 180 foot-pounds [ft-lbs], which Watt (over)estimated at about 33 000 ft-lbs per minute).

To compare steam engines, Watt developed the concept of "duty" around 1776 CE, defined as the amount of physical work performed by an engine, measured in ft-lbs per bushel of coal burned (Nuvolari and Verspagen, 2007). A bushel of coal weighed approximately 94 pounds and was an expensive input, so much so that Watt charged steam engine purchasers one-third of their savings in coal costs compared with a Newcomen engine as their due. The term duty thus applied both to the physical performance of the engine and to economic charges for the engine's reduced coal costs (Cardwell, 1993–1994; Symons, 2003, App. 1).

Watt and partners were secretive about their innovations, but steam engine owners were not. They wanted comparative data on engine duties, and commissioned Joel Lean to publish Lean's Engine Reporter, which ran from 1811 through 1904 (Nuvolari

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and Verspagen, 2007). Comparative analysis of engine data recorded impressive gains in engine efficiency during the early to mid-19th century from millions to tens of millions of ft-lbs per bushel.

The earliest concept of duty focused on water-lifting. There were stray references to rivers and water performing a duty, i.e., work, in early 19th century English and Scottish publications (e.g., a stream does its duty, Marshall, 1805, 314–315). An 1852 article argued that steam engines would give irrigators in Britain a competitive advantage over countries that had lower labor costs (Johnson, 1852). However, there were important differences between the duty concept in irrigation and the intensely competitive steam engine business in Britain. The norm in steam engine pumping period was to maximize physical and economic efficiency; irrigation norms were more complex.

4 The duty of water in 19th century canal irrigation in India

Irrigation is even more ancient than water lifting technologies. Pre-modern irrigation systems in South Asia included floodplain farming in large perennial river valleys; many types of local well, tank, and check dam irrigation; and a few long-distance canals (Agarwal and Narain, 1997; Hegewald, 2002; Mosse, 2003; Wescoat, 2012).

The duty of water concept was adapted for large canal irrigation systems that ran tens to hundreds of kilometers in length. Their pre-colonial antecedents may be briefly described. The earliest documented large canal in north India was commissioned by Sultan Firoz Shah Tugluqh in the mid-14th century (Habib, 1999, 34). It diverted water from the Yamuna River north of Delhi to the towns of Hansi and Hissar to the southwest. After lapsing in periods of political instability, it was renovated by a provincial governor in the Mughal period around 1570–1571 CE. A half-century later it was renovated again by the Mughal ruler Shah Jahan, and a branch was extended approximately 120 km eastward to the new Mughal capital of Shahjahanabad (known today as Old Delhi) for urban and agricultural water supply. Two other large 17th century canals were constructed on the Ravi and Chenab rivers in the Punjab plains, and an 18th century canal

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was taken from the east bank of the Yamuna River. Court historians described the normative aims of these works as extending cultivation for the prosperity of subjects and rulers (ibid., 35–36). There were thus only a few precedents for the massive extension of large-scale canal irrigation systems that developed from the 19th century onward.

British irrigation schemes in India had tentative beginnings and mixed aims, with surprisingly limited connection to contemporary European advances in water and agricultural sciences. There was nothing comparable to Lean's Engine Reporter and few references to irrigation in the colleges that trained officers for service in India at Haileybury, Addiscombe, and the Royal Indian Engineering College at Cooper's Hill. Nineteenth-century British administration was still headquartered in humid Calcutta while Delhi and more drought prone regions belonged to the peripheral North Western Provinces.

As early as 1805, an entrepreneur proposed to reopen the West Jumna Canal above Delhi at his expense in return for the revenues it might yield, but the East India Company declined (Colvin, 1833; Baird Smith, 1852). Company sanction for canal repairs began in 1810 but had little to show on the ground until 1820, and even then with reportedly poor quality earthworks (Colvin, 1833). Increased staffing led by John Colvin and Robert Smith an artist-engineer contributed to large-scale surveys for irrigation development on the interfluve (*doab*) between the Ganges and Yamuna (Archer, 1972; Skempton, 2002, 148–149). Colvin (1833) published one of the first wide-circulation reviews of the emerging aims of irrigation, emphasizing its general improvement of the country through abundant water for land reclamation. Writing in the mode of an engineer, he represented irrigation finance more as the avoidance of financial waste rather than as the generation of revenue. He discussed a wide list of canal uses in addition to irrigation, including waterpower, water supply, transport, fishing, and forest tree planting. In all of these discussions, however, Colvin did not mention the area of land irrigated or the amount of water used per unit of land. Aside from stray references, such as an 1835 piece in the Meerut Universal Magazine that estimated the quantity of water withdrawn from a well by a Persian wheel, there was little evidence of emergent standards of water use during the first third of the 19th century (Bayley, 1835).

