Visiting Scholar Program

August 2008

Energy–Water Nexus. Why Should the Corps Care?

2008-VSP-01

US Army Corps of Engineers®

IWR

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Visiting Scholar Program

Throughout its history, the Institute for Water Resources (IWR) has invited preeminent water resources academicians and practitioners to take up residence at the Institute to foster scholarly exchange. At any given time, IWR frequently has faculty from universities spending time in residence at the Institute. Both IWR and the Corps benefit from such faculty engaging in ongoing water resources studies and research on a reimbursable basis. Visiting scholars are expected to help infuse new energy and ideas to the IWR program, while the practical work environment at IWR and/or the Hydrologic Engineering Center (HEC) provides a stimulating context for mutual exploration of potential advances in hydrologic engineering and planning analysis. Such experiences have proven to be intellectually invigorating for both the Institute staff and the visitors themselves.

American Association for the Advancement of Science Science and Technology Policy Fellows Program

Through the American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellows Program, IWR sponsors post-doctoral and senior fellows to work on water resource policy issues such as analyzing the linkages between water resources development and water resources problems (e.g. drought, floods) and the economies of developing nations. Individuals with a systems engineering, economics, public participation or water resources background are especially encouraged to apply. This highly selective fellowship program gives scientists and engineers a real-world introduction to how science interacts with policy in Washington.

Leo R. Beard Visiting Scholar Program

For many years, the Hydrologic Engineering Center (HEC) has invited prominent hydrologic and hydraulic professionals to take up residence at HEC in Davis, CA to foster scholarly exchange. Faculty from a number of universities have spent some of their sabbatical with HEC and on occasion HEC has also had prominent engineers from other agencies join the Center in the same capacity. The experience and the exchange of ideas that these scholars bring to HEC have proven to be intellectually satisfying and productive for both HEC staff and the visitors themselves. Such scholars in residence are known as "Leo R. Beard Visiting Scholars."

Maass-White Visiting Scholar Fellowship

The Maass-White Visiting Scholar Fellowship is designed to ensure that today's water resources challenges benefit from innovative thinking of the nation's top academics, and to promote a deeper understanding of real-world water resource problems by those in academia. The fellowship honors the late Arthur Maass and Gilbert F. White–two scholars who had a revolutionary impact on the practice of water resources planning and management.

National Research Council Research Associateship Program

Through the National Research Council (NRC) Research Associateship Program, IWR sponsors postdoctoral and senior research awards to conduct relevant research for one to two years at one of IWR's locations. Fellowships are given for the purpose of conducting research (chosen by the doctoral level scientists and engineers) to apply their special knowledge and research talents to areas that are of interest to them and to the host laboratories and centers.

UCOWR Water Resources Fellowship

The Universities Council on Water Resources (UCOWR) and IWR developed a visiting scholar program in 2003. The program invites academicians to the Institute to focus on emerging water resource issues of relevance to the civil works mission. While on sabbatical these scholars are expected to perform applied, policy-relevant research to extend the Corps of Engineers knowledge of and thinking about emerging water resources needs and issues. UCOWR Fellows, chosen via a UCOWR/Corps panel, are university professors who have substantial applied experience in water resources planning and management, as well as strong teaching credentials.

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American Association for the Advancement of Science
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Energy–Water Nexus. Why Should the Corps Care?

Alexey Voinov

> Water "will be to the 21st century what oil was to the 20th."
>
> *Fortune magazine, 2000*
>
> "That's a big no. The president believes ... that it should be the goal of policymakers to protect the American way of life. The American way of life is a blessed one."
>
> *Ari Fleischer, White House Press Secretary responding in May 2001 to whether Bush would ask Americans to curb their first-in-the-world energy consumption.*

Abstract

Water and energy are the two renewable resources that are most essential for human livelihood. Whereas we have been mostly concerned with non-renewable resources, as the human population grows in size and in terms of the impact that it has on the biosphere, the renewable resources become equally important. Even renewable resources may become limiting if the rate of their renewal is not fast enough. Renewal of water is dependent on energy. Production of energy, especially of renewable energy (biofuel and hydro), is dependent on water.

The water sector, including treatment and conveyance, is presently one of the largest users of energy, comparable to the paper and refining industries. Water acquisition, management, movement, distribution, purification and post-use treatment are large users of energy (Anderson, 1999). Water sector energy demand will likely substantially outpace growth in other high-energy use sectors. Water is similar to oil in that it is embedded in all human systems, even if it is not directly recognized as such. An average American consumes 7 times more water via the dietary food production (3997 liters/day – 1000 gal/day) than with all of the other daily domestic uses (Chapagain, Hoekstra, 2004).

By all accounts it seems unlikely that the current goal of providing additional supply for the growing water and energy demand will be sustainable and even feasible. We will have to focus on meeting our needs, rather than wants, in terms of both energy and water. As it will become increasingly hard to provide additional supply, we will need to pay attention to managing demand. By providing expertise and technology for integrated water management, as well as by discharging its regulatory missions, the Army Corps of Engineers is uniquely placed to recognize energy/water interactions and to contribute to demand reduction efforts.

Disclaimer

Executive Summary

Water and energy are the two renewable resources that are essential for human livelihood. Renewable resources may become limiting if the rate of their renewal is not fast enough. Renewal of water is dependent on energy. Production of all energy, especially of renewable energy (biofuel and hydro) and alternative fossil energy (liquid coal, oil shale), is dependent on water. In any case, for energy and water, we compensate the shortage of flow by digging into the stock. The fossil fuels and water are the non-renewable reserve that we are quickly depleting. This is an unsustainable practice that leaves future generations with less option and more risks. Both energy and water belong to the so-called Critical Natural Capital category, which means that they are essential for human survival. As they become scarce, they exhibit high price inelasticity of demand, so that a small reduction of quantity leads to a huge increase in price.

Water and energy are intimately intertwined. Water is required in production of all forms of energy. Energy is essential for water supply, treatment, desalinization, etc. For a valid assessment of these resources we need a Life Cycle Assessment (LCA) that would track all the flows and storages and figure out the inputs and outputs. Two parallel indicators are useful to compare various water and energy related technologies and uses: the Energy Return On Water Invested (EROWI), and the Water Return on Energy Invested (WROEI).

As demand for water grows there will be less water available and more competition with regards to energy production. As water becomes limiting, there will be more pressure on water-intensive energy production to seek alternatives. The EROWI helps compare various methods of energy generation in terms of water consumption. The best EROWI for biofuels (sugar cane ethanol) is over two orders of magnitude lower than the most water efficient fossil energy sources, which means we will likely need more water to produce the same amount of energy as we shift from fossil fuels. As the cost of energy increases, more energy efficient technologies and modes of operation will become in more demand. In particular, since the cost of transportation by water is one of the lowest, there will be an increased role of navigation throughout the country.

If there were unlimited energy, we would never have a problem with water scarcity. We could simply desalinize vast amounts of saline ground and seawater to provide for all the imaginable water demands. But with energy becoming increasingly scarce energy efficiency becomes a major concern. Water supply in this case will need to compete with many other energy uses, and the Water Return on Energy Invested (WROEI) concept will become a useful measure to compare various water supply projects. The major sinks of energy in connection with water are for building and maintaining the infrastructure, for pumping water, for wastewater treatment, directly for transportation, and for desalinization.

So far the solution to both energy and water shortage are found on the supply side. The traditional approach is to forecast the growth trends for demand, and then seek resources, either through new and improved technologies, or through new drilling, damming, pumping, and transporting. Most of the Federal and State effort is focused on increasing the supply. Yet problems with energy and water supply are looming. Two major factors may have a negative impact on the supply side: climate change and diminishing availability of low cost petroleum as we pass through the peak of oil production, while global demands continue to grow.

These two factors have the potential to have a strong destabilizing effect on world economy and energy markets, which may likely result in calls for lower environmental standards, deregulation and privatization. There is a growing sense of urgency because both water and energy related projects require significant time and investments and cannot be implemented as a last minute fix when emergencies already hit.

USA has one of the highest water consumption rates in the world. It also consumes 22.5% of world energy, while it has 4.8% of world population. This makes USA especially vulnerable to any changes in water or energy supply.

Curbing demand is probably the cheapest and fastest solution to most of the problems with supply. Improved energy efficiency and lower consumption of energy saves both energy and water. Optimal water use saves both water and energy. More and more people are realizing this and governments in the US and around the world have begun to respond (through energy saver regulations, voluntary and domestic energy efficiency programs). But as public awareness and costs of our high use rates increase (as they naturally will), the focus on water and energy efficiency and reduced demand will likely shift from the solely technical, engineering arena to the socio-psychological domain. From the growth paradigm, which is central to most of the policy of today, we will move to alternative sustainable approaches.

There is an urgent need for a paradigm shift from promoting growth to sustainability. It is unlikely that demand will be able to determine supply on a finite planet. There are clear limits to supply whereas demand is unlimited. It would make more sense to manage demand and to peg demand to the supply that is available. This also applies to spatial distribution of resources: we should develop demand in those places where we have supply, and to the level, which can be sustained.

The overall principle would be that instead of focusing on help with supply, Federal Agencies should be focusing on demand, finding better ways to constrain growth in areas that are limited by water and energy, subsidizing plans that would work for a more sustainable future. At present some States turn out to be much more restrictive and conscious in their development plans than the Federal level. States are starting to seek alternatives to traditional energy and water supply, and develop restrictions that are more stringent than the Feds require. The Federal government has a duty to provide leadership in terms of developing technology and policy alternatives geared toward quantum leaps in water and energy demand reduction, promoting less damaging technologies and more sustainable futures.

There is a clear need for an integrated Federal Water and Energy Policy that would assist states in planning, assessment and management.

Among other priorities that can be solved in the **Federal level** are:

- Information and data sharing – the Corps should collaborate with DOE, EPA, USGS, BuRec and other agencies in developing an open access information and knowledge base that would contain data, tools, methods and models to facilitate decision making at local and regional levels.
- National drive to efficiency should include outreach and public education. Public announcements on TV and radio can be an effective method of education.

- Enhancing the available water supply through the development of new technologies, conservation, metering, more efficient storage, water banking and other water transfers.
- Enhancing energy supply through conservation, CAFE standards, cap & trade and taxes for CO_2, etc.

The role of the Corps could evolve towards a water stewardship and planning function. From a project-to-project approach that has mostly dominated in the Corps operations, a more holistic watershed approach should be encouraged. The Corps could take the role of resource management contributing to overall energy and water sustainability. As we have seen water and energy planning has to be integrated.

We have identified five **priority areas** for the Corps to stress in order to help the nation address water-energy connections:

1. **Infrastructure rehabilitation and optimization.** The Corps large infrastructure portfolio includes significant hydropower generation. Yet inefficient operation on a systemic basis and rehabilitation needs reduce the production of this low cost environmentally-friendly energy source. Working with DOE, FERC, and the private energy sector, the Corps could increase hydropower production through system-wide optimization and infrastructure rehabilitation.
2. **Demand expertise.** Inject expertise and best management practices for demand management into the planning and permitting processes. Prioritize demand reduction alternatives when issuing permits. Use Corps labs to develop technologies, models and tools to assist manage demand. Foment technology transfer of energy and water efficiency technologies from other parts of the Army and DoD laboratories, and back from civil research to the military, which is also very concerned about water and energy efficiency.
3. **Systems perspective in planning and operations.** Foster a stewardship approach to watershed planning and management. Research on navigation / energy supply /support to states on assessment and demand management. With energy experts, develop expertise on how to incorporate energy and water linkages in support of watershed planning. Work with other federal and state agencies to ensure that this information is readily available for stakeholders and to support other planning efforts**.** With a tighter resource base and higher risk of large climatic and infrastructure disruptions build more resilience into engineering projects and develop clear strategies for flood and drought mitigation. This links directly to two major missions of the Corps – navigation and ecosystem restoration.
4. **Outreach and Education.** To fully implement its evolving role as a natural resource manager, the Corps will need to delve into more outreach and education programs. Already the Corps' natural resource management community has embraced that role, and this could be expanded to distribute information aimed at different sectors on water efficiency technologies and energy-water linkages and assessment methods. In this task the Corps can take advantage of its distributed network of Districts, Divisions and local installations to offer educational materials to the public, water-intensive industries, and municipalities.

5. **Governance and Collaborative problem solving.** Most of the controversies with the state level can be resolved if we open up the regulatory process to stakeholder participation in various stages of the decision-making. The Shared Vision Planning process institutes an on-going collaborative learning effort when there is an iterative exchange between federal, state and local levels on priorities, data, analysis, scenarios and decisions. It is an open ended adaptive process that is the only possible way to manage open evolving systems, such as watersheds, and SVP and other similar methods and techniques become essential. The Corps can work with other federal and state partners to further develop and popularize such alternative dispute resolution methods and technologies.

We should bear in mind that currently the political situation is quite favorable for change in this area. We need a concerted effort between several federal agencies to frame the right strategies and priorities in this field.

1. Connections and feedbacks

Water and energy are the two renewable resources that are essential for human livelihood. (Along with the others such as clean air, biomass, etc.) Whereas we have been mostly concerned with non-renewable resources, as the human population grows in size and in terms of the impact that it has on the biosphere, the renewable resources become equally important. Renewable resources may become limiting if the rate of their renewal is not fast enough. Renewal of water is dependent on energy. Production of energy, especially of renewable energy (biofuel and hydro), is dependent on water. In both cases, for energy and water, we compensate for the shortage of flow by digging into the stock. The fossil fuels are a non-renewable reserve that we are quickly depleting. It is actually that stock that allowed humans to develop into a force, which could match the force of geological processes, such as earthquakes, or hurricanes (Vernadskii, 1986). This also means that human action is now seen in the global level, so that crises of civilization and extinctions that we used to see locally or regionally (Maya, Incas, Ancient China, etc.) this time is more likely to occur at the global scale. There is a clear need for alternative development goals and paradigms. As with energy, we are compensating lack of water flow by extracting from fossil groundwater reserves and depleting aquifers where pumping exceeds recharge. In both cases this is an unsustainable practice that leaves future generations with less options and more risks.

