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Non-Dam Alternatives for Delivering Water Services at Least Cost and Risk

Michael P. Totten
Chief Advisor, Climate Freshwater and Ecosystem Services, Conservation International, Arlington, VA, US; m.totten@conservation.org

Timothy J. Killeen
Senior Research Scientist, Centre for Applied Biodiversity Science, Conservation International, Arlington, VA, US; t.killeen@conservation.org

Tracy A. Farrell
Senior Director of Conservation Initiatives, Conservation International, Arlington, VA, US; t.farrell@conservation.org

ABSTRACT: The World Commission for Water in the 21st Century estimated the annual cost of meeting future infrastructural needs for water at US$180 billion by 2025, including supply, sanitation, waste-water treatment, agriculture, and environmental protection. These estimates assume that future global demand for water-related services will mimic those of industrialised nations that rely on centralised water supply and treatment infrastructural systems. This large annual expenditure excludes an estimated US$40 billion that will be invested annually on new hydropower dams and other large-scale water transfer systems. These estimates exclude the environmental and social cost from improperly designed dams, and the true long-term cost to society will be many times greater. Many hydropower schemes are at risk from irregular flow regimes resulting from drought and climate change, while increased land-use intensity leads to sedimentation rates that diminish reservoir storage capacity. Methane emissions from rotting vegetation can be higher than displaced fossil-fuel power plants, while fragmented aquatic habitats and altered flow regimes threaten biodiversity and inland fisheries – a primary protein source for millions of poor people.

We present evidence that a value-adding and risk-minimising water planning process can be achieved by shifting from the conventional focus on supply expansion to one that concentrates on efficiently delivering services at and near the point of use. The State of California has two decades of experience with this approach, demonstrating that market-based policy and regulatory innovations can unleash efficiency gains resulting in more utility water services and energy services delivered with less supply expansion at lower costs, while minimising climate-change risk, pollution and the social cost that accompany large infrastructural projects. Efficiency in delivered water services could be accomplished with investments in the range of US$10-25 billion annually, while obviating the need for spending hundreds of billions of dollars on more expensive hydropower and related infrastructural expansion projects. The shift to a regulatory system that encompasses cost-effective end-use efficiency improvements in delivering water and energy services could eliminate the need for an estimated half of all proposed dams globally, thus allowing for the maintenance of other ecosystem service benefits and offer the best hopes of meeting basic human needs for water at a more achievable level of investment.

KEYWORDS: Utility services, utility decoupling, integrated portfolio planning, water sufficiency, water efficiency, end-use efficiency, ecosystem services, greenhouse gas emissions, climate change, price volatility, Mekong river, Amazon river, Africa

INTEGRATED RESOURCE PLANNING OF DELIVERED UTILITY SERVICES

The WCD report and contributing papers discussed or highlighted a barrage of seemingly intractable social, ecological, and economic problems related to hydro dams. In the end, readers were left to draw their own conclusions as to when and where hydro dams and associated water infrastructure are appropriate. However, a decade later we now have a much more acute appreciation of the dimensions and immediacy of the threat from non-sustainable use of water resources – notably far more rapid and severe climate change, increased poverty, chronic sickness and malnourishment, accelerating ecosystem destruction and species extinction, and multi-trillion dollar resource wars and conflicts. Business as usual is no longer an acceptable option and incremental change will achieve 'too little too late'. Trans-disciplinary and integrative social and market transformations are essential not only to avoid adverse consequences but to actually accrue multiple benefits for society.

Water use is pervasive throughout the global economy, but concentrated in agriculture (~75% of water withdrawals worldwide) and thermal power plants (48% of off-stream use in the USA).[1] From the perspective of delivering water services for these needs, the core concern is how to do it at least cost and risk while addressing issues of social equity and ecological integrity.

The WCD report did cite examples of very low cost 'demand management' options that should be taken into consideration as part of Integrated Water Resources Management and Integrated River Basin Management. But it neglected to glean important insights from a number of contributing papers to the WCD that discussed and contrasted the traditional supply expansion model with the experience of a more comprehensive least-cost option based on the concept of the delivery of efficient utility services at the point of use (Eberhard et al., 2000).

In spite of its many positive and insightful recommendations, the WCD report failed to identify three essential criteria for overcoming severe limitations to selecting least-cost and risk utility service options in the standard regulatory paradigm. Fiscally prudent and financially responsible criteria which should govern the design and operation of utility delivery systems (whether water, electricity, natural gas, or sewage) are given below:

- Adoption of a comprehensive *Integrated Resource Plan* (IRP) that ranks all supply and demand-side (customer-site) resource opportunities according to cost and risk for delivering utility services at the point of use. Costs also include transmission and distribution expenses, plus risk-adjustment for exposure to price volatility from long-term dependence on fuel and water requirements, and for externalities like CO_2 emissions, air pollutants, and ground and water contaminants).
- Remove the regulatory disincentive that undermines utility investment in least cost customer-site resource options. This requires aligning the financial interests of the utility provider with those of their customers which can be achieved by regulatory agencies *decoupling* utility revenues from gross sales.
- Allow utilities to recoup lost earnings from declining revenues as a result of helping customers reduce their bills by taking advantage of cost-effective end-use efficiency opportunities. Combine this with performance incentives for the utility to apply its long-term, low cost capital in financing the customer-site efficiency gains, along with providing technical assistance in identifying what products perform best, as well as removing other transaction costs through partnerships with stakeholder groups and government agencies (Totten, 2007a).

[1] US off-stream use in 2000 was 1.5 billion m^3 (Bm^3)/day, with irrigation consuming 520 million m^3 (Mm^3)/day and thermopower plants using 740 Mm^3/day (USGS, 2004). Withdrawals may not always consume water, but they take water from the hydrological systems, return it hotter (in the case of thermal power plant cooling), or degraded in quality, changing watershed environmental flow regimes, and having potentially adverse impacts on aquatic species.

These regulatory innovations can result in five to ten times more customer-site services through efficiency gains ranking as least cost options. Without the innovations, utility customers are unlikely to capture more than 10% to 20% of the cost-effective opportunities available because of their much higher discount rates and rate of return (ROR) requirements than the utility's, combined with customer inertia induced by a host of transaction costs and multiple market barriers (Golove and Eto, 1996; D'Sa, 2005; Turner et al., 2006; RAP, 1994, 2005, 2007).