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This began to change after a horrific drought and famine in 1837–1838. The first major planning study for a Ganges Canal was completed in 1840, which estimated that one cfs could irrigate 218 acres of land (i.e., 350 *bighas* in local units of measurement) (Cautley, 1840). An ambitious new engineering school was planned at the town of Roorkee by engineer Proby Cautley in 1841. It opened in 1848, located strategically at the headworks for the new Ganges Canal. Similarly grand plans were laid out for Punjab rivers by Richard Baird Smith (1849a), again using the water planning standard of 218 acres per cfs. Finally, a report titled Sketch of Mairwara by Lieutenant-Colonel C. J. Dixon (1850) referred explicitly to the irrigative duty of that region. Although Dixon's study did not have much impact on the field, its timing indicates that the duty of water concept developed in 1840s irrigation planning – a good half-century after its use in steam engine pumping.

The literature on irrigation in India then developed in rapid and impressive ways with early accounts in the Calcutta Review (Baird Smith, 1849b) and the North American Review (Norton, 1853). British engineers published detailed comparative studies of irrigation duties in India and southern Europe (Baird Smith, 1852; Scott-Moncrief, 1868). The East India Company created a Department of Public Works in 1854 which was responsible for major canal irrigation and issued annual reports about its achievements and challenges (Government of India, 1857). However, the Revolt of 1857 led to transfer of power from the East India Company to the Crown which, along with a famine in 1860–1861, marked a major shift toward public irrigation and explication of the duty of water concept. In 1864, a report on the Ganges Canal used the duty of water standard for analytical and planning purposes (Crofton, 1864). Duties of water for different canal commands in India ranged from 170 to 528 acres per cfs diverted, depending upon canal losses, soil conditions, crop water requirements, and cultivation practices. Three years later, the irrigation duty of water concept was said to be well-known (Wilson, 1867).

Finally, Beresford (1875) explicitly compared the estimation of irrigation duty on the Ganges Canal with the calculation of steam engine duty, thus completing the chain of

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analysis that developed over the course of a century. The duty concept was not directly transferred from one socio-hydrologic context to another, but was instead a slow multi-linear process. The emerging norms for irrigation were heterogeneous compared with steam engine efficiency. Of the dual colonial irrigation concerns with efficiency and waste, the latter was more salient in the writings of engineers, if not administrators (Gilmartin, 2003). The logic of large irrigation duties in India was to spread water as extensively as possible, maximizing the area irrigated, in what some have called protective irrigation (Jurriens et al., 1996). While this provided a measure of crop insurance against drought, it contributed to the predictable under-performance of deficit irrigation. Water-spreading aggravated scarcity in the tail-ends of unlined canals and watercourses (Bandaragoda, et al., 1994, p. 31). It may also have slowed adoption of higher value drought-sensitive horticultural crops.

Postcolonial irrigation historians have shed light on these normative crosscurrents of imperial science and the science of empire, and their consequences (Gilmartin, 1994). It was a socio-hydrologic system that conflated resource efficiency with revenue generation, elite cooptation, pacification, famine protection, territorial control, strategic positioning in changing international cotton markets, and the diverse interests of colonial engineers (Ali, 1988). Although useful as a planning standard for reclaiming vast tracts of land, the duty of water concept in India had limited value for measuring, administering, and increasing water use standards at the field and farm levels.

5 Emerging water norms and duties in the western US

The US followed irrigation development in British India with keen interest. The first detailed publication on the subject was by a literary scholar and art historian Charles Eliot Norton (1853), editor of the North American Review. The duty of water became a focus of attention in 1873, however, as the State of California grappled with irrigation alternatives for its Central Valley (Davidson, 1874; Wescoat, 2001). The State of California Board of Commissioners (1874) published international comparative data on the sub-

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ject, as did the State Engineer of California (1880). They contrasted the low, wasteful duty of water in California with higher standards in Italy, Spain, Australia, and India. Also in 1874, the pioneering conservationist and US Senator George Perkins Marsh published Irrigation: its Evils, the Remedies, and the Compensations, which was one of the first documents to link duty of water standards with social ethics.