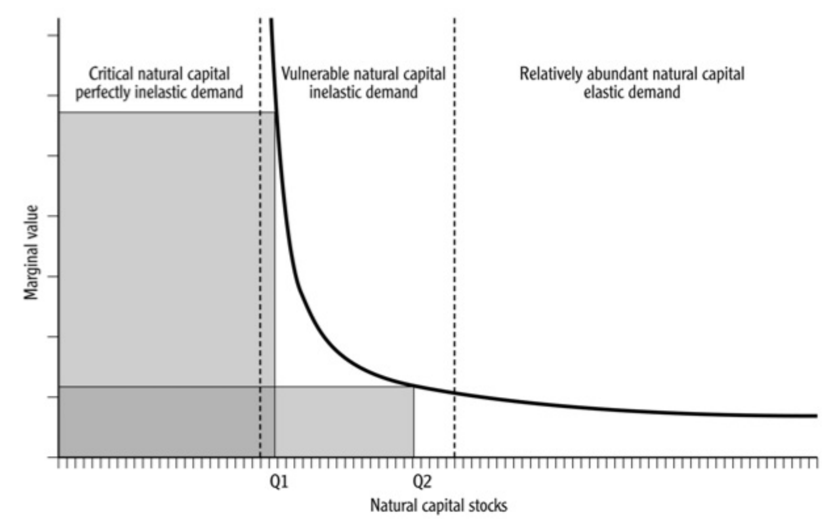

Fig.1. Demand and supply curve for a critical natural capital.

Both energy and water belong to the so-called Critical Natural Capital category, which means that they are essential for human survival. As supply becomes scarce, they exhibit high price inelasticity of demand, so that a small reduction of supply leads to a huge increase in price (Fig.1). At this stage the total value (price x quantity) paradoxically increases as total quantity declines (Farley, Gaddis, 2007). This is true for any resource that is essential and non-substitutable. As there is less water or energy available their price quickly increases towards infinity. This creates havoc in markets and stresses the whole economic system, which is what we have already seen during the energy crisis of the 1970's. With diminished water supply, this may lead to direct conflict and violence, as it has developed in Africa in Chad and Darfur, where according to experts, the underlying tensions between mostly nomadic Arabs and sedentary black farmers – both of whom are Muslim – is their centuries-long competition for water and land, a competition that has been exacerbated by decades of drought. When energy and water supplies are abundant their value is low, it may seem that we have an infinite supply, and there is no need to worry.

However, as we approach depletion, even small perturbations due to unforeseen climatic events or technical malfunction results in disproportionate changes in their values and prices, if the market is allowed to work.

It should be also noted that as long as we rely upon purely renewable energy and water they are non-rival and non-excludable. That is, solar energy and rainfall are available more or less uniformly, over vast territories. Whoever is located there has access to that water and energy. We cannot prevent our neighbor to have equal access to sunshine or rainfall, we cannot exclude someone from using it, and since there is no rivalry it makes no sense to attempt to do that. However as we need to dip into reserves, into fossil water or energy, or even into the temporary reserves (lakes, reservoirs, or forest and crop biomass), immediately the resources become excludable and rival (Daly, Farley, 2002). You can put a fence around a reservoir, or you can outlaw pumping water from underground, like Israel did in Palestine. This changes the whole political landscape and requires different types of management. As resources become scarcer and we dip into stocks, we create potential for conflict situations (water and energy wars).

For both energy and water it is not just the quantity that matters, but quality as well. For water, quality is measured by the concentration of impurities, constituents dissolved or suspended in the water, as well as by its physical characteristics, such as temperature. For most part, we use water of much higher quality than actually needed for many uses beyond drinking and cooking, economizing on the infrastructure that is built to deliver water of only one type of quality. For energy, quality means efficiency, reliability and continuity of supply. The efficiency can be measured by the EROEI index, discussed below. More efficient supply is also more reliable and easier to provide.

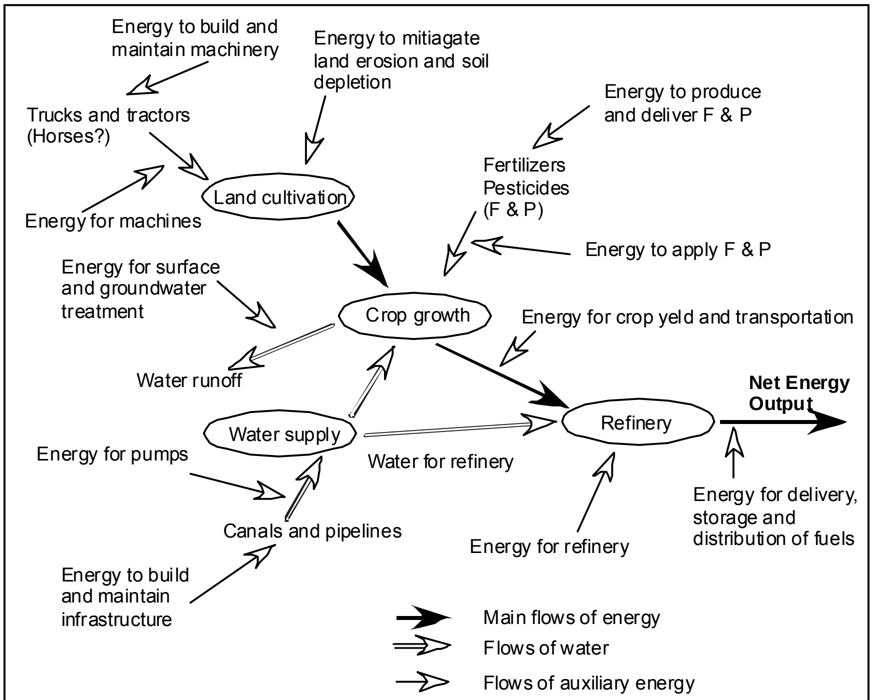

Fig.2. The life cycle of energy from biomass production.

Water and energy are intimately intertwined in almost any application field. For example, in biomass production we can see how water is essential for energy, while energy is needed to produce water (Fig.2). For a valid assessment of these resources we need a Life Cycle Assessment (LCA) that would track all the flows and storages related to both water and energy and figure out the inputs and outputs.

With this level of system complexity and feedback it becomes increasingly hard to produce reliable quantitative estimates of flows and outputs, with much uncertainty involved. Many of the processes have indirect effects that may considerably change their overall impact on the system. For example, in many water supply studies evapotranspiration would be considered as a net loss of water for the system. It will be argued that crops with lower evapotranspiration (say corn) are less consumptive for water resources than perennial grasses or woody species (say willow or sorghum). In this same context forests would be positioned as landcover with a relatively high evapotranspiration rate. However this calculation does take into account the orders of magnitude higher infiltration rate that comes with grasslands and forests. In fact it is exactly this fast recharge of the atmospheric moisture with very little losses to surface runoff that powers the intracontinental moisture transfer, which makes the whole Amazon forest possible. Evapotranspiration in this context appears as a much lesser loss than the increased impermeability or faster runoff that comes with some of the other agricultural or residential land uses.

Moreover, we are dealing with open systems, which boundaries are difficult to draw and which are constantly influenced by external factors. Such systems tend to change on the fly, especially once we start managing them. This makes it only more important to provide for a large margin of error, to make sure that there are sufficient resources available to compensate for erroneous predictions. The precautionary principle should be applied to its fullest extent. The analysis requires a watershed based full ecosystem approach. This can only boost new invention and alternative technologies, as well as development of improved predictive tools and models.

Otherwise simple solutions, like growing corn for ethanol, may easily lead to undesired externalities (increased soil erosion, higher food prices, water shortages, and water pollution by pesticides, nutrients and sediment), as well as risks (climatic dependencies).

> To produce a liter of ethanol absorbs three to five liters of irrigation water and gives off 13 liters of waste water. It takes the energy equivalent of 113 liters of natural gas to treat this waste, increasing the likelihood that it will be released into the environment to pollute streams, rivers and groundwater (4). Intensive cultivation of fuel crops also leads to high rates of erosion, particularly in soy production - from 6.5 tons/hectare in the US to up to 12 tons/hectare in Brazil and Argentina.
>
> The Ecologist, 21 May 2007

> Rainfall is at least 20 inches below the normal 32 inches and in some places far lower than that. Jerry Newby, president of the Alabama Farmers Federation, said: “It’s gone from bad to worse. All of the corn is pretty much lost that’s not under irrigation.”
>
> On Monday, the entire state was declared a drought disaster area by the federal Department of Agriculture, making many farmers eligible for low-interest emergency loans. “Nobody alive has ever seen it like this,” said Perry Mobley, the beef and hay director of the farmers’ federation. And the National Weather Service says conditions are unlikely to change until fall.
>
> Out at Mr. Bragg’s 7,000-acre, third-generation spread just north of Huntsville, immediate worries are pressing: he is facing the classic farmer’s debt squeeze, with heavy investment $1 million in giant new silos, a down payment on an ethanol-based future and little revenue to pay for it. Mr. Bragg is contemplating a $500,000 loss.
>
> ADAM NOSSITER, Drought Is Sapping the Southeast, and Its Farmers.
> The New York Times , July 2, 2007

There may be different metrics to account for energy and water stocks and flows. The footprint approach accounts for the total amount of water used by a country, region, business or even an individual. The water footprint has been developed in analogy to the ecological footprint concept as was introduced in the second half of the 1990s

(Wackernagel and Rees, 1996; Wackernagel et al, 1997; Wackernagel and Jonathan, 2001). The 'ecological footprint' of a population represents the area of productive land and aquatic ecosystems required to produce the resources used, and to assimilate the wastes produced, by a certain population at a specified material standard of living, wherever on earth that land may be located. Whereas the 'ecological footprint' thus shows the area needed to sustain people's living, the 'water footprint' indicates the annual water volume required to sustain a population. According to this metrics the global water footprint is 7450 Gm^3/yr (1,960,000 Ggal/yr), which is 1240 m^3/cap/yr (326,120 gal/cap/yr). This is total water uptake and does not include water returned and recycled. The differences between countries are large: the USA has an average water footprint of 2480 m^3/cap/yr (652,240 gal/cap/yr), while China has an average footprint of 700 m^3/cap/yr (184,100 gal/cap/yr) (Chapagain, Hoekstra, 2004). The internal water footprint of a nation is the volume of water used from domestic water resources to produce the goods and services consumed by the inhabitants of the country. The external water footprint of a country is the volume of water used in other countries to produce goods and services imported and consumed by the inhabitants of the country. While the water footprint is affected by geographical and climatic conditions, it still gives an idea of overall water supply and demand in various locations. It also explains the patterns of water demand. For example, the high water footprint of the USA is primarily because of high meat proportions in the diet of the people and high consumption of industrial products.

As noted above, most of these calculations for water are hard to interpret, because they estimate the overall water withdrawals, but do not take into account that significant quantities of water are returned back to the hydrologic cycle through evapotranspiration, seepage, direct return flows. Theoretically, no water is entirely lost; it just changes its form, or quality. For example, only a small proportion of water that is used for irrigation is entirely removed from the system with the exported crop. Most of the water remains in the system, but in a form that is no longer useful for consumption. Only through considerable inputs of energy the water may be brought back to the standards needed for its reuse.

Water quality can be significantly affected by energy related projects. Water used for cooling purposes in power stations is returned to the river with a higher temperature, which may prove detrimental to some fisheries. Hydropower that requires dams can also significantly affect physical and chemical parameters of water. Mining destroys whole landscapes including streams. Water serves as an integrator of all kinds of activities on the watershed and is one of the prime indicators of ecosystem health.

Mountaintop removal mining does exactly what it says - in order to get at thin seams of coal that lie within, like cream through the middle of a sponge cake. Millions of tons of rock are blown up, scraped away and poured into surrounding valleys, filling them to the brim. What was a mountain range is turned into a flat and almost barren desert of rock.

It is the damage to the water system that is the biggest disaster. The mining has been blamed for a massive increase in flash floods that wash away people's homes. It is also blamed for cancer-causing selenium in water and other pollution that has poisoned fish. West Virginians have been advised by the government that locally caught fish are too dangerous to eat more than once or twice a month.

For Gunnoe the issue is an immediate one. Since the mountains and valleys went, her property has almost been washed away. Her home is now isolated behind a deep gorge that cuts her off from any road. 'It used to be just a little stream you could step over,' she said. The stream has now cut a gully 20ft deep and 67ft wide. Gunnoe's house has lost all its value. She cannot get insurance. She knows that she will eventually have to leave.

Paul Harris. A ravaged US state is fighting back against mining bosses who backed Bush, Paul Harris reports in Charleston, West Virginia. Guardian Unlimited, Sunday January 16, 2005

On the other hand, certain technologies can improve water quality. For example, the carboxylate ethanol refinery can take raw sewage as water input and provide distilled water as output, while it's the overall EROEI of this fuel is an order of magnitude higher than that of corn ethanol (Holtzapple, personal communication).