A comprehensive IRP methodology is a key decision support tool used by both regulators and utility operators to evaluate and rank all investment options. It goes beyond simply comparing one supply option with another. The IRP expands the comparison to the myriad of end-use efficiency improvements and consumer-site resources. The common goal is delivering safe, clean, secure and affordable utility services, while sustaining robust earnings for utility investors, and accruing ancillary benefits for society and the environment.

Accumulated empirical experience over the past several decades in regions with a more integrated utility service framework – e.g. in western, Pacific northwest and northeast US states, in a number of Australian states and cities, and in China's Jiangsu province – provides compelling evidence for adopting the IRP methodology (Hopper et al., 2006; ACEEE, 2009). Under such practices, utility service systems are required to inventory and develop rigorous least cost curves that include the full range of cost and risk factors in the delivery of local utility services (NPCC, 2010). The methodology also proves to be a more open and transparent process combined with broader stakeholder engagement, the reduction of subsidies and negative externalities, and greater consideration of the unique local and regional social and ecological conditions (CEC, 2005).

The IRP approach is a comprehensive and market-transforming regulatory framework that is highly synergistic with other innovative policy initiatives being promoted in international forums to avoid the worst impacts of climate change (NREL, 2009; World Bank, 2009a). Like climate-change policy initiatives, the reform of the water services sector will create opportunities to alleviate poverty, protect and restore threatened and degraded ecosystem services, and sustain human well-being in a fiscally prudent, financially responsible, and socially equitable manner (Howe and White, 1999; Fane et al., 2002; Brooks et al., 2009).

IRP approaches that integrate electricity and water planning, as in California, have identified multiple least-cost opportunities which have saved electricity and natural gas by delivering water services more efficiently. This opportunity came to light in an assessment by the Pacific Institute and the Natural Resources Defence Council, which found that California water uses consumes 20% of the State's total electricity and one-third of the State's total natural gas in pumping, distributing, heating and disposing of the State's water (Cohen et al., 2004).

Not surprisingly, water efficiency assessments similar to McKinsey energy assessments (MGI 2007, 2009b) show that, by adopting the IRP methodology in regulatory systems, end-use efficiency options can reduce water and energy consumption, while accruing substantial monetary savings and avoiding air pollution and greenhouse gas (GHG) emissions (CEEP, 1996; Wilkinson, 2000; Gleick et al., 2005; MGI, 2009a). This has special importance to large water-consuming nations like China and India with long distances separating water supplies from water demands (Zhi et al., 2006).

Half of humanity now lives in urban areas and nearly three-fourths of the global population, or more than six billion people, will be urban residents by 2050. Financing the provision of water services, on top of electricity, natural gas, sanitation, waste treatment, mobility access, and other urban services, is a monumental burden for local governments. An increasing number of coastal countries and localities are choosing (many prematurely) to invest in expensive desalination plants, with the output piped over long distances (Cooley et al., 2006; NAS, 2008).

Desalination costs vary by a factor of seven or more, depending on the: (1) type of feed water (brackish, waste, or sea water); (2) available concentrate disposal options; (3) proximity to distribution systems; and (4) availability and cost of power. Desalination's primary operation cost is for energy – one Bm^3 of desalination per year requires about 500 MW of generating capacity. However, the reduction in unit energy use by desalinisation plants has been among the most dramatic improvements in recent years due to enhanced energy recovery systems, albeit still very much a costly supply augmentation option for most localities (Pique, 2005).

Estimates considered valid today for countries facing water crises like China or India, range from a cost of US$0.65 per m^3 for brackish and waste-water desalination to US$1/ m^3 for sea-water desalination by reverse osmosis (Zhou and Tol, 2003). By comparison marginal priced water in Beijing is about US$0.70/$m^3$ (and nearly ten times that for the island territory of Cayman). Desalination and waste-water reuse powered by high-efficiency combined heat and power technology potentially offer urban centres in developing countries multiple benefits: the input is waste water, reducing the contaminated discharges into rivers, and expands the city's potable water supplies at lower cost than importing remote freshwater resources.

For example, China's total waste-water discharges annually exceed 60 Bm^3, and as of the late 1990s less than one-seventh of this was treated. Close to 600 million Chinese people have water supplies that are contaminated by animal and human waste. Harnessing 30 GW of co-generation at sites available in cities and industrial facilities could operate high-performance reverse osmosis technologies to purify waste-water, while providing ancillary energy services for industrial, commercial, institutional and residential space and water heating and cooling (Zhi et al., 2006).

Integrating energy and water planning is an efficacious method for identifying potential lost opportunities resulting from examination of energy and water needs separately (Shrier et al., 2009).

DECOUPLING UTILITY REVENUES AND SALES

Unfortunately, most utility regulatory bodies overseeing the electricity, natural gas and water services sectors still preclude end-use efficiency opportunities from fully competing in the utility resource planning process. Customer-site efficiency and generation options are actively opposed by utilities because they erode profits under traditional regulatory practices.

Traditional regulation does not set a utility's revenues, only its prices. Once prices are set, the utility's financial performance depends on two factors: its levels of electricity sales and its ability to manage its costs. Because, under most circumstances, a utility's marginal revenue (i.e. price) significantly exceeds its short-run marginal costs, the impacts on profits from changes in sales can be profound. Moreover, the change in profits is disproportionately greater than the change in revenues. A utility therefore typically has a very strong incentive to increase sales and, conversely, an equally strong incentive to protect against decreases in sales. This is referred to as the 'throughput incentive', and it inhibits a company from supporting investment in and use of least-cost customer-site resources, when they are most efficient, and it encourages the company to promote incremental sales, even when they are wasteful (NAPEE, 2007a; Shirley et al., 2008; Weston, 2008).

Several decades of economic and engineering analyses of utility service cost curves have consistently ranked end-use efficient energy and water-service opportunities as least cost options (Ford, 1975; Meier et al., 1983; Koomey et al., 1990; Fane et al., 2002; Rosenfeld, 2008; MGI, 2009a, 2009b).

The traditional regulatory structure of coupling a utility's earnings to revenues via sales was sensible when supply expansion was the least cost way of delivering utility services and maintaining stable utility rates. But this truncated planning methodology is proving more expensive and risky given the continuous science and technology breakthroughs and engineering advancements sustaining a vast and still expanding commercially available pool of ultra-low cost end-use efficiency options for delivering utility services.

