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Water Resources Sustainability: An Ecological Economics Perspective

Christopher Lant

Southern Illinois University Carbondale

Sustainability is both a vague and politicized term, yet it is precisely because the world community has rallied around sustainability and sustainable development as normative goals of ecological-economic performance that the stakes are high for defining the concept in a manner that is true to its spirit. To do so, one must counteract definitions that either suit particular interests or are so broad and vague that most of what people do for self-interested reasons fits within them. Like other fields, water resources has struggled to bring the concept of sustainability to bear in the realm of practice. For example, what allocation of water in the Klamath River basin best achieves sustainability? Are plans to pipeline fossil ground water from the Ogallala of North Texas to the growing cities of Dallas and San Antonio consistent with sustainability? Is it sustainable to forego renewable hydroelectric power in hopes that it will prevent the extinction of a strain of chinook or coho salmon? Is the recent completion of the Three Gorges dam project on the Yangtze River an example of sustainable development? How sustainable is it to live in a world where about one billion people lack access to safe drinking water and two billion lack access to the basic benefits of the sanitation revolution (DeVilliers 2000)?

To bring life to the concept and goals of sustainability, it must guide us toward the best answers to these questions. Building a functional and operational definition of sustainability is the challenge. Ecological economics helps us make more sustainable water resources decisions in three important ways. First, it provides a needed *theoretical* revision to neo-classical economic analysis. Second, this theoretical perspective points us toward better *methodologies for measuring* the value of water in competing uses. Third, it helps us identify the program of *institutional reform* that has the best chance of delivering more sustainable water resources management practices.

An Ecological Economics View of Sustainability

An ecological economics view of sustainability is inevitably based in systems thinking (Capra 2002; Costanza et al. 1993; Costanza 2001). Figure 1 presents a systems conceptualization of sustainable development where natural, human, intellectual and manufactured capital are transformed continuously, one into another, by the processes of the market economy. The system is driven by low-entropy solar energy and evolves through the process of interactions among its interdependent components (Capra 1996), releasing high entropy heat as waste. A component of this system is the market economy as analyzed by neo-classical economics, where land, labor and capital are obtained as factors to produce goods and services for consumption and investment that are measured as economic output.

In contrast to neo-classical economics, ecological economics views production and consumption of marketable goods and services as only an important part of a larger process. Neo-classical economics views manufactured capital (i.e., infrastructures of various kinds) as essential to economic production.

