Virtual Water - the Water, Food, and Trade Nexus Useful Concept or Misleading Metaphor?

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Abstract: *The purpose of this contribution is first, to respond to the request for clarification of the term virtual water by Stephen Merrett. Second, it provides a narrative for those who might not be aware of the origin and development of the concept. Third, the discussion will draw attention to the problems encountered in gaining entry for the idea into those water policy discourses where the it was most relevant. The concept has been in currency for almost a decade. The use of the term increased rapidly after 1995 and by the millennium the idea had become central to many dialogues relating to water security preliminary to the Kyoto World Water Forum in March 2003. Merrett's (2003) challenge that the water community should give attention to the language used by its diverse professionals and scientists is timely. Inter-disciplinarity is always difficult. In the water sector such difficulties have been magnified not just by the perversity of its tribal dynamics but especially because the political stakes are high. This account and response will not meet the standards of philosophical analysis set by Merrett. It is written in the spirit of having a further impact on an important on-going discourse. And in the hope that the ideas reach water policymakers. Others might want to comment on whether they think virtual water is a scientifically respectable term or perhaps that it is just a potentially misleading, though useful, metaphor.*

Linking Water, Food, and Trade

"..communities and nations that live in river basins (watersheds) operate in "open" economic systems (problemsheds) where resource shortages can be compensated" (Allan, 2001a).

The purpose of this article is first to respond to the comments of Stephen Merrett on the problems he has as an economist/philosopher with the term virtual water (Merrett, 2003), and secondly, to provide a narrative outlining how the idea has been received during the past decade. The second goal is addressed first and the discussion concludes with a response to Merrett's comments. Throughout it will be shown that the impact of what the author terms, the "virtual water remedy to local water scarcity," will be shown to depend more on political processes rather than on the scientific authority of the idea or precision with which it is defined.

The term "virtual water" was coined at a seminar at SOAS in about 1993. If the idea was invented independently by another individual or group it is hoped that this article will stimulate them to enter the discussion. Before 1993 the author had used the term embedded water (Allan 1993; 1994), which did not capture the attention of the water managing community. The idea was of course derivative. Israeli economists had by the mid-1980s spotted that it was less than sensible from an economic perspective to export scarce Israeli water. This was in effect what they argued was happening every time water intensive oranges or avocados were exported from semi-arid Israel. (Fishelon, 1992). The idea has been elaborated more recently for Israel (Yegnes-Botzer, 2001) and for Egypt (Wichelns, 2001). Hoekstra and Hung (2002) suggest that in 1999 Israel exported 0.7 cubic kilometers of virtual water and imported 6.9 cubic kilometers. For Egypt, they calculated the net virtual water import to be 15.3 cubic kilometers.

The term "embedded water was" under-whelming in its impact. Virtual water, by contrast, had an immediate impact. It was accessible and people appeared to accept it readily as a useful metaphor. The author thereafter used the term to draw attention to the notion that serious local water shortages could be very effectively ameliorated by global economic processes. As a Middle East specialist, he was particularly aware that the Middle East and North Africa were facing increasing water deficits. This was especially the case if total water self-sufficiency, including water for food, was taken to be the criterion of deficit. Total water self-sufficiency requires that a national economy has sufficient local water to provide drinking water, domestic water, water for industry and services, and water for food and other essential agricultural production. Since the late 1970s, and especially since the early 1990s, self-sufficiency has also included – at least in the best managed economies – an explicit allocation to support the environmental services underpinned by water in the environment.

At meetings with very senior Middle Eastern cabinet level officials during the first half of the 1990s the author discovered that linking strategic food deficits with water deficits was a no-go area in public discourse. He later called the problem of linking water food and trade in such public discourse in the Middle East, a sanctioned discourse (Allan 2001a), after discussing the phenomenon with his SOAS politics colleague Charles Tripp (1996).

He also found that the term could irritate economists and engineers both inside and outside the region: the former argued that it was confusing to suggest that water was being traded in the process of moving water intensive commodities, such as grain, from one place to another. This is one of the issues taken up by Merrett (2003). It is not water that is being traded; it is food. Economists prefer to capture the value of the water input as part of the value of the land where the product is produced. A moist tract would be more valuable and command more rent, and produce more output than a neighboring dry tract. Engineers generally felt the idea was fanciful.