This pervasive regulatory shortcoming was first recognised nationally in 1989, when the US National Association of Regulatory Utility Commissioners (NARUC, 1989, 2007) adopted a resolution expressly recognising this serious impediment to greater use of the end-use efficiency resource, and recommended a simple and unequivocal response: reform regulation to align the utility's financial interest with the interests of its customers in having end-use efficiency integrated into the utility's resource portfolio (Tellus, 2000; RAP, 1994, 2000a, 2000b, 2001, 2002, 2005, 2007). As regulatory utility experts Shirley et al. (2008) note the following:

> All regulation is, in one way or another, incentive regulation. A question all policymakers should ask is: how does a regulated company make money? What are the incentives it faces and do they cause it to act in a manner that is most consistent with, and most able to advance, the state's public policy objectives? And, if not, how should regulatory methods be reformed to correct such deficiencies?

Full decoupling can be likened to the setting of a budget. Through currently used rate case methods, a utility's revenue requirement is determined, i.e. the annual total revenues it will need to provide safe, adequate, and reliable services. The utility then knows exactly how much money it will be allowed to collect, no more, no less. Its profitability will be determined by how well it operates within that budget. Actual sales levels will not, however, have any impact on the budget. The most common form of full decoupling is revenue-per-customer (RPC) decoupling, in which the allowed revenue requirement between rate cases is changed only as the number of customers served changes. Full decoupling renders a utility indifferent to changes in sales, regardless of cause. It eliminates the 'throughput' incentive. The utility's revenues are no longer a function of sales, and its profits cannot be harmed or enhanced by changes in sales. Only changes in expenses will then affect profits. An example of a formula for adjusting a revenue requirement or an allowed RPC figure is the following (Shirley et al., 2008):

$$RPC_{t+1} = [RPC_t * (1 + i - p)] \pm Z$$

where, RPC_t = revenue requirement in year *t; i* = inflation rate; p = productivity rate and Z = exogenous costs, if any.

The inflation rate would be a national measure of general changes in price levels in the economy, appropriate for the sector, e.g. the Consumer Price Index-Urban (CPI-U). The productivity adjustment would be based on the industry average for similar firms. Exogenous costs might be the significant changes in the tax code (before they are captured by the inflation measure) or out-of-the-ordinary expenses for storm damages. Table 1 demonstrates the mathematics of the calculation.

Table 1. Periodic decoupling calculation.

From the rate case	
Allowed revenues	$10,000,000
Test year unit sales	100,000,000
Price	$0.10/unit
Post-rate case calculation	
Actual unit sales	99,000,000
Allowed revenues (from above)	$10,000,000
Required total price	$0.10101/unit
Decoupling price 'adjustment'	$0.00101/unit

It is important to note that decoupling does not 'guarantee' a specified amount of earnings for the utility. Under decoupling, only the level of revenues is predetermined. The utility's ultimate earnings will continue to be a function of the utility's managerial and operational performance. Furthermore, while it can remove disincentives for utilities to promote efficiency, decoupling is not designed to create an incentive for energy efficiency (NARUC, 2007; APPA, 2009).

Given the varieties of decoupling mechanisms (i.e. full, partial, limited), decoupling may not completely neutralise a utility's efforts to maximise sales or avoid significant decreases in load (Shirley et al., 2008; Lazar, 2008). Decoupling removes the dominant disincentive, but does not ensure pursuit of all cost-effective consumer site resource options. For best results, there are mechanisms that create positive performance incentives for a utility to proactively engage in harnessing end-use efficiency, conservation, on-site and distributed service opportunities (Kushler et al., 2006; Steinhurst et al., 2006; Cappers et al., 2008). In effect, all such mechanisms involve ratepayer payments to utilities associated with efficiency programmes that enhance their earnings.

Since the 1980s, California has become a world leader in developing a utility regulatory process that aligns the financial interests of the utility with those of their customers to capture end-use efficiency opportunities. California achieved this alignment by decoupling utility sales from revenues to eliminate the throughput incentive of expanding supplies that are costlier than end-use efficiency gains. The result is delivery of more services with less energy or water resource inputs (i.e. KWh, litres of water, m^3 of natural gas), and less emissions, pollutants and waste outputs (CEC 2007; CPUC, 2008a, 2008b).

Most importantly, the utility's capital investment, previously limited to large power plants and transmission infrastructure operating over 30- to 50-year time horizons, is diversified by focusing on a large and expanding pool of lower cost end-use efficiency services. Decoupling also removes a utility's financial incentive to discourage on-site generation. And, increasingly, the investment in customer's end-use efficiency is being leveraged through combination with distributed generation from solar hot water, solar photovoltaic electricity systems, and combined heat and power systems (SEPA, 2009a, 2009b; Brown and MacLean, 2010; City of Palm Desert, 2010; NYSERDA, 2010).

When combined with California's world leadership in setting continuously stronger appliance, building, lighting, motor and water efficiency standards, these efforts have allowed the state to save on average US$1000/household/year on electric and water utility bills, and the utility sector has CO_2 emissions 50% below the national average (Rosenfeld, 2006). If all states had followed California's efficiency model, the US energy bill would be several hundred billion dollars less and the country would have surpassed the CO_2 reduction targets of the Kyoto Protocol.

A dozen US states have adopted or are pursuing decoupling in the electricity sector (Lazar, 2008), 31 states have adopted gas utility decoupling regulations (AGA, 2009), and California is pioneering a similar reform in the water utility sector (CPUC, 2005; CEC, 2005; Morse, 2006).

In other countries, three provinces in China – Jiangsu, Shanghai and Beijing – are in the process of adopting similar decoupling regulations so that aggregated efficiency savings opportunities, referred to as 'efficiency power plants' (EPPs), can compete in the IRP process along with coal, nuclear and large hydroelectric plants (Niederberger and Finamore, 2005; Hu et al., 2005; Totten, 2007b). Similarly, states and municipalities in Australia are among the foremost leaders in implementing IRP for water services (Howe and White, 1999; White and Fane, 2001; Fane et al., 2002; Turner and White, 2003; White, 2008; White et al., 2009).

END-USE EFFICIENCY SERVICES

There is a vast pool of high-productivity and high-efficiency end-use services now available for satisfying a several-fold increase in utility services, at less cost per delivered services than comparable investments in extracting, processing, shipping, distributing, treating, cleaning, disposing and delivering expanding supplies of water or energy (Lovins et al., 2002; Gleick, 2003a, 2003b; Lovins, 2004).