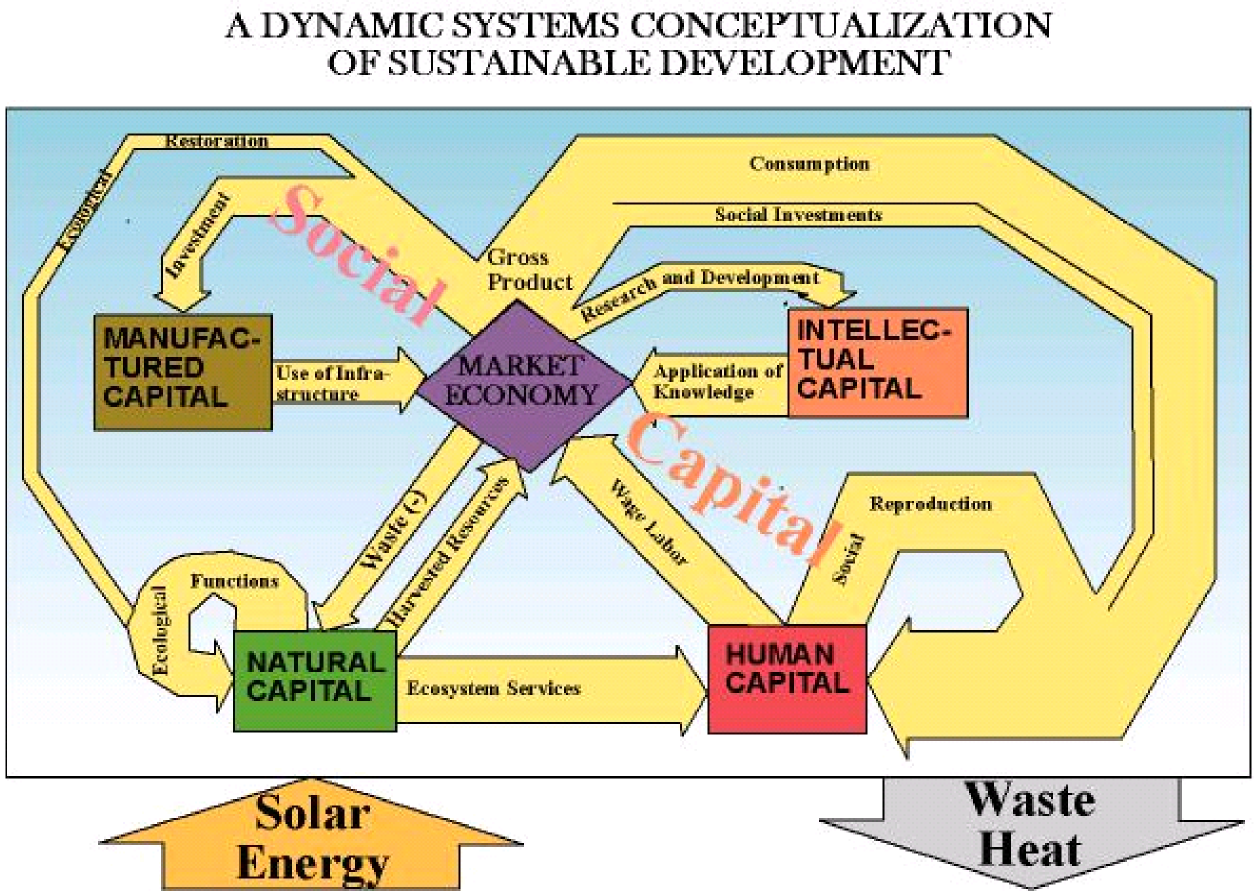

Figure 1. A systems conceptualization of sustainable development.

Recent literature emphasizes the critical importance of intellectual capital as the driving force of the information revolution. Social scientists have extended the analysis to include human and social capital and ecological economics has extended it further to include natural capital. Human capital is the set of attributes (e.g., knowledge, skills, attitudes, mental and physical health, etc.) that determine individuals' capacity to contribute to society. While definitions of social capital vary, it is usefully conceived as the set of historically developed institutions that structure the productive and reproductive process as a whole. Natural capital is both the standing stock of natural resources that await future use and the characteristics of ecosystems that maintain ecological and environmental processes, such as biological productivity and diversity and biogeochemical cycling.

Economic production is absolutely dependent in the medium-to-long term on each of these forms of capital: natural, human, manufactured, intellectual and social. Consequently, increasing economic output in the short term by diminishing one or more of these capital stocks is "unsustainable," unless that capital stock is in long-term surplus supply. For instance, the 18th and 19th Century American pioneers found a frontier enormously rich in natural capital (e.g., forests, fertile soils, fish and wildlife populations, useful mineral deposits, unpolluted waters), but impoverished in human-derived forms of capital in a form suitable to their purposes (as opposed to Native American forms and purposes). For them, liquidating this natural capital in order to transform it into manufactured and human capital increased the value of the overall capital stock available to frontier society and was necessary for the development process to be sustaining. But times have changed. Natural capital, historically taken for granted as a free good or accounted for only when it is used as an industrial raw material, is more and more often one of the limiting factors in the system as a whole, in the same sense that Phosphorus is often the limiting factor in algal growth. A sustainable economy must therefore limit withdrawals from and produce investments in all forms of capital, working synergistically with non-economic processes of natural and social reproduction, to ensure that no form of capital is diminished in order to increase short-term output of marketable goods and services. That is sustainable development.