Another example of the complex feedback mechanisms that we need to consider is associated with ecosystem services. Ecosystem services are not a matter of our choice and recognition. We may include them in our valuation and price mechanisms, or not, we may recognize their importance or not, but they are still there. Allocating water to provide for ecosystem services is generally considered as a negative in overall water balances. The claim is that by diverting water to wetlands and estuaries to protect habitat and wildlife we may be depriving human systems from access to that water (Dziegielewski and Kiefer, 2006). Allocation of water for ecosystem services does not necessarily come with a "minus" sign on the demand balance sheets. On the contrary, it may well be a way to save water. Applying LCA and full feedback accounting we can easily relate ecosystem services to net gains in, say, energy and water quality and quantity. By protecting watersheds, for example, we may be providing clean water and eliminating expensive and energy thirsty water treatment that would be required otherwise. Similarly creating and protecting natural rivers and pervious land cover we may be securing groundwater recharge, providing for water supply and avoiding extreme draught and flooding condition, saving on energy needed otherwise. The classic example is the Catskills in NY. In the Catskills study it was shown that the restoration of the Catskills watershed would be more cost-effective than constructing a new drinking water filtration system as a way of addressing New York City's drinking water quality problems. As a result, New York City decided to spend more than one billion dollars on increased protection and restoration of the watershed (NRC, 2000).

There should be a clearer distinction between water demands for recreational purposes, and using water to support ecosystem services. While pure recreational use may indeed happen at the expense of other water withdrawals (agriculture, industry, domestic), this is not the case with ecosystem services, where the feedbacks are much more complex and multifaceted. By reserving water for protecting ecosystem services we may as well be increasing the overall water supply and its quality.

2. Water for energy

As demand for water grows, there will be more competition with regard to water needed for energy production. As water becomes as limiting as energy, there will be more pressure on water-intensive energy producers to seek alternative supplies. The Energy Return On Water Invested (EROWI) becomes a useful indicator to compare various methods of energy generation. Ideally, EROWI can be estimated for a given technology by applying the Life Cycle Analysis (LCA) methodology (International Standard Organization 1997) to calculate the energy produced per unit of freshwater used (megajoules/litre, MJ/L or kcal/gal, 1 joule = 0.24 cal = 0.00028 watt/hour) for a given technology. Variations of the LCA methodology are generally used to calculate the EROEI for a technology (see Spreng 1988 for an overview) and the application to water is analogous. However things become complicated since water does not necessarily have to be consumed to produce energy. Much of the water withdrawn for energy production is returned back and can be reused. The only consumption occurs when water is either lost through evapotranspiration (in which case it may also reappear but at a different place with precipitation) or degraded through contamination that changes its chemical (toxic additions, including nutrients, pesticides, herbicides, etc.) or physical (water temperature, oxygen content, etc.) properties.

The EROWI index can be calculated in a way similar to the EROEI (Energy Return on Energy Invested) index. If e_{out} is the amount of energy produced, and e_{in} – the amount of energy used in production then EROEI, $e = e_{out} / e_{in}$. In some cases the net EROEI index is used, which is the amount of energy we need to produce to deliver a unit of net energy to the user: $e' = e_{out} / (e_{out} - e_{in})$. Or $e' = e / (e - 1)$.

Similarly the EROWI index would then be: $e_w = e_{out} / w_{in}$, and net EROWI, $e_w' = (e_{out} - e_{in})/w_{in} = e_w / e'$. The EROEI index is usually criticized for not taking into account all the other resources (including social and environmental ones) that are required to produce energy. One could assume that as long as a technology has an $e > 1$, it can be then chained as many times as needed to produce infinite energy. This is certainly not the case. So EROEI is a good indicator to make comparisons between technologies, always keeping in mind the other limiting factors that can play a crucial role (such as availability of land, environmental carrying capacity, CO_2 and other GHG emissions, etc.). Water is one of such other limiting factors, so the EROWI index is a good supplement to the EROEI index, taking into account the water needs for energy production.

Mulder et al. (2007) estimate EROWI and net EROWI by technology showing that it can range from 0.025 MJ/L for electricity production from biomass up to 285.3 MJ/L for petroleum diesel. Net EROWI for the same technologies was 0.02 and 228.4 MJ/L respectively. The best Net EROWI for renewables (sugar cane ethanol) is 0.903, over two orders of magnitude lower than the most water efficient fossil energy sources.

Indeed, the study by Kannan et al. (2004) for a petroleum power plant in Singapore shows that even electricity production, one of the least water efficient forms of fossil energy production, can be made very water efficient when necessary. Singapore has perennial shortages of fresh water and the petroleum power plant studied there has an EROWI seven times higher than typical recirculating power plants. This is because direct water withdrawals are reduced to less than 0.02 L/MJ, a number dwarfed by the lower-bound water withdrawals of 13 L/MJ for biomass electricity production from Berndes (2002). This implies that the most water-efficient fossil electricity source we discovered yields almost 600 times as much energy per unit of water invested as does the most water efficient biomass source of electricity reviewed by Berndes (2002). See Appendix for more data.

Ethanol refining currently consumes 4-8 liters (1-2 gal) and uses ~ 130 liters (34.34 gal) of water for each liter of ethanol, so we need 480

> The mass quantity of water needed for Iowa's booming ethanol industry - billions of gallons each year - has raised concerns among state officials who say laws may be needed to prevent a water shortage in the state. Several lawmakers say that a close look at the issue is necessary and that laws may be needed to require ethanol facilities to recycle water.
>
> "As it relates to water, I'm more concerned about the production of ethanol right now" than with the proximity of livestock facilities to streams, said state Sen. Matt McCoy, a Des Moines Democrat. "That's got me very, very concerned."
>
> Ethanol advocates say the fear is unfounded and that, in general, the industry already pushes itself to conserve and maintain a reliable source of water.
>
> "Ethanol stirs fear of water shortage. Some say Iowa fuel plants may be depleting supplies". By JASON CLAYWORTH. July 19, 2007. http://desmoinesregister.com/apps/pbcs.dll/frontpage

Table 1. Estimated use of water for various technologies of biofuel production (M. Holtzapple)		
	Irrigation use	Refinery use
Oil	0.5 – 1 liter water/liter gasoline	
Corn	0 - 1909 l water/l ethanol	2 - 5 l water/l ethanol
Cellulose (Sorghum)		
Sugar:	0 - 398 l water/l ethanol	5.9 l water/l ethanol
Thermochemical:	0 – 380 l water/l ethanol	1.65 l water/l ethanol
Carboxylate:	0 – 277 l water/l ethanol	2.28 l water/l ethanol

million to 4 billion m^3 (127-1056 billion gal) of water to provide for the Presidents' 2025 goal of producing 120-240 billion liters (30-60 billion gal) of ethanol. Some new technologies converting cellulose to fuel uses even more water per liter of fuel gained than converting corn to ethanol, though other technologies can be actually using sewage and producing clean water. Irrigated seed and field corn needed for ethanol add another 4 to 7 liters of water for each liter of fuel. Irrigating marginal land will need 1000 times more.

It should be also noted that various technologies have different patterns of water consumption. For example, in biofuel production irrigation requires orders of magnitude more water than biorefineries (see Table 1).

However the intensity of water consumption can be much higher for refineries, where thousands of cubic meters of water are to be withdrawn on the spot, significantly changing local hydrology and requiring additional infrastructure to provide that water.

To produce one barrel of coal-to-liquid, a refinery uses 2.5 barrels of water. China, which had embraced this technology, announced just days before the August Public Energy Authority meeting that it needs to curb coal-to-liquid, because of concerns over pollution and the volumes of water consumed. More than 4 liters of water are needed for every liter of transportation fuel produced, threatening our limited water supplies (DOE Report, 2006, p.80). Water required to produce one liter of Fischer-Tropsch liquid product varies between 4.6 liters to 6.8 liters (1.2-1.8 gal), depending on the coal used for the process (160 to 250 liter per Mbtu or 0.14-0.22 gal/kW-hour) (Marano and Ciferno, 2001). For a 22,000 barrel-per-day operation, that means 5-6 billion liters (1.32-1.58 billion gal) of water per year—the same amount that would be used by the proposed Highwood Generating Station in Great Falls, and enough water to meet the domestic needs of 26,000 people.

Climate change will add to the synergies between water and energy. Most of the water used in energy production is used for cooling purposes. This means that there are strong requirements on the temperature of water that is used. In addition, environmental concerns usually impose limitations on the temperature of water discharged back into the streams and reservoirs. As temperature at the intake increases, there is a rising demand for water if we need to provide the same cooling effect with restrictions on the outlet water temperature. Since most plants do not or cannot adjust their withdrawal rates, in the short run it means that they will get less cooling, a corresponding decrease in turbine backpressure, less efficient generation, and less electric energy for the same amount of raw energy input. Also, many nuclear plants have safety limits on intake temperature that could trigger complete shutdowns more frequently in altered climate scenarios.

As the cost of energy increases, more energy efficient technologies and modes of operation will become in more demand. In particular, in the energy-thirsty transportation sector since waterborne transportation is frequently low in energy and total costs, demand for waterborne **navigation** throughout the country is likely to increase. This means more ships in rivers, canals, docks and ports. Since this requires much new infrastructure, it is unlikely that the system will react to short-term disruptions in energy supply like in the

1970s. But if the supply crunch will last, we will likely see more waterborne traffic, a higher rate of accidents, and more dependence throughout the transportation system. In particular, large amounts of coal are transported by barges on waterways. As energy production and overall economic performance depend more on waterborne transportation, there will be even more dependency upon smooth navigation. Navigation disruptions because of draught or flooding will have more serious consequences that may propagate through the whole economic system. As we will see later, climate change can only exacerbate the risks for the water-energy system.

Finding enough water for nuclear plants "is front and center of everything we will do in the future," said Craig Nesbit, a spokesman at Exelon, a Chicago-based company operating the largest group of U.S. nuclear plants. Officials at Electricite de France have been preparing for a possible rerun of a ferocious heat wave that struck during 2003, the hottest summer on record in France, when temperatures of some rivers rose sharply and a number of reactors had to curtail output or shut down altogether. The French company operates 58 reactors - the majority on ecologically sensitive rivers like the Loire.

During the extreme heat of 2003 in France, 17 nuclear reactors operated at reduced capacity or were turned off. Electricite de France was forced to buy power from neighboring countries on the open market, where demand drove the price of a megawatt hour as high as E1,000, or $1,350. Average prices in France during summer months ordinarily are about E95 per megawatt hour.

The heat wave cost Electricite de France an extra E300 million. The state-owned company "swallowed it as a one-off cost of doing business in extreme circumstances," Philippe Huet, an executive vice president at Electricite de France, said. The company was not allowed to pass along price surges to customers.

In Britain, where the government has given the green light for a new generation of reactors, almost all plants are by the sea, virtually eliminating problems in hot conditions. Countries like China and India that are rolling out new nuclear generators could, in theory, put all plants by their coasts, too. But significant amounts of electricity would be lost in transmitting to faraway inland population centers. In the United States at least two-thirds of nuclear plants are on lakes and rivers.

James Kanter, Could climate change be the latest jinx on nuclear power? 2007-05-21 International Herald Tribune. http://www.industrywatch.com/pages/iw2/Story.nsp?story_id=106610095&ID=iw&scategory=Energy%3ANuclear&P=&F=&R=&VNC=hnall#

3. Energy for water

If there were unlimited energy, we would never have a problem with water. There are vast resources of saline water, which could be desalinized to provide for all the imaginable demands for water if there is energy to run those operations and then pump water to wherever it is needed. That is certainly not the case. In fact energy is becoming an increasingly scarce and expensive commodity and energy efficiency is now a major concern. Water supply in this case will need to compete with many other energy uses, and the Water Return on Energy Invested (WROEI) concept will become a useful measure to compare various water supply projects.

The WROEI index can be calculated also in a way similar to the EROEI (Energy Return on Energy Invested) index: $w_e = w_{out} / e_{in}$. Just like EROEI, the WROEI index does not taking into account any other resources besides energy (including social and environmental ones) that are required to produce water. So again when using WROEI to compare technologies, always keep in mind the other limiting factors that can spring into play: WROEI is one of several indicators to use in decision-making.

There are many ways that energy is required for production and distribution of water.

- **Building and maintaining the infrastructure**. Water related projects require huge capital and energy investments. This includes energy for **pumping** water, which is the main means for water supply and transportation. This also includes pumping municipal and industrial wastewater.
- **Wastewater treatment**. In addition to pumping this would include energy for aeration, stirring, heating, etc. See Appendix for some numbers.
- **Direct transportation**. Some water is moved in trucks and trains. The $15 Billon bottled water industry is entirely dependent on energy to haul bottled water across huge distances. According to Fishman (2007), "we're moving 1 billion bottles of water around a week in ships, trains, and trucks in the United States alone. That's a weekly convoy equivalent to 37,800 18-wheelers delivering water."
- **Desalinization**. Minimum amount of energy reported for seawater (34,000 ppm) desalinization is 0.79 W-hr/liter (3 W-hr/gal). An indirect way to identify the WROEI index is to look at the dollar cost of delivering water from various sources. Table 2 lists some of the costs of water at current prices. It also gives an idea of what the relative costs of different technologies are. See Appendix for more data on energy demands for water. Direct coupling of renewable energy generation to desalinization facilities (e.g. wind-powered desal) is a promising way to further increase efficiency.

Table 2. Current Average Unit Costs of Water (Shannon, 2007). Assuming that most of the cost is for energy this can give us an idea of relative energy consumption in different technologies.

