Technology Drivers of World Water Scenarios

World Water Assessment Project (WWAP) Round 2

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Global water resources are becoming an increasingly important issue. This paper is dedicated to outlining some of the significant technology drivers affecting world water resources over the next forty years. Technology advancement in remote sensing, nanotechnology, salt water agriculture, desalination, and meat without animals provide opportunities for more efficient and effective water use and water purification. The strategy deployed included literature surveys, Internet searches and technology expert information resources.

Introduction

It is quite a challenge to map out the existing and future technologies that should be taken into consideration when developing scenarios for world water over the next forty years. The rate of innovation is expanding rapidly as measured by the increased issuance of patents and peer reviewed articles and yet in many ways the system as a whole is broken. Decision-makers are being overwhelmed with information and there needs to be new ways of gathering and prioritizing data, developing and testing models, and making collective decisions across national, institutional, and discipline boarders. A global collective intelligence system for water is needed.

In collecting and synthesizing data for world water scenario development we face a major hurdle. A single issue such as whether and how decision makers should promote and drive the adoption of salt-tolerant agriculture crosses many discipline borders: applied genomics, botany, economics, energy, hydrology, consumer behavior, ethics, sustainable development, etc. There has been no forum to bring together experts from all these fields; the experts do not necessarily share a consensus. Since we are not trained in all these disciplines, we have a very steep learning curve. The Internet can help us identify experts all over the world, but not necessarily the right questions to ask. Getting these experts attention and time is also a challenge. People who are channels for institutional and societal decision making are generally overloaded with email. Delphi studies of cross discipline experts is a solution but getting experts to dedicate the time and energy is a challenge and can be frustrating if the experts don't come quickly to consensus.

There are thousands of water technologies that merit attention for increasing the amount of water for drinking, agriculture, and manufacturing or which will allow us to use water more efficiently. In this paper, we have focused our attention on eight cutting edge technologies that were mentioned in our statement of work:

- Remote Sensing
- Weather Control
- Desalination
- Nanotechnology
- Salt-tolerant agriculture
- Meat without Animals
- Information Technology
- Eco Technologies/ Bio-Technologies

We have however developed methods, expertise and social networks that will allow us to focus rapidly on any water technological issue, which may require invention to solve. In our research, we have tested different strategies for gathering information such as whether to start with Google searches of the Web, searches of the academic literature, or expert interviews. The challenge is, of course, to find what are the right questions to ask. Our finding is that all three must be used. There is the potential of using more sophisticated knowledge management tools (besides Google search and Google alerts) to make it easier to build cross-disciplinary expertise. It is clear to us that it is impossible for computers to do what we have done in this report. This is a very important finding. Our society faces a major challenge creating jobs in the face of wide spread automation. Though the term knowledge work is often bandied about, what we are doing in the WWAP study is an actual example of the kind of knowledge work that takes advantage of computers, but cannot be replaced by them.

Computers can store tremendous amounts of useful information, but they are not yet proficient at making value judgments on the merits of the information. In fact, it may be that so much stored information can impede early adoption of the best technologies because the assessment process is confounded by the quantity of options that might be proposed for testing before real progress can be made, hence the need for collective intelligence system approach (Green, 2010).

As a naïve starting basis for the primary keyword search topics the three main categories of Google Searches, Patent Searches and Academic Database Searches are summarized in Table 1.

Keywords	**Information Sources**		
	Google Searches	Patent Searches (WIPO)	Academic Database
"Remote Sensing"	8,720,000	27,756	30,535
"Micro irrigation"	109,000	2,231	134
"Desalination"	2,000,000	1,819	5,150
"Nanotechnology"	7,060,000	3,058	9,685
"Salt tolerant agriculture"	1,780	893	-
"Meat without Animals"	197,000	6,056	7,533
"Eco friendly Technology"	330,000	300	11
"Information Technology"	66,300,000	187,859	15,973
"Water"	758,000,000	510,179	>100,000

Table 1: The number of key "hits" as related to keyword searches.

Clearly, the naïve starting point is not the entire story as keyword substitution may be used as a way to more appropriately filter out less relevant information as well as include more relevant sources. For example, choosing "sensors" rather than "remote sensing" returns 130,008 patents compared to 27,756 patents at the World International Patent Organization (WIPO). Likewise, "nanotechnology" AND "water" returns 1,926 patents at the WIPO compared to 3,058 and 510,179 for the individual keywords "nanotechnology" and "water" respectively. Relaxing the quotations around "salt tolerant agriculture" produces 1,954 journal articles rather than zero. Additionally, some of the limitations inherent in each source include:

- Some websites are not cached by Google;
- Internet marketing strategies may bury more relevant information with search engine optimized content;
- Other search engines such as Yahoo and Bing may prioritize different sources;
- Reliability of the Internet is generally uncertain;
- There are additional national patent offices;
- The academic database was limited to 100,000 "hits"; and
- Academic databases are not readily available to the public.

Table 1 illustrates an apparent challenge not only to arrive at a state-of-the-art overview of this topic, but it also illustrates the increasing challenge faced by decision makers and policy makers regarding what would traditionally be considered an "informed decision." Although there is greater access to information, there is an increasing difficulty in becoming "informed" in order to make decisions. This is a static snapshot of a dynamic landscape that is only going to become vaster over time. Hence, the system as a whole referred to above as being "broken" refers to the expansion and transformation of information channels faced presently by policy and decision makers. Furthermore, the relationship among decision makers at various levels is disorderly and hence any unified water strategy would be difficult to define (but maybe necessary) and worse still, to implement and monitor. The result is an increased difficulty at arriving at an "informed decision."

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Weather Control

1) A brief current assessment/conditions of the driver and how it affects water resources and their use today, and if available, forecasts of this relationship over the next ten to twenty years.
Weather control of getting water to the right plants at the right time has had a history of promise over the past fifty years that has not been fully realized. It will take twenty years of concerted effort to realize the promise of weather control according to the Weather Modification Board **(Cleveland, 1978)**

2) A list of the possible developments that may have a potential *effect* on the driver's impact on water resources and/or use to 2050.
Better computer models will us to move beyond statistical models.

3) For each of these possible developments, a description where possible of:
a) What might make this happen?
More research. We have seen the Chinese use weather control extensively during the Chinese Olympics.

b) When might it happen?
It is happening now and has been used to mitigate hurricanes and seed clouds.

c) What determines when it will happen?
Clouds are a public good that may go over national boarders. There needs to be international coordination.

d) What would be the positive and/or negative impacts on water resources and their use?
Getting the right water to plants at the right could greatly enhance the future of water.

e) What are possible 'wild card' or 'out of the blue' developments that could influence the driver?
The ability to bring rain and shine just when needed is a wild card.

f) Who were the principal sources of information with regard to this development (name of institution, individual and contact coordinates)

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Remote Sensing

1) A brief current assessment/conditions of the driver and how it affects water resources and their use today, and if available, forecasts of this relationship over the next ten to twenty years.
Remote sensing or multispectral imagery is an increasingly deployed technology in regards to water related resources and agriculture. Among many other drivers affecting water resources, multispectral imagery is among the more mature technologies. Essentially, remote sensing leverages spectral ranges of radiation bands by subdividing them intervals allowing sensors to form multispectral images (Huang, Y. 2005). They may be used for detecting leakage of canals as well as from water storage locations.

While there is active research for remote sensing of agriculture and remote sensing applications, it is characterized as more of a diffusing technology rather than an inventive technology. Increases in bandwidth sensitivity and sophistication of computational analysis are increasing the diffusion and accuracy of remote sensing. Deep penetrating radar (GPR) is limited by three prime factors: frequency, conductivity and material type. Increased frequency increases penetration. The material type and conductivity significantly affect this ability. NASA has developed radar for Mars exploration which could help to find water deep earth's deserts.