In 1980, for example, per capita US water withdrawals were around 7.3 m^3/day, including power plant cooling water and irrigation water, as well as residential and commercial use. Today there are 80 million more Americans and, if water-use efficiency had not improved, total withdrawals of water would have been 586 Mm^3/day more, the equivalent of ten additional Colorado river flows. Fortunately, improvements in efficiency have been able to meet rising demand for water services without increasing total water supply. Currently, US national water use is below 5.7 m^3/person/day (Gleick, 2009).[2]

According to the McKinsey Global Institute's detailed energy efficiency assessments, "By capturing the potential available from existing technologies with an internal rate of return of 10% or more, we could cut global energy demand growth by half or more over the next 15 years" (MGI, 2007). Perhaps more accurately, not 'cut' but employ efficiency measures to deliver a comparable level of service with less resource supply and less cost – while also providing more ancillary benefits and less negative externalities.

Currently, most utilities and regulators worldwide are simply unaware of the immense size of end-use opportunities, despite more than a quarter century of detailed analyses, extensive utility programme delivery experience, and a rich analytic literature evaluating what works that have resulted in developing higher-yielding programmes at lower total costs (EPRI, 2001; CPUC, 2004, 2006; NAPEE, 2007a, 2007b). A clear example of this is the persistence of obsolete and inefficient electric motor drive systems around the world.

Half of the world's electricity is consumed by industrial electric drive systems – electric motors, pumps, compressors and fans (60% in China). Savings of 50% are achievable in new motor systems if more energy-efficient technology was adopted by manufacturers and retailers. However, the conventional practice is to install components that require the lowest capital cost, but which are inefficient in terms of energy consumption. In some instances, these inefficient devices will consume up to 20 times more in electricity costs when compared to the perceived savings based on the purchasing price.

IRP-based utility incentive programmes have been instrumental in overcoming this distortion, and utility financed efficiency upgrades to existing systems can achieve 30% savings at five to ten times less cost per KWh when compared to building new-generation facilities to power the inefficient devices that dominate the current market (DOE, 2002; Lovins, 2004; Rosenfeld, 2008; CGGC, 2010).

Worldwide, an initiative for transforming the efficiency of electric motor systems would 'deliver' 2 trillion KWh per year, equal in services to one-fourth of all power plants planned for construction through 2030. A successful market transformation would reduce global energy bills by ~US$1.6 trillion per decade.[3] Experts in scores of countries are now engaged in spurring the market transformation process, by promoting Standards for Energy Efficiency of Electric Motor Systems (SEEEM, 2007); an IRP and decoupling process would spur that process forward so that these gains can be achieved over the short term.

If these electric motor efficiency gains were used to displace thermal power plants, the savings in water use would range between 2 and 200 Bm^3/year.[4] Alternatively, if these efficiency gains were used to displace planned electric power facilities, then ~450 GigaWatts (GW) of questionable hydropower projects could be avoided. For comparison, in 2007 there was 770 GW of installed hydropower generating 16% of the world's electricity.

[2] Even more stunning efficiency improvements occurred in the energy sector. Without faster, smarter, more efficient ways of delivering energy services, energy consumption in the US would have risen from 79 exajoules (EJ) in 1973 to 179 EJ in 2005. Instead, energy consumption in 2005 was only 104 EJ. The difference (75 EJ) also avoided $700 billion/year in higher energy bills. How much is 75 EJ? Envision a freight train annually hauling nearly 18,000,000 railcars of coal, which would wrap around the world seven times. The 39% drop in Energy/Gross Domestic Product from 1975 to 2000 represented, by 2000, "an effective energy 'source' 1.7 times as big as US oil consumption, [and] five times domestic oil output" (Lovins, 2004).

[3] This assumes 400 GW of displaced power plants, each GW generating 5 billion KWh, a delivered cost of electricity averaging 9 cents per KWh, and an average cost of 1 cent per KWh saved through electric motor drive improvements, resulting in *net* revenue savings of US$1.6 trillion.

[4] The m^3 of water needed to generate each gigawatt-hour (GWh) of electricity vary by three orders of magnitude depending on the type of thermal power plant – coal, natural gas, nuclear, geothermal, or solar-thermal-electric. Water requirements range from ~250,000 m^3/GWh (e.g. super-efficient natural gas combined cycle plants with closed loop cooling) to several hundred million m^3/GWh (e.g. nuclear reactor with open loop cooling). In sharp contrast, solar photovoltaic and wind power systems require 93 to 99% less water amounts, respectively, compared to thermal plants (Jacobson, 2009; Service, 2009).

In China, the potential energy savings from efficiency gains from electric motors are worth US$220 billion/decade, which would displace the need for 63 GW of planned power plants (Totten, 2007a). Jiangsu province is leading the effort and has identified 10 GW of motor efficiency gains that can be delivered at a cost of US$0.01/KWh (Niederberger and Finamore, 2005). By comparison, the Jiangsu electricity price delivered to the industrial sector in 2009 was US$0.07-0.14/KWh (LETDZ, 2009).

Applied comprehensively to all power-consuming uses throughout China's residential, commercial, institutional, industrial and agricultural sectors, end-use efficiency and decoupling methodologies could avoid half of an estimated US$10 trillion projected in power plants to be built by 2030.

The Chinese economy is expected to grow four times over the next two decades and will build half of all new buildings in the world; consequently, there are ample opportunities for regulators to align incentives to promote end-use efficiency. For example, a utility company's long-term, low-cost capital can be used to provide incentives and technical assistance for factories that install high-efficiency motors, pumps, and compressors, while assisting manufacturers to develop high-efficiency appliances.

Similar incentives can assist builders to design and construct 'green' buildings that consume zero-net-energy (through combinations of high efficiency, on-site generation and distributed systems). If builders, retailers and customers were to adopt only the 10% most efficient appliances, lights, consumer electronics, and office electronic equipment, then utility electric gas and water services could be delivered with 50% less resource supply.

An investment of perhaps US$1 trillion in incentives to promote efficiency would lead to almost US$5 trillion in avoided power plant construction and subsequent operating costs. The savings could be used to transform the building sector by providing incentives for other energy-related investments, such as 'building-integrated photovoltaics' (BIPV) that replace building components, such as roofs, window glazing, curtain walls and assemblies, and awnings. Existing BIPV used in new constructions in Beijing and Shanghai have a payback period of between one and two years when incentivised with a 15% tax credit. BIPV is economically attractive because it not only delivers energy services but also accrues savings by displacing other expensive building materials, e.g. polished stone or aluminium facade cladding (Byrne et al., 2001).

In addition to energy and water savings, BIPV installations could also avoid externalities related to human health and environmental damages associated with other energy sources, such as hydro-dams and coal-fired power plants (Zhi et al., 2006). An IRP with an adjusted risk mechanism should reflect these BIPV benefits (Awerbuch, 2004, 2005, 2006).