It would be wrong to suggest that all engineers rejected the idea. The approach was shared with a senior South African engineer, Alan Conley, in May 1995 at a conference in Oman. He immediately saw the relevance of the thinking to the regional water resource predicament of southern Africa. Post-Apartheid South Africa had emerged from its siege predicament. Water professionals there had the chance to take a more comprehensive global view of their water security options. They had begun to recognize the merit of trading food within the southern African region rather than embarking on a new hydraulic mission involving ambitious inter-basin water transfers. As a result of the enthusiasm of Alan Conley a paper was requested for the ICID Congress in Cairo in 1996. One of the first articles outlining the virtual water concept appeared, therefore, in the ICID Journal in 1998. (Allen, 1998).

Agricultural engineers also showed an interest in the economic processes that are part of the complex that achieve agricultural commodity production. An invited paper appeared in *Agricultural Water Management* in 1999, which drew attention to the role of virtual water in addressing regional water deficits (Allan, 1999). The editor of the journal, *International Water and Irrigation*, also invited a contribution on the topic in 2001. This article (Allan, 2001b) consciously popular, is the author's preferred summary in that the metaphor has been much enhanced by cartoon graphics by the editor which make the idea accessible with just a very cursory scan of the material by very busy people. Some of the cartoons accord with part of Stephen Merrett's vision of ships carrying cargoes of grain supposedly followed by additional vessels loaded with the free water that had been used to raise the grain. The cartoonist, without the constraints of philosophical rigour, seems to have captured the idea of virtual water through judicious use of the image and some well placed text. They have labeled the sack of wheat, "water." This is a metaphor and certainly not truth.

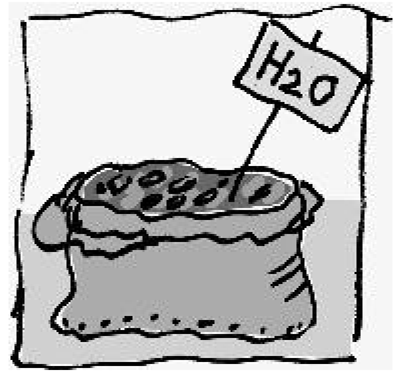

Figure 1. Water in commodities. Virtual water - the "intensive" (Weber, 1904) version of the concept (Allen, 2001b).

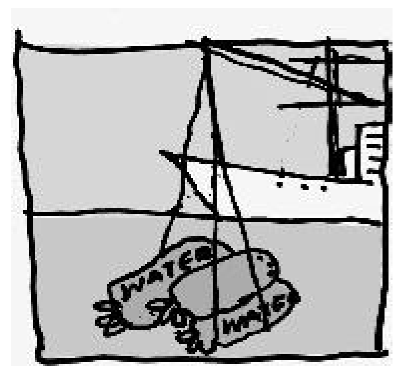

Figure 2. Virtual water trade - the "extensive" (Weber, 1904) version of the concept (Allen 2001b)

Virtual Water: A Definition

Operationally effective, and water deficit ameliorating, global trading systems were shown by outsiders to exist. But awareness of them was of such destabilising potential that the social and political systems of the MENA region trapped the region's hydro-politics in a 'sanctioned discourse' of non-awareness (Allan, 2001a).

Virtual water is the water needed to produce agricultural commodities. The concept could be expanded to include the water needed to produce non-agricultural commodities. The author has not attempted to expand the scope beyond agriculture.

It requires about 1,000 cubic meters of water to produce a ton of grain. If the ton of grain is conveyed to a political economy short of freshwater and/or soil water, then that economy is spared the economic, and more importantly, the political stress of mobilizing about 1,000 cubic meters of water. The author observed that by the millennium the Middle East and North Africa (MENA) was importing at least 50 million tons of grain annually. This tonnage required 50 cubic kilometers (billion cubic meters) of water to produce it, which is the volume of freshwater that flows into Egypt each year down the Nile.

The volume is also equivalent to about 30 percent of the freshwater resources of the MENA region. Mobilizing the annual flow of the Nile would be an unimaginable challenge to the engineer. Farmers and grain traders make light work of such tasks and have done so since antiquity. The patterns of such trade are of course very different now than they were 2,000 years ago. Europe currently exports grain to Egypt whereas Egypt exported grain and other food commodities to Rome 2,000 years ago.