If various forms of capital were completely substitutable, the "weak" sustainability criterion would be satisfactory. As long as we maintain the aggregate capital stock, shortages in one form of capital (e.g., natural capital) could be substituted for by investments in other forms (e.g., manufactured capital). But since these forms of capital are incompletely substitutable in practice, the "strong" sustainability criterion should hold—each form of capital must be protected from degradation (Pearce et al. 1992; Tietenberg 2003). Manufactured capital can occasionally substitute for natural capital in the production of ecosystem services.[1] For example, levees and flood control reservoirs contain flood waters formerly held by wetlands and organic matter in soils. Wastewater treatment plants accelerate the rate at which aerobic bacteria oxidize organic matter. In most cases, however, natural capital (i.e., nature itself) is the most efficient and effective producer of ecosystem services. Even in the example given, levees and reservoirs can provide flood control services in lieu of wetlands, but they do not provide equitable services in terms of habitat or biogeochemical processing. This illustrates the need to maintain natural capital as the best means to generate multiple ecosystem services in most instances. Achieving a better understanding of ecosystem services, the ecosystem functions that maintain them, and the ways in which they contribute to human capital is, consequently, a key research agenda as identified by the National Science Foundation (NSF Advisory Committee for Environmental Research and Education 2003).

Sustainable development as an evolving political program focuses on the reform of social capital (i.e., institutional rules and cultures) such that the economic production process sustains stocks of human, intellectual, manufactured and natural capital. Natural capital is of special concern because it provides not only essential resources for future economic use, but also essential ecosystem services such as nutrient cycling, waste treatment, disturbance regulation, atmospheric gas exchange, soil formation and binding and habitat for the tremendous diversity of life of this planet. The ecosystem functions that generate these ecosystem services are the biogeochemical processes that make some parts of the Earth, and no other place that we know of, habitable.

An ecological economics approach to sustainability provides a valuable critique of neo-classical macroeconomics by pointing out that economic growth can occur in positive, neutral, or negative ways with respect to sustainability. Sustainable economic growth occurs when new applications of knowledge (intellectual capital) allow a society to increase the efficiency with which various forms of capital are utilized to produce goods and services. This occurs through new or improved technologies, better systems of social organization, better means of making the experience of work an investment in rather than a withdrawal from human capital, or more efficient transformation of natural capital into products. Hawken et al. (1999) provide convincing evidence that the modern western industrial system, especially that of North America and Australia, is very efficient at utilizing labor and manufactured capital, but is not an efficient transformer of natural capital into economic value. Huge improvements can thus be made with current technology; the developed western European and Japanese economies provide working examples of some of these improvements. Because this type of economic growth reinforces each of the system components in the long term, it is the core of sustainable development.

Neutral economic growth occurs when important social processes (e.g., cooking meals, raising children, growing food) or natural processes (e.g., maintenance of soil fertility) that have heretofore occurred in the non-market spheres of ecological or social reproduction are incorporated within the market economy, increasing measured economic output without necessarily improving the effectiveness of the larger ecological-economic system. Examples can be found in the rapid development of the low-wage service economy in Western societies and the transformation of subsistence to commercial farming in developing countries.

Unsustainable economic growth occurs when an increase in the output of market goods and services comes at the expense of reductions in the value of natural capital (e.g. pollution, use of renewable resources beyond sustainable yield), human capital (e.g., labor exploitation), intellectual capital (e.g., reduced investment in education and research) and/or manufactured capital (e.g., severe depreciation of urban water supply infrastructures) that exceed the value of the additional goods and services produced. When this occurs, the processes of social or ecological reproduction are disrupted, undermining the entire systems' ability to recreate itself in the long term. Repetto (1992), for example, has documented how relatively high rates of economic growth in Costa Rica and Indonesia are the consequence of the liquidation of natural capital stored as forests, soil, wildlife, and watershed protection. Bartelmus (1994) offers a modification of natural income accounts to take natural capital and ecosystem services into account when measuring economic (i.e., ecological-economic) performance.

Water plays at least three critical but distinct roles in the ecological-economic process diagrammed in Figure 1. First, water is a raw material, a factor of production, of a number of marketable commodities, some of which are themselves factors of production of other final goods. Electricity, transportation, crops, livestock, industrial goods of various kinds, and residential and commercial landscapes each generate a derived demand for water. Second, because of its contribution to human health, treated potable water for domestic use is enormously valuable in producing human capital, whether it is delivered as a commodity by a private-sector firm, as a public service by a government-owned utility, or by some other institutional arrangement. Third, water in oceans, estuaries, rivers, lakes, wetlands, soil, and other components of the hydrologic cycle is a, if not *the*, critical factor of production of ecosystem services. In fact, one could argue that without water no ecosystem services could be generated. Wetlands are the most illustrative example of water-defined environments that produce multiple ecosystem services such as flood control, water purification, wildlife habitat, carbon sequestration, nitrogen cycle regulation, and sediment control to name just a few (Mitsch and Gosselink 1993).

