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Clean Water Matters: Challenges and Research Perspectives Workshop in Beijing, China, April 18, 2014

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SYNTHESIS REPORT

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This workshop benefited from significant contributions from 32 active participants including our partners, including Peking University (PKU); Wuhan University; the International Society for Water Solutions (ISWS) of the American Institute of Chemical Engineers (AIChE), and HDR Inc. Special thanks go to the staff of the Center for Water Research (CWR) at PKU, including Chunmiao Zheng, Ph.D., Professor and Chair, Water Resources and CWR's Director, Jie Liu, Ph.D., Associate Professor, PKU, and Xioali Wang, M.S., Executive Assistant, CWR, for their indefatigable work in making this a successful event and for hosting the workshop at PKU.

NYIT would like to take this opportunity to thank the workshop's organizing committee for their time and untiring dedication, assisting us to secure both seasoned researchers and the next generation of researchers, which ensured that the workshop successfully achieved its goals. In particular, we would like to acknowledge the contributions by the session leaders, listed here following the sessions order: Drs. Chunmiao Zheng, Director, CWR, PKU; Richard Hooper, Executive Director, Universities Allied for Water Research – CUAHSI; Danny Rieble, Donovan Maddox Distinguished Engineering Chair, Texas Tech University; and Xiaohui Cui, Dean, International School of Software, Wuhan University.

We would also like to recognize the participation of Aibing Hao, Vice Director of the Department of Water and Environment, China Geological Survey from the Chinese Geological Service, as well as Yongpan Liu, Division Leader for Water Resources at the Ministry of Hydrology. Our thanks also go to all workshop participants, including the U.S.-China Eco-partners. Without their generous contribution of time and expertise, as well as their suggestions for future research directions, this synthesis report would not have been possible. While this report has benefited greatly from the participants' guidance, the views presented by the report's authors may not necessarily reflect those of the workshop sponsors and participants.

[1] http://www.nsf.gov/awardsearch/showAward?AWD_ID=1438644

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EXECUTIVE SUMMARY

The overarching goal of the "Clean Water Matters" workshop was to initiate joint research collaborations among scholars in China and the United States to address pressing water challenges affecting both nations, with potential applicability to other regions of the world. The event was structured to favor dialogue and exchange among participants with various perspectives and backgrounds. It brought together lead water protection and management scholars, seasoned policy professionals, and representatives from agencies that support science and research advances, together with young investigators in the early stages of their careers, post-doc fellows, and graduate students pursuing research in the workshop topical areas.

The interdisciplinary nature of the workshop resulted in a broad-based research framework drawing from academia, the scientific and academic community, and entities that focus on the advancement of science and technology, including national agencies, foundations, and corporate partners. The following offers a synthesis of the four sessions held during the workshop, noting recommendations by participants:

1) *Water quality modeling and approaches for megacities and rural areas*:

1.a. Models grounded on theory-driven experimentation and multi-scale testing are recommended for long-term monitoring, and intelligent guided remediation (e.g. hydraulic fracturing sites) and better understanding of fundamental processes in sub-surface systems (e.g. dimensionality, conductivity). To support such models, scale-up challenges are to be addressed, in particular when moving from nano-scale lab experimentation to field scale simulations. Additionally, the use of wireless sensor networks and real-time continuous data feed can enhance monitoring efforts.

1. b. Improved management and monitoring tools and technologies are needed for the effective detection and prevention of water infrastructure failures and/or the prioritization of maintenance and rebuilding projects. Comparative studies and projects in sister cities (e.g., in New Orleans and Shanghai) are recommended.

1.c. A promising approach to water purification is the use of "artificially created wetlands," which require less area than natural wetlands, have low maintenance fees (as compared to treatment plants) and can easily address 70% of the water purification process. Scale-up of current pilot projects under varying conditions is an important next step towards vetting this approach.

1.d. Dynamic water quality simulation models are needed to understand the chemical transport of pollutants through the environment. An experimental study of the transport of PAHs in run off provides their spatial distribution and correlates with activities in urban centers, energy consumption, and meteorological conditions. An industrial ecology approach that models contaminant flow through the environment was also suggested.[2]

[2] See for example: Valle, S.; M. Panero and L. Shor; 2007; Pollution Prevention and Management Strategies for Polycyclic Aromatic Hydrocarbons in the New York / New Jersey Harbor; New York Academy of Sciences, http://www.nyas.org/WhatWeDo/Harbor.aspx

2) Water scarcity and hydrologic challenges

2.a. Multi-disciplinary perspectives, place-based[3] science and observations that represent actual phenomena at the site, as well as research collaborations are recommended to advance the state of the art of watershed science. Moreover, new collaborative information technologies and data formats (GIS mapping, dynamic grids, google fly-over information) can improve data access and research collaboration, and thus increase the predictive capacity of watershed models. Access to the CUAHSI's Hydrological Information System is an example of a data-sharing platform for investigators working on sites that face comparable challenges, such as watersheds in the United States and China.