Analytically, the duty of water became a focus of research in newly established state water research centers in public universities at the end of the 19th century. Professor Elwood Mead (1887) of the Colorado Agricultural College prepared a Report of Experimental Work in the Department of Physics and Engineering based on campus irrigation experiments. He then took a position as the first Territorial Engineer in Wyoming which adopted a statewide duty of water of 70 acres per cfs in 1890, based on Mead's engineering reports. Mead (1903) convincingly argued that the duty of water should be measured in acre-feet per acre to assess farm and field scale performance, which became widespread practice in the western US.

These norms drew upon international data, comparing and contrasting them with the wide range of situations in the western states. The US Senate (1890) charged consuls around the world to provide information about the state of irrigation including the duty of water, and received detailed responses from countries on every continent including India. The American Society of Civil Engineers published a major monograph on Irrigation in India by Herbert Wilson (1890–1891, 370) who wrote:

"Though the conditions of government and people are so different in India from those in America, many useful examples and lessons may be drawn from the methods of administration and legislation practiced there, as well as from the financial success or failure that has attended the construction of their works."

While the duty of water standard in India was commonly 218 acres per cfs, in the western US duties ranged from 40 to 80 acres per cfs (Weil, 1911). Why this difference? Both areas aimed for maximum utilization. However, canal irrigation in British India established a standard for maximum area irrigable with a given flow of water. In the US the duty of water concept was applied in precisely the opposite way – i.e., as the

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minimum standard for private water rights appropriation and use. The socio-hydrologic aims of irrigation in the US were pursued through private property rights to water, which made intensive, rather than extensive, water use the norm for development. In the initial phase of development, intensification involved applying more water to the land, i.e., increasing productivity by increasing water inputs. Later there would be pressures to increase water use efficiency, i.e., increase the area irrigated and crop production on it per unit of water. A California court recognized that the duty of water should increase over time – "What is beneficial use at one time may, because of changed conditions, become a waste of water at a later time" (State of California Supreme Court, Tulare Irrigation District v. Lindsay-Strathmore Irrigation District, 3 California 2d 489, 45 Pac. 2d 972, 1935). Although in principle the duty of water could increase over time in the western states (as could standards of beneficial use in water law), that rarely occurred in practice, in part because water rights are a form of property in the American west. Anything that might diminish the size of a presumed property right is resisted vigorously (though legally one only owns what one uses beneficially and without waste).

Interestingly, the first irrigation law treatises in the US surveyed irrigation laws in other countries but did not mention the duty of water concept (e.g., Kinney 1894). Later editions did discuss cases in which the duty of water was cited as the measure of a water right and in cases where it was used to bring a lawsuit or to resolve one (e.g., Kinney, 1912, 1592–1605). By the 1950s, courts recognized the declining significance of the duty of water as a scientific measure and standard of water use:

"Although the expression "Duty of Water", in the opinions of some present-day scholarly hydrologists and technical engineers, may be outmoded, provincial, unscientific and otherwise objectionable, nevertheless it is a term well understood and accepted by every rancher an farmer who has had practical experience in the artificial irrigation of land for the production of crops." (State of Colorado Supreme Court, Farmers Highline Canal & Reservoir Co. v. City of Golden, 272 P.2d 629, 129 Colo. 575, 1954).

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The concept continues to be used to some degree. For example, the Soil Science Society of America website includes duty of water definitions in its glossary of terms, and it has been the subject of recently proposed legislation in New Mexico (State of New Mexico, 2011). However, these applications are waning along with the public reclamation programs that supported them, as the science and technology of crop water use efficiency become increasingly sophisticated in technical terms and rationalized in political economic terms.

The duty of water has been guided by social values as well as irrigation standards over the past 150 years. The values that guided colonial irrigation in India took a different direction in the western US where private ownership was predominant. As public and private socio-hydrologic regimes continue to evolve in different venues and discourses, what future might the concept of duty hold? Waning operational usage may open up new opportunities for reconstructing the duty of water in ethical terms.