The contribution of water toward sustainable development in these various uses must be evaluated if we are to understand the "highest and best use" of water, keeping in mind that it is the *marginal* value of water (or marginal value of changes in water quality) that needs to be compared among various uses. Here "marginal" refers to incremental changes from a base condition, or the rate of change in total costs and benefits. For example, the summer 2002 low-flow tragedies on the Klamath River, where 33,000 spawning salmon died, and on the Rio Grande, where the silvery minnow nearly lost its fight against extinction, are cases where the *marginal ecological opportunity costs* of reduced flows in those rivers under conditions of drought exceeded the *marginal economic benefits* of the agricultural products made possible by the water allocated to irrigation. Results from a number of studies, for example, indicate the low marginal value of water applied inefficiently to crops that are in surplus supply or are used as animal feed rather than for direct human consumption (Zilberman 2002). In contrast, most ecosystem services provided by water are public goods and are thus subject to all the problems of market failure where private property rights to flows of value are not well established (Randall 1983). The key, then, is to redesign policies and institutions so that local water managers making short-term decisions about water allocation, water quality, and the physical condition of aquatic ecosystems account for the costs and benefits of their actions on natural capital and ecosystem service flows. For example, had a system of leasing water rights similar to that applied in California in the 1990s been in place, these high ecological costs might have been avoided. In other situations, changes may be required in the evaluation of the costs and benefits of water resources engineering projects, water prices, property rights and access rules to water, or the roles of various levels of government, NGOs, and private sector firms.

Measuring the Ecological-Economic Value of Water

Ecological economics improves our ability to *measure* the relative value of water in competing uses. In a widely read and controversial paper, Costanza et al. (1997) estimated that the annual value of ecosystem services is $33 trillion, slightly exceeding the annual output of goods and services in the world economy of $31 trillion. Of course this estimate is inaccurate, but it shows that "utility," viewed as contributions to human capital, is derived

Table 1. Estimated Value of Ecosystem-Services Provided Ranked by Ecosystem Type.

Ecosystem Type	**Annual Value of Ecosystem Services ($ per hectare)**	**Global Area (hectares x 10^6)**	**Total Annual Value of Ecosystem Services ($ billion)**
Estuaries	22,832	180	4,110
Swamps/floodplains	19,580	165	3,231
Seagrass/algal beds	19,004	200	3,801
Tidal marsh/mangroves	9,990	165	1,648
Lakes/rivers	8,498	200	1,700
Coral reefs	6,075	62	375
Tropical forest	2,007	1,900	3,813

Source: Costanza et al. 1997.

from ecosystem services as well as from marketable goods and services (along with other sources). Moreover, ecosystems that generate the greatest value of ecosystem services per hectare are environments that are defined by water (Table 1). From this we know that the global value of water's role in producing ecosystem services is large, but in any given specific situation, we need to know the current local *marginal ecological economic costs and benefits* associated with various management or policy options. Accurately measuring these is the methodological challenge for ecological economics as a guide to decision-making rather than more accurately calculating the $33 trillion figure (Toman 1998).

The contingent valuation method (CVM), for all its flaws, has proven useful in evaluating how individuals make trade-offs between marketable goods and services and non-market ecosystem services (Braden 1997; Mitchell and Carson 1989). CVM and other environmental economics methods such as the property value method therefore have important roles to play in doing ecological economics, but ecological economics may provide a different interpretation of willingness to pay (WTP) and willingness to accept compensation (WTA) bids. For example, the high WTA bids often received by CVM researchers for diminishment in water-derived ecosystem services has sometimes been explained as risk- or loss-aversion, but may also be strong evidence of the high value people place on ecosystem services as a source of utility beyond that derived from marketable commodities. Secondly, while CVM treats ecosystem services as a source of individual utility similar to purchased goods and services, they of course are rarely individually owned but instead generally accrue to geographically defined communities over long periods of time. All of the time-honored debates about discount rates and the distinction between "consumers" and "citizens" therefore apply, with ecological economics generally favoring citizens with low discount rates. High WTA bids may also indicate ethical problems with receiving individual payment for diminishment of a community benefit. These vigorous debates over CVM illustrate the theoretical distinctions between neo-classical and ecological economics and provide a guide to better utilizing this valuable methodology in ecological economic analysis.