Remote sensing has been deployed as a successful tool to help farmers with issues concerning soil wetness and watershed rehabilitation projects (Aubert, et al, 2010).

2) A list of the possible developments that may have a potential *effect* on the driver's impact on water resources and/or use to 2050.
Satellite imagery and analysis are currently commercially available. Possible developments that may have a potential effect on remote sensing's impact on water resources and/or use to 2050 include continual refinement of Geographic Information Systems (GIS) with the ability for real-time monitoring of agricultural crops and water quality and quantity. This is also determined by the availability of such information by farmers in developing countries.

3) For each of these possible developments, a description where possible of:
a) What might make this happen?
Remote sensing for water and agricultural analysis is already occurring. Market forces and adoption of the technology by commercial and national entities is likely to continue to increase the diffusion of the technology. As the technology is refined and system integration packages come online improved water usage and pollution detection can improve the knowledge of water resources and their use (Kao, et al, 2009).

b) When might it happen?
Remote sensing is commercially available. It may soon become commonplace for agriculturists to capture real-time data about their crops via remote satellites combined in order to make informed decisions regarding more efficient watering schedules.

A program on the Diane Rehm Show (2010) pointed to efforts in Australia and Israel to tie real time satellite data with irrigation pumps for the most efficient allocation of water.

c) What determines when it will happen?
Like several of the other drivers under consideration, cost is a significant determinant for the diffusion of the technology. The cost of performing remote sensing analysis for soil wetness, concentrated surface runoff, precipitation estimation, water pollution levels and other environmental measurement is becoming increasingly less expensive. The hardware costs are decreasing and the software functionality is increasing providing a platform for an increasing number of nations and large commercial growers use remote sensing technology. The costs of ground-truthing should also be considered.

d) What would be the positive and/or negative impacts on water resources and their use?
Remote sensing allows for an increasingly reliable method to detect water stress on crops (Suarez, et al, 2009), detect water quality, and analyze water usage. It may also allow for overexploitation of superficial and ground water resources.

e) What are possible 'wild card' or 'out of the blue' developments that could influence the driver?
The development of sensible business models that would drive adoption in the developing world could make a big difference. Several developing countries are already using remote sensing; however, their use is not extended, and certainly the poor farmers do not have access to it at the present time. Breakthroughs in cognitive science can make new and powerful forms of visualization, which would help individuals make sense of special information in a dynamic, multi-scale, and multidimensional way. Advances in Deep penetration radar would also contribute to finding water. Additionally, the deep underground sensors that track water movements and quality to provide dynamic maps based on such information is also considered a "wild card".

f) Who were the principal sources of information with regard to this development (name of institution, individual and contact coordinates)

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Desalination

1) A brief current assessment/conditions of the driver and how it affects water resources and their use today, and if available, forecasts of this relationship over the next ten to twenty years.
Currently most desalination plants that convert sea water into potable water are run using oil. The most popular form of desalination uses reverse osmosis which puts pressure on salt water so that the water goes through a membrane and the salt stays inside the membrane. Additionally, on the salt water side of the membrane water is pumped-out in order to mitigate otherwise high concentrations of salt to build up reducing filtration efficiency. As a result, there is a trade-off between water that exits through the filter and water that is expelled as waste.

Another desalination strategy is to use the heat generated in the process of cooling nuclear power plants to distill water. Additionally, there are some small low-tech solar stills and large scale low tech solar stills can also provide an option for many developing counties.

Desalination will become more economical over the next ten years as new membranes are developed. There is ongoing research on ceramic based membranes.

As noted in our nanotechnology section, many believe that nanotechnology can greatly increase the efficiency of the desalination process though there is a lack of consensus on when this will happen.

There is thus a concern about increases in our planet's carbon footprint if oil based desalination grows (Cooley, Gleick, and Wolf, 2006). As a result, there is significant interest in building wind driven desalination plants (Spang, 2006).

Solar energy can drive reverse osmosis or solar humidification/dehumidification. Though these technologies have been around since the 1950s, they have not been cost effective (Wikipedia, 2010). However, this may change dramatically as water becomes scarce.

2) A list of the possible developments that may have a potential *effect* on the driver's impact on water resources and/or use to 2050.
There is no shortage of salt water. The diffusion of desalination technologies over the next forty years will depend on the extent of shortages of potable water. If potable water is expensive then there is a business model for funding desalination efforts. Simple solar stills of the variety mentioned above are a good option for developing countries. They are low cost, but are also low volume.

Advances and focus on water pump and wastewater pump efficiency may also be a contributing factor in water desalination efforts.

3) When will this happen?

Geoff Debelko, Director of Environmental Change and Security at the Wilson Center, says that cost-effective wind and solar desalination solutions are a ways off and that we will need to focus on conservation (Diane Rehm Show, 2010).

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Nanotechnology Driver

1) A brief current assessment/conditions of the driver and how it affects water resources and their use today, and if available, forecasts of this relationship over the next ten to twenty years.

Nanotechnology is a promising technology in the application of sensors and many water purification and desalination processes. In the investment industry a distinction is drawn between nanotech and nanoscale. Nanotech refers to the ability of very small machines to build useful objects one atom or molecule at a time while, nanoscale is referred to the technology that creates very small objects. Nanotech by this definition is much farther away from commercialization than nanoscale. While there are several developments that may occur over the next ten to twenty years, the application of nanotechnology for desalination, water reclamation, heavy metal extraction, and microbial purification is promising and likely to continue in making great strides in development. The deployment of nanoparticle catalysts is a significant driver of the technology across energy, petrochemical, fuel cell, sensor, environmental and water domains (Moshfeigh, 2009). There are several reactions which may gain increased benefit from catalytic control as a result of nanotechnology to help supply the rapidly growing demand.

Areas such as enhanced phosphate removal from waste (Pan et al, 2009); heavy metal removal (Jai et al, 2008; Liu et al, 2008; Su et al, 2009); and organic pollutants (Allabashi et al, 2007) has been an active research area in nanotechnology with promising results.

A major consideration for the feasibility of nanotechnology in water purification and desalination is the cost of industrial-scale raw material production. Although there are several researchers that believe that carbon nanotubes (CNTs) are still too expensive to be used for large scale applications, there are recent experimental studies that suggest CNTs can be produced in high quality at lower costs. The technique of using catalytic chemical vapor deposition (CCVD) reactors is well established for lab scale production and may be extended to industrial scales with a plug flow reactor (PFR) or a fluidized bed reactor (FBR) containing a solid catalyst. CNTs may be produced with either design, CCVD-PFR or CCVD-FBR with a production rate of 595kg/h with an average cost of $25 to $38/kg. Less expensive carbon materials such as liquefied petroleum gas (LPG) at $400/ton have been attempted to replace pure carbon sources such as ethylene, carbon monoxide, methane, etc. in large scale production at $1200/ton with a purity greater than 97% (Upadhyayua, 2009). While manufacturing plants are producing commercial quantities at around $80/kg with an expectation of eventual cost reduced to $10/kg, the mass production of CNTs suitable for large scale water treatment and desalination is getting closer to commercialization and industrial use. At present, CNTs are primarily feasible for point of use (POU) applications for water purification rather than on industrial scales due to cost.

The large variety of commercial applications of CNTs is driving dramatic increases in annual production rates. Anticipated production rates of 200 tons/yr in 2009 and 3,000 tons/yr by 2012 (Smith, B. et al., 2009).

Furthermore, CNTs have less weight loss compared to other adsorbent media in water treatment applications (Lu and Su 2007). The implication is that it helps to balance the high investment cost of CNT filters and release negligible amounts of CNTs into the environment and ecosystem, which may reduce the risk associated with environmental and human exposure to CNTs. Additionally, metal oxides that are used as an adsorbent for pollutant removal from wastewater may be more efficiently reused through the combustion of the adsorbent species providing advantages over regeneration of activated carbon (Song, 2009).