Method	Cost per 1000 m^3 (263,000 gal)
Old water	$4-81, $40 average across U.S.
Reclamation non-potable	$81-122 for industrial reuse
New conventional water	$81-162 aquifer, direct draw (river, lake) $243-405 for new developed water (dams, cannels, etc.)
Direct reuse	$348-405for potable
Desalination (brackish)	$405-486 for reduction from 8,000 ppm to 1,000 ppm
Desalination (seawater)	$527 for next generation 200 million m^3/yr plant Israel $583 claimed in Tampa Bay (not achieved) $648 actual current state-of-art RO costs $770-1135 multistage flash distillation, depending on salinity and local energy costs

4. Supply side

So far most of the solutions for energy and water are sought on the supply side. The traditional approach is to forecast the growth trends for demand, and then seek resources, either through new and improved technologies, or through new drilling, damming, pumping, and transporting. In most cases the Federal Agencies are charged to provide the supply necessary to meet the demand. For example, the DOE is responsible to "promote a diverse supply … of reliable, affordable and environmentally sound energy". Demand is treated as a given, it is rarely managed or controlled, and it drives supply (Fig. 3). Most of the Federal and State effort is focused on increasing the supply. In Nevada, the Southern Nevada Water Authority states: "One of the main objectives of the Authority is to obtain additional water from Colorado River to support urban growth of its member agencies." The Report of the Western Water Policy Review Advisory

Commission (1998) lists 12 federal agencies with their responsibilities as related to water. None of them deal with managing or reducing demand.

At the same time problems with energy and water supply are looming. There are two major factors that may have a very negative impact on the supply side: climate change and peak oil.

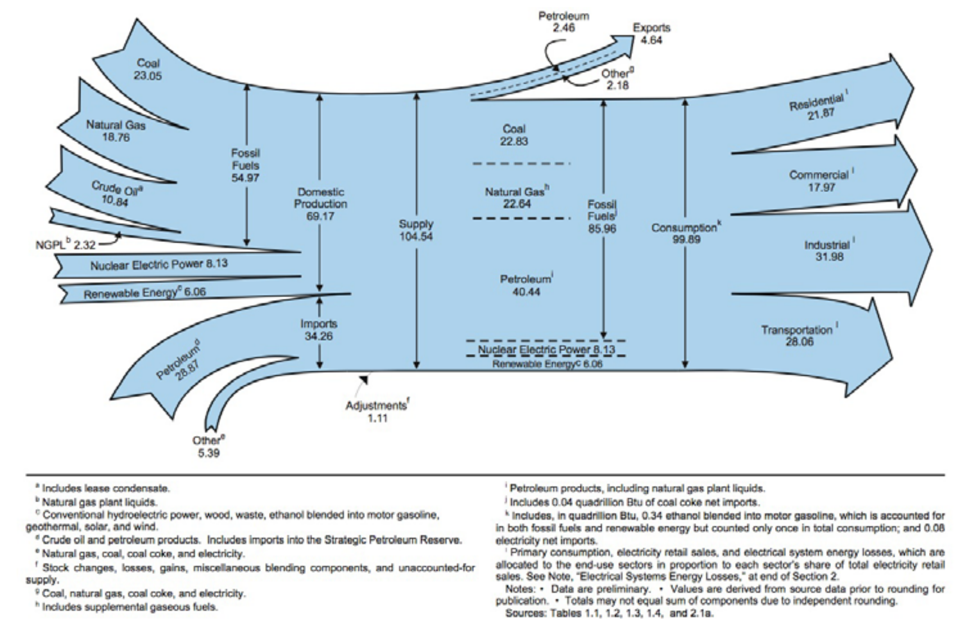

Fig.3. Supply and use of energy in USA.

Climate change will have several important impacts on supply of both energy and water. It is hard to predict the exact extent and rate of these processes, but the direction is quite clear and we should certainly make provisions and adapt to the forthcoming changes (Table 3).

Table 3. Water related changes associated with climate change and their impacts on energy and water.

Changes	Effects
Melting glaciers and snow-packs.	Loss of long-term storage of water, lower baseflow, unreliable water supply, more floods and draughts.
Intrusion of saline water due to seawater rise.	Problems with drinking water, need for treatment of brackish water.
Changed patterns of precipitation ("That 'Drought' in Southwest may be normal, report says").	Changes in spatial patterns of rainfall, loss of wetlands in certain places, occurrence in others. Migration of habitat. Changed hydroperiod, impacts of hydroelectric production.
Increased frequency of "natural" disasters.	Changes in temporal patterns, hurricanes, floods and draughts, damage and loss of infrastructure. Higher risk and insurance costs.
Heat waves	Higher temperatures, higher evapotranspiration, more losses from reservoirs, problems with cooling for nuclear and fossil electric

Global warming boosts the cost of natural disasters so fast that one of the world's largest reinsurance firms, Swiss RE, warns that this all by itself can bankrupt the world economy before 2060[1].

[1] Greer J.M. (2004). The Long Road Down: Decline and the Deindustrial Future, http://www.oilcrisis.com/whatToDo/decline.htm. The Swiss RE web site states:

ARLINGTON, Va.—Arlington, Va. --The percentage of Earth's land area stricken by serious drought more than doubled from the 1970s to the early 2000s, according to a new analysis by scientists at the National Center for Atmospheric Research (NCAR) in Boulder, Colo. Dai and colleagues found that the fraction of global land experiencing very dry conditions rose from about 10-15 percent in the early 1970s to about 30 percent by 2002. Almost half of that change is due to rising temperatures rather than decreases in rainfall or snowfall, according to Dai.

"Droughts and floods are extreme climate events that are likely to change more rapidly than the average climate," says Dai. "Because they are among the world's costliest natural disasters and affect a very large number of people each year, it is important to monitor them and perhaps predict their variability." Though most of the Northern Hemisphere has shown a drying trend in recent decades, the United States has bucked that trend, becoming wetter overall during the past 50 years, says Dai. The trend is especially notable between the Rocky Mountains and Mississippi River.

NSF Press Release, NSF PR 05-003 - January 11, 2005

WASHINGTON -- By the end of this century, global warming threatens to raise the sea level enough that a heavy storm would send flood waters into Boston's downtown waterfront, the Financial District, and much of the Back Bay, based on projections in a federally funded report to be released today.

The five-year study, commissioned by the US Environmental Protection Agency and completed by university researchers, indicates that the mildest impact of global warming would leave local landmarks such as Massachusetts General Hospital, the Public Garden, the Esplanade, and MIT in a pool of water after a strong storm surge in the harbor. If no improvements are made in structures, the flood damage alone would amount to $57 billion in the next 100 years -- $26 billion more in damage than would occur if there were no global warming, the report said.

Susan Milligan. Study predicts city flood threat due to warming. February 15, 2005.
The New York Times Company

Much of the western U.S. may be headed into a prolonged dry spell - a "perfect drought," scientists say, that could persist for generations. The West already has been dry for six years and is looking to be dry again in 2007, said Glen Macdonald, an ecology professor at the University of California, Los Angeles (UCLA). But that's nothing compared to what has happened in the region in the past, according to Macdonald and other scientists. In a study published today in the journal Geophysical Research Letters, a team from Arizona and Colorado found that the Southwest suffered a six-decade megadrought from 1118 to 1179. For 62 years mountain snows - one of the area's main sources of water - were frequently diminished, reducing the river's flow during the heart of the drought by an average of 15 percent. And for an extended period there were no high flows at all, said Connie Woodhouse, a study co-author from the University of Arizona in Tucson.

A thousand years ago such a change was likely caused by natural alterations in volcanism and solar radiation. Today global warming may be producing similar results, Macdonald said this week during a meeting of the American Geophysical Union in Acapulco, Mexico.

A superdrought isn't likely to be limited to California and the Southwest. The tree ring data suggest that the ancient droughts extended all the way from Canada's Yukon Territory to southern Mexico, said Edward Cook of Lamont-Doherty Earth Observatory in Palisades, New York. In addition, <http://www.ncdc.noaa.gov/paleo/drought/drght_laird96.html> studies of fossil diatoms, a common type of algae, at Moon Lake, North Dakota, have revealed traces of long droughts in the Great Plains about a thousand years ago.

Richard A. Lovett
Ancient "Megadroughts" Struck U.S. West, Could Happen Again, Study Suggests
<http://news.nationalgeographic.com>National Geographic News, May 24, 2007

CANAL POINT, Fla., May 30 °© This state seems to seesaw perpetually between crises related to water: either too much or too little. Wednesday was no exception, as the retreating waters of drought-sapped Lake Okeechobee, a vital reservoir for millions of residents in dry times, sank toward a new low.

Signaling the intensity of this once-a-century drought, roiling smoke clouds rose from exposed stretches of the saucerlike 730-square-mile basin midway between the crowded coasts. The plumes came from wildfires sweeping a 12,000-acre stretch of lakebed exposed as the waters retreated and sank about half an inch a day, water officials said.

“This year is definitely a larger challenge than 2001,” said Carol Wehle, executive director of the water district. “We have drought all the way from Disney to Key West.” Thunderstorms predicted for this week, even a hurricane or two, are

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“Today, global warming is a fact. Since the beginning of industrialisation and the rapid growth of world population, man’s activities – along with natural variability – have contributed to a change of climate manifesting itself as a considerable increase in global temperature. Climate change has the potential to develop into our planet’s greatest environmental challenge of the 21st century.” (http://www.swissre.com/INTERNET/pwswpspr.nsf/fmBookMarkFrameSet?ReadForm&BM=http://www.swissre.com/INTERNET/pwswpspr.nsf/alldocbyidkeylu/ULUR-6SGFZA?OpenDocument&PT=Swiss+Re+-+Our+position+and+objectives)

unlikely to end the water woes, Ms. Wehle said. “We need feet of rain, but coming every day throughout the summer,” she said. “When you have one big storm dumping a lot of water, the system can’t catch it.”

Andrew C. Revkin. Lake Okeechobee Drops to a Record Low <http://topics.nytimes.com/top/reference/timestopics/people/r/andrew_c_revkin/index.html?inline=nyt-per> The New York Times, May 31, 2007

Most importantly climate change will significantly increase risk along many supply chains. According to findings of the Military Advisory Board, “climate change acts as a threat multiplier for instability in some of the most volatile regions of the world”. Also it “will add to tensions even in stable regions of the world” (CNA, 2007).

Peak Oil is the term used to describe the inevitable future with fossil fuel production, characterized by:

- Reduced discoveries, declining production (Fig.4);
- Increasing demand;
- Politically sensitive reserves, “resource nationalism”;
- Vulnerable infrastructure.

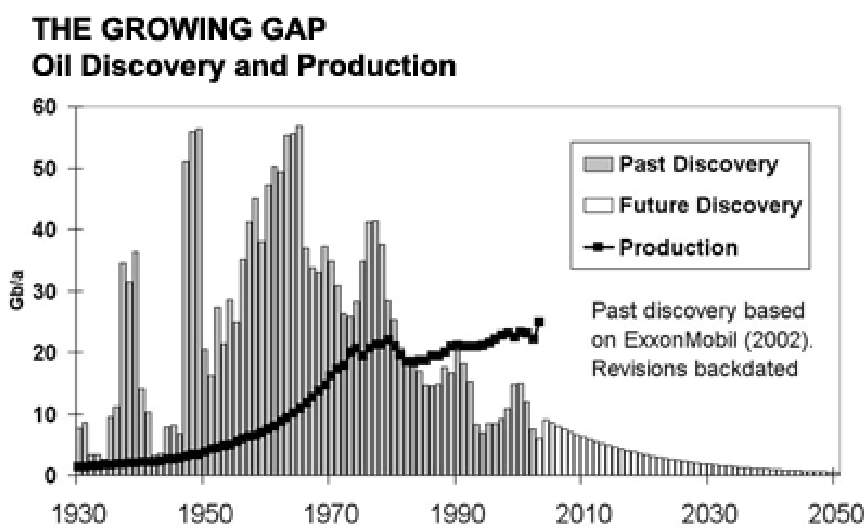

Fig.4. Very few new discoveries while demand and production continue to grow.

The Hubbert Curve, devised by geologist M. King Hubbert in 1956, tracks production over time for any oil reserve from a single oil well to a planet. It's a bell shaped curve: oil comes slowly at first, rises to peak production, then falls gradually to zero. The peak arrives when roughly half the oil is gone (Fig.5). As Hubbert was right to predict, the continental US reached a peak in 1970, and production has slumped ever since. Many energy scientists put the worldwide peak before 2010. After the peak, according to the Hubbert Curve, global oil production will decline at about the same rate as it rose before. With a peak before 2010, production in 2030 will be somewhere around production in 1975 or 1980, or maybe 20 billion barrels. 2030's oil will have to meet the needs of a doubled world population.

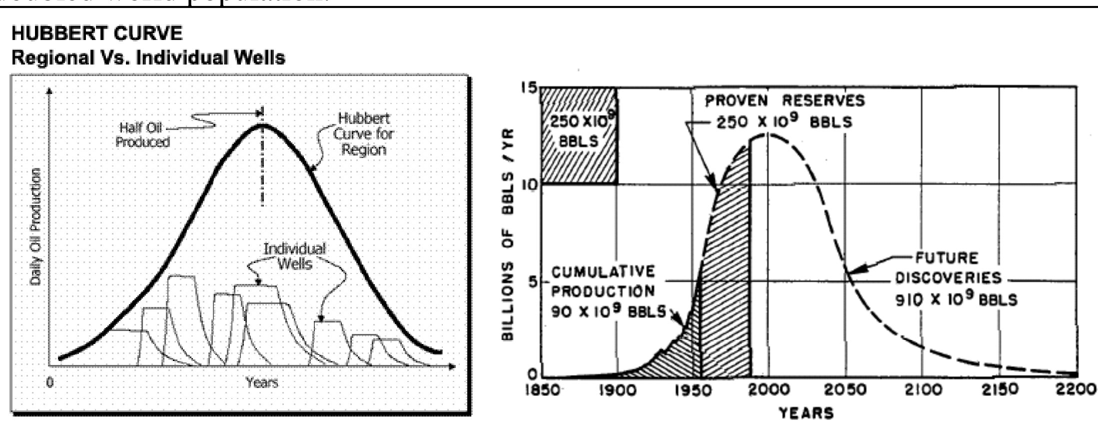

Fig.5. The pattern of oil extraction according to King Hubbert and his projections for peak oil.