Perhaps more powerful than CVM and other valuation techniques in the long run for evaluating management and policy options in a complex ecological-economic system are advancements in evolutionary algorithms, such as genetic algorithms (GAs). GAs have proven successful for decision support in a variety of water resources applications, including water supply system design (Murphy et al. 1993), groundwater management (Hilton and Culver 2000), pavement drainage design (Hellman and Nicklow, 2000), and reservoir management (Esat and Hall 1994; Nicklow and Bringer 2001). GAs thus show promise for tackling problems of finding the highest and best multiple objective use of water in mathematically complex ecological-economic systems models where critical feedbacks within and among the various spheres of capital are taken into account. The NSF Biocomplexity in the Environment program may provide us with needed methodological advances to bring evolutionary algorithms into practice in water resources management.

Toward Sustainable Management of Water Resources

Ecological economics provides a better way of evaluating what *institutional reforms* are needed to make water resources management more sustainable. Much of the recent literature on reforming water resources management that *Update* readers are familiar with is consistent with sustainability. In applying ecological economics to policy, I will briefly discuss three current ideas for reforming water resources in terms of their relationship to sustainability: a human right to water, integrated water resources management (IWRM), and virtual water.

A Human Right to Water

Between 1970 and 2000, the proportion of people in developing countries that have access to potable water has increased from 30 percent to 80 percent. For sanitation the increase is from 23 to 53 percent (Lomborg 2001). This represents a success story of sustainable development. Nevertheless, the billion or more people still lacking safe drinking water and the two billion or more lacking wastewater services are precisely those who lack sufficient money income needed to generate the effective market demand for water that would make investment in delivery infrastructures profitable. These same societies also lack the financial capital to build infrastructures that can deliver safe drinking water as a public service. Yet the delivery of safe drinking water and basic wastewater management to populations that have lacked these basic human needs has the potential to cause a domino effect of development improvements. These improvements more than justify the investments despite their unprofitability in a narrow sense. For example, the accessibility of safe drinking water greatly decreases the (unpaid) labor requirements of women to gather water and the incidence of gastro-intestinal diseases in children. These effects in turn improve the ability of young children to gain the full nutritional benefit of the limited food supplies that they eat, decreasing infant mortality. In turn, by decreasing infant mortality, the practice of having large families to ensure that some children survive to provide support during old age becomes less important as a survival strategy among the poor. Therefore, fertility rates fall, freeing woman for other important roles in earning income or in contributing to the life of the community, and so on. In other words, where safe drinking water and basic wastewater services are not present, this lack of manufactured capital represents a human capital crisis and the limiting factor in sustainable development.

The first 50 liters per capita per day used of potable domestic water has very positive effects on human capital in the form of public health. Moreover, the volume of water that this represents is equivalent to only about 7 percent of mean rates of domestic use in the U.S., a volume that rarely presents large opportunity costs in the allocation of water itself. On this basis, Peter Gleick at the Pacific Institute and others have argued that this small but essential amount of potable water is a “right” rather than a “good.” While the manufactured capital needed to capture, treat and deliver this water is substantial, the high public health values and high potential indirect effects on development justify national or international subsidization of delivery infrastructures to bring this water to most now lacking it, whether one conceives of the water delivered as a “right” or a basic good. While the value of potable domestic water has diminishing marginal value, the second and third increments of 50 liters per capita per day are also worthy of the investments needed for delivery.

Integrated Water Resources Management.

Integrated water resources management (IWRM) is based on the four 1992 Dublin principles:

I) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

II) Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.

III) Women play a central part in the provision, management and safeguarding of water.

IV) Water has an economic value in all its competing uses and should be recognized as an economic good.

Principle I is discussed in some depth above and Principle III has been touched upon, but Principles II and IV need to be further explored because they are at the heart of the program of institutional reform that sustainability demands.