Many of the fundamental discoveries in nanotechnology essentially improve upon the pre-existing methods for water purification. For example, membranes, catalysts, and other nano materials are able to provide increased filtration flow and increased catalytic reaction with lower energy costs as a result of carbon nanotubes fibrous shape and high aspect ratio, large accessible external surface area, and well developed mesopores, which increase flow rate and enhance filtration of macromolecular biomolecules and microorganisms.

> "Use of nanotechnology for using light irradiation for the remediation of toxic organic compounds in water is a rapidly growing field...most early work has been the in the US. Most volume is now coming out of Asia and EU. The focus here is to move to visible light photocatalysts, which are active in the blue light regime, so that sunlight and affordable electrically generated light can be used. Most work elsewhere is in UV light irradiation, which is effective and growing, but is very expensive and will likely stay that way due to inherent quantum inefficiencies in generating UV light, including using new UV LED's. Blue light LEDs are much more efficient (Shannon, 2010). "

Nanotechnology has a great potential to provide additionally fine sensor sensitivity capable of detecting lower concentrations of impurities.

The rate of nanotechnology development has been on an increased trend of development as measured by the number of publications and the number of patents (Chang, et al, 2009; Hullmann and Meyer, 2003; Kostoff, et al, 2006; Meyer and Persson, 1998; Mattes, et al, 2006). This is in part due to the social, economic and scientific significance of nanoscale particles as well as a means to make the explosive growth in multiple disciplines more tractable.

2) A list of the possible developments that may have a potential *effect* on the driver's impact on water resources and/or use to 2050.

Nanotechnology's potential impact on water resources and/or use to 2050 is likely to have an ever increasing prominence over time. The potential for nanotechnology to replace currently deployed water sensors, water purification and desalination is almost certain from a technological perspective. However, from a sustainable development standpoint it will require a broad alliance among scientists, policy-makers, and industry representatives (Fleischer and Grunwald, 2008). In some sense, the goal of technology assessment for sustainable development is to mitigate situations of severe risk. Nanotechnology research and development funding for the creation of the technology by governments and industry will continue by across the world. Through the multidisciplinary breadth of nanotechnology, it is also highly probable that many of the technological hurdles and cost barriers will be overcome over the next forty years; however, the social infrastructure on a global level may remain well behind the development curve. Furthermore, attention to the adverse health effects of nano particles in the environment may delay or derail large scale nano deployments.

The environmental dimension of sustainability has been addressed in the literature; however, the economic and social dimensions of sustainability are presently underrepresented (Fleischer and Grunwald, 2008).

3) For each of these possible developments, a description where possible of:

a) What might make this happen?

As cost-effective and environmentally acceptable nanomaterials gain more maturity, they will become more critical components of industrial and public water purification. The development of smart membranes with biofilmresistant surfaces embedded with sensors and actuators that can automatically adjust membrane performance is a key long-term goal for 2020 as part of the Desalination and Water Purification Roadmap prepared by the US Bureau of Reclamation and Sandia National Laboratories (US Bureau of Reclamation, 2003). Automated feedback and control at the nano scale can improve overall efficiency. Reduction in organic carbon load through oxidative photochemical degradation via visible-light activated Ti02 nanoparticles could also have an impact on water supply (Savage, 2005). Additionally, nanomaterials are anticipated to help solve desalination of brackish water, recovery of valuable and toxic metal ions from membrane concentrates (Van der Bruggen et al. 2003), development of chlorine-free biocides (USEPA, 1999), and the purification of water contaminated with toxic contaminates such as perchlorate, pharmaceuticals, chiral compounds and endocrine disrupting compounds (Richardson, 2003). There is also a potential that the metal ions could provide economic value offsetting the cost of new membranes.

b) When might it happen?

Regarding nanoscience and nanotechnology (NST), there are some peculiarities regarding a foresight study when compared with a traditional foresight study (Salerno, 2007). For example, the technology is more suited for mid to long-term studies rather than short to mid-term studies respectively. The global participation in research and development by academic, governmental, and industrial entities increase the geographical relevancy as compared to traditional foresight studies. The participants include experts addressing stakeholders' needs; the increased relevance of social implications and effects on people's lives are also somewhat different from traditional studies. Additionally, there is a requirement for the use of databases with structured techno-scientific information as a result of publications, patents, projects and the interdisciplinary nature of NST.

c) What determines when it will happen?

Nanotechnology is forecasted to become one of the fundamental enabling technologies for the 21st century. The trend of innovation as measured by number of nanotechnology peer reviewed articles and patents have been on an exponentially increasing rate over time (Compano 2002). The number of patents was doubling about every 1.6 years and the number of publications was doubling about every 2 years (Salerno, 2007). Clearly, the technology is still in its early stages of development. When considering the outlook to 2050, many of the early stage patents will have expired, resulting in increased competition and reduced cost.

The increased rate of spending in nanotechnology research and development worldwide will help to drive the technology toward more economically feasible solutions. In many regards, nanotechnology research and development is somewhat of an international technology race (Hullman, 2007; Kostoff, et al, 2007; Liu, et al, 2009; Marinova, et al, 2002; Wong, et al, 2006). Between 2000 and 2007, the annual average growth rate in nanotechnology papers in China was 31.43%, Russia was 11.88%, and India was 33.51% with corresponding rates of patent growth rates of 31.13%, 10.41% and 5.96% respectively. Over 60 countries have started their own national nanotechnology research programs (Roco 2001, 2007). The US, Europe, Japan, South Korea, Germany and France are also considered major players (Huang, et al 2004; Kostoff, et al, 2006). Forecasts from different sources suggest that the nanotechnology industry would show a substantial market for nanotechnology increase in 2010. Additionally, the pessimistic forecast for the 2015 world market is the neighborhood of 750 billion US dollars to optimistic projections potentially exceeding 2.5 trillion US dollars by 2015 (Hullman, 2007). The key determinant will be a demonstration of a cost effective high volume desalinator based on nanotechnology or a similar technology. Once demonstrated, the business path becomes clear.

d) What would be the positive and/or negative impacts on water resources and their use?

Nanotechnology is promising not only for improving water resource use through more efficient and effective filtration, purification and desalination methodologies, but also in sensing water quality measurements with real time monitoring and real time response capability (Rickerby, 2006). There are some critical gaps that still need to be overcome. The rate of nanotechnology emergence is outpacing the ability to test and provide thorough lifecycle analysis. Gaps in understanding the environmental impacts and nanotoxicity are not well-understood aspects of the technology. As a result, a holistic understanding of nanotechnology is required for evaluating claims of the emerging technology to include toxicity, resource consumption, and energy use (Khanna, 2008).

In many urban areas, the water supply near industrial areas contains cadmium and arsenic, which has increased the demand for monitoring and filtration technology improvements. The use of commercial nanofabricated sensors and satellite imagery has been investigated for environmental pollution detection, monitoring and remediation giving rise to public awareness concerns and policy prioritization (Vaseashta, et al, 2007). Developments in nanophotonics will assist in increased satellite resolution and improved nanofabrication techniques with the promise to improve the ability to sense, monitor, and remediate environmental pollution.