6 From water use standards to ethical duties

Judicial opinions often articulate the social justifications for water use standards, which include a range of ethical rationales based on theories of utility, labor, virtue, liberty, duty, and just desserts (cf. Becker, 1981). Among this array of ethical approaches, those based on theories of duty have particular relevance for this study. Philosophies of duty are sometimes referred to as deontological ethics, a major source for which is Kant's Metaphysics of Morals (1996). These are not duties inherited by social custom, associated with public office, or undertaken for some beneficial end. Instead, Kant argued that the only perfect duties that have moral value are those that arise solely from good will detached from any aim and without regard for consequences. Good will strives to identify maxims that one can will to become universal laws (i.e., categorical imperative), for which individual moral actors must have freedom and autonomy. Kant insisted that humans treat other humans as ends in themselves, solely out of good

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will, and never merely as a means. These perfect duties are poles apart from utilitarian ethics that focus on the consequences of rules and acts.

Both poles seem removed from the lived realities of socio-hydrologic systems where water users and uses jointly engage one another as means and ends. A balanced approach to means-ends relationships, and the pursuit of duties based on moral experience, experimentation, and pluralism may be found in pragmatist ethics (Dewey, 2002; Katz and Light, 1996; Minteer, 2011; Wescoat, 1992). The pragmatist alternative may be briefly outlined in historical and socio-hydrologic terms. In South Asia, it can help understand the multiple justifications for colonial irrigation in relation to their respective moral philosophies, which historian Eric Stokes (1969) referred to as paternalist, utilitarian, and evangelical. Similarly diverse ethical positions existed in the US reclamation movement at the turn of the last century, with evangelicals arguing for reclamation in Biblical terms as 'making the desert rejoice and blossom as a rose,' utilitarians arguing for its net social benefits, and conservationists warning against its moral hazards (Isaiah, 35:1; Lee, 1980; Smythe, 1905). George Perkins Marsh (1874, 4) argued that the relations between capital and labor in irrigation, "... is really a moral rather than a financial problem." He believed that the relations between labor and resources were unsatisfactory in European irrigation, as they had led to the land accumulation by a few as well as dispossession and demoralization of small landholders. "Water rights are a constant source of gross injustice and endless litigation", which argues for a strong public role in irrigation (ibid., 5). Late-19th and early 20th century debates about the moral philosophy of irrigation have continued in various threads up to the present, including the environmental ethics of irrigation.

7 Anticipating the emergent duties of water

With this historical perspective in mind, we can turn to emergent duties of water internationally. The following examples are sometimes framed as reforms or rights which, as they gain traction, may become socio-hydrologic duties.

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7.1 Duty of intensification

The original concept of duty involved the efficiency of steam engines. Subsequent duties of water involved measures, standards, and values of irrigation efficiency. There is enormous potential for further increases in water use efficiency and productivity – from technologies of sensing, monitoring, and control systems; to analyses of water footprint, supply chain, and virtual water trade; and through policy reforms in water resource economics, regulation, and governance. Pitfalls of intensification range from environmental impacts to third party injury and increased aggregate consumption (Scott, 2013).

7.2 Duty of safe water and sanitation

There are at the same time growing movements to recognize human rights to safe water and sanitation. They have justifications based on natural rights; constitutional rights to life, livelihood, and development; and human rights law (Sultana and Loftus, 2012; Winkler, 2012). Despite advances in access to safe water, legal recognition of human rights to water has been slow. These social norms may gain greater prospects for implementation if framed as expanding bundles of social duties at multiple levels from the person to community, civil society, state, and global humanity (cf. Demsetz, 1967 for an influential yet more limited theory of rights as bundles).

7.3 Duty of equitable access, allocation, and use

Similarly, advocacy for equitable irrigation rights has grown in recent decades (e.g., with regard to gender, race, class, indigenous peoples, and tail-end canal users). Rights-based approaches have gained greater recognition by the courts, both as oppositional social struggles to prevent expropriation, and in first nations' water rights. However, some of these remain paper rights rather than wet water. They may be transformed

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from rights into water through the establishment of concrete social duties for implementing equitable access and allocation.