In its latest forecast the International Energy Agency has already clearly acknowledged that supply of oil will not be growing fast enough to match the demand. World oil demand will rise faster than expected to 2012 while production lags, leading to a supply crunch. In its Medium-Term Oil Market Report, the adviser to 26 industrialized countries said demand will rise by an average 2.2 percent a year between 2007 and 2012, up from a previous medium-term forecast of 2 percent.

"It is possible that the supply crunch could be deferred -- but not by much. Either we need to have more supplies coming on stream or we need to have lower demand growth."

(http://www.msnbc.msn.com/id/19677734/)

Very similarly to oil reserves, we have the luxury of fossil water – huge reserves of pristine water accumulated over many thousands of years and securely stored for us underground. We are now quickly pumping those reserves out, compensating for any lack of surface water supply that we may have. In the United States, the U.S. Department of Agriculture reports that in parts of Texas, Oklahoma, and Kansas--three leading grain-producing states--the underground water table has dropped by more than 30 meters (100 feet). As a result, wells have gone dry on thousands of farms in the southern Great Plains (Brown, 2006). The depletion of the Ogallala aquifer became apparent in the 1970s. It is the largest freshwater aquifer in the world, but it is already depleted in parts of northern Texas and west central Kansas. A large share of Ogallala water lies beneath the Nebraska Sandhills, where the resource remains largely untapped because crop irrigation is uneconomic (Peterson et al., 2003).

Supplying water always requires energy. With energy becoming limiting, water supply immediately gets affected by higher energy prices. Moreover, with higher prices and demand for energy there will be a higher demand for water to generate energy from traditional and alternative sources. So increased energy production comes at the expense of water. Decreased production due to the peak oil factor is likely to play a strong destabilizing effect on world economy and energy markets, which may likely result in calls for lower environmental standards, deregulation and further privatization. There is a growing sense of urgency because both water and energy related projects require significant time and investments and cannot be implemented as a last minute fix when emergencies already hit.

5. Demand side

It is getting increasingly clear that humanity can survive only by living within the limits of resources that it has. In this context, fossil fuels appear as winning a lottery ticket, or inheriting a fortune, which indeed is exactly what it is. Without that, we have only the steady supply of energy coming from the sun, the water that comes from rainfall, and whatever other resources we can recycle. The windfall of energy that came from fossil fuels was our chance to learn how to harness more of the solar energy that comes to Earth. Whatever we learn and whatever technologies we build while we still have access to cheap fossil fuels is what we will be left with in the long years to come after we run out of the fossil reserve.

USA has the third highest domestic water consumption – 217 m^3/cap/yr (57,325 gal/cap/yr) (after Australia – 341 (90.083) and Canada – 279 m^3/cap/yr (73,704 gal/cap/yr)). To compare, in China it is 26 (6.868). This indicator does not correlate with economic development: in Germany the domestic water consumption is 66 (17,435), and in the Netherlands – 28 m^3/cap/yr (7,397 gal/cap/year) (Chapagain, Hoekstra, 2004). These figures are hard to compare directly, since they do not account for climatic conditions (there is little irrigation in the Netherlands, including lawn irrigation). However, they certainly reflect some of the trends in consumption, including relatively high water prices and the culture of low domestic use that is dominant in most European countries and still quite foreign in US. The US agricultural water consumption is also boosted by the high calorie meat diets that we choose.

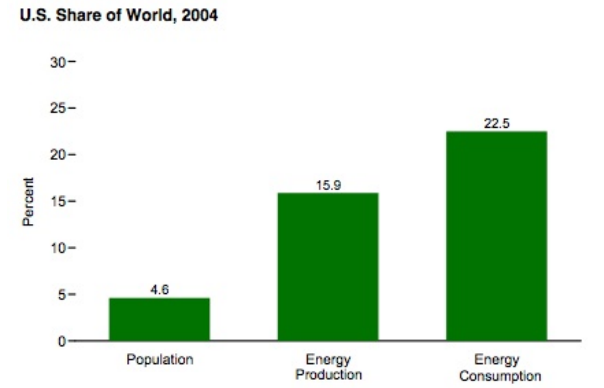

Figure 6. US share of the World, 2004.

The same applies to energy consumption, as well as consumption of other goods and services (see Fig.6). C.Hall (1994) estimated that in terms of resource consumption every human born in the USA is equivalent to 200 people born in Bangladesh. In this context it seems strange to blame China for its share of CO_2 emissions and use that as a pretext for not controlling our GHG, while at the same time USA has a higher population growth rate (0.894% in the United States, compared to 0.606% in China[2]), and emits more than 5 times the amount of CO_2 per capita (20.4 metric tons compared to 3.84 in China[3]). It does not matter whether our population grows because of high birth rates or because of high immigration. In both cases because of our very high consumption rates every person in America comes with a very high price tag for the resources of this planet. It does not matter that some of the resources (including water) are not entirely consumed in a sense that they are removed from the system. The fact that they remain in the system in a different quality (as wastewater, or landfill items) is of little comfort, since their entropy has been increased and will invariably require more energy and resource input to recycle them back to original quality.

Demand growth has a positive feedback that magnifies itself. Additional goods and services provided to meet new demand require additional infrastructure and maintenance that further increase demand. Every additional car put on the street requires more roads, more repair shops, more gasoline, more traffic control, etc. It is a vicious circle that becomes almost impossible to break if we stay within the standard "business as usual paradigm".

"Human actions have no doubt been motivated by efforts to survive and flourish, and one way to read the earth's history is to see it as the story of the rise to primacy in the animal world of homo sapiens. The problem has been that, in this rise to the top, human

[2] https://www.cia.gov/library/publications/the-world-factbook/fields/2002.html

[3] http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions_per_capita

actions have had the consequence of undermining the "conditions of production" in ways that may ultimately sap the ability of humans and others to survive on this planet." (Wallerstein, 2003).

The Club of Rome's epochal report The Limits to Growth (1973), the first of many persuasive studies, warned that unrestricted economic growth would collide with laws of thermodynamics and hard planetary limits sometime in the early twenty-first century. While criticized and ridiculed by many mainstream economists, the Report remained unchallenged in its main idea, that is there is no way we can have unlimited consumption of resources on a limited planet. It advocated expensive and politically unpopular precautionary steps to ensure continuity of human civilization if not the presence of humans as a biological species on this planet. Of course those steps were not taken at all. A failure of vision and political will on the part of leaders and constituencies alike threw away the decades that could have made a difference. Today we still have all those problems (plus other ones like climate change that were not realized at that time), but much less time to react, and increased risks of failure.

Curbing demand is cheaper and faster than increasing supply. Conservation of energy saves both energy and water. Optimal water use saves both water and energy. More and more people are realizing this and governments in the US and around the world have begun to respond (through energy saver regulations, voluntary and domestic energy efficiency programs). But as public awareness and costs of our high use rates increase (as they naturally will), the focus will likely shift solely from the technical, engineering arena to the socio-psychological domain. From the growth paradigm, which is central to most of the policy of today, we will have to move to alternative sustainable approaches.

Thus far, private sector advertising focused on increasing demand and production rather than decreasing them. Can the same tools be used to promote the opposite goals? Or we need something entirely different[4]?

There examples in the past, when public perception was driven towards a common goal in such a way, that for instance, during WWII it was considered to be patriotic to purchase Treasury Saving Bonds, in this way removing excess money from the consumer market and saving it for a good purpose. It should be possible to devise incentives to reduce demand for goods and services and thereby reduce demand for energy and water.

[4] Some of this understanding seems to slowly percolate into mainstream politics. In his presidential race speeches, Dennis Kucinich describes talks about a "cap and share" approach. "People should be able to participate in a program where we reduce carbon emissions, and everyone benefits". We need the "capacity of the American people in this great call to save our planet".

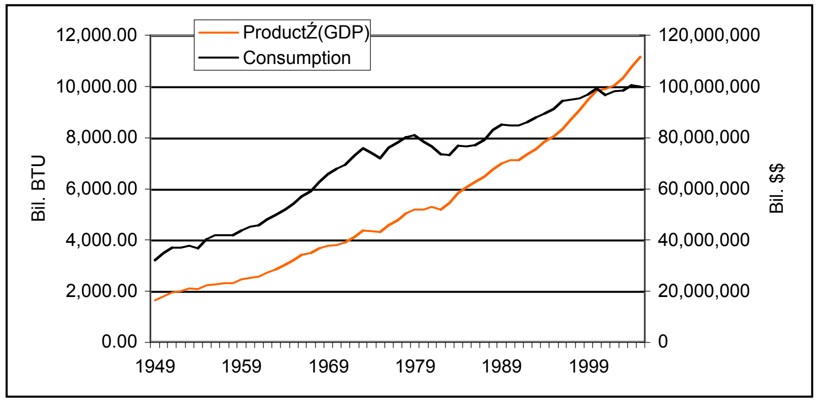

Fig.7. Energy consumption from all sources and GDP in USA (EIA, 2006)

There is a clear correlation between energy consumption and economic development (Fig.7). At the same time there is no obvious correlation between GDP and such indicators as life satisfaction, or life expectancy (Fig.8). We can see that with no sacrifice to life quality we can at least halve the per capita GDP, and therefore energy consumption. It is really a matter of choices, social attractiveness and cultural priorities. These can be changed only with a strong leadership that should be advanced and promoted by the federal government.

Decreasing consumption may be an unpopular measure but that makes federal involvement especially important. So far most of the advertisement industry is working towards increasing consumption, which directly translates into using more energy and water. Federal action can address that and help shift awareness of the population towards conservation and efficiency.

There is an urgent need for a paradigm shift from promoting growth to sustainability. Sustainable growth is impossible on a finite plant; we can only talk about sustainable development. It is unlikely that supply will be able to forever respond to demand increases assuming finite planetary resources. There are clear limits to supply whereas demand is unlimited. It would make more sense to manage demand and to make it dependent upon the supply that is available. This also applies to spatial distribution of resources: we should develop demand in those places where we have supply, and to the

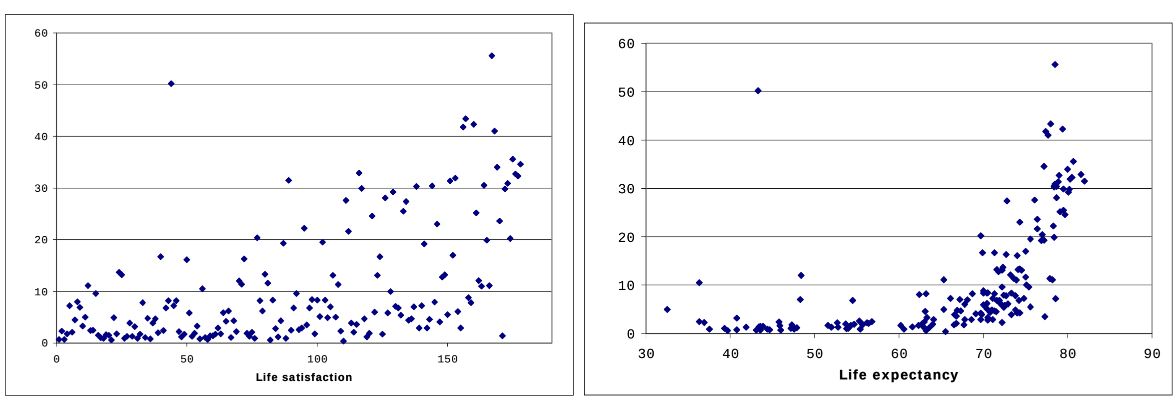

Fig.8. Relationship between GDP per capita and life quality indices calculated for 178 countries (NEF, 2006).

level, which can be sustained. Ironically now we have exactly the reverse: nationally population is growing most rapidly where water is least available. Conveying energy creates losses. Conveying water requires much energy and also results in significant losses of water due to evaporation and seepage. As mentioned above, demand tends to feed itself. In this case growing demand in areas where the supply is limited even further magnifies itself because of the transportation costs.

6. Challenges and opportunities

There are several factors that only increase the complexity of the human-dominated system on planet Earth. We no longer deal with dispersed oases of civilization, which barely affect each other. We have created a global system that is closely coupled and crises in one location send waves of disruption throughout the system. The fact that we live in a globalized system creates new opportunities, but also increases our risks, since there may be no refugia in case of a collapse. It will be unlikely that one developed country or region will be able to maintain its high quality of life if the rest of the world will be in substantial crisis. We became very much interdependent worldwide.

At the same time as humans exert increasing levels of impact upon the life support system, they are creating increasingly complex systems of governance. The democratic decision support system is robust and resilient, and renews itself very well. However it is not efficient in times of crisis, when fast decisions and actions are required. The checks and balances, which are essential for the renewal and maintenance of the democracies, slow down the change that may be needed for fast response. As the complexity of the system increases it becomes harder to expect average voters to have the level of education and knowledge needed to make the right decisions. It becomes even more natural to delegate the decision making to elected officials who know what they are doing. At the same time that may erode the democratic process, as the knowledge gap between well-informed officials and general electorate grows. This degrades the democracy and requires further checks and balances that impede the decision-making.