The mechanisms for nanoparticles to pass through cell membranes are poorly understood. There is evidence that they may accumulate in prokaryotic and eukaryotic cells, which may have an effect on the cells of animals, plants, algae, bacteria, fungus and humans. While a forum dedicated to nanotechnology toxicity was first established in 2007 in Stockholm, much of the focus has been on CNTs and their affect on cells with little emphasis on heavy metals and their oxides. Additionally, wastewater is becoming an increasing source of environmental pollution as nanoparticles in sunscreen and other sources may contribute to bioaccumulation in natural systems (Bystrzejewska-Piotrowska, et al., 2009). There are no conclusive data that indicates that the toxicity effects of nanoparticles will be a major problem or that they cannot be addressed scientifically (Fleischer and Grunwald, 2008). Furthermore, there is also no conclusive data to the contrary.

Nanoparticles do not behave the same way as normal waste products; therefore, standard tests may not be suitable for the disposal in landfills. Legal regulation is a significant issue. There is presently no nanowaste material that is regulated as hazardous waste (Bregin and Pendergrass, 2007). A means of remedying the situation tagging nanoproducts has been proposed in order to facilitate the separation and recovery of nanomaterials (Bystrzejewska-Piotrowska, et al., 2009). As a result, there is a need for full life cycle analysis (LCA) of nanomaterials in order to avoid making nanowaste a problematic legacy of nanotechnology.

Lifecycle analysis

Although one could argue that toxicological studies of carbon nanofibers (CNFs) must occur prior to the application of the most appropriate intervention strategy, risk analysis and prevention measures for worker exposure to carbon nanofibers (CNF) is a recommended (Genaidy, A. et al. 2009).

A fundamental issue that needs to be addressed concerns the proprietary nature, global distribution, rapid evolution, and current state of voluntary reporting. This leads to a demand for scientific and policy maker information access regarding safety profiles and nanotechnology characteristics. The risk of a serious nanomaterials-related health issue in one area of the world could greatly influence public perception of the emerging industry (Linkov, I. et al, 2008). This is especially relevant since the average layperson has heard “little” or “nothing” about nanotechnology (Siegrist, M. 2007). As a result, there is value in understanding the health and environmental impacts of nanotechnology from manufacturing, to use, to recycling, and to disposal. This kind of information should be available in a water collective intelligence system.

Several of the positive and negative impacts can be influenced by the assistance of mathematical models and simulations (Frenkel and Smit, 1996; Werder, et al, 2001; Werder, et al, 2003). This may be accomplished through a wide range of granularities from technical molecular simulations for water flow across a CNT (Fang, 2008) to larger social and environmental simulations.

e) What are possible 'wild card' or 'out of the blue' developments that could influence the driver?

Regarding nanotechnology, ‘wild card’ technologies such as advances in quantum computing, quantum physics, Super Symmetry, Quantum Yang-Mills Theory, and resolution of the P vs. NP problem in computer science all may result in uncertain advances in technology and understanding of the physical world. While quantum computing promises to assist in enhanced capabilities in combinatorial chemistry, combinatorial biology, and material science, the fundamental research at the Large Hadron Collider at CERN may yield a wealth of knowledge regarding questions of the Higgs Boson, Super

Symmetry, and Quantum Yang-Mills Theory, which could lead to the advancement of nanotechnology industry.

Open questions regarding nanotoxicity and potential legal lawsuits from nano workers or users of nano-based sunscreen could have an effect on the technologies adoption. Graphene, or single carbon atom thick sheets and other advances in ultra-smooth materials may also provide assistance in water distribution efficiency through a reduction of the Reynolds number in low drag pipes. This in combination with high efficiency pumps may provide a means to distribute fresh water from water rich regions to water poor regions.

f) Who were the principal sources of information with regard to this development (name of institution, individual and contact coordinates)

Sarge Green, IRWMP Coordinator, California Water Institutes at California State University Fresno

In discussions regarding nanotechnology and water resources Sarge Green offered raised the following questions:

Where does nanotechnology fit in an integrated approach that yields the most benefit for the least cost and least impact to natural resources?

If the goal is calories (food) for sustainability of a stable human population, how does using nanotechnology that is designed to create a water supply adequate for plant growth of existing cultivars compare with other investments in meeting the food supply goal such as what we have discussed, modifying plant species to grow in differing water qualities including high salinity water?

Which will be ready sooner given the same investment?

Perhaps the driver is adequate drinking water supplies of an acceptable quality?

How does nanotechnology applied to the specific goal fit with other investments after water-use efficiency is exhausted?

Does nanotechnology have a focus of results-driven progress based on the greatest benefit overall? For example, often the first spinoff of high technology is in the human health field. In this case I can see artificial kidneys as a potential outgrowth of carbon tube nanotechnology. Energy (electrons) may be the second highest use of [priority for] the technology and water/food supply third.

Can this usual hierarchy be analyzed in the integrated approach such that the best use of the technology gets the R&D in a way the greatest comparative benefit can be obtained?

The answer for nanotechnology may be human health is the highest and best use but an examination is in order.

In communication with Sarge Green, he offered the following insight:

“An example of the trickle-down effect of technology I experienced in the water business is in the water contaminant analysis field. Computer-aided gas chromatography/mass spectrometry came out of the health field. I have a friend who opened an environmental chemistry laboratory by buying the gc/ms from the outfit that did blood chemistry in the 1984 Olympics, the graphics library in the computer obviously focused on performance enhancing drugs, however, it wasn't long before the library was locally expanded to detect pesticides and other organic chemicals in the environment to the extent it helped (regionally and nationally, the lab is now a reference lab for USEPA) markedly in moving detection levels so far down (ppt) that eventually all the existing water quality objectives had to be thrown out the window. It also changed the regulatory atmosphere such that if you could find it (a detectable material), it became the regulatory goal. The moral of the story is that the unintended consequences of technology can be as important as the original goal and that is why it is important to have the integrated approach to find the best uses as early as possible in the R&D efforts (Green, 2010)."

In correspondence with Mark A. Shannon, he stated:

> "…The questions you ask below are actually fairly complicated and many people, even experts in the field can be confused. I spent a very large amount of time trying to help National Geographic, which is running an article on the use of nanotechnology for desalination. They received a fair amount of expert advise, a lot from vendors themselves, that simply was not true. I will do my best to answer precisely to your questions…(Shannon, M., 2010) "

One of the primary questions we have is how much more efficient nanotechnology membranes are for desalinization than conventional membranes for reverse osmosis?

> "There is a huge amount of work going on in developing new generations of nanotechnology enabled reverse osmosis membranes. The work ranges from including nanoparticles of metal oxides, such as zeolites, to carbon nanotubes (CNTs), to aquaporins, to macrocyclic super molecules. All can be functionalized to give different chemical properties. All of these have companies starting to produce them, in order in terms of technology listed above: NanoH2O, Porifera, Aquaporin, and one that cannot be revealed due to an NDA. Many are what we call "super flux" membranes, which means that they offer much smaller resistance to the flow of water through them, making them much more efficient than current membranes. But being superflux by itself will not necessarily increase the overall efficiency of RO [Reverse Osmosis] efficiency, as I will discuss below (Shannon, M., 2010)."

We have heard of numbers between 5 and a 1000 times more efficient, which is rather broad.

> "You are right on the numbers. The nano-zeolite membranes give about 2 to 5 times higher flux. 100 to 740 times higher per CNT's, and up to 1000 times higher per aquaporin (this is just an estimate). Now here is where it starts to get really murky. Lots of issues such as density of pores (low densities mean the real gain is much lower), crossover of salt (high flux can mean higher crossover, which negates some of the effect of the higher flux), and the big one, that membrane resistance at most accounts for only 40% of the energy needed for desalination. The rest goes to the osmotic pressure of the salt solution itself, product to rejection ratio (low product to rejection means lower energy, but little product water...not good), and losses due to fouling, module losses, and concentration polarization impedance. These last three all go UP with increasing membrane efficiency. They can actually go up faster than the reduction in

energy due to better membranes. This last fact is very well understood by those who make real RO systems. So the overall effect of going up in flux by a factor of 5 to 1000 is that the overall RO efficiency may, if other nanotechnology improvements are made, go up by 20% or so. While this may not seem exciting, it is to those in RO who have been optimizing systems for 40 years and have really squeezed lots of efficiencies out already.