7.4 Duties to non-human beings

Water rights for animals and environmental flows also have a mixed record. In the US they have advanced most through the Endangered Species Act. In Islamic water law, by comparison, animals have rights to water necessary for their survival in principle if not in practice (Wescoat, 1995). In most cultures, there are recognized duties to provide water to domestic and farm animals as part of expanding measures of animal welfare and anti-cruelty movements, even where no rights exist per se. Duties to consider plant water needs are further out on the horizon but not beyond ethical imagination (Hall, 2009, 2011).

8 The duty to re-balance the duties of water in socio-hydrologic systems

These emergent duties may be considered separately or jointly, with predictions made about their direction, scope, and pace of development. The public trust doctrine provides a good example. Taken separately, it articulates the duty of a state to fulfill its inalienable trust responsibility to manage submerged lands on behalf of the public. It dates back to Roman times, but was rediscovered and applied along the Chicago lakefront in the 1890s and later to protect Mono Lake in California in the 1980s. Some predicted that it would advance rapidly as a new environmental norm that would constrain private water rights. That did not happen in the US to the extent anticipated, but US precedents have been influential in South Asia where continuing extensions seem likely (Wescoat, 2009).

Although emergent norms like the public trust doctrine can be studied individually at one level, they develop in tandem with other social values that shape and constrain one another. Emergent water norms would ideally be studied jointly with the type of plu-

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ralistic pragmatic approach that continuously re-balances socio-hydrologic processes and outcomes (see Pappas, 2008, 172–184 on balance in pragmatist ethics). For the present, the findings of this study are: first, that an historical approach is useful for reconstructing emergent water duties; second, to understand these duties it is important to study the linkages among water measurement, standards, values, and justifications; and third, that a pragmatic pluralistic approach shows promise for future research on the normative dimension of socio-hydrologic problems and processes.

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References

Agarwal, A. and Narain, S.: Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting System, Center for Science and Environment, Delhi, 1997.

Ali, I.: Punjab Under Imperialism: 1885–1947, Oxford University Press, Delhi, 1988.

Andrew, J. H. and Allen, J. S.: A confirmation of the location of the 1712 "Dudley Castle" Newcomen engine at Coneygree, Tipton, Int. J. Hist. Eng. Technol., 79, 174–182, 2009.

Archer, M.: An Artist Engineer: Colonel Robert Smith in India, 1805–1830, The Connoisseur, 179, 79–88, 1972.

Baird Smith, R.: Agricultural Resources of the Punjab; Being a Memorandum on the Application of the Waste Waters of the Punjab to Purposes of Irrigation, Smith, Elder and Co., London, 1849a.

Baird Smith, R.: Canals of irrigation in the North-Western Provinces, Calcutta Rev., 12, 79–183, 1849b.

Baird Smith, R.: Italian Irrigation, W. H. Allen & Co., London, 1852.

Bandaragoda, O. J. and Rehman, S.: Warabandi in Pakistan's canal irrigation systems: Widening gap between theory and practice, International Irrigation Management Institute, Country Paper No. 7, Colombo, Sri Lanka, 1995.

Bayley, W. B.: On the amount of irrigation from wells in the northern dooab [sic], Meerut Universal Magazine, 1, 427–428, 1835.