Watersheds, while long recognized as essential spatial units of hydrologic analysis, have increasingly been viewed in a number of countries as essential units of water governance. This trend has been driven by a change in the nature of water resources management problems away from engineering projects designed for water resources development, flood control, and waste treatment and toward integration of surface and ground water management, management of polluted runoff, floodplain zoning and flood warning systems, management of water-based recreation, and protection and restoration of wetland and aquatic ecosystems and the services they deliver to local populations (Lant 1998). This latter set of water resources management problems interfaces closely with land use and therefore with institutions of local social capital. In the U.S., most of the thousand-plus recently-created watershed groups and initiatives lack the institutional capacity to manage the above list of issues. Nevertheless, institutions organized around relatively small-scale watersheds are very likely to grow as fora for stakeholder participation and to acquire legal authority in the process of meeting challenges such as TMDL development (Ruhl et al. 2003). Watersheds are geographically-defined units of natural capital, yet the social capital to manage these enormous assets is just beginning to develop. IWRM provides a way forward to accomplish this essential step toward sustainability.

Figure 2, adapted from Global Water Partnership (2000), shows how Principle IV is central to an ecological-economic approach to sustainability. The market value of water is only a portion of the economic value of water, to which must also be added the non-market values to human capital and ecosystem service values if the total ecological-economic value of water is to be identified. On the cost side, the fixed and variable cost of manufactured capital used to deliver water is the supply cost, but in order to find the total economic cost, the opportunity cost of allocating the water itself to its next best use, and any economic externalities (positive or negative) associated with this allocation must be added. The total ecological-economic cost,

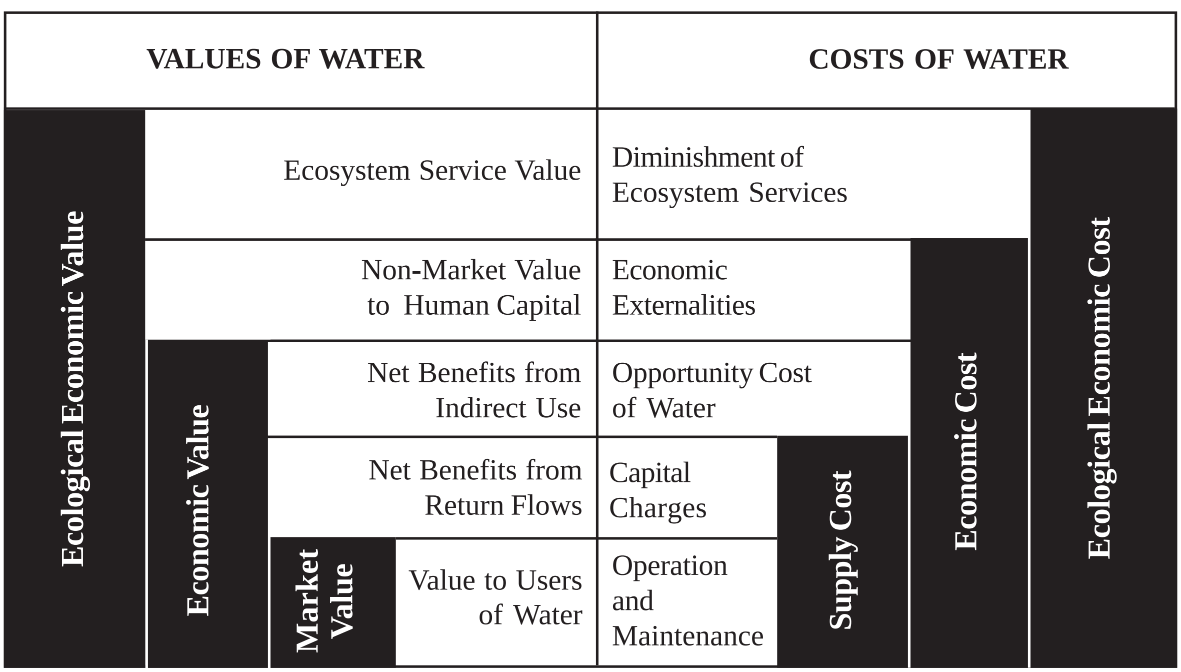

Figure 2. Comparison of market, economic, amd ecological-economic values and costs of water.

however, also includes any diminishment in ecosystem services associated with the allocation of water away from the site of its natural origin, a reduction in the quality of water returned, or the physical manipulation of aquatic environments. The highest and best ecological-economic use of water is the use with the greatest net value as shown in Figure 2. As is apparent, this use often differs from current uses of water. Consequently, IWRM has been touted as an evolving framework for applying the concept of sustainability to the practice of water resources management.