Other new nanotechnologies on the horizon including active nanochannel ion pumping to eliminate the polarization impedance, and new micro-nanotechologies aimed at eliminating fouling resistance and decreasing module resistance. If all these can be achieved, RO can be brought down to half the energy of the best systems today, which puts it near the theoretical minimum possible. Again, 50% sounds small to some, but it would be huge in an industry that gets very excited by 1 to 2% (Shannon, M. 2010)."

Additionally, what would be an appropriate estimate for implementation time for these technologies?

"All the nanotech membranes mentioned above are in the process of being commercialized. Likely will first appear within 2 to 3 years as active products. The others mentioned after are still in the laboratory. If they work, might be another 2 to 3 years after that. Depends on the funding available for R&D, which is quite low in the water sector, so it could be much longer. More money is starting to flow from overseas, so these technologies might be accelerated and implemented and inserted into the marketplace from the EU and Asia, which is far outspending the US now in nanotechnology for water (Shannon, M., 2010) ."

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Saltwater Agriculture

Saline agriculture could reduce water stress for communities by allowing the communities to grow food, fiber, biofuel, and trees with saline or brackish water, freeing up potable water for drinking and other uses for which it is required.

Different communities have different amounts of saline or brackish water available, but having saline agricultural technology will increase many communities' potential sustainability. Depending on the degree of climate change that we experience, saline agriculture could play an important role in agricultural viability of land as the balance between fresh and brackish water changes.

According to the Food and Agricultural Organization (FAO, 2002) "World Agriculture: Towards 2015/2030," the demand for water for agricultural irrigation is going to continue to increase in response to human population growth and an increase in the standard of living for humans.

> Irrigation is crucial to the world's food supplies. FAO studies suggest a total irrigation potential of some 402 million ha in developing countries, of which only half is currently in use. However, water resources will be a major factor constraining expansion in South Asia, which will be using 41 percent of its renewable freshwater resources by 2030, and in the Near East and North Africa, which will be using 58 percent. These regions will need to achieve greater efficiency in water use. (FAO, 2002)

There is of course a plentiful access to sea water in certain parts of the world and another 1% of the world's water is partially saline (brackish) and has not traditionally been suitable for fresh water irrigation.

Today, only about 1% of the species of land plants can grow and reproduce in coastal or inland saline sites. (Rozema, 2008) Salinity can decrease crop yields for fresh water plants. (Munns, 2005)

There are plants—known as halophytes—that do well in saline water. The challenge is that many deal with saline stress by concentrating salt in their tissues which makes them unsuitable for food. However, they may be used for energy crops with potential for animal feed. Many halophytes can flourish in saltwater concentration levels half that of sea water. Many can have high bulk compared to normal plants (Niazi, 2000). (Flowers, 2004). Although halophytes often deal with saline stress by storing salt in their tissue making the tissue inappropriate for food stock (NRC, 2001) the seeds of halophytes don't necessarily have the same problem. Halophyte seeds provide a potential opportunity to develop food stocks, which would reduce demand for fresh water. There have also been efforts in Australia to develop saline forestry practices (NRC, 2001).

Dr. Dennis Bushnell, NASA's Chief Scientist, believes that halophytes are an ideal source of biofuels. (Bushnell, 2010). Instead of making biofuels from corn using fresh water, Dr. Bushnell sees that growing biofuels from salt water will solve both water scarcity and energy scarcity problems. He does see considerable resistance to doing this; resistance that he thinks is cultural:

> My take on why this has taken so long to gain traction is that farmers at birth are evidently inoculated with the fact that SALT IS BAD, which it is for fresh water plants. BUT, there is the alternative universe of Halophytes which they know NOTHING about. (Bushnell, 2010)

As a result, there is a great need to educate farmers, particularly in 3rd world countries. Perhaps we need a "farmers without borders" training corps.

There has been significant success with genetic engineering for increasing yields of crops and resistance to disease. There has been less success in genetic manipulation to increase salt resistance. "So, although between 1996 and 2006 there were more than 30 reports of transformation of rice with different genes aimed at increasing salt tolerance, transgenic salt-tolerant rice is not close to release. The likely explanation is that salt tolerance is a complex trait determined by many different genes, so that transformation of multiple genes into a plant is required (Flowers, 2004), (Munns, 2007).

Research and Development

Worldwide, initiatives are being undertaken to develop saline vegetable crops, as well as crops for fuel and fiber (Ahmad, 2002). For saline architecture to be successful, it will require the development of saline tolerant seed stock. There continues to be a need for basic research. The NRC (1990) says that more research is needed into how plants respond to saltwater. Recent advances in applied genomics are opening up doors for isolating genes that can allow plants to survive in saline waters and make them suitable for human consumption.

There was an important breakthrough in Australia this year in isolating a gene that prevents salt from being absorbed into the leaves of a plant, greatly increasing its resiliency. (Science Daily, 2009) Through genetic modification (GM) this gene and its benefits can hopefully be integrated into other plants.

There is a significant amount of private sector research. Research (FuturaGene, 2010) is focusing on the development and licensing of genes that control the Salt Overly Sensitive (SOS) pathway, which are involved in controlling the level of the toxic sodium ion (Na+) in the cytosol. These genes play important roles in a number of mechanisms for salt control that include:

- minimizing Na+ entry into the cell,
- secretion of Na+ from the cell, and
- sequestration of Na+ from the cytosol into vacuoles.

In addition to finding the genes of plants that make them salt tolerant, there is the possibility of inventing whole new mechanisms and creating genes that create the mechanism to make plants less salt sensitive.

Though outside the realms of this paper, there is significant discussion about genetic modification (GM) and whether it will be allowed in the food supply chain. The jury is still out. While some countries are deciding to ban genetic modification of the food supply chain there are others that have reversed the ban. Intellectual property constraints are a limiting factor for adoption. Additionally, salt tolerant agriculture through GM fit for human consumption shows demonstrates great promise.

There are many uncertainties and risks: variable germination, propagation, plant diseases, scaling up, processing halophyte biomass, market demand, and economic competition with conventional bulk-produced raw materials such as potato, sugar beet, and sugar cane. Traditional barriers between disciplines need to be broken down if there is going to be significant success developing saline philic crops.

> Interdisciplinary communication is particularly important in research on salt-tolerant plants. Cooperation among plant ecologists plant physicologists, plant breeders, soil scientists and (and

> hydrologisits) and agricultural engineers could accelerate the development of economic crops. Further universities could introduce special programs to allow broad study of the special characteristics of saline agriculture to serve growing needs in the field (NRC, 1990).

When might it happen? What determines when it will happen?