Virtual water is a term that links water, food, and trade. Figure 3 attempts to map the resources involved in achieving water security. The diagram shows that the 10 percent or so of water needed for drinking, domestic, industrial, and service uses must come from freshwater or from manufactured sources. The 90 percent of water need for food and other agricultural production can come from freshwater, from soil water or it can be accessed in effect via food imports. Virtual water and manufactured water are the very successful means by which water deficit economies can remedy their deficits. The author is grateful to Malin Falkenmark for her tireless campaigning for the idea that soil water is the major water input to the productive sector of agriculture. She also emphasises the role of soil water in the environment in supporting natural vegetation (Falkenmark, 2000).

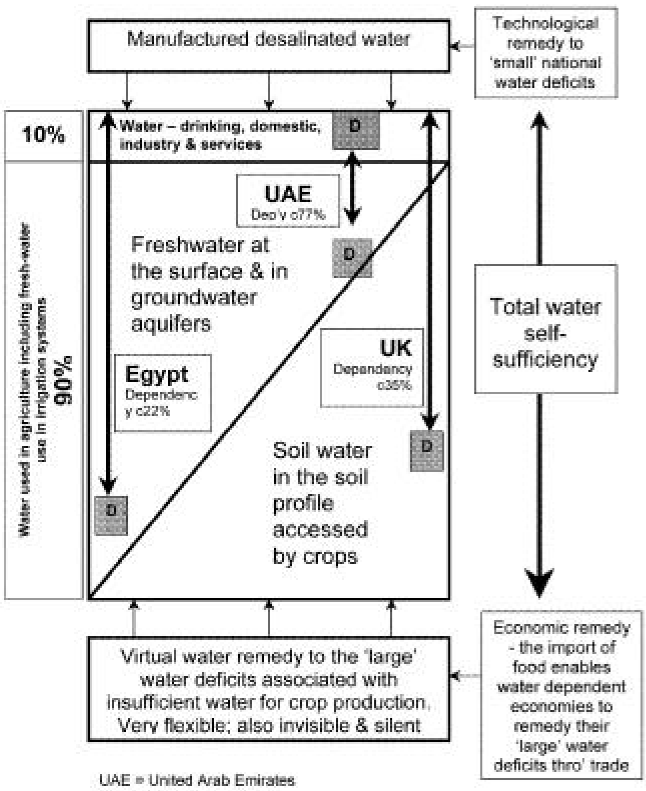

Figure 3. Showing (1) The extent of water dependency (D) of different water deficit economies (Hoekstra & Hung, 2002); (2) How local water can come from freshwater sources and soil water sources; and (3) How manufactured water and virtual water can remedy the water deficits.

Virtual water has proved to be a very accessible concept at least in some epistemic communities in the water sector, if not in all. When shared with those not actually involved in the tough conflictual realities of making and implementing water policy the idea has proved to be readily grasped and accepted. Thousands of students at all levels have taken the idea in their stride after a few minutes of explanation; sometimes by using material on the internet. Even larger numbers of outsiders to the water profession, detached again from the tough politics of water policy-making and implementation, have also found the concept easy to embrace and share. The recent publication by Hoekstra and Hung (2002), which will be discussed at the Third World Water Forum in Kyoto in March 2003, shows that some water engineers liked the idea so much that they have devoted months to adding quantitative substance to the conceptual utility of the idea.

However, water policy makers and water professionals who know there is much at stake have rejected the idea (Allan, 2001a) with the same passion that national fishing communities greet proposals that they should reduce their catches according to international collective action principles, or with the same total opposition with which the French Government faces its partners over the reform of the Common Agricultural Policy. France's European partners advocate reform to meet international collective action principles and environmental goals but these reforms are not in the French interests (Financial Times, 2003). In developing countries, including some that are oil enriched, the notion of virtual water appears to threaten vital farming livelihoods. Drawing attention to where national security actually lies is potentially very controversial. Making the link between water and food security a high profile issue is associated with high risks and high political prices for water policy makers.