Becker, L.: Property Rights: Philosophical Foundations, Routledge, London, 1981.
Beresford, J. S.: Duty of water, Roorkee Institute Professional Papers no. 212, Roorkee, India, 1875.
Cardwell, D. S. L.: Steam engine theory in the nineteenth century: from duty to thermal efficiency; from Parkes to Sankey, Newcomen Soc., 65, 117–128, 1993–94.
Cautley, P.: Report of the Central Doab Canal, Allahabad Mission Press, Allahabad, 1841.
Cicero, M.: On Duties (De Officiis), edited by: Griffin, M. T. and Atkins, E. M., Cambridge University Press, Cambridge, 1991.
Cleveland, C. J.: Horsepower, Encyclopedia of Earth, http://www.eoearth.org/article/Horsepower (last access: 16 May 2013), 2007.
Colvin, J.: on the restoration of the ancient canals in the Delhi territory, J. Asiat. Soc. Bengal, 2, 105–128, 1833.
Crofton, J.: Report on the Ganges Canal, Roorkee, 1864.
Davidson, G.: Irrigation and reclamation of land for agricultural purposes, as now practiced in India, Egypt, Italy, etc., Exec. Doct. 94, US Senate, 44th Cong., 1st Sess., Washington, 1876.
Demsetz, H.: Toward a theory of property rights, Am. Econom. Rev., 57, 347–359, 1967.
Dewey, J.: The Moral Writings of John Dewey, edited by: Gouinlock, J., Prometheus Books, Amherst, NY, 2002.
Dixon, C.J.: Sketch of Mairwara, Smith, Elder and Co., London, 1850.
Eagleson, P.: Ecohydrology: Darwinian Expression of Vegetation Form and Function, Cambridge University Press, Cambridge, 2005.
Falkenmark, M. and Folke, C.: Ecohydrosolidarity: a new ethics for stewardship, in: Water Ethics, edited by: Brown, P. and Schmidt, J., Island Press, Washington, 247–264, 2010.
Fraenkel, P. F.: Water-Lifting, FAO Irrigation and Drainage Paper 43, FAO, Rome, 1986.
Gerlak, A. K., Varady, R. G., Petit, O., and Haverland, A. C.: Hydrosolidarity and beyond: Can ethics and equity find a place in today's water resource management?, Water Int., 36, 251–265, 2011.
Gilmartin, D.: Scientific empire and imperial science: colonialism and irrigation technology in the Indus basin, J. Asian Stud., 53, 1127–1149, 1994.
Gilmartin, D.: Water and waste: nature, productivity and colonialism in the Indus basin, Econom. Polit. Week., 48, 5057–5065, 2003.

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Glantz, M. H. (Ed.): Societal Responses to Regional Climatic Change: Forecasting by Analogy, Westview, Boulder, 1988.
Government of India: Progress Reports of the Public Works Department, For the Year 1854–55, Calcutta, 1857.
Habib, I.: The Agrarian System of Mughal India, 1556–1707, 2nd rev. Edn., Oxford University Press, Delhi, 1999.
Hall, M.: Plant autonomy and human-plant ethics, Environ. Ethics, 31, 169–182, 2009.
Hall, M.: Plants as Persons: A Philosophical Botany, SUNY Press, Albany, 2011.
Hegewald, J. A.: Water Architecture in South Asia: A Study of Types, Developments, and Meanings, E. J. Brill, Leiden, 2002.
Johnson, C.: Recent improvements in irrigation, The Farmer's Magazine, 3rd series, I, Rogerson and Tuxford, London, 69–73, 1852.
Jurriens, M., Mollinga, P., and Wester, P.: Scarcity by Design: Protective irrigation in India and Pakistan, International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands, 1996.
Kant, I.: Metaphysics of Morals, edited by: Gregor, M., Cambridge University Press, Cambridge, 1996.
Katz, E. and Light, A. (Eds.): Environmental Pragmatism, Routledge, London, 1996.
Kinney, C. S.: Treatise on the Law of Irrigation and Water Rights, 1st Edn., Bender-Moss Company, San Francisco, 1894, 2nd Edn., 1912.
Lee, L. B.: Reclaiming the American West: An historiography and Guide, ABC-Clio, Santa Barbara, 1980.
Marsh, G. P.: Marsh, Irrigation: Its Evils, the Remedies, and the Compensations, 43rd Cong., 1st sess., Senate Misc. Doc. 55, Washington, 1874.
Marshall, W .H.: The Rural Economy of the West of England, G. and W. Nichol, London, 1805.
Mead, E.: Report of Experiments in Irrigation and Meteorology, Colorado Agricultural College, Colorado, 1887.
Mead, E.: Second Annual Report 1889, State Engineer, Laramie, Wyoming, 1890.
Mead, E.: Irrigation Institutions, Macmillan, New York, 1903.
Meyer, W.B. et al.: Reasoning by analogy, in: Human Choice and Climate Change: Tools for Policy Analysis, edited by: Rayner, S. and Malone, E., Battelle Press, Columbus, 217-90, 1998.