We have asked a number of experts in the field for their projections for innovation and diffusion

Ed Glenn at the University of Arizona responded:

> I do think it will be possible to produce salt tolerant crops on salinities up to and even beyond seawater (see attachments for an entry to the literature). However, they will not be available for all staples immediately. Our approach of domesticating halophytes can produce oilseeds, forages and some grains. So far, the promise of introducing high salt tolerance into conventional crops has not been fulfilled, as salt tolerance is a complicated multi-gene set of traits. There are no technical "breakthroughs" needed in my opinion. Up to now, world crop land has been sufficient to meet world food demands, and new crop lands can be cheaply created from rainforests [although this would generate serious ecological and climate problems]. As the limits of these croplands are reached, salt water agriculture will become economically and environmentally attractive. (Glenn, 2010)

Manzoor Qadir of the International Center for Agricultural Research in Dry Areas (ICARDA), part of the Consultative Group on International Agricultural Research (CGIAR) responded:

> While several still feel that improving freshwater-use efficiency or productivity of freshwater per unit volume is the answer to such freshwater shortages, many also consider salt-tolerant agriculture by switching to seawater-based food and biomass production is the answer to the looming freshwater scarcity scenario by freeing up completely the freshwater currently used for conventional agricultural production systems. I see a way between them as the way to move forward.
>
> I partly agree with Dennis Bushnell with the view that salt-tolerant agriculture has a significant role to play in the future agricultural production systems, but cannot see this happening now or even in the next decade. The reasons are that the progress is slow both in terms of improving germplasm of field crops for enhanced salt tolerance as well as using halophytes as food/feed crops or their domestication at a large scale. The scientists had been looking for breakthroughs in improving salt tolerance of conventional crops for the last three decades, but the success is limited. According to Ed Glenn 'the promise of introducing high salt tolerance into conventional crops has not been fulfilled, as salt tolerance is a complicated multi-gene set of traits'. The research efforts continue with optimism. And that should be the case. However, considering world agriculture just based on salt-tolerant field crops or halophytes in the next even 2-3 decades is something I am not convinced with. There are several 'small-scale' success stories and people are thinking of changing the whole system to be based on seawater. One of

the major issues is marketing and market-value of the halophytes. I have been involved in several large projects and although we were able to demonstrate the performance of salt-tolerant under salt-affected environments through biophysical approaches, there was little appreciation at the market level. The farmers go for the profits remain uninterested or show little interest under such circumstances.

The concept of using halophytes for food/feed is not a new one as Dennis Bushnell rightly illustrated, particularly for the Indian sub-continent. Being from the same region, I know it only on a limited scale. The looming water scarcity will trigger the move towards saline agriculture, but will take decades as I see foreseeable future. I personally see a gradual move towards this direction. We need to look at the water scarcity issue from other perspectives as well. It is not just the freshwater scarcity, there are current problems stemming from water quality deterioration. The UN has already started focusing on this. This year World Water Day has a theme addressing water quality. With increasing volumes of wastewater generated by ever-increasing urban population, there is a need to treat and reuse this water resource more efficiently. Similar is the case with saline drainage water generated by the irrigated agriculture. Although efforts are underway to make best use of such type of marginal-quality water resources, there is a need to focus more on this aspect as the safe and productive use of such water resources also helps in environment conservation and improvement in water quality. The use of saline water (less salts than seawater) or seawater would also need other arrangements such as soil drainage to keep the soil salinity levels at suitable levels.

Crop diversification systems based on salt-tolerant plant species or varieties are likely to be the key to future agricultural and economic growth in regions where saline water would be used for irrigation. Such systems linked to secure markets, should support farmers in finding the most suitable and sustainable crop diversifying systems to mitigate any perceived production risks, while ideally also enhancing the productivity per unit of saline water and protecting the environment. An appropriate selection of plant species capable of producing adequate biomass is vital while using saline water for irrigation. Such selection should be based on the ability of the species to withstand elevated levels of salinity in irrigation water and soil while also providing a saleable product or one that can be used on-farm. I have attached a paper on a similar subject for your information. This takes into consideration a range of plant species.

And finally – your question – what hurdles need to be overcome to create salt tolerant crops? ***Limited use and limited/slow success on improving germplasm of field crops for enhanced salt tolerance as well as domestication of halophytes as food/feed crops; limited/lack of markets; limited human and institutional capacity; limited awareness; and lack of appreciation at the political front.*** (Qadir, 2010)

As we can see from Bushnell and Qadir's comments, the barriers to using saline agriculture to reduce water stress are more than just technical, they are cultural, institutional, and political. The United Nations and the world community through concerted effort can significantly change the adoption curve for salt tolerant plants and reduce water stress for people on the planet.

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Meat without Animals

A significant amount of our fresh water goes towards growing meat. Table 2 below shows the amount of water that goes into growing meat.

Table 2 (National Geographic, 2010)	
	Gallons of Water Used to Produce One Pound of Meat

Beef	1,857
Pork	756
Chicken	469
Sausage	1,382
Processed Cheese	589
Eggs	400
Fresh Cheese	371
Yogurt	138

Jason Matheny (2010) of New Harvest, a NGO that focuses on the subject, points out that there are two forms of meat substitute that need to be considered:

- plant based meat substitute
- cultured (in vitro) meat

He sees the main technical hurdle to having meat without animals from plant based meat as involving the development of techniques for improved texturizing of plant proteins, so that it better resembles meat and reducing the levels of allergens, acids, and phytoestrogens in order to make them acceptable to more consumers. The current state of soy substitute is quite good my many consumers. He points to the semi-moist extrusion process as a key for solving the texture problem. Matheny points to the success of Gardein in Canada to demonstrate continued progress in extrusion. He sees the plant proteins (mostly beans) with lower levels of allergens, acids and phytoestrogens. He writes, "Already, I think many existing products could achieve greater market share with more marketing and a move beyond niche pricing."

Matheny identifies the major obstacle to cultured meat is "finding inexpensive and efficient culture media, good cell lines, and automated tissue engineering processes." The technical solutions include microalgae as a nutrient source, prolific cell lines, and improved bioreactors. All of these are being pursued by Dutch universities; the Dutch government has been investing in cultured meat research. Matheny believes that these breakthroughs can be achieved in 5-10 years.

In an effort to drive the technology for PETA has offered a million dollar prize for the best commercially available cultured meat at a competitive price (ABCNews, 2010). Additionally, the choice for many individuals to become vegetarians can also provide significant impacts on water resources.

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Integrated Water Resource Management and Information Technology

An assessment of the available water resources is a pre-requisite to undertake an analysis of the stress on the water resources and to subsequently adopt appropriate management strategies to avoid adverse environmental effects and reconcile conflicts among users (Xu and Singh, 2004).

There are large disparities in terms of the amount of hydrological information available to decision-makers in different parts of the world.

The paradox of integrated river basin management is that although stakeholders demand technically sound decisions and their involvement, as situations become more complex, fewer people have the technical competence to either contribute to the decision or even critique the decision.

Even with access to state of the art tools, the existing segmentation of institutions responsible for water resources planning and management often severely inhibits optimal management for the majority of the population. Furthermore, there are many barriers to the use of climate forecasts by water managers such as low forecast skill, lack of interpretation and demonstrated applications, low geographic resolution, inadequate links to climate variability related impacts, and institutional aversion to incorporating new tools into decision making (Callahan et al., 1999). This situation poses difficulties for effective regional, national, and international water resources management. Moreover, the situation becomes even more complicated by the looming climate change which, in the longer term, has the potential to decrease the availability of natural water resources in many areas of the world due to probable changes in the rainfall distribution and the increase in temperature (Xu and Singh, 2004). As a result, in many river basins around the world, local decision makers have insufficient knowledge of exactly how much water is available and the risks to its future availability (Xu and Singh, 2004).

SAHRA (Sustainability of Semi-Arid Hydrology and Riparian Areas) has published a paper that explores how to link science with environmental decision-making using information technology (Liu, Gupta, Springer, Wagener, 2008). They point to Jacobs (2002) who lays out the nature of the information that decision-makers need from scientists:

1. relevant to answering the specific policy question
2. readily accessible and understandable by decision-makers
3. acceptable in terms of accuracy and trustworthiness
4. compatible and useable in the specific decision making context
5. provided in a timely fashion

From their 5 year experiment as scientists working with decision-makers, Liu, Gupta, Springer, Wagener (2008) have distilled the following lessons:

1. Importance of identifying focus questions
2. Importance of explicit conceptual modeling
3. A multi-resolution, multi-disciplinary integrated modeling approach

4. “Scenario analysis is a practical, effective way to put integrated environmental models into more beneficial use for long-term real-world decision making under uncertainty.