With China *annually* producing several hundred million appliances and constructing two billion m^2 of new buildings, the Chinese market also needs more stringent standards and effective enforcement mechanisms, as well as the transfer of more efficient technologies for appliances.

A key assumption in conventional water planning is that future global demand will match consumption in industrialised nations and that centralised water supply and treatment infrastructure will be used to provide these services (Cosgrove and Rijsberman, 2000). However, research and modelling indicate that improved efficiency in delivered water services could be accomplished by investments in the range of US$10 – 25 billion/y for the next two decades, which would obviate the need for hundreds of billions of dollars to be spent on expanded central water facilities, hydro-dams, and related infrastructure (Gleick, 2003a, 2003b).

A case in point is delivering safe, clean and affordable potable water to an impoverished population, now approaching two billion. Fetching water is a hard daily grind – a chore that falls almost exclusively on women and girls, often leading to chronic neck and back injuries. Conventional centralised treatment and house connections average US$110 per capita in investment costs for water provision and treatment, nearly US$50 per capita for community water stand posts, and more than US$30 per capita for dug-wells.

In sharp contrast, the investment cost for an end-use-oriented safe water delivery system designed for the challenging conditions facing poor communities is less than US$20 per capita (Gadgil, 2008; WHI, 2009). For example, the system produced by WaterHealth International, now being used by

500,000 people in 500 locations across four continents worldwide (WHI, 2010), exceeds World Health Organisation criteria for disinfection and is both cheap and energy-efficient, requiring just 60 watts for an ultraviolet lamp to disinfect one m^3 of contaminated water per hour at just US$0.04/$m^3$. These lightweight units are built from reliable, mature components that are both modular and scalable, while treating unpressurised water with low maintenance requirements and are fail-safe with no risk of overdose.

Its widespread success under demanding conditions finally led the International Finance Corporation in 2009 to provide US$15 million in project financing for long-term loans to help more than 600 communities in India fund the purchase of WaterHealth Centres with the capacity to serve more than three million people (Reuters, 2009). However, a population of over 600 million needs safe drinking water in rural India; finding solutions of this magnitude highlights the need for water utility reform following the IRP/efficiency/decoupling framework.

Consumer-site efficiency improvements are integral parts of delivering 'smarter' utility services, facilitated by utilising information-rich systems that foster continuously innovative designs for delivering utility services with less energy, water, resources, pollution and waste. These benefits can be captured all along the value chain, encompassing the manufacture of smarter electric motors, pumps and compressor systems, equipment and machinery, appliances, toilets, drip irrigation systems, lights, consumer electronic devices, and vehicles, as well as constructing and operating smart buildings, factories and farms.

The opportunities for promoting increased reliance on smart energy services have greatly accelerated since the 2000 WCD report due largely to the pervasive expansion of the Internet. Citizens worldwide now recognise the value-added benefits from harnessing the Internet connectivity for accelerating insights, understanding, implementation, operation and delivery of smarter utility services (Tapscott and Williams, 2006; Alaq, 2008; EC, 2008a, 2008b, 2009). Best practices and policies can be shared faster, widely and thoroughly. In the near future, the installation of hundreds of millions of embedded wireless smart sensor networks (WSN) linked via the Internet will further enhance productivity, while reducing water, energy and resource inputs, as well as waste and pollution outputs.

The market transformation from Internet connectivity cannot be overemphasised: five thousand days ago there was no commercial Web to speak of; within the next 5000 days, computer experts project an open access global cloud network (Kelly, 2007; Shirky, 2008; Anderson and Rainey, 2008). People worldwide will be web connected in a veritable wealth of networks, which we already see in the immense activity engaged in telecommuting, social collaborations, and peer-to-peer productions that create a global commons of intelligence (Engelbart, 2004; Benkler, 2007; CISCO, 2009; SMR, 2009).

The so-called 'global cloud network' will also encompass WSNs, which are projected to be embedded in and networked with tens of billions of water-, energy- and resource- using and -consuming devices. These devices will play a key role in providing delivery of declining cost and 'smarter' utility services. Smart WSNs have the capacity to continuously propagate data aggregated into the increasingly smarter utility grid, enabling real-time pricing that will shift demand to maximise efficiency, profits and benefits for individuals, corporations and society (ON World, 2007a, 2007b, 2007c, 2007d, 2008).

A wealth of analysis finds efficiency standards for buildings, motors, appliances, consumer equipment, and vehicles are among the most cost-effective ways to deliver electricity, gas, water and transportation services while reducing energy consumption, preventing multiple pollutants (CO_2, acid rain, urban smog), while also saving money for the consumer (Wiel and McMahon, 2005; Neubauer et al., 2009; ACEEE, 2010).

The dimensions of future utility services will be determined by the nature of buildings and devices that do not yet exist, most of which will be built in emerging economies. These yet to be built structures and machines are likely to account for about half the world's GHG emissions; consequently, the fastest, cheapest and cleanest way to minimise emissions is to ensure that the maximum possible energy and water efficiency is incorporated into their design prior to their construction or manufacture.

DIRECT AND ANCILLARY BENEFITS

Utilities operating under a comprehensive IRP, with decoupling and performance-based incentives, derive fiscally prudent and financially responsible benefits for shareholders, customers and society. Assessing and adjusting risk is a key component for avoiding indirect costs and loss of ancillary benefits. For example, the hydrological cycle is inextricably entwined in the social and economic crises that characterise post-cold-war conflicts, including multi-trillion dollar oil wars, tension over shared natural resources, as well as land and water rights (Bilmes and Stiglitz, 2008). The vulnerability and price volatility of oil supplies prompted the US and other oil-dependent governments to subsidise and accelerate the large-scale production of biofuels. One unintended consequence has been increased water use for irrigated corn and soybean for ethanol and biodiesel. Compared to the water demands of petroleum extraction and refining, corn ethanol irrigation requires 23,000 to 43,500 times more, and soybean biodiesel irrigation requires 140,000 times more water (Service, 2009).

A decade of additional climate science since the WCD report, coupled with graphic evidence from weather-triggered disasters worldwide, indicate the current rate of increasing GHG emissions is leading to worse-case scenarios (Sokolov et al., 2009). Greater climate sensitivity and clues from paleo-climate research point to a rise in global atmospheric temperature of 4-6 ºC this century, not the earlier estimated 2-3 ºC (Hansen et al., 2008).