Virtual Water

If soil water used in rainfed agriculture is included in the analysis, most societies devote about 90% of water consumption to food production. Allan (2001) argues that regional differences in the total opportunity costs of using such vast quantities of water gives humid regions a substantial comparative advantage over arid regions in food production. Arid regions therefore greatly benefit by importing “virtual water” in the form of food trade, and in fact are increasingly doing so, often behind the scenes, as the only economically sound means available to overcome regional water shortages. For example, Israel imports 87 percent, Jordan 91 percent and Saudi Arabia 50 percent of their grain supply (Lomborg, 2001). Allan (2002), in applying the virtual water concept to the arid Middle East/North Africa (MENA) region, shows that MENA countries are now importing 50 million tons of grain annually and that these imports are the primary reason why political conflict over water (as opposed to conflict over other issues) has been minimal. In fact, the Joint Water Committee governing the water resources of the Jordan River basin continued to hold meetings even during the height of the second *Intifada* in 2001 and 2002. Wolf (2003) similarly points to the role water can play in maintaining lines of communications even during times of political conflict and the dominance of cooperation over conflict in the international management of water. By bringing to bear the international trading system in grain and other nonperishable agricultural products, the virtual water strategy makes it possible for arid regions such as MENA to meet their water needs by transporting, in a thousand-fold more condensed form, water falling as rain and infiltrating into the fertile soils of the U.S. Midwest, the Pampas of Argentina, the Loire Valley of France, or other regions where favorable conditions of climate, soil, and population density allow food production to exceed regional demand. Closer to home for most readers, the virtual water strategy also holds promise for western states willing to find a way to reallocate water now earmarked for irrigation to higher value municipal and industrial uses or to in-stream flows that generate ecosystem services.

It is consistent with an ecological economic approach to sustainability for populations living in arid regions to import most of their food from more humid regions and thereby preserve their scarce local water supplies for high value municipal and industrial use and ecosystem services. The economic and ecological opportunity costs of allocating water to agriculture are much higher in arid than in humid regions, often even after transaction, transportation and storage costs are accounted. However, a few caveats must be offered. First, pursuing the virtual water strategy can undermine agricultural communities in arid food importing regions (while augmenting those in humid food-exporting regions). Second, continued above world average rates of population growth in arid regions will exhaust even the power of the virtual water strategy to meet food and water needs. Arid regions must soon begin to follow the trend in the rest of the world toward lower total fertility rates, or be forced into massive and expensive desalination projects to meet even domestic and industrial water needs.

Where Sustainability Takes Us

Water is never an end it itself. It is always a means to more fundamental ends. If we are to manage our water resources sustainably, what is it that we want to sustain? Fortunately, the answer isn’t that difficult. We want to sustain human welfare, widespread prosperity, peace, and ecosystem health, recognizing that sustaining each of these depends upon sustaining the others. We want to avoid, as competition for freshwater resources intensifies, sacrificing any of these for the sake of the others or for special interests.

Ecological economics, I have argued, provides us with the best normative and analytical guide to identifying sustainable paths and rectify unsustainable paths by, essentially, expanding the meaning of “efficiency” to include system interactions and non-market components such as ecosystem services and human capital (Figure 1). Employing a bit of intuitive sensitivity analysis at this point, what would ecological-economic analyses of water resources decisions tell us we should do and what policy approaches would it identify as the best means to do it? In other words, if full ecological-economic cost and value of water (Figure 2) were incorporated, how would water resources management change?

Ecological economics tells us that we need a global effort to continue to increase the proportion of people with potable water and basic sanitation from its current 80 percent and 53 percent, respectively, to over 95% on both measures. As is commonly pointed out in other terms, delivery of potable water is, like education, an investment in human capital with a very high rate of return, whether or not either water or education is a "right."