The democratic process draws from market based mechanisms and incentives, and, in turn, creates them. In some cases these mechanisms can be very effective to decentralize the decision-making and streamline it by making the market forces guide the system. However markets are never perfect and operate under strict regulations that can skew the playing field through subsidies and regulations. Besides, markets are blind to substantial human needs and treat critical natural capital and resources, such as energy and water, as any other goods and services. As a result laissez fair markets can easily disrupt the system if they are not regulated.

Let us consider some of these factors in more detail as they apply to energy and water nexus.

Global linkages

It makes increasingly less sense to consider local or even regional water and energy supply in separation from the global level.

Virtual water is the hidden water that gets moved from one geographical location to another with the goods and services that embody the water used to create them. For example, China imports significant quantities of "virtual" water from the United States and other suppliers through imported grains. Likewise the irrigated agriculture in South Africa results in massive exports of "virtual" water (through fruits and vegetables) to the rest of Africa. Consideration of virtual water when making water policy should become a part of the paradigm shift. Likewise the imbedded energy costs of products need to be considered.

Production of different goods in different places requires different amounts of water and energy. Being part of the global system it makes sense to produce goods in the USA as long as its water and energy footprint is lower than when it is produced elsewhere. For example, from a global perspective, the trade of cereals from the USA to Mexico saves 8.5 Gm^3/yr. Therefore this kind of production of virtual water should be encouraged. However this also becomes part of the energy-water nexus, since it will be possible to move around virtual water only as long as there will be energy available to provide for transportation needs. Ideally, and, most efficiently, this would be accommodated through pricing, incorporating information about societal preferences (through taxes or incentives) into the costs of production (and transportation). However with prices skewed by subsidies, with poor valuation of social costs and ecosystem services, probably an LCA can be a more reliable tool to take into account all the flows of energy and water that go into the production, including costs of transportation of raw materials (including water) and products. This could also be an important part of the planning process and could yield insights on public policy regarding subsidies, and consideration of externalities for production and consumption.

International technological and scientific exchange becomes increasingly important since it makes little sense to keep new energy and water saving technologies from developing countries at the same time blaming them that they are not doing enough to curb emissions of GHG, which are largely related to the energy production sector. It is much more cost efficient to fight pollution in places where it is still almost untapped and where you get the largest "bang for the buck". In this context certain parts of patent law become obsolete. Patents stifle technical progress instead of promoting it as it was originally intended. The Military Advisory Board realizes that it is also in the interest of the U.S. that we "commit to global partnerships that help less developed nations build the capacity and resiliency to better manage climate impacts" (CNA, 2007).

Water security is no less important than **energy security**. As our reserves of fossil reserves dwindle it becomes an issue of intergenerational equity. Underground water reserves can provide clean drinking quality water if they are not polluted or depleted. By destroying these reserves through withdrawal or contamination we increase the vulnerability of future generations to climatic and economic disturbances.

Global resource conflicts are likely to occur as resources get depleted. Yet military conflict also further increases the rate of depletion since most military activities are very energy intensive. In addition, conflicts can also contaminate large stocks of water, making them unusable for long periods of time. So we get another positive feedback that only aggravates the problem. The Pentagon is very aware of the high energy demands of the military and is trying to be at the forefront of demand conservation (Energy conversation, http://www.energyconversation.org/cms/).

Failures of governance

As our systems become highly complex we find that more facts are uncertain, more values are in dispute, stakes are high and decisions - urgent (Funtowicz and Ravetz, 1994; Funtowicz and Ravetz, 1993). As a result in many cases standard governance and decision making become inadequate and start to fail. Many more regulatory decisions end up in court in lengthy and costly litigation procedures, creating social discontent, aggravation and frustration among people.

To deal with this increasing complexity of decision-making, one option is to delegate the decision making process to experts, who have the knowledge and skills to make the right decisions in a timely manner. By delegating decision authority we gradually become more dependent on the selected few and run the risk of divorcing governance from the general public, putting the whole democratic process at risk.

Alternatively, we could invest in creating means and methods for public education and participation in the decision-making process. Such an investment would help infuse public decision processes with local knowledge and generate iterative participatory interactions and improve the chances of deriving politically feasible, and scientifically sound solutions. For those reasons governments and international organizations have embraced concepts of public involvement, and devolution of decision making to lower and lower levels (e.g. the internationally recognized Dublin Principles for Water Management call for devolving water management decision making to the lowest possible level). The Congressionally-commissioned Western Water Policy Commission report of the mid 90's likewise endorsed devolving or at least coordinating management authority at a watershed level, and the embrace by multiple federal agencies of the watershed approach signals a willingness to engage multiple stakeholders in water management decisions. Domestically during the past 15 years, the Corps of Engineers' has developed the Shared Vision Planning process as a way to find understanding and acceptance among the various stakeholders that may be interested in the outcomes of a project, and allows for consideration of complex, connected processes such as energy-water interactions. Moreover, this process creates a lasting framework and network that can be instrumental for on-going adaptive management of the systems. In addition, new web technologies and services provide every-increasing means of interaction and dissemination of data and knowledge.

Market mechanisms

Are the price mechanisms sufficient to resolve the problem? Price it right and it will resolve itself. However we have a market that is heavily skewed by subsidies.

Privatization is one of the widely discussed solutions. Unfortunately, just like with energy deregulation and privatization, it does not work seamlessly in case of water. Once again the two resources have much in common, being essential with very inelastic demand at low supply. The World Bank predicts that two-thirds of the world's population will run short of adequate water in the next 20 years. This clearly makes water a very lucrative target for privatization and speculations. We see this happening around the world as well as in this country (Hightower, 2002).

In many cases privatization seems like a simple solution for federal and state governments to fix the aging infrastructure that according to estimates may need up to $11 bln more each year than it gets. However in most cases privatization inevitably leads to price hikes (25% and more), charges for public services such as fire hydrants, and overall less security in water supply. Whenever we deal with Critical Natural Capital there seems to be an urgent need for strong governmental regulation and control over privately managed resources. It is not a problem that prices go up: indeed in most cases water supply is underpriced. However prices cannot go up overnight and it is important that they remain within the income rates of the local population. The privatization can easily exclude huge numbers of consumers making water unaffordable to low income families. As with other CNC, this is not an option. Public partnerships and cooperatives seem to be way more promising to handle this (Water for all, 2007).

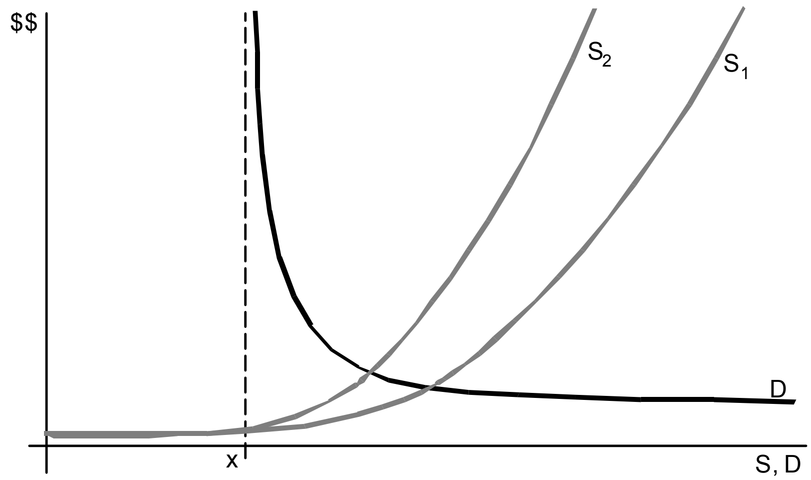

Fig.9. Water should be provided at a minimal price or free up to the critical level x, that is essential for subsistence. Beyond that the price should rapidly increase discouraging excessive consumptions (S_1). If there is less supply available the curve can be made even steeper (S_2) providing more incentives for conservation.

This certainly does not mean that market mechanisms should not be used to improve water supply and distribution. But they should mostly target the demand side creating incentives for lower consumption. In most cases so far water charges are flat and do not reward lower consumption. It would make much more sense to have a flat rate for the minimal consumption level that covers the subsistence needs, or even provide this water for free. Beyond that, in reverse proportion to the curve in Fig.1 water rates should be rapidly increasing (Fig.9).

Another approach is the **Cap and Trade** mechanism, when all consumers are assigned a certain quota, which they can either use, or sell if they consume less. This scheme helps stay within the resource limits and works well when the resource is in a common pool. This is why the C&T approach worked well when applied to manage air quality. In this case it did not matter where geographically the pollution was emitted, you could still trade the quota. It does not work that well when the resource is more localized. For instance, for water we will need a mechanism to deliver the extra water from the seller to the buyer. It would work if they share the same source (say withdrawals from the same aquifer or reservoir), however such markets tend to be quite small and it may be hard to generate enough trade to justify the scheme. Long distance transactions, when sellers and buyers are sitting on different supply chains, would not work due to lack or high price of delivery methods.

Green tax reform is probably the most comprehensive approach that is eloquently described by the slogan "Tax bads not goods". The idea is that by taxing polluting, depleting, and ecologically damaging products and processes, instead of income, the market can send immediate and clear price signals based on internalizing what used to be the externalities of pollution, depletion and ecological damage (Morrison, 2003). As ecological consumption taxes are phased in, income taxes are phased out. In a decade we could totally abolish all federal taxes on income and replace them on a dollar for dollar basis with ecological consumption taxes. Ecological consumption taxes, such a BTU tax on energy, tax on water and an ecological value added tax (VAT), can be indexed to impose higher tax rates on all goods and services as the amount of pollution, depletion, and ecological damage increases.

Efficiency compensations. Conserving one kWt is the same as producing it. If we conserve it we do not need to produce it. “Efficiency Vermont” is a non-profit that works exactly on this principle (http://www.efficiencyvermont.com/pages/): it gets paid for every kWt of energy that it manages to conserve. Very similar arrangements could be made for water. Except so far water is cheap or free.

Adaptations. What can we do as a nation?

Quantum reduction in demand. This is the most obvious low-cost solution. Both energy and water use in USA exceed all estimates of real needs by an order of magnitude (see Fig.6). The average American use of 300 to 375 liters, or 80 to 100 gallons in a day, according to the US Geological Survey[5] is becoming prohibitively expensive and is drawing resources from all other areas. There are several ways to decrease demand:

- Increase efficiency (which actually is an alternative to increasing supply);
- Use market tools and mechanisms:
    - Tax luxury consumption.
    - Increase prices
    - Encourage more use of increasing block rates
- Use regulation:
    - Penalize luxury consumption;
    - Peg water pricing to income levels.

A combination of these methods will be in order.

Dam construction. Despite likely and justified concerns from the environmental community, more dam construction may be a reasonable alternative to control both water supply and release. As more frequent extreme water events (draughts and floods) brought by climate change will require additional regulation capability, dams will become essential means of mitigation and adaptation. Such dams can also be a source of additional hydropower.

Localization. Increasing transportation costs will be calling for more closed and locally self-sufficient systems. Small hydro, wind, solar, biogas installations can help produce additional energy at the point of service, reducing conversion losses. They will also help lower water demands and will provide essential stability for the whole system. A distributed network is more stable than a centralized one and is better suited to deal with emergencies to avoid such repercussions as the countrywide gasoline price hike as a result of a hurricane in Louisiana. Local water storage in small cisterns, pools, or underground reservoirs will decrease flooding and erosion, and can help recharge the underground water supply.

[5] Note that this estimate is different from number that comes out of the water footprint methodology.

7. Role of USACE and other Federal Agencies

In a future that is increasingly defined by energy and water stresses what should be the federal role? Research, national standards and regulations, and incentive systems are all vital and appropriate roles to address these stresses. And, with these increasing stresses, the federal government will be forced to act. Below we outline what the components of such a federal initiative might be, and the role of the Corps of Engineers in implementing or promoting such and initiative.

> To a person, each of these top oil executives said essentially the same thing. They are aware of the problem, but they are unable to act unilaterally. One executive summed it up by saying: "If I put lots of money into solar, my company will be undercut by ExxonMobil. My company will lose market share. Its stock price will drop. And I'll be out of a job." (Because all these conversations were conducted on an off-the-record basis, the executives insisted on anonymity both for themselves and their companies.)
>
> The only way out of this impasse, according to these executives, was summed up by one oil company CEO: "We need the governments of the world to regulate us so we can all make the transition [to clean energy] in lockstep. If we are all regulated to make these changes simultaneously, we can do it without any one company losing market share to the competition."
>
> Ross Gelbspan. Two Paths for the Planet, The American Prospect - June 18, 2007
> http://www.heatisonline.org>www.heatisonline.org

The overall principle would be promoting a national focus on demand – funding research to develop quantum leaps in water and energy efficiency, promoting national standards and incentive systems that spur innovation, and developing and distributing information on best practices and opportunities that reduce demand in economically and socially attractive ways. But we are already behind - per capita productivity in the USA and Japan are comparable level and the highest in the world. Yet Japan needs only half of the energy that the USA needs, emitting less than half of the amount of CO_2/capita. In the absence of strong federal leadership, states are taking the initiative in seeking alternatives to traditional energy and water supply, developing restrictions that are causing a patchwork of standards nationally and thus reducing economic competitiveness and efficiency. By acting now, the federal government has an opportunity to provide leadership in terms of developing policy alternatives that will move the country, in quantum leaps towards radically lower energy and water demands and becoming the world leader in energy and water efficiency technologies.