At the same time as the metaphor of virtual water was gaining currency in the mid-1990s, the trade economists at the World Bank had started to use another term the "water, food, and trade nexus" (McCalla, 1997). The concept is the same as virtual water but the longer and more explicit term has failed to gain a place in water policy terminology just as embedded water did not capture the attention of water sector professionals. Merrett' s preferred definition for virtual water is the "crop water requirements of food exports." We shall see later that this is only a partial definition of the idea. It is an intensive definition, involving water and crop production, rather than an extensive definition involving the impact of the traded food on the water economies and the water policies of water deficit economies.

Diffusion Towards A More Precise Quantification

The author gained satisfaction from the rapid diffusion of the idea in the second half of the 1990s. It was especially satisfying to hear the term used by professionals who had originally been unhappy with the idea. That the topic would be addressed in Kyoto at the World Water Forum was additionally gratifying. Finally, it is very pleasing indeed that the challenge of adding quantitative substance to conceptual acceptance has been achieved by the "value of water" research group at IHE in The Netherlands (Hoekstra and Hung, 2002).

Valuing virtual water was an early problem for the author. The cost of accessing water in a soil profile in a temperate region could be counted as free. The only possible costs would be the social costs of farmers enduring the privations of remote and inclement locations – often in the absence of a mate. On the other hand, water accessed by irrigated farms could be counted in US cents per cubic meter or as high as more than US$0.50 per cubic meter if principles of marginal pricing of water were adopted.

Associating products and commodities with the inputs needed to produce them is not new. Ricardo (1846) and later Marx, argued persuasively that the labor content of production was important in determining the price of commodities. Over a century later, oil economists labored mightily to enumerate the energy content of commodities and services after the oil shocks of 1973 and 1979–1980 seriously heightened awareness of the strategic significance of oil. Conversations with those who had followed the oil/energy analysis of the 1970s led the author to realize that attempting to quantify in detail such complex economic processes would lead to frustration. The energy content analysis was related to the complex global oil and energy markets, enmeshed in constantly changing and diverse taxation regimes, which did not prove to be susceptible to attempts to match theory with available data and outcomes.

With this experience in mind, the author judged that the main intellectual return would be achieved by gaining currency for the virtual water concept. Quantification of the detail would be a time-consuming project with ambiguous and inconclusive outcomes. The author also found from the first sharing of the idea that understanding the political economy into which the notion of virtual water was introduced appeared to be more important than mapping volumes and movements. Introducing sound numbers into the discourse had not proved to be important in that the water policy community, at least in the water challenged political economies in semi-arid regions, had no appetite for the numbers associated with the virtual water process. Any numbers would be rejected along with the rejection of the idea.

The author also very quickly found that economists, engineers, lawyers, international lawyers, and international relations specialists could get their analyses wrong because they were not aware of the role of virtual water in international economies.

Virtual water played havoc with the narrow, environmentally deterministic assumptions on which such specialists generally based their analyses. All the analysts who have conjured the prospect of water wars have ignored the role of virtual water in ameliorating regional water deficits. For example journalists such as Bulloch and Darwish (1993) and academics such as Homer-Dixon (1991; 1994). Statements by leading political figures such as the late King Hussein of Jordan and the late President Anwar Sadat of Egypt and even a Vice-President of the World Bank, Ishmail Serageldin, that there would be water wars in the Middle East, were made in response to particular public circumstances and, though frequently requoted, have less authority as the decades roll on. When the public relations department of the World Bank was interrogated about the reliability of the Serageldin comment the response was inconclusive but it appeared that a publisher had been overhasty in attributing the comment.

The London Water Research Group has looked at the role of virtual water in the Middle East and North Africa and in Southern Africa on the grounds that these are the most water insecure regions (SOAS, 2002). But this was a small venture compared with the very promising and globally comprehensive report of Hoekstra and Hung (2002). The IHE group has provided a preliminary quantification and analysis of the role of virtual water in the global food system. The study is very promising in terms of insight and revelation. This has been possible because of their collation of a number of sources that have become available in the past five years. First, estimates of crop water requirements in different countries and environments (FAOSTAT, 2002). These numbers permit a much more textured set of estimates of local water use than have been possible in earlier studies. Secondly, they have used estimates of the levels of use of green water flows of water in all the countries of the world (Rockström and Gordon, 2001; Raskin et al., 1997). Thirdly, the global trade in agricultural commodities has been tracked by FAO (2002) for over forty years. Their research concludes that of the 6,000 cubic kilometers of soil and freshwater water mobilized each year (Shiklamanov, 1997; 2000) to meet the needs of the world's 6.5 billion people at the millennium, 695 cubic kilometers were embedded in food commodities traded internationally. They conclude:

> ...the global volume of crop-related virtual water trade between nations was 695 cubic kilometers per year on average over the period 1995 to 1999. For comparison the global water withdrawal for agriculture (water use for irrigation) was about 2,500 cubic kilometers per year in 2000 (Shikhlamanov, 1997). Taking into account the use of rainwater by crops as well, the total use by crops in the world has been estimated at 5,400 cubic kilometers per year (Rockström and Gordon, 2001). This means that 13 percent of the water used for crop production in the world is not used for domestic consumption but for export (in virtual form). This is the global percentage; the situation varies strongly between countries (see Hoekstra and Hung, 2002) and from year-to-year see Figures 5.1 to 5.29

(Hoekstra and Hung, 2002).

They also show that wheat is the dominant traded food commodity in terms of water content- comprising from 26 to 33 percent of the total virtual water associated with food commodity trade in the period 1995 to 1999. Soybean ranged form 13 to 22 percent in the same period. The data for rice were 9 to 24 percent, and for maize 7 to 10 percent (Hoekstra and Hung, 2002).

Another very useful contribution of the Hoekstra and Hung (2002) report is their association of the virtual water idea with the concept of the water footprint. Wackermagel and Rees (1996) developed the powerful idea of the ecological footprint in the mid-1990s. They demonstrated that political economies such as the United States and those in Europe draw in substantially more natural resources than their own endowments. This privileged situation contrasts with that of many poor economies in the South. Many Southern economies export their natural resources, often in markets where they endure very unfavorable terms of trade. Hoekstra and Hung (2002) show that in the water sector the temperate climatic endowment of the United States and France make it possible for their water footprints to be substantially smaller than the water withdrawn by them from the environment. In the case of the United States the water footprint is 35 percent smaller than the amount withdrawn. For France the figure is 48 percent smaller.

Virtual Water and a Very Little History of Economic Ideas

For two centuries a much more important idea than virtual water – that of comparative advantage – has been in undisputed currency (Ricardo 1846), even if it has been difficult to square the Heckscher-Ohlin model with actual trading patterns. Trade was shown to be a very effective and mutually advantageous means of satisfying local strategic commodity needs. Ricardo drew attention to the effective mutual dependence of England and Portugal with respect to wine and cloth. The notion of comparative advantage takes on major political significance, in addition to its economic significance, when related to strategic commodities such as first, food and secondly, energy related commodities such as coal and oil.

The concept virtual water is something of a descendant of the concept of comparative advantage. Virtual water happens to be integral to the strategic commodity food and is at the same time unable to escape a contentious role in discourse on the political economy of food security. The potential role of virtual water is so contentious that those actually managing water and developing water policy in water scarce economies ensure that the concept is kept out of water policy-making discourse (Allan 2001a).

More than most commodities, staple foods, which are very important indeed as a proportion of world trade, are inextricably political. People have a deep intuitive aversion to being dependent on other economies for their water and also for their food. People living in economies, which are very little or only partially diversified and industrialised, are particularly subject to collective paranoia on food and water insecurity. Awareness of a dependence on water and staple food coming from outside there own sovereign territories can be very destabilising. Because virtual water is economically invisible and politically silent it has the wondrous virtue of making it possible for water policy-makers and managers to cultivate a policy discourse where it can be assumed that there is no national water or food deficit. The strategic water deficit is invisibly and silently solved by importing commodities, which, through Northern subsidies, are available – extraordinarily - at half their production cost. (ABARE 2001) Every subsidised ton of wheat imported at the millennium has been associated with 1000 tons (cubic metres) of free water.