2.b. A hydrological model that integrates climate scenarios may be used to estimate the effect of higher temperatures on stream flows. Trends indicate that climate change is affecting snow-dominated water systems that are shifting to rain dominated regimes. In this context, water systems are increasingly dependent on precipitation over short periods rather than on snow melting through the summer, spring, and summer months. This model may be applied to the western United States and northern China.

2.c. Another model has been developed to analyze sub-surface water resources, in particular natural springs. It has been applied in China, Tanzania and Ecuador and is relevant to the United States. Remote sensing can improve observations to monitor precipitation and thus springs recharge rates, given changes in climate conditions.

2. d. An integrated model of the surface water – groundwater exchange, is being applied at the Heihe river basin, in northwest China. This second largest river in China faces severe water scarcity challenges due to intense agricultural demand and climate change. The model uses temperature as a tracer of water exchange, measured via distributed temperature sensing (using fiber optics) as well as airborne thermal infrared remote sensing techniques. Combined with hydrological data, temperature can offer an independent constraint for calibrating coupled surface water - groundwater models.

2.e. Most water scarcity models only consider water *quantity* (blue water). Pollution induced water scarcity (gray water) should also be considered, thus the significance of integrating water *quality* parameters into scarcity models was emphasized. This integrated approach may be used to develop water scarcity indices, which may serve to educate the public about the need for water conservation.

3) Research advances in water management for hydraulic fracturing in oil and gas production

3. a. The water energy nexus is most evident in hydraulic fracturing operations, which often takes place in areas that are water stressed. Potential substitutes for potable water include reuse of flow-back and produced waters as long as treatment facilities are available. Local brackish groundwater supplies are another option; however, further

[3] CUAHSI has called for "place-based science and observatories" and hydrologic information systems projects to advance hydrological research agenda. https://www.cuahsi.org/PageFiles/docs/dois/CUAHSI-SciencePlan-Nov2007.pdf

research is needed to characterize their chemistry and potential productivity to determine if they may be used hydraulic fracturing.

3.b. Practices to drill wells by hydraulic fracturing are similar from a process perspective. However, impacts of these operations, which are mostly related to the transport of produced waters, seem to be a function of regional conditions, managerial practices, and regulatory decisions at the local scale.

3.c. A life cycle analysis at Sandia National Laboratories compares hydraulic fracturing's water demand against different ways of generating electric power. It offers a holistic view of available water resources, competing usages and costs, along with associated environmental risks. Thus, it may be used to evaluate locations for new hydraulic fracturing developments.

3.d. Along several regulations to manage water scarcity and imbalances among different provinces in China, new water markets and trading mechanisms have also been set up based on an allocation regime for each province. Provinces that implement water resource efficiency measures or experience more rain are able to sell to those experiencing shortages. While the price of water remains low, it may increase over time depending on total availability.

4) Information Systems for real-time water quality monitoring and analysis

4.a. In China, a project is underway to launch a system of seven high-resolution satellites capable of collecting global information about water resources, as well as other variables (e.g. air quality). Further research is needed to improve data integration and processing frameworks, capable of analyzing datasets collected at various scales over time (from small mobile to satellite data) on multiple variables affecting water availability.

4.b. Real time sensors, sensing networks and other information and cyber-physical systems are being used for water quality monitoring and analysis. They may be used for rapid response to water contamination incidents, or for long-term assessments, such as a project to track erosion of the coastline in Dubai.

4.c. Several technologies and approaches are being tested to improve sensors capabilities and sensing networks assessments. These include:

- minimizing their power demand while increasing storage and transmission capabilities;
- improving the design of bio-sensors and micro-fluidic nano-devices, by better understanding the behavior of cell mechanisms so that they may be used as real-time detection systems.
- Addressing sensor nodes failure and sensing networks reliability problems by applying "matrix completion" methods to map or recover data. This approach allows for strategic siting of sensor nodes, thus minimizing costs.