Yet in addition to spurring technological development, the federal government has a role to help shift awareness of the population towards conservation and efficiency. In the 1960's the federal initiative to send a man to the moon captivated the public's imagination. Similarly a major federal focus on demand reduction to promote national security and economic competitiveness would involve not only research and incentive systems, but outreach and education campaign and national call to make efficiency a national trait instead of simply a personal virtue.

The components of this multi-agency federal initiative on efficiency would include:

- Research and development to enhance the available water and energy supplies through new technologies, market mechanisms (metering, water banking), increased efficiency of water and energy storage and transmission infrastructure.
- Development of a next generation of national standards and federal regulations that have shown success such as the CAFE standards, the energy star program and

national building and appliance codes and standards (e.g. energy star, plumbing codes).

- Information and data sharing. Multiple federal water and energy agencies (e.g. Corps, DOE, EPA, USGS, BuRec) should develop an open access information and knowledge base that would contain data, tools, methods and models to facilitate the assessment of energy and water supplies, demands and linkages, as well as promote collaborative decision making at local and regional levels.
- Outreach and public awareness. Aggressive outreach and education programs, aimed not only at the public but also at specific water and energy use sectors, can rapidly increase adopting of water and energy efficiency technologies. The USDA's agricultural extension service is one avenue to be built upon and coordinated with. Another rarely used avenue is public announcements on radio and television that could be used to promote conservation, efficiency, and lower consumption. We need a concerted effort to educate the public about opportunities and economic and social benefits to imbue efficiency as a national trait.

The overall principle would be that instead of focusing on help with supply, Federal Agencies should be also focusing on demand, helping manage it by both increasing efficiency and decreasing consumption.

Role of the Corps

But where does the Corps fit in? How can the Corps, with its extensive water resources infrastructure across the nation, its expertise in water resources planning, its research and development laboratories, its natural resource management and regulatory responsibilities, support coordinated Federal action to address energy-water challenges?

First of all the Corps can look to make the most of its existing infrastructure through ***infrastructure rehabilitation and optimization***. Multi-purpose Corps reservoirs have storage already dedicated for water supply, and many have significant hydropower operations. The Corps can help augment water and energy supply by ensuring that its facilities operate at maximum effectiveness. Such steps would include rehabilitation of existing hydropower facilities, optimizing operations across turbines at an individual site and across hydro generation facilities in a given river system, and reviewing and revising operational rules to increase benefits (incorporating forecasting and monitoring as needed).

Secondly, the Corps can use the resources of the Army's research and development laboratories and the experience in its water supply regulatory program to develop ***expertise on demand and energy-water linkages***. The military has long been invested in research on energy and water efficiency in support of the warfighter. Combining this Army expertise with expertise from the Civil Works mission will help the nation make the quantum leaps in energy and water use efficiencies

In addition, the Corps responsibilities under Section 404 of the Clean Water Act means that most any new water supply project applicant must undergo a review by the Corps of its need for additional water supply. Although current, the Corps does not require that demand (need) reduction is considered as a stand-alone alternative, a revised Corps regulatory process could guide the applicants towards ways of meeting the needs by reducing demand, so that more can be achieved by the same supply. With increased consideration of energy-water linkages and technological improvements, this “soft” solution may very well be the desired “Least Environmentally Damaging Practicable Alternative.” Similar to the Best Management Practice (BMP) approach advocated by EPA for water quality regulation, the Corps could require that all the water/energy saving **Best Technologies and Reductions** (BTR) be considered as **alternatives**. Such a requirement would be directly analogous to the consideration of non-structural alternatives for Corps flood damage reduction projects. Such a requirement would stimulate innovative analysis and technological solutions and may spur growth management measures in areas where water and energy are scarce. (Youthquake, 2007). By becoming a center of expertise for water demand management, the Corps can support state and local governments and other federal agencies in addressing water and energy challenges.

> Surrounded by foreign officials but no one from the Bush administration, Gov. Charlie Crist warned Thursday that global warming poses such a dire threat to Floridians that the state must take immediate, dramatic and unilateral action.
>
> The first phase of that initiative begins today as Crist signs unprecedented orders intended to help reduce pollution, slow global warming and position the state as a national model -- even as the federal government remains on the sidelines.
>
> “We cannot afford to ignore this issue any longer,” Crist told about 600 people attending his Summit on Global Climate Change. “We have a responsibility to face this reality head-on and take action to address it.”
>
> Asked about the notable absence of federal officials, Crist said: “They're not here, but we are. I'm the governor of Florida, and this is my focus.”
>
> Martin Merzer. Crist sets Florida on a green path. 2007 Miami Herald Media Company.

Thirdly, the role of the Corps can continue to evolve from a project by project orientation to a ***systems perspective in planning and operations***. Such a systems perspective would consider the complex feedbacks and connections between energy and water in Corps projects for navigation, ecosystem restoration and flood damage reduction and other purposes. By teaming with DOE labs and other experts in energy assessment, the federal government’s expertise can be pooled to evaluate the systemic interactions in water resources planning. This would include potential impacts of investments in navigation systems to consider energy water interactions in moving of commodities. It would include looking at energy water connections when analyzing the potential impacts of flooding or of water shortfalls. Such systemic consideration of energy water connection would also benefit planning for emergency response. Hurricane Katrina showed the extent of linkages between energy, water and emergency management as energy production, refining and distribution were significantly affected and the Mississippi was closed to navigation for coal barges. Such a systems perspective would be a natural extension of existing planning expertise of the Corps and result in better information in the formulation and evaluation of plans for new projects, major rehabilitation and operations.

Dziegielewski and Kiefer (2006) point out that “The restrictive nature of existing Federal laws, policies and funding has left the Corps in a classic catch-22 situation. States and localities are taking the initiative for seeking out water supply alternatives, which is consistent with Corps policy. However, in doing so, … these entities more often than not perceive Corps involvement as a barrier and are more likely to encounter the Corps in regulatory proceedings than engage the Corps as a partner... This 'problem' presents the Corps with its single best opportunity to help, which is to lead regional water supply planning studies that would facilitate the design of the most cost-effective and environmentally-friendly water supply options, thus reducing the cost and length of the permitting process." This approach is again centered on the supply side. By bringing expertise on demand management technologies and water-energy linkages, the Corps only becomes a more valuable resource for locals and states to assist in their planning processes. Note that at present some states turn out to be much more restrictive and conscious in their development plans than the Federal level. So there may be no catch-22 situation if we bring the demand side into concern. Presently states are starting to seek alternatives to traditional energy and water supply, and develop restrictions that are even more stringent than required by federal regulation. In response the federal government is creating obstacles for the States to move to less damaging technologies and more sustainable futures by proposing restriction on states from imposing emission standards that are more stringent than Federal level[6].

Fourth, to fully support a federal response to energy water issue, the Corps must engage more fully into ***outreach and education programs***. Such activities would naturally flow from various Corps activities and policies on public involvement in planning, risk communication, and public interactions in the Corps natural resource management community. Such an extension of the Corps' evolving role as a natural resource manager could be expanded to distribute information aimed at different sectors on water efficiency technologies and energy-water linkages and assessment methods. In this task the Corps can take advantage of its distributed network of Districts, Divisions and local installations to offer educational materials to the public, water-intensive industries, and municipalities.

Finally, to help the nation address energy water challenges, the Corps must continue to develop innovative approaches to collaborative problem solving. Recognizing the primacy of states in water allocation, and the pivotal role of local communities, the Corps must continue to forward collaborative approaches to water resources governance, as espoused by the 2004 Cooperative Conservation initiative (see www.cooperativeconservation.gov), the Corps' guidance on collaborative planning (see www.usace.army.mil/publications/eng-circulars/ec1105-2-409/entire.pdf) and the general push towards a more participatory approach to water resources decision making. With complex energy water interactions and problems becoming increasingly salient to the general public, federal water managers will need to develop and promote new collaborative ways of problem solving. The Shared Vision Planning (SVP) process institutes an on-going collaborative learning effort when there is an iterative exchange between federal, state and local levels on priorities, data, analysis, scenarios and decisions. It is an open ended adaptive process that is the only possible way to manage

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[6] See: EPA gets push on emissions controls Congressional backers of laws in Md., 11 states try to force agency to act: http://www.baltimoresun.com/news/local/politics/bal-te.emissions13aug13,0,3089789.story,

Democrats Face Off Over Emissions Bill. California Lawmakers Lead Opposition to a Draft That Would Prevent States From Taking Tougher Action Than The Federal Government. http://www.commondreams.org/archive/2007/06/08/1750/

open evolving systems, such as watersheds. While SVP has been mostly used in application to water resources, there is no reason it cannot be used in other situations where resource planning and environmental decision-making and conflict resolution is required. The Corps can work with other federal and state partners to further develop and popularize such alternative dispute resolution methods and technologies.

To summarize, we have identified five **priority areas** for the Corps to stress in order to help the nation address water-energy connections:

A. **Infrastructure rehabilitation and optimization.** The Corps large infrastructure portfolio includes significant hydropower generation. Yet inefficient operation on a systemic basis and rehabilitation needs reduce the production of this low cost environmentally-friendly energy source. Working with DOE, FERC, and the private energy sector, the Corps could increase hydropower production through system-wide optimization and infrastructure rehabilitation.

B. **Demand expertise.** Inject expertise and best management practices for demand management into the planning and permitting processes. Prioritize demand reduction alternatives when issuing permits. Use Corps labs to develop technologies, models and tools to assist manage demand. Foment technology transfer of energy and water efficiency technologies from other parts of the Army and DoD laboratories, and back from civil research to the military, which is also very concerned about water and energy efficiency.

C. **Systems perspective in planning and operations.** Foster a stewardship approach to watershed planning and management. Research on navigation / energy supply /support to states on assessment and demand management. With energy experts, develop expertise on how to incorporate energy and water linkages in support of watershed planning. Work with other federal and state agencies to ensure that this information is readily available for stakeholders and to support other planning efforts**.** With a tighter resource base and higher risk of large climatic and infrastructure disruptions build more resilience into engineering projects and develop clear strategies for flood and drought mitigation. This links directly to two major missions of the Corps – navigation and ecosystem restoration.

D. Outreach and education. To fully implement its evolving role as a natural resource manager, the Corps will need to delve into more outreach and education programs. Already the Corps' natural resource management community has embraced that role, and this could be expanded to distribute information aimed at different sectors on water efficiency technologies and energy-water linkages and assessment methods. In this task the Corps can take advantage of its distributed network of Districts, Divisions and local installations to offer educational materials to the public, water-intensive industries, and municipalities.

E. **Governance and collaborative problem solving.** Most of the controversies with the state level can be resolved if we open up the regulatory process to stakeholder participation in various stages of the decision-making. The Shared Vision Planning process institutes an on-going collaborative learning effort when there is an iterative exchange between federal, state and local levels on priorities, data, analysis, scenarios and decisions. It is an open ended adaptive process that is the only possible way to manage open evolving systems, such as watersheds, and SVP and other similar methods and techniques become essential. The Corps can work with other federal and state partners to further develop and popularize such alternative dispute resolution methods and technologies.

Key partnerships and collaborations

To address these priority areas, the Corps will have to engage others in the federal family. Although the Corps will need to work with many federal and state agencies, four key partnerships immediately come to mind.

1 - In the area of infrastructure rehabilitation and optimization, the Corps will need to work with experts at DOE to improve hydropower turbines and their efficiency, as well as to optimize the production across turbines and across production facilities.

2 - The Corps will also need to share experiences with FERC on their approaches to hydropower dam operation and in adopting collaborative approaches to hydropower regulation.

3 – The Corps will need to collaborative closely with EPA for joint regulatory standards and BTR requirements and for requirements of a demand reduction alternative when evaluating water supply permits. Furthermore, any outreach and education initiative would have much to learn from and share with EPA's watersense program to increase public awareness for water conservation.

4 – Finally, the Corps will need to partner with the Bureau of Reclamation and the Tennessee Valley Authority to share experiences on everything from infrastructure rehabilitation and optimization to systemwide planning and operations to public outreach and education for water resources management.