Greenhouse gas emissions from reservoirs represent another poorly understood trade-off between increased water use and renewable energy (see Mäkinen and Khan, this issue). Improperly sited and designed dams emit methane from the flooded and rotting vegetation, which in some cases are greater than the displaced emissions from fossil fuel power plants. Extrapolating from measurements compiled for 30 basins, the emissions from hydro-dams may be responsible for 8% of total global greenhouse gases (St. Louis et al., 2000). Not all dams emit high emission levels, but clearly this possibility should be assessed prior to any approval process, especially in tropical forest regions.

Humanity's historical and conventional exploitation of watersheds has come at a high price. Watershed conversion and water flow diversion have inevitable impacts, since the flow regime is a key functional attribute that determines the primary productivity of wetland ecosystems (Bunn and Arthington, 2002; Arthington et al., 2003a, 2003b, 2006). Moreover, freshwater ecosystems contain a concentration of unique species far out of proportion to their geographic area, which is higher than both terrestrial and marine ecosystems. Freshwater ecosystems cover 0.8% of the earth's surface but account for about 10% of all animals. Inland waters contain nearly half of the world's fish species – a concentration 4000 times greater than in the oceans. As a result of human overuse and misuse through discharges of contaminants, ecosystems in rivers and lakes are collapsing and extinction rates for freshwater species are currently four to six times the rates for terrestrial and marine species (Diversitas, 2009).

Taking advantage of efficiency gains, and displacing the large water requirements of thermal power plants through power generation options from near-waterless solar PV and wind power, will significantly reduce but not eliminate the need for hydro-dams. Nonetheless, a more rational power generation paradigm will moderate the demand for increased power generation capacity and improve the probability that decisions to build hydro-dams will be based on more objective criteria.

Rivers with high biodiversity value can be removed from lists of possible sites, while dams can be sited in basins that will minimise the fragmentation of wetland habitats and associated valuable ecosystem services. For example, rather than exploit all watersheds within a basin, a decision to conserve one sub-basin might accompany a parallel decision to build multiple facilities on another sub-basin, thus improving the probability of conserving the biodiversity within a basin, while improving management efficiencies on the other. Similarly, the consideration of social criteria in basin development strategies and the risk associated with the resettlement of established communities will improve equity and social justice, while minimising conflict.

As the electricity end-use efficiency opportunities demonstrate, drivers and policies outside the water sector have major impacts on water management, sometimes more than the policies championed and implemented by water-related ministries. Identifying the myriad of trade-offs and synergies between water and other policy sectors can enhance policy impacts in all sectors and avoid some adverse effects on water (Cosgrove and Talafré, 2009).

BARRIERS TO REALISATION

The IRP and decoupling regulatory framework is not inevitable, no matter how many benefits it promises. A number of potent impediments could block or indefinitely delay adoption in many nations. At the top of the list is corruption and lack of public accountability. Transparency International's Global Corruption report (TI, 2008) found corruption is a cause and catalyst for the water crisis afflicting the more than 1 billion people.

The *World Commission for Water in the 21st Century* (Cosgrove and Rijsberman, 2000) estimated a cost of US$180 billion/y to 2025 to meet future infrastructural needs for water supply, sanitation, waste-water treatment, agriculture, and environmental protection. Additionally, the proposed investment in hydro-dams over the next two decades will exceed US$2 trillion in construction costs. These large numbers create multiple opportunities for graft and corruption, particularly via civil works contracts that account for ~60% of dam construction (TI, 2008, 2009). Regulatory transparency and strong enforcement are fundamental to achieving a portfolio of preferred least cost options, which should simultaneously ensure human health and well-being, economic prosperity, and the health and integrity of freshwater ecosystems.

Corruption is a corrosive problem that permeates public- and private-sector transactions in many developing nations, infecting society well beyond the utility sector. Kleptocratic-controlled nations ruled by dictatorships, oligarchies, or military juntas, lock in such widespread corruption that it leads many sceptical analysts to dismiss the promise of IRP from ever happening. Cynical observers view corruption as an ever-recurring dynamic afflicting much of economic activity, sometimes capable of being dampened but incapable of being eliminated. African states lose 25% of GDP to corruption each year, while proceeds of corruption in bribes received by public officials from developing and transition countries are estimated to be US$20 – US$40 billion/y – equivalent to 20% to 40% of Official Development Assistance (World Bank, 2007).

Corruption also arises through other less-obvious lawful forms, which involve collusion between parties typically both from the public and private sectors. Legal lobbying contributions by the private sector and entrenched vested interests are a case in point. This legalised graft 'influences' officials to push passage of preferred legislation and block passage of undesirable lawmaking. Likewise, allocation of non-bid procurement contracts to campaign contributors, cronies and nepotism are commonplace examples of interaction of both private- and public-sector representatives where the second makes use of their publicly invested power at the expense of broader public welfare (Kaufmann and Vicente, 2005).

Numerous governmental and non-governmental initiatives are combating corruption, with some noteworthy successes (Norad, 2008; OECD, 2008; Hussmann et al., 2009; GI, 2010). Both public and private actors, and the banks and export credit agencies that finance projects, need to work together to eliminate corruption. In respect of the chances of successful utility IRP implementation, history is populated with seemingly impossible and intractable conditions (e.g. human enslavement, persecution, exploitation, subjugation, genocide) that human persistence has succeeded in overcoming, preventing or mitigating many of these circumstances (Lauren, 2003).

A fundamental strength of the comprehensive IRP process incorporating consumer-site resource options is the methodical rigor of the IRP methodology. It dramatically improves transparency around planning decisions, making corruption more difficult. It also increases the probability that full consideration is taken of the calculated social and ecological costs, risks and benefits of the entire portfolio of options.

As insidious as corruption is the longstanding bias for large-scale utility construction projects by government officials, financial institutions and supply companies. End-use efficiency options are summarily dismissed, as when former US Vice President Dick Cheney claimed, "Conservation may be a sign of personal virtue but it is not a sufficient basis for a sound, comprehensive energy [including utility] policy". Such deeply entrenched beliefs, unencumbered by data and facts, is a key reason it has taken a quarter century for two dozen US states to finally follow California's lead in adopting IRP and decoupling. But there are reasons to believe that future adoption could occur faster.

Thomas Malone, Director of the MIT Centre for Collective Intelligence, has infused a new dimension into the common observation 'Just because something is possible, doesn't mean it will happen'. This has been frequently said about adoption of the IRP process and of the customer site resource opportunities highlighted above, e.g. there are too many opposing and confounding factors that militate against the fruition of these least-cost, low-risk, and high-value opportunities. What Malone cogently argues, and is echoed in an expanding literature by a myriad of experts, practitioners and prescient observers, is that a connected and networked society increasingly engaged in collective intelligence collaborations is radically altering this platitude (Shirky, 2008; Tapscott and Williams, 2006; Leadbetter, 2008; Malone, 2009; Hagel et al., 2010).