Water crosses borders. It is clear that integrated water management needs to be decentralized down to the water-shed level. This can of course span political boundaries, but it is essential to do.
The water management field is characterized by a diffused decision-making process that spans farmers to regions, from municipal suppliers to countries, and from country scale to global scale. Decisions are based on short-term profit. The goal of collective intelligence systems is to increase the likelihood of more unified strategies that can allow the decisions made at various levels to reinforce one another, or at least not work in contrary directions. Developing integrated water management systems are a very important first step towards this.

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Water from Air

There are many paradigm shifting products that are coming to the market such as Element Four’s Watermill that produces enough potable water for a family of six from the air. More information at http://www.elementfour.com/

Eco Friendly Technologies

Though this paper has focus primarily on high tech solutions it is important to emphasize there is not limited to human ingenuity in developing solutions to water stress through eco friendly methodologies. One school that has picked up considerable momentum over the past twenty years is called permaculture which utilizes methods found in nature for creating sustainable communities. These solutions tend to be decentralized and require little capital input. One permaculture technology that bares special attention here is rainwater harvesting, which collects and distributes rainwater to meet drinking and gardening needs. Bill Mollison’s book, “Permaculture: A Designers’ Manual” is the authority on permaculture technologies.

It should also be mentioned that there are many indigenous technologies for bringing human community into balance with the eco system and managing the supply of water. Though there has been very little scientific research into the effectiveness of rain dances and sun dances work, it is predicted that such indigenous technologies may contribute to a collective solution.

Water Recycling and reclamation techniques

There are significant efforts to recycle gray water as a way of reducing water stress. For example, the Hawaiian golf courses are all watered with reclaimed or recycled water. Reclaiming water from industrial and municipal sources can have significant impacts on the ability to reduce water stress. Added benefits are expected as these technologies develop and become more prevalent.

Technological means for controlling the degradation of aquifers, land reclamation, and rehabilitation

Using technology like information systems and sensors to monitor and control degradation of aquifers is essential for a sustainable water use. Additionally, land reclamation and rehabilitation are also means by which action can be taken to better manage water usage. There are several reclamation recovery projects that are presently underway. The impact of such efforts cannot be understated.

Control of evaporation from agricultural fields, water storage sites, and canals

Evaporation control systems are another emerging set of technologies. From agricultural fields, to water storage sites and canals the major focus is to reduce the amount of water that is lost due to evaporation. Research is underway to address the impacts of evaporation control.

Improved probabilistic models of water use—insect infestation, and agricultural production

Probabilistic modeling of water use and access to surface irrigation water resources is an important step in the determination of water resource allocation and infrastructure planning. These types of models can be of great benefit in order to understand the variations in water supply and demand. Additionally, models mapping insect infestation and agriculture production can be of benefit in understanding risks associated with water resources.

Rapid growth trees and other crops

Rapid growth trees and other crops that reduce water stress may also contribute to reducing water stress. Aeroponics has been studied by NASA since the 1990s. It allows plants to grow considerable root systems without soil and far less water than what is traditionally considered necessary for plant growth. It essentially uses an air/mist system to rapidly grow plant crops. Additionally, there are advantages in choosing to grow and harvest rapid growth trees. While tree growth varies among species and climate, the focus on producing rapidly growing trees can assist in reducing water stress. This technology especially in combination with agri-biotech advances can provide significant differences in the amount of water required for plant growth.

Water conservation technologies

Water conservation technologies on the federal level suffer from: inadequate information about the amount of water a facility uses; low current water costs, insufficient knowledge about the cost-effectiveness of water conservation projects; lack of funding to carry out projects; and misconceptions about the use and benefits of water-efficient technologies. On the domestic side, low-flow sensored faucets, low-flow showerheads, pressure-reducing valves, horizontal-axis clothes washers, water-efficient dishwashers, low-flush tank toilets, low-flush flushometer toilets, low-flow urinals, and waterless urinals are slowly becoming more prevalent and can help to reduce water stress. It is expected that these technologies will provide a greater impact in the future.

Information Technology

Information Technology (telephone, Internet, Google, Wikipedia, and social media) have greatly increased our ability to communicate and organize around the world and to access information. However, they have also caused problems for knowledge management and decision-making.

In the past when a few institutions controlled the flow of information, it was easier to drive society to consensus. Now we have a global society that is rapidly evolving and no one really understands how to work the system as a whole. We are seeing an incredible explosion of knowledge through science and technology. People, or experts in institutions, who are channels for information often are overloaded with email and phone calls. These experts have little time to educate people in other domains (who speak different technical languages) about what they see as important.

Computers are very good at doing things like searching millions of documents for patterns and keywords, but so far there have been few breakthroughs in cross-domain knowledge management (Chen, 2010). There is considerable debate as to whether computers can learn to do this or whether we need to make things easier for computers by creating a semantic web (BBC Digital Planet, 2010).

When we asked computer experts about how to create a global collective intelligence system, we quickly ended up receiving multi-page emails. Instead of quoting them all here, we have created a website (http://sites.google.com/site/globalcollectiveintelligence/) that summarizes the debate and provides links to our experts emails to us.   If you go to the website you will see that the term "ontology" is thrown around a lot, without actually being defined. An "ontology" is the system of categories that make discussion possible within a discipline. It thus structures what questions can be asked and studied. Creating an ontology that spans multiple disciplines is a challenge.

This is not to underestimate the power of telecommunications and computing, rather the challenge is to strategically deploy them in order to greatly increase the ability of "knowledge workers" to work more freely across multiple domains; therefore, reducing the barriers for knowledge synthesis. MIS techniques such as data mining and multi-agent simulations can help analysts understand vast data sets.

The real challenge is to capture the knowledge of experts in a way that may also be synthesized by the broader public. Perhaps one of the most valuable information sources that the public could have are transcripts of Delphi processes, email trails or conference proceedings that show experts and scientists from across disciplines debating.

Dennis Van Dusen, a long time technical consultant in the knowledge management field, believes that it is possible to collect information on expert's web browsing and email habits to prioritize and contextualize information with the goal of creating a global collective intelligence system (Van Dusen, 2010). Students and motivated members of the general public would be empowered to participate in a structured way. The fact that they are not on information overload means that they could make contributions that institutional experts might not be able to make. Human and computer knowledge processors would sanitize information flows and remove sensitive pieces of information such as email addresses.

Hyperlinks are an excellent technology for providing easy access to relevant sources. For public information dissemination, reports and studies, such as from the UN, should have the text of their citations available to the public for free or at a nominal cost by a click of a mouse button.

Nora Savage from the US Environmental Protection Agency working with nanotechnology commented that water is the next cause for conflict. Additionally, most of the funding in the nanotechnology arena is going toward other medical and other consumer applications (Savage, 2010). As a result, a water centric information system that incorporates water related patents, scientific journal abstracts, and regulatory requirements; which streamlines the entrepreneurial due diligence process could lower barriers for water-related investment and commercialization; therefore, hastening the time for water-related technologies to get to market.

The New York Times has reported that the scientific community is rethinking how to open the scientific vetting process up to the public, rethinking brought on by the inability of our planet to make meaningful decisions about climate change (Broder, 2010). Some worry that the signal to noise ratio will only decrease if more data and discussions are opened up. Others believe that we must raise the scientific literacy of the general public and propose that every high school student take a science class (Severinghaus, 2010). In fact, it is our opinion that the skills needed to make sense of the climate change debate are ones taught in a PhD program.