Water is a factor of production and it was hoped it would be susceptible to analysis according to the approach of Hecksher-Ohlin (Bowen, Learner and Sveikauskas 1981 and Krugman and Obstfield 1995) which aimed to analyze past commodity trade of the embedded basic factors of production – for example, land and labor. An initial attempt to test whether the factor of production, water, would be susceptible to such analysis proved to be unrewarding in southern Africa. (Earle 2001) Further work along the same lines enabled useful insights for the economies of the Middle East and North Africa. (Hakimian 2003) The reason for the less than satisfactory results was mainly because only freshwater was taken into account; soil water estimates were not available. The inclusion of soil water will improve the predictive results of the Hecksher-Ohlin model. But the initial negative experience of deploying the theory seemed to confirm that it was the power of the virtual water concept to draw attention to the ameliorating process of the virtual water trade that was its main value. Rather than its capacity to predict exact volumes "transacted."

Within a couple of days of receiving the 2002 Hoekstra and Hung report in Delft, the author was in Sri Lanka, a relatively water rich country. The island does, however, endure periods when the monsoon rains are seriously below average. A very serious deviation from the rainfall norms occurred in 1996, 1997, and 1998. As a result, Sri Lanka's food imports rose dramatically (Hoekstra and Hung, 2002). The levels of imports were such that for the five year period ,1995 to 1999, Sri Lanka topped the global list of virtual water "importers," even outranking Japan by 44 percent. Yet in normal years, Sri Lanka imports scarcely any food (Hoekstra and Hung, 2002).

The Sri Lankan case is very important in highlighting the immense flexibility of the virtual water solution. In addition to its three major virtues of being first very effective indeed in addressing water deficits, it is secondly economically invisible, and thirdly, politically silent. Virtual water has a fourth very important quality.

Water embedded in food commodities can be mobilized very quickly and flexibly to remedy the ever-changing demands of those enduring water and staple food deficits. This flexibility to remedy periodic water shortages out-matches any security measures deployed by engineers to store water behind dams. The hydraulic measures have local impacts. The virtual water remedy is global in its reach. The virtual water remedy is also immensely more powerful than any policies deployed to manage demand. Water use can end managed in industrialized economies located in arid and semi-arid regions, but slowly. Water use in irrigated agriculture – the big user – was reduced by about 20 percent in California after 1980 and by 30 percent in Israel in the 1986 to 1991 period (Allan, 2001a). But no hydraulic system can bring on stream the volumes of water needed to mobilize the availability of staple foods as can the virtual water system.

Conclusion: Intensive and Extensive Ideas

Economists have proved to be particularly adept in their capacity to theorize. Theory helps explain and sometimes predict. Just as important theory helps us communicate. If a theory can be captured in a word or a phrase, communication, especially across disciplinary divides, can be immensely facilitated. Coase's (1960) timeless phrase, "law reduces transaction costs," is a powerful example.

> "Theory provides guidelines; it sensitizes observers to alternative possibilities; it highlights where levers might be pulled and influence wielded; it links ends to means and strategies to resources; and perhaps most of all, it infuses context and pattern into seemingly disarrayed and unrelated phenomena" (Rosenau, 1997).

Economic theory has been made very influential through the coining of such terms as political economy, comparative advantage, the falling rate of profit, shadow price, opportunity cost and transaction costs. In all cases these concepts link elements of economies and in some cases of society and politics, which together explain and illuminate general and particular socio-economic, socio-political, and socio-legal phenomena.

Weber (1904; 1917) provided a very useful way of analyzing the nature and scope of such ideas. He suggested that concepts could be intensive and extensive. Applied to the concept virtual water the Weberian analysis helps in the identification of virtual water's intensive and extensive features.

Virtual water is an intensive concept in so far as it links water, both freshwater and soil water, in the productive process of crop production. Here water and food have been linked in the activity of crop production. Implicit is the idea that crop production, and therefore indigenous food security, can be limited locally by the availability of water. This intensive linkage is the one with which Stephen Merrett is comfortable. He correctly argues that it is the food produced which is traded and not water.

The main contribution of the term virtual water is, however, in the opinion of the author, its capacity to be extensive. The term links water and food and in addition links the availability of these commodities across national economies so that consumers as well as producers are considered. Traders link consumers in water deficit political economies with producers and resources in distant water surplus national economies. Like Ricardo's generic term, comparative advantage, virtual water is an extensive idea albeit in a narrower field.