Vintage e-government projects of the past decade have already demonstrated improved governance by reducing corruption and abuse of discretion, thereby making vital contributions to development. In India, a survey found that fewer users were required to pay bribes to accelerate service delivery under e-government projects than under manual systems, and that the frequency of paying bribes to service officials has fallen. Officials are also more aware of the need to comply with service standards specified in citizen charters (World Bank, 2007).

The Web and commercial-scale Internet are less than 5000 days old. Yet, its rapidly evolving capabilities are accessible by more than 70% of North Americans and 1.5 billion people worldwide as of 2009. This emergent digital network phenomenon permits an unprecedented richness and diversity of interactive learning experiences, knowledge-sharing collaborations, and self-organising peer-to-peer productions (computationally and in multi-media formats). Already the 'network is the platform', and within 5000 days a next level of emergence is expected of a semantically linked, open access, global cloud network of humanity and its ubiquitous sensing devices (Englebart, 2004; Kelly, 2007).

Given the enormity of the global challenges confronting humanity, and the need to overcome corruption, powerful entrenched interests, bureaucratic risk-averse behaviour, indifference or ignorance, and a myriad of market failures and institutional, economic and technical barriers, there could not be better timing for the emergence of 'the participatory Web', enabling the harnessing of knowledge-in-action (Prahalad and Hammond, 2001; Benkler, 2007; Nokia Siemens Networks, 2008; Sullivan, 2007).

The global diffusion of mobile smart web phones lowers the bar and raises the opportunities for citizen and stakeholder engagement and advocacy. Web networking enables rapid and continuous sharing of experiences and evidence; it also enhances transparency and scrutiny through easier citizen tracking and monitoring of public policy and regulatory decision-making. Herein resides the civic opportunity for demanding implementation of non-dam alternatives for delivering utility water and energy services at least cost and risk, and sustaining an ongoing IRP inventory of the continuous innovations capable of addressing the recurring and acute problems of water scarcity that is a major impediment in improving the health, livelihoods and economic growth in the developing world (Gleick, 2003a, 2003b; Postel and Richter, 2003; Postel and Vickers, 2004; Brooks et al., 2009).

BALANCING ACT – WATER FOR PEOPLE AND NATURE

Water has been consumed largely as a free resource for centuries and water prices barely cover distribution costs, while the real cost and productive value of water resources are rarely considered in establishing water prices. One estimate indicates the current price of water used in agriculture is usually 10-50% of what is required to cover the full operating and maintenance of irrigation systems, while that figure is 10-50% of the value water is worth in terms of agricultural productivity. Consequently, a valuation system for agricultural water that recovered the full cost of agricultural water would raise the price to farmers by 4-100 times the current level (Perry, 2003).

Subsidised water undermines incentives to use water more efficiently, while excess water withdrawals impact base flows that are essential for maintaining ecosystem services (Poff et al., 1997; Arthington et al., 2003a, 2003b, 2006; Hirji and Davis, 2004). This leads to declines in riparian diversity and productivity that also adversely impacts communities dependent upon the ecosystem services provided by rivers. Large river flood plains comprise some of the most productive landscapes on the planet and the fisheries of large rivers are intricately linked to wetlands that are an integral part of flood plains (Welcomme, 2001).

Fisheries are a major source of food and income for sustaining the livelihoods of hundreds of millions of people worldwide, but particularly the rural poor in large areas of the developing world where hydro-dams have yet to be constructed – but which are currently being planned. For example, fisheries are the single most important source of income for flood plain dwellers in the Amazon (Almeida et al., 2002), and are the primary source of protein for rural households in Cambodia and Lao PDR (Baran, 2005).

Water prices have been increased in many locations in recent years as costs have risen for extracting, pumping, transporting and treating water. In Tunisia, for example, the price of irrigation water increased fourfold over a decade, while Australian water prices climbed 20-fold in 2006 due to a prolonged drought (Clark, 2007).

Full pricing is the economist's solution, reflecting the user-pays and polluter-pays principles, but history has shown it can be a Procrustean bed that fails to take contextual complexities into account, especially in the case of small-scale farmers in developing countries (Molle and Berkoff, 2007a, 2007b). Full marginal pricing is neither sufficient nor equitable. Raising prices will motivate many consumers to conserve, reduce waste, and invest in water-saving measures and efficiency gains if they have the financial resources. Full pricing, however, simply burdens the poor forcing them to do with less, or worse, to go without.

Moreover, full pricing in the absence of regulatory mechanisms does not address the need to sustain ecological health or the integrity of watersheds; on the contrary, recent water-sector reforms have unwittingly fostered an increase in the diversion of environmental flows beyond what aquatic ecology science deems sustainable (Takacs, 2009). That is why the IRP regulatory framework outlined above is critical to ensure ecological integrity and adequate water service delivery to the poor, by buffering higher water rates with lower bills, but just as importantly from a societal standpoint it also fosters the retention of water within catchment basins to sustain seasonal variation in base flows.

RATIONALISING HYDROPOWER DEVELOPMENT AND ECOSYSTEM BENEFITS ON WILD RIVERS

The demand for energy and water services that accompanies development and economic growth is now threatening to change the nature of the last great wild rivers of the humid tropics. The development of the hydrological resources in most of these watersheds is probably inevitable in the absence of a comprehensive IRP process, and the scale and design of any exploitation will depend on the degree to which policy makers adopt criteria of ecological integrity and environmental flows into their basin development strategies (Arthington et al., 2006).

The emphasis in almost all emerging economies and developing countries is understandably focused on expanding supplies of energy and water to grow their economies, reduce poverty, and improve the lives of their citizens. However, it is precisely for these reasons that a reformed regulatory framework is imperative that focuses on delivery of services at the point of use (Swisher et al., 1997; Foran, 2009; Sarkar, 2006, 2009; IFC, 2008; World Bank, 2009a). Failing this, the limited investment capital available in many of these countries deprives investment funds for educational and health systems that underpin the development of human capital.

The ongoing plans to develop the hydrological resources of the Mekong river are emblematic of the trade-offs that come with the exploitation of an intact wild river, which is a treasure trove of biological diversity, as well as a productive system that supports tens of millions of people.

The current set of plans to develop the Mekong river is now the product of the strategic development strategies of the independent and sovereign nations that are found within the boundaries of its physical watershed: China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam. The development of the Mekong river is probably the most ambitious basin development initiatives under way at the moment (MRC, 2008). According to an Asian Development Bank commissioned assessment, some 73,000 MW of 'expansion candidate' hydro projects have been identified (Norconsult, 2003).