Ecological economics tells us that we need to arrest and reverse the steep decline in the health of many aquatic and coastal ecosystems through a program of ecological restoration that has only recently taken its first uncertain steps. The ecological improvements in Lake Erie and the Hudson River, while partial, demonstrate the great benefits that could be derived if we ultimately prove to be successful in the Everglades, the Chesapeake Bay and the Columbia Basin salmon runs. But the list of aquatic and coastal ecosystems whose services have been diminishing is much longer. Coral reefs are being devastated by a rise in ocean temperatures. The 20,000 watersheds on TMDL 303(d) lists does not begin to exhaust the set of watersheds where polluted runoff or past engineering greatly inhibits aquatic ecosystem health. Building momentum on this great task requires a synergy among traditional policy approaches, such as TMDL regulation and Congressional funding for Army Corps of Engineers restoration projects, and new ones, such as an empowerment of watershed-based institutions and, especially, a change in water resource economics.

Incorporating full ecological-economic value and cost would, for example, overhaul the way water is used in agriculture in the U.S. and perhaps abroad. In rain-fed agriculture, the wettest lands currently used for crop production would become less profitable in that use than reallocating those lands to riparian zone protection and wetlands, the best multi-purpose ecosystem service factories that we have. Carbon credits would induce farmers to "re-carbonized" remaining croplands, with benefits not only to climate but to flood water retention in soils, future soil productivity, and the constructive utilization of livestock manure. Agri-chemical use would become more expensive through taxation, tradable permits organized by watershed or some other means. Reduced use would ameliorate the runoff and leaching of N, P, and pesticides into surface water and N and pesticides into groundwater. The quantities of water needed to produce meat, especially beef, are enormous because of the inefficiency in converting water-consuming pastures and feed grains into meat–2500 gallons of water per pound of meat has been estimated. If the total ecological-economic costs of this water were incorporated into the price of the final product, the cost of meat production would increase significantly due to these reasons as well as the internalization of ecological costs of large-scale feedlot operations and the opportunity costs of using cropland for livestock feed rather than for crops for human consumption to be exported to water-short regions of the world. The resulting reduced demand for meat would decrease rates of heart disease (Willett and Stampfer 2003), an excellent investment in human capital even after taking into account the loss of jobs in cardiology.

In irrigated agriculture, farmers irrigating crops for livestock feed would find that leasing their water rights to utilities or to in-stream flows is far more profitable than irrigation in dry years and perhaps in all years. Farmers irrigating crops for human consumption would find, like Israeli farmers, that investments in efficient irrigation technology quickly pay for themselves in more expensive water saved. They may also find excellent export markets for their products in regions where very scarce water supplies need to be reserved for high-value domestic and industrial uses. Thus, in arid regions, confining irrigation to the highest value perishable crops and, in humid regions, reducing the proportion of meat in human diets to free water resources for virtual water export or for maintenance of local ecosystem services are the cornerstones of sustainable water resources management. These would likely be the market outcomes of applying total ecological-economic cost to the price of water.

The water resources picture painted in the paragraphs above is one that could be pushed into reality by an ecological economics approach and is one that, more than the current picture, sustains human welfare, widespread prosperity, peace, and ecosystem health. Painting this picture would also, of course, be frought with political challenges that the reader can readily identify. Do we want the picture? Are we up to the challenge?

Author Information

Christopher Lant is Executive Director of the Universities Council on Water Resources and Editor of *Water Resources Update*. He is also Professor and Chair of the Department of Geography and co-Director of the Environmental Resources and Policy Ph.D. program at Southern Illinois University Carbondale. From 1994-2001, he served as Editor of the *Journal of the American Water Resources Association*. He can be contacted at: Christopher Lant, Executive Director, Universities Council on Water Resources, 4543 Faner Hall, Southern Illinois University Carbondale, Carbondale, IL 62901-4526. 618-453-6030; clant@siu.edu.

Notes

[1] The term "environmental services" is also used, for example, by the National Science Foundation (NSF Advisory Committee for Environmental Research and Education, 2003). In this paper, the term "ecosystem services" is used to maintain consistency with the ecological economics literature discussed. However, there is considerable merit to the former term, given that some services are essentially abiotic, such as flood water retention or, stepping outside the water realm, filtering of ultraviolet radiation by stratospheric ozone.

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