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Appendix

Table A1. – EROWI, EROEI, and Net EROWI by technology (from Mulder et al.,2007)

Technology	Key Specifications	Water Use (l/MJ)		EROWI (MJ/l)	EROEI	Net EROWI	Data Sources
		Direct	*Indirect*				
Nuclear Electric[6]	- Once-through cooling - National average	33.25 (0.145)	NA	0.030 (6.897)	10	0.027 (6.21)	(Kidd 2004, Stiegel et al. 2006)
Nuclear Electric[6]	- Recirculating - National average	1.162 (0.659)	NA	0.861 (1.517)	10	0.775 (1.37)	(Kidd 2004, Stiegel et al. 2006)
Coal Electric[6,7]	- Once-through, sub-critical - National average	28.62 (0.146)	NA	0.0349 (6.849)	NA	NA	(Stiegel et al. 2006)
Coal Electric[6,7]	- Recirculating, sub-critical - National average	0.560 (0.488)	NA	1.786 (2.049)	NA	NA	(Stiegel et al. 2006)
Coal Electric[6,7]	- Cooling pond, sub-critical - National average	18.922 (0.849)	NA	0.0528 (1.178)	NA	NA	(Stiegel et al. 2006)
Tar Sands		(0.061–0.122)	NA	(16.39 – 8.19)	NA	NA	(Griffiths et al. 2006)
Biomass Electric[2]	- 113 MW Biomass IGCC - US - Non-irrigated hybrid poplar	0.238	0.021	3.86	15.6	3.61	(Mann and Spath 1997)
Biomass Electric[3]	- IGCC - Irrigated hybrid poplar – Italy	0.238	3.85	0.245	1.60	0.092	(Rafaschieri et al. 1999)
Biomass Electric[8]	- IGCC with various feedstocks -Irrigated at a rate of 400 L/kg dry biomass.	40	NA	0.025	5.0	0.02	(Berndes et al. 2001)
Petroleum Electric[4]	- 250 MW plant - Singapore - 25 yr. expected plant lifetime	0.01943	0.00057	50.0	3.73	36.6	(Kannan et al. 2004)
Petroleum Diesel	- Average data for US refining	0.0035	NA	285.3	5.01	228.4	(Sheehan et al. 1998) (Tyson et al. 1993)
Soy Biodiesel[1]	- 1990 average US soy production - 18.4% oil content	0.0152	23.0	0.0434	2.66	0.027	(Sheehan et al. 1998)
Methanol from Wood[8]	- Prototype technology only - Various feedstocks - Irrigated at a rate of 400 l/kg dry biomass.	36.8	NA	0.0271	5.5	0.022	(Berndes et al. 2001)
Hydrogen from Wood[8]	- Prototype technology only - Various feedstocks - Irrigated at a rate of 400 l/kg dry biomass.	28.3	NA	0.0353	4.67	0.028	(Berndes et al. 2001)
Corn Ethanol[5]	- Dry milling technology - 8700 kg/ha corn yield, 0.37 l/kg ethanol yield	1.86	9.60	0.0873	1.38	0.024	(Shapouri et al. 2003, Pimentel and Patzek 2005)
Sugar Cane Ethanol	- From non-irrigated sugar cane production in Brazil - Bagasse burned to process ethanol	0.973	NA	1.027	8.3	0.903	(De Oliveira et al. 2005, Smeets et al. 2006)

[1]Data was adjusted to account for price allocation instead of mass allocation of co-products which was used by Sheehan et al. This also adjusted the EROEI.
[2]Water data taken from Table 22. Only water used in gasification plant was considered direct withdrawals.
[3]Direct water inputs are not reported and so are taken from (Mann and Spath 1997).
[4]Data did not include water usage in oil recovery. Water from dedicated desalination plants could be used at an energy cost of 0.006 MJ per MJ produced. This would reduce the EROEI to 3.65 but reduce freshwater withdrawals to zero.
[5]Water input data from Pimentel and Patzek (2005). EROEI and allocation data from Shapouri et al. (2003).
[6]Numbers in parentheses are for water consumption.
[7]Assumes wet flue gas desulphurization which adds approximately 0.065 l/MJ to both withdrawals and consumption.
[8]All energy inputs are assumed derived from biomass with proportional water requirements.

Table A2. - EROWI, EROEI, and Net EROWI for Biomass Energy Technologies (from Mulder et al., 2007)

Biofuel/ Feedstock	Water Usage (l/MJ)	EROWI (MJ/l)	EROEI Estimate	Net EROWI
Biodiesel				
Rapeseed	? – 100 – 175	? – 0.010 – 0.0057	2.33	? – 0.0057 – 0.0033
Ethanol				
Sugarcane	0.7 – 38 – 156	1.43 – 0.026 – 0.0065	8.3	1.26 – 0.023 – 0.0057
Sugar Beet	0.5 – 71 – 188	2 – 0.014 – 0.0053	2.25	1.11 – 0.0078 – 0.0029
Corn	? – 73 – 346	? – 0.014 – 0.0029	1.38	? – 0.0039 – 0.00081
Wheat	? – 40 – 351	? – 0.025 – 0.0029	2.40	? – 0.015 – 0.0017
Lignocellulosic Crops				
Ethanol	0.5 – 11 – 171	2.0 – 0.091 – 0.0058	4.55	1.56 – 0.071 – 0.0045
Methanol	1.0 – 11 – 138	1.0 – 0.091 – 0.0072	5.5	0.82 – 0.075 – 0.0059
Hydrogen	4.9 – 15 – 129	0.204 – 0.067 – 0.0078	4.67	0.16 – 0.053 – 0.0062
Electricity	0.5 – 13 – 195	2.0 – 0.077 – 0.0051	5.0	1.60 – 0.062 – 0.0041

Table adapted from Berndes (2002 - Tables 2 and 3). The first number denotes water usage in the conversion process alone. The second and third numbers incorporate the range of water consumption (evapotranspiration) in feedstock production. The low water usage numbers for lignocellulosic crops are based on non-irrigated M*iscanthus* production. EROEI estimates not used in Table 1 are from Mortimer et al. (2003 - Rapeseed biodiesel and ethanol from sugar beet and wheat) and Lynd and Wang (2004 - Lignocellulosic ethanol).

Table A3. WROEI for some selected technologies of water production, recovery and application

Reverse Osmosis (Shannon, 2007)	50% water recovery min Elec. 1.77 W•hr/liter best Elec. 2.22 W•hr/liter	80% water recovery min Elec. 5 W•hr/liter best Elec. 8.40 W•hr/lite

Total annual energy for typical 3,785 m^3/d (1 Mgal/d) wastewater treatment system (electrical plus fuel, expressed as 1,000 kwh/yr) (Middlebrooks, 1979)

Treatment system	Effluent quality, mg/L BOD	SS	P	N	Energy, 1,000 kWh/yr
Rapid infiltration (facultative pond)	5	1	2	10	150
Slow rate, ridge + furrow (facultative pond)	1	1	0.1	3	181
Overland flow (facultative pond)	5	5	5	3	226
Facultative pond + intermittent filter	15	15	--	10	241
Facultative pond + microscreens	30	30	--	15	281
Aerated pond + intermittent filter	15	15	--	20	506
Extended aeration + sludge drying	20	20	--	--	683
Extended aeration + intermittent filter	15	15	--	--	708
Trickling filter + anaerobic digestion	30	30	--	--	783
RBC + anaerobic digestion	30	30	--	--	794
Trickling filter + gravity filtration	20	10	--	--	805
Trickling filter + N removal + filter	20	10	--	5	838
Activated sludge + anaerobic digestion	20	20	--	--	889
Activated sludge + anaerobic digestion + filter	15	10	--	--	911
Activated sludge + nitrification + filter	15	10	--	--	1,051
Activated sludge + sludge incineration	20	20	--	--	1,440
Activated sludge + AWT	<10	5	<1	<1	3,809
Physical chemical advanced secondary	10	10	1	--	4,464

NOTE: RBC = rotating biological contactor.

Table A4. The Federal Water Agencies and their responsibilities. From: Water in the West: The Challenge for the Next Century. Report of the Western Water Policy Review Advisory Commission, June 1998	
Agency/Department	Major water-related activities and responsibilities
Reclamation/Interior	Irrigation, municipal and industrial, flood control, hydropower, fish and wildlife enhancement, recreation.
Corps/Army	Flood control, navigational improvements, hydropower, recreation, irrigation, and municipal and industrial. Administers permit process for Clean Water Act.
Bureau of Indian Affairs/Interior	Administers federal programs for Indian tribes. Operates water storage and irrigation projects with total storage capacity of more than 2.5 maf.
NRCS/USDA - Formerly Soil Conservation Service.	Helps farmers and ranchers establish conservation systems; helps urban and rural communities reduce erosion.
Western/Energy	Markets and transmits power in 15 western states—from 55 powerplants. Has 599 wholesale power customers, selling enough power to meet needs of more than 10 million people for 1 year.
Federal Energy Regulatory Commission/Energy	Regulates nonfederal hydroelectric projects that effectnavigable waters, occupy U.S. lands, use federal water, or affect interstate commerce. Reviews rates for all electric utilities.
USGS/Interior	Provides most hydrologic data collected in the U.S. Maintains nationwide system of stream and river gaging stations, groundwater observation wells, and water quality sampling locations.
Bonneville Power Authority/Energy	Markets power generated at 29 federal plants in Columbia-Snake River basin. Sells about 46 percent of electric power consumed in Northwestern U.S.
Environmental Protection Agency	Protects public health through safeguarding and improving water resources. Helps implement and enforce Clean Water Act, Endangered Species Act, and Safe Drinking Water Act.
Service/Interior	Protects plants and animals in danger of extinction. Manages National Wildlife Refuge System and works with wetlands.
National Marine Fisheries Service/ National Oceanic and Atmospheric Administration	Supports fishery management, development; protects species and conserves habitat.
Forest Service/USDA	Helps public enjoy national forests while conserving environment. Manages more than 190 million acres. Protects natural resources, including water and watershed lands, on its lands.

Visiting Scholar Program

AAAS Science and Technology Policy Fellows

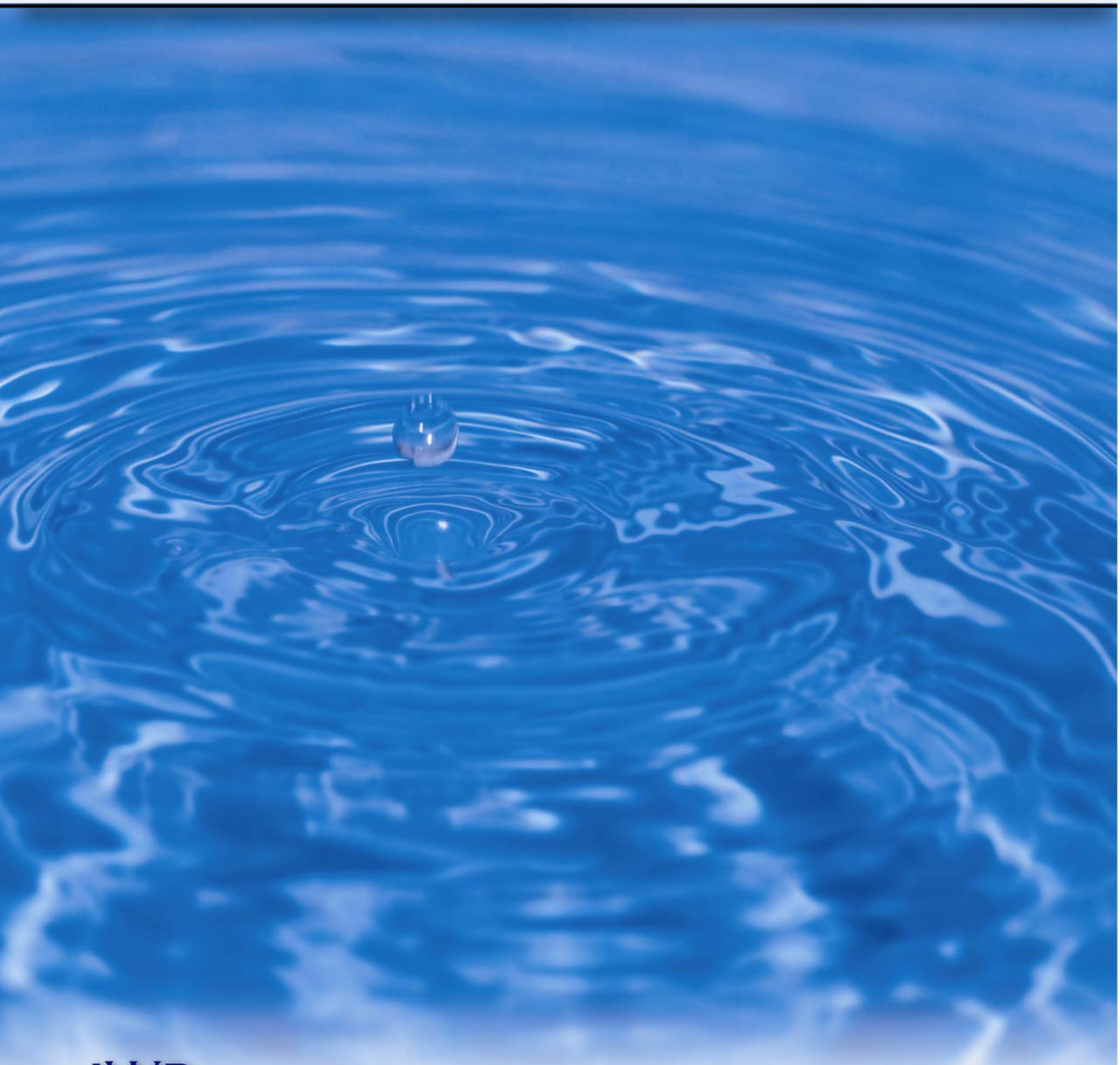
2006 – 2007: Dr. Alexey Voinov

Alexey Voinov was IWR's first Science Policy fellow through the American Association for the Advancement of Science. He worked with Gene Stakhiv and Hal Cardwell on participatory modeling. Alexey joined IWR for a year from the University of Vermont where he has a joint appointment with the Gund Institute for Ecological Economics and the Computer Sciences Department.

His research was supported by grants from EPA, NSF and other federal and state sources. He has taught courses in simulation modeling around the world while exploring web based teaching and community modeling approaches. Alexey is Associate Editor of Environmental Modeling and Software Journal and vice-president of the International Environmental Modeling and Software Society. He also serves as board member for the Russian Society for Ecological Economics and the Working Group for Ecological Economics at the Society for Conservation Biology.

Alexey received his PhD and Masters in Applied Mathematics and Ecological Modeling from Moscow State University (Russia) and was at the University of Maryland for eight years before moving to Vermont in 2002.

About the Fellowship
Through the American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellows Program, IWR sponsors post-doctoral and senior fellows to work on water resource policy issues such as analyzing the linkages between water resources development and water resources problems (e.g. drought, floods) and the economies of developing nations. Individuals with a systems engineering, economics, public participation or water resources background are especially encouraged to apply. Applications are taken once a year in January, with interviews in the March. This highly selective fellowship program gives scientistis and engineers a real-world introduction to how science interacts with policy in Washington.



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