In diffusing the term virtual water over the past decade the author has sometimes verged on hyperbole – *mea culpa*. The overstatement particularly involved attaching the word trade to virtual water. One must agree with Stephen Merrett that there is no actual trade in virtual water. But then there are no transactions made in shadow prices. The concept of the shadow price is not diminished by its limitation to a theoretical role. The concept of the shadow price remains very valuable in providing an analytical perspective on underlying fundamentals. Similarly, the concept of virtual water, it could be argued provides an analytical perspective on how economies achieve water security.

One now tends to avoid the use of the term virtual water trade because it can misrepresent the process. The punchy term virtual water trade has been replaced, at least in my own material, by the more awkward and lengthy sentence – a ton of wheat when imported by a water short political economy enables those managing scarce water in such economies to escape the economic and political stress of mobilising 1,000 tons (cubic meters) of water. However, the titles listed below suggest that the term virtual water trade may have already acquired an immovable place in the vocabulary of the interdisciplinary epistemic community that addresses the complexities of water policy-making. The term is scientifically redundant, according to the Occam's razor maxim cited by Stephen Merrett, in that it can be better defined, if less accessibly, by existing vocabulary. But the discursive processes in which language constantly evolves, will determine over the coming decade whether the virtual water and the virtual water trade metaphors retain a place in the terminology of water professionals.

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References

ABARE. 2000. *The Impact of Agricultural Trade Liberalization on Developing Countries*. Canberra, Australia: ABARE. http://www.abare.gov.au.

Allan, J.A. 1993. "Fortunately there are Substitutes for Water Otherwise our Hydro-political Futures would be Impossible." In *Priorities for Water Resources Allocation and Management.* London, United Kingdom: ODA: 13–26.

Allan, J.A. 1994. "Overall Perspectives on Countries and Regions." In P. Rogers and P. Lydon, eds. *Water in the Arab World: Perspectives and Prognoses.* Cambridge, Massachusetts, USA: Harvard University Press: 65–100.

Allan, J.A. 1995. "Water Deficits and Management Options in Arid Regions with Special Reference to the Middle East and North Africa." In *Water Resources Management in Arid Countries.* Muscat, Oman,: Ministry of Water Resources. 1–8

Allan, J.A. 1998. "Virtual Water: A Strategic Resource: Global Solutions to Regional Deficits." *Groundwater* 36, No. 4: 546.

Allan, J.A. 1998. "Moving Water to Satisfy Uneven Global Needs: "Trading" Water as an Alternative to Engineering It." *ICID Journal* 47, No. 2: 1–8.

Allan, J.A. 1999. "Productive Efficiency and Allocative Efficiency: Why Better Water Management May Not Solve the Problem." *Agricultural Water Management* 40: 71–77.

Allan, J.A. 2001a. *The Middle East Water Question: Hydropolitics and the Global Economy*. London, United Kingdom: I B Tauris.

Allan, J.A. 2001b. "Virtual Water – Economically Invisible and Politically Silent: A Way to Solve Strategic Water Problems. *International Water and Irrigation Journal.* November 2001.

Allan, J.A. 2002. "Hydro-peace in the Middle East: Why No Water Wars? A Case Study of the Jordan River Basin." *SAIS Journel* XX: 255–272.

Bowen, H.P., E.E. Learner, and L. Sveikauskas. 1981. *The American Economic Review* 77, No. 5: 791–809.

Bulloch, J. and A. Darwish. 1993. *Water Wars.* London, United Kingdom: Gollancz.

Coase, R. 1960. "The Problem of Social Cost." *Journal of Law and Economics*: 1–44.

Earle, A. 2001. "The Role of Water in Food Security in Southern Africa." SOAS Water Research Group. Occasional Paper 33. http://www2.soas.ac.uk/geography/waterissues/occational papers.

Falkenmark, M., 2000, Plants: The Real Water Consumers, *GWP Newsflow,* Stockholm, Sweden: Global Water Partnership (see www.gwpforum.org and article by Malin Falkenmark in *Water International* 25, No.1 on the same topic).

FAO. 2002. *International Trade Statistics*. Rome, Italy: FAO.

FAOSTAT. 2002. "Actual Crop Yields for the Countries of the World. *FAOSTAT.* Rome, Italy: FAO.