None of these candidate hydro-dams have been assessed in national comprehensive IRP cost and risk ranking methodologies, let alone at the regional scale akin to the multi-state IRP process in the US northwest region successfully operating for three decades (NPCC, 2010). If required to do so a substantial number of them would be uncompetitive against a large pool of lower-cost options. Currently, demand projections are constructed in a closed process strongly influenced by monopoly electric utilities that are incentivised to overestimate demand. Moreover, many hydropower projects in the region are not feasible without substantial subsidies such as grants and risk guarantees, soft loans, and political intervention in power purchase agreements; as well as without a subsidised regional transmission grid (Greacen and Palettu, 2007).

In addition, the potential impact of these multiple facilities on the ecosystem of the basin is the subject of a vigorous debate, because the Lower Mekong basin is arguably the world’s most productive freshwater fishery. For example, ~2.6 megatons of fish are harvested annually and provide 50-80% of the protein consumed by the tens of millions of people who live within the confines of this watershed (MRC, 2009).

Moreover, the fisheries resource provides not only sustenance to impoverished subsistence fishermen and farmers but also the basis for a commercial fishing industry that includes small-scale fishermen and middlemen who commercialise the harvest in urban markets of Vientiane, Phnom Penh and Ho Chi Minh City. One major concern is the impact of the main stem dams, which will act as physical barriers to fish migration and lead to wide-scale alteration of economically important fish populations and the probable extinction of numerous species. Just as important, however, is the potential impact of modified water flows on a river system characterised by extreme seasonal fluctuations driven by a strong monsoonal climate (Lamberts and Koponon, 2008).

The Mekong is emblematic of challenges facing proposed hydropower facilities in other large catchment basins around the world. For example, Brazil is proceeding with numerous mega-dam projects on the Madeira river, one of the principal tributaries of the Amazon, while the world’s third largest hydropower project, Belo Monte on the Xingu river, continues unabated – none going through a rigorous and comprehensive IRP cost and risk ranking methodology review process (Killeen, 2007). Ironically, Brazil’s own recent past provides a powerful example of the power of efficiency gains to resolve constraints to power supply and spur economic growth, as well as the risk of developing an over-reliance on hydropower (Jannuzzi, 2005; Taylor et al., 2008).

In 2000, a severe drought associated with the 1999/2000 La Niña event decreased power generation by 15% at the Itaipú hydro facility that supplies 20% of Brazil’s electricity. It plunged Brazil into an energy crisis with severe economic consequences. In response, the Brazilian government implemented a public relations campaign coupled with energy rationing measures that promoted energy efficiency in industry and commercial businesses. Once the drought receded and energy production returned to normal, the growth in energy demand was suppressed for several years as companies had mainstreamed these efficiencies into standard business practices. As a result, the expected growth in consumption of natural gas did not materialise and the national oil company, Petrobras, was forced to pay for natural gas it did not consume as part of a 'take-or-pay' contract it had signed with its principal supplier, the national oil company of Bolivia (Glachant and Hallack, 2009). The Brazilian experience highlights both the risk of over-reliance on hydropower in areas that experience periodic large-scale, drought events, as well as the potential for end-use efficiency gains to improve profits.

Mega-hydropower schemes are also being pursued on the African continent, again without any comprehensive IRP cost and risk ranking methodology. Both the World Bank and the Chinese are driving investment in Africa's hydropower infrastructure. Most African countries have poorly developed distribution networks that impede the consumption of inexpensive electrical energy by rural populations, while developing hydropower is seen by many as a necessary first step in developing these systems. However, hydropower is frequently used to subsidise industrial facilities with little benefit for native populations, as is the case with the Inga hydropower station on the Congo river which provides power to the Katanga mining district located 2000 km away from the power plant. The existing Inga power stations are linked to two relatively small dams that block off just a small single channel located just 90 km from the mouth of the river, where the Congo drops approximately 90 metres over a distance of a few kilometres. However, the Inga site is undergoing evaluation for a massive expansion involving complete blockage of the river for a 150-metre high dam with 40,000 MW of installed capacity – twice the size of China's Three Gorges dam.

The Inga mega-dam would not pass an objective environmental evaluation, and its consideration only highlights the need for a comprehensive reform of the hydropower sector. Mega-projects are predicated on aggregating the energy and water needs of several nations, since a project's output would greatly exceed the domestic demand in any one country. However, for several decades it has been known that demand-side aggregations offer compelling competition, especially given the market transformation opportunities in promoting high-efficiency in all the new construction, manufacturing, and market for appliances, office equipment, electric motors, lights, etc. (Totten, 1991; Totten, 2010).

CONCLUSION

The balance between human water use and watershed health and ecological integrity is one of the great conundrums of our time. Humanity's moral imperative to end poverty and its aspirations for prosperous well-being have come up against the human recognition that the ecosystem services provided by healthy watersheds are collapsing from human overuse and abuse (MEA, 2007). Only smarter and sagacious policies, regulations and practices, informed and updated by ongoing scientific research, give us hope of resolving this intricate and difficult dilemma. This paper has highlighted a critically important one – IRP/decoupling/end-use efficiency; and other integrated policy, regulatory and financial mechanisms are emerging that hold great promise, such as 'soft water' strategies (Gleick, 2003a; Brooks et al., 2009). These innovative market transformation policies and regulatory tools offer immense opportunities for expanding greener economies while reducing poverty and reducing or preventing GHG emissions, other air and water pollutants, and reducing the overuse and abuse of watersheds.

Scientists are the first to recognise and emphasise that there are no static, one-answer-fits-all-cases to the question of 'How much water does a river need, or how much can we change a river's flow regime before the aquatic ecosystem becomes degraded'? (Arthington et al., 2003a, 2003b, 2006). Dynamically complex ecosystems like watersheds, coupled with dynamically complex human social-economic systems, require evolving adaptive management decision-making processes. Nevertheless, we do have available, and need to apply, the different environmental flow methodologies capable of addressing these questions, depending on whether the focus is on retrieving flows in over-allocated and regulated streams where dams and substantial water extractions are already ever present, as opposed to where the water resource is still undeveloped. In the latter case a benchmarking methodology can be used to help decide, in advance, what components of the flow regime should be preserved to maintain biodiversity, ecological processes and the evolutionary potential of water-dependent ecosystems, including estuaries and coastal waters (Brizga et al., 2002).

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