HESSD
10, 7517–7536, 2013
Reconstructing the duty of water: a study of emergent norms in socio-hydrology
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Minteer, B.: Refounding Environmental Ethics: Pragmatism, Principle, and Practice, Temple University Press, Philadelphia, 2011.
Moseley, H. and Mahan, D. H.: The Mechanical Principals of Engineering and Architecture, John Wiley, New York, 1866.
Mosse, D.: The Rule of Water: Statecraft, Ecology, and Collective Action in South India, Oxford University Press, Delhi, 2003.
Norton, C. E.: Canals of irrigation in India, North Am. Rev., 77, 439–466, 1853.
Nuvolari, A. and Verspagen, B.: Lean's Engine Reporter and the Development of the Cornish Engine: A Reappraisal, T. Newcomen Soc., 77, 167–189, 2007.
Oleson, J. P.: Greek and Roman Mechanical Water-Lifting Devices: The History of a Technology, Springer, Dordrecht, 1984.
Pappas, G. F.: John Dewey's Ethics, Indiana University, Bloomington, 2008.
Schiøler, T.: Roman and Islamic Water-Lifting Wheels, Odense University, Copenhagen, 1973.
Scott, C.: Resource-use efficiency, once paradigm now paradox: The socio-hydrology of waste, Paper presented at the American Association for the Advancement of Science, Boston, http://aaas.confex.com/aaas/2013/webprogram/Paper9286.html, last access: 16 May 2013.
Scott-Moncreiff, C. C.: Irrigation in Southern Europe, E. & F. N. Spon, London, 1868.
Sivapalam, M., Savenije, H., and Blöschl, G.: Socio-hydrology: A new science of people and water, Hydrol. Process., 24, 1270–1276, 2012.
Skempton, A.: Biographical Dictionary of Civil Engineers in Great Britain and Ireland, volume 1: 1500–1830, Thomas Telford, London, 2002.
Smythe, W. E.: The Conquest of Arid America, The Macmillan Company, New York, 1905.
State of California, State Engineer: Annual Report of the State Engineer to the Governor of the State of California, Sacramento, 1880.
State of California, Board of Commissioners: Report of the Board of Commissioners on the Irrigation of the San Joaquin, Sacramento, 1874.
State of Colorado Supreme Court: Farmers Highline Canal & Res Co. v. City of Golden, 272 p.2d 629, 129 Colo. 575, 1954.
State of New Mexico: An Act. Relating to water; amending a section of chapter 72 NMSA 1978 to provide for a single duty of water for all irrigated crops in a stream system, 50th Legislature, First session, House Bill, 279, 2011.
Stokes, E.: The English Utilitarians and India, Oxford University Press, Oxford, 1969.

HESSD
10, 7517–7536, 2013

Sultana, F.and Loftus, A. (Eds.): The Right to Water: Politics, Governance and Social Struggles, Earthscan, Abingdon, Oxon, 2012.

Symons, J. C.: The Mining and Smelting of Copper in England and Wales, 1760–1820, Masters thesis, Coventry University in collaboration with University College, Worcester, 2003.

US Senate, 51st Cong., 1st Sess.: Report of the Special Committee of the United States Senate on the Irrigation and Reclamation of Arid Lands. Senate Report 928, part 5, Letter from R. J. Hinton to US consuls, dated 23 April 1889, Government Printing Office, Washington, 249–250, 1890.

Weil, S. C.: Water Rights in the Western States, 3rd Edn., 2 vols., Bancroft-Whitney, San Francisco, 1911.

Wescoat Jr., J. L.: Water rights in South Asia and the United States: Comparative perspectives, 1873–1996, in: Land, Property and the Environment, edited by: Richards, J. F., ICS, Oakland, 298–337, 2001.

Wescoat Jr., J. L.: The “right of thirst” for animals in Islamic water law: A comparative approach, Environ. Plan. D, 13, 637–654, 1995.

Wescoat Jr., J. L.: Common themes in the work of Gilbert White and John Dewey: A pragmatic appraisal, Ann. Assoc. Am. Geogr., 82, 587–607, 1992.

Wescoat, J. L.: Submerged landscapes: The public trust in urban environmental design, from Chicago to Karachi and back again, Vermont J. Environ. Law, 10, 435–475, 2009.

Wilson, A.: Irrigation in India and in Spain: Institution of Civil Engineers and Clowes and Sons, London, 1867.

Wilson, H. M.: Irrigation in India, U.S.G.S. 12th Annual Report, Part II, Irrigation, Washington, 1890–1891.

Winkler, I.: Human Right to Water: Significance, Legal Status and Implications for Water Allocation, Hart Publishing, Oxford, 2012.

HESSD

10, 7517–7536, 2013

Reconstructing the duty of water: a study of emergent norms in socio-hydrology

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