Financial Times. 2003. "France Adamant over Opposing CAP Reform." London, United Kingdom: *Financial Times,* 8 January 2003: 7.

Fishelson, G. 1992. "The Allocation of the Marginal Value Product of Water in Israeli A griculture." *Israeli Agriculture*. Reference Number WP/028.

Hakimian, H. 2003a. "Water Scarcity and Food Imports: An Empirical Investigation of the "Virtual Water" Hypothesis in the MENA Region." See Occasional Paper 46: http://www2. soas.ac.uk/geography/ waterissues/occasional papers/.

Hakimian, H. 2003b. "Water Scarcity and Food Imports: An Empirical Investigatin of the Virtual Water Hypothesis in the MENA Region." *Review of Middle East Economics and Finance*. London, United Kingdom: Taylor & Francis.

Hoekstra, A.Y. and P.Q. Hung. 2002. "Virtual Water Trade: A Quantification of Virtual Water Flows Between Nations in Relation to International Crop Trade." *Value of Water Research Report Series* No 11. Delft, The Netherlands: IHE.

Homer-Dixon, T.F. 1991. "On the Threshold: Environmental Changes as Causes of Acute Conflict." *International Security* 16, No. 1: 76–116.

Homer-Dixon, T.F. 1994. "Environmental Scarcities and Violent Conflict: Evidence from Cases." *International Security* 19, No.1: 5–40.

Krugman, P.R. and M. Obstfield. 1995. *International Economics: Theory and Policy*. 3rd Edition. New York, New York, USA: Harper Collins.

McCalla, A. 1997. *The Water, Food, and Trade Nexus.* Paper delivered at MENA-MED Conference convened by the World Bank in Marrakesh, May 1997.

Merrett. S. 2003. "Virtual Water and Ocean's Razor." *Water International 28*, No. 1.

Raskin, P., P. Gleick, P. Kirshen, G. Pontius, and K. Strzepek. 1997. *Water Futures: Assessment of Long-range Patterns and Problems - Comprehensive Assessment of the Freshwater Resources of the World*. Stockholm, Sweden: Stockholm Environment Institute.

Raskin et al. 1999. "Estimates of Annual National Water Withdrawal." *Global Freshwater Assessment*. Stockholm, Sweden: Swedish Environment Insitutute (SEI) for the Second World Water Forum 2000.

Ricardo, D. 1846. In *Collected Works of David Ricardo*. London, United Kingdom: J.R. M'Culloch.

Rockström, J. and L. Gordon. 2001. "Assessment of Green Water Flows to Sustain Major Biomes of the World: Implications for Future Ecohydrological Landscape Management." *Phys. Chem. Earth* 26: 843–851.

Rosenau, J.N. 1997. "Many Damn Things Simultaneously: Complexity Theory and World Affairs." In D.S. Alberts and T.J. Czerwinski, eds. *Complexity, Global Politics, and National Security*. Washington, D.C., USA National Defense University: 73– 100.

Shikhlamanov, I.A., ed. 1997. *Assessment of Water Resources and Water Availability in the World. Comprehensive Assessment of the Freshwater Fesources of the World.* Geneva:, Switzerland World Meteorological Organization.

Shikhlamanov, I.A. 2000. "Apprasisal and Assessment of World Water Resources. *Water International* 25, No. 1: 11–52.

SOAS. 2002. *Occasional Papers* of the SOAS/King's College

London Water Research Group. www2.soas.uk/geography/waterissues/.

Tripp, C.T. 1996. Personal communication.

Wakemagel, M. and W. Rees. 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth.* Gabriola Island, BC, Canada: New Society Publishers.

Weber, M. 1904 and 1917. *The Methodology of the Social Sciences.* Translated and edited by Edward A. Shils and Henry A. Finch, New York, New York, USA: Free Press and published in 1949.

Wickelns, D. 2001. "The Role of Virtual Water in Efforts to Achieve Food Security and other National Goals, With an Example from Egypt." *Agricultural Water Management* 49: 131–151.

Yegnes-Botzer, A. 2001. *Virtual Water Export from Israel: Quantities, Driving Forces and Consequences.* Unpublished MSc thesis DEW 166, Delft, The Netherlands: IHE.