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Conclusion

One month ago when we started this project we knew virtually nothing about water technologies. By reading the Wikipedia article on “Water”, we quickly increased understanding of this molecule that is so important to life on earth. We then set up Google alerts for the keyword “water”, but by the next day realized that the signal to noise ratio was way too low. We then set up Google alerts for “potable + water”, “desalinization + water” and “salt + agriculture” and started to get a sense over the next couple days of the issues involved with water and the people and organizations involved with these issues. Our search of the Twitter space was basically useless.

In our reading, we focused on the issues specified in our statement of work and tried to understand the right questions to ask. We realized that we needed to combine Google searches, with searches of the academic literature, and expert interviews. It was not obvious to us which order to combine these methods. We decided to run an experiment and try different strategies with each technology driver under investigation.

The more we explored the domain, the more we realized how many technologies there are out there that could impact world water. We had a good conversation with Sarge Green (2010) of the California Water Institute about how he is overrun with people pushing alternative water technologies.

The use of nanotechnology to clean water and for desalination is perhaps the most technically complicated technology we were faced with. We read over 50 papers to develop ontology of the issues that WWAP needs to consider. We shared our white paper with experts who we identified or were referred to. These experts appreciated our questions and were very forthcoming.

Genetic modification of plants to make them more salt tolerant is also complex. For this issue, we used the three methods in parallel.

After a month of working on the WWAP, we feel confident that we can quickly research and do justice to any technical driver that could impact water scenarios. The big challenge is how deep to go into specific issues associated with the driver and how to present this depth to those developing the scenarios. In this paper, we have chosen to quote extensively some of the experts we corresponded with. With the information technology driver, we saw the dialogue becoming very complex very quickly so we set up a website (http://sites.google.com/site/globalcollectiveintelligence) to condense the dialogue while providing links to the text of emails from experts.

We faced major struggles when looking at the future impact of nanotechnology, applied genomics, and information technology. On one hand, the experts we talked to wavered between a view that almost anything was possible very rapidly and a view that positive change could take years due to the fact that our world's innovation system is broken.

One of the real challenges we faced with both genetic modification and nanotechnology is the fact that these are not purely technical issues and cannot be viewed without looking at them in a political, ethical, and economic contexts. We have tried to point out some of these connections in Table 3. Nanotechnology has been in part driven by the defense establishment and in case of health applications by the venture capitalists. Clean water is a public good and it is not clear how rapidly we will see innovation without public sector investments.

Table 3:Drivers and their connection to other WWAP research topics

	Nanotechnology	**Low Cost Desalination**	**Eco technologies**	**Salt Water Agriculture**	**Growing Meat without Animals**	**Remote Sensing**	**Information Technology**

Water Resources and Ecosystem	Somewhat Important Cleaner industrial processes and increased purification efficiency	Strongly Important Water resources determine need for desalination	Strongly Important Harmonize human systems with ecosystem	Strongly Important Liberating fresh water resources	Somewhat Important Reduced water consumption for meat sources	Strongly Important	Strongly Important – integrated water management
Climate Change	Strongly Important – Need for low cost desalination	Strongly Important Climate change can result in increased salinity of fresh water resources	Somewhat Relevant Need ecotechnologies that can deal with hydrological change	Strongly Important Salinization of fresh water resources Need to reduce carbon footprint	Somewhat Important Reduce methane footprint	Strongly Important – new sources of water	Strongly Important – models the change.
Governance (Institutions)	Strongly Important Must fund research and development	Strongly Important Funding for low cost technology development	Strongly Important Commitment required for eco support	Strongly Important Funding of salt tolerant species	Strongly Important Funding for research and development and food regulation	Strongly Important – Research across boarders	Strongly Important – make decisions about water stress.
Technology	Strongly Important Technology needs to be developed	Strongly Important	Strongly Important Development and diffusion of eco technologies	Strongly Important Applied Genomics	Strongly Important Need to overcome quality issues	Strongly Important – Diffusion of technology	Strongly Important – develop responses and diffusion of technology
Economy and Security	Strongly Important Cost of water	Strongly Important Need for fresh water	Strongly Important Ability to create affordability and feasibility	Strongly Important Cost competitiveness? Bio-fuel application and energy independence.	Somewhat Important Cost of meat production	Strongly Important – Availability of water	Strongly Important – Driving efficient use of water
Agriculture	Somewhat Important Need for fresh water	Strongly Important Need for fresh water	Strongly Important Sustainable agriculture	Strongly Important Need to increase food supply and bio-fuels	Somewhat Important Competition with traditional animal meat	Strongly Important	Strongly Important – Right water at the right time.
Infrastructure	Somewhat Important Some infrastructure adjustments required	Somewhat Important Some infrastructure adjustments required	Somewhat Important Eco friendly infrastructure	Somewhat Important Need infrastructure for sea water inland distribution	Somewhat Important Some infrastructure adjustments required	Somewhat Important	Strongly Important – integrated water management and infrastructure
Demography	Strongly Important Increasing demand for fresh water	Strongly Important Increasing demand for fresh water	Strongly Important Stress on eco system	Strongly Important Need to increase food supply – need for people to live on marginal land	Strongly Important Increasing rate of consumption along with population increases	Somewhat Important – reduce water stress	Strongly Important –need to plan integration for demography
Ethics, Society, and Culture	Somewhat Important May be viewed as savior or panacea	Not Relevant	Strongly Important Cultural and societal sustainability	Strongly Important Diffusion of information to break paradigm	Strongly Important Change taste and cultural food preferences	Somewhat Important	Strongly Important – Lessons learned and rapid adoption of best practices
Politics	Somewhat Important Conflict over fresh water resources	Somewhat Important Conflict over fresh water resources	Somewhat Important Political importance of sustainability	Somewhat Important Reduce conflict over fresh water resources	Not relevant	Somewhat Important	Strongly Important – Integration water management is where political progress is

							made.

While researching world water, we touched on nanotechnology, patent law, botany, genetic, economics, community development, hydrology, integrated water management, environmental studies, information technology, remote sensing and many other disciplines. In doing this study, we did not use any automated tools for creating ontologies (system of categories) for how each discipline thinks about water, nor we did we use tools that created ontologies across disciplines.

We believe such tools are going to become needed if we are going to develop a global collective intelligence system for water. On the other hand, we do not believe that this paper could have been created by a computer. Knowledge workers are essential for doing the data gathering across disciplines and the analysis and synthesis that is needed as an input into the scenario development process.

Key Unresolved Issues

There are a number of areas that decision makers need to be informed about in order to make better decisions regarding water stress. This includes the problems with resource allocations in order to best address water stress concerns. For example, our research has shown that experts are undecided as to whether CNTs can increase reverse osmosis efficiency. Some of the people believe the number is five times while others 1000. Getting a higher number to increase efficiency could really make wind and solar desalination a possibility. Some governments such as the state of California have chosen not to embark on oil based desalination because of their concern for increasing the carbon footprint. Another issue that needs to be resolved is potential toxicities as a result of carbon nanotubes in our water system. Another example of a problem that we face is that we do not know how well lab scale results scale to industrial use. Clearly a global dialog is needed about where we should invest research dollars and the meaning of the research.

Another issue that requires public dialog is in the area of genetic modification to develop salt tolerant crops. This has great potential and may require some changes in current thinking.

As we argued in the conclusion, there is a need for a global collective intelligence information system for water that utilizes scenario planning to facilitate dialogue among all of the stakeholders. Such a system also needs to provide incentives to innovators as well as a best practices outline for water management down to the watershed level. One of the things heard repeatedly is that a global collective intelligence, though it draws global collections, must address the issues at the local watershed level. Access to global patent information and creation of incentives for investors to increase innovation and diffusion of technologies that reduce water stress is an important issue.

Recommended Expert Panel

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Bill Mollison and his book, "Permaculture: A Designers' Manual" is the authority on permaculture technologies.

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