BACKGROUND AND GOALS FOR THE WORKSHOP

In 2013, the International Year of Water Cooperation, UN General Secretary Ban Ki-moon called attention to water scarcity as a global issue, stating that one-third of the global population already suffers from water scarcity and that by 2030 nearly half of the world population could be affected by severe water shortages. Noting that demand could outstrip available water supplies by 40%, Ban Ki-moon called for an end to the unsustainable use of water.[4] Such water scarcity challenge is affecting vast regions across the world, including the U.S. mid- and western States, as well as China, with Beijing facing worse water shortages than countries in the Middle East (e.g., Israel).

As a way to respond to the global water predicament, New York Institute of Technology convened the workshop, "*Clean Water Matters: Challenges and Research Perspectives*" on April 18, 2014 at Peking University's Water Research Center in Beijing, China. The goal has been to foster a long-term collaborative research network that advances an integrated approach to the challenges of achieving water resources sustainability and protection in China and the United States. It is expected that the findings form this workshop will also be relevant to other nations.

Specific objectives of the workshop were, first, to identify future collaborative research directions that may be consistent with the research agendas advanced by funding agencies in both nations (e.g., U.S. NSF, EPA; USGS; and in China: NNSFC, CAS, EPA); and second, to promote joint research collaborations among scholars in China and the United States to address pressing water challenges affecting both nations, focusing on research innovations and solutions with potential applicability to other regions of the world.

Participants from the US and China sought to build research collaborations around priority topics, review their research capacity, discuss best models for data sharing, and develop mechanisms for joint research projects that may be supported by research agencies in both nations.

Partially funded by the National Science Foundation, the workshop was organized by New York Institute of Technology (NYIT) and Peking University (PKU), in association with Wuhan University's International School of Software, AIChE's International Society for Water Solutions and HDR, Inc. The workshop's programming team led by NYIT and PKU, initiated their EcoPartnership[5] on Groundwater Monitoring, Protection, and Training in 2013. The U.S.-China EcoPartnership Program is intended to promote innovative models for collaboration between the United States and China on clean water and environmental sustainability and is an initiative of the U.S.-China Ten-Year Framework (TYF) for Cooperation on Energy and Environment.[6]

The workshop was designed to promote roundtable discussions and engagement of all

[4] Secretary-General's opening remarks at Budapest Water Summit October 2013 http://www.un.org/sg/statements/index.asp?nid=7184
[5] https://ecopartnerships.lbl.gov/partnership/nyit-pku-clean-water-management and http://www.nyit.edu/about_nyit/news/new_ecopartnership_to_address_clean_water_challenges_in_china
[6] http://www.state.gov/e/oes/eqt/tenyearframework/

convened, ranging from representatives from U.S. and Chinese research organizations, academia – including senior, and junior faculty and students – as well as NGOs, government agencies and industry. The workshop was structured around four major topics concluding in a wrap-up session. Each of the four topics was covered in a 110-minute session that included platform presentations and a roundtable discussion. The presentations and full agenda can be found at: www.nyit.edu/waterworkshop/2014, as well as in Appendix I.

PROGRAM HIGHLIGHTS

SESSION I: WATER QUALITY MODELING FOR MEGACITIES AND RURAL AREAS

This session contributed to advancing the understanding of models for hydrologic processes and water quality evolution. Challenges in the modeling of groundwater contaminants transport for improved monitoring, as well as new approaches for identifying contaminant sources (e.g., ModGA code for contaminant source identification, substance flow accounting; industrial ecology) were described. The session presentations and roundtable discussion considered both urban and rural aquifers.

The session was moderated by ***Chunmiao Zheng***, ***Ph.D.,*** *Professor and Chair of Water Resources at Peking University; and Founding Director of the Center for Water Research at PKU,* who presented and also led the open discussion following presentations by other four leading researchers in water quality modeling. The presentations ranged from those focusing on challenges of models to monitor water quality in the face of catastrophic natural disasters and failing infrastructure such as New Orleans, to the need to ground models on observations, as well as enhancing the understanding of fundamental processes by theory-driven experimentation and multi-scale testing.

Shieh-Tsing Hsieh, Ph.D, *Professor and Chair Electrical Engineering Department, Tulane University*, highlighted failures in key water infrastructure and natural systems in New Orleans, a major United States port and the largest city and metropolitan area in the state of Louisiana. These failures came to view in the face of challenges such as natural and man-made disasters – ranging from hurricanes Camille (1965) and Katrina (2005, which flooded 85% of the City), along with the 2010 BP rig blow up and spill in the Gulf of Mexico. Besides failing dams, there was encroachment of saline water on wetlands, which serve as flood protection systems.

Dr. Hsieh called attention to the need to repair aging water distribution systems including broken pipes resulting in bacterial contamination and unsafe drinking water supplies. Given limited financial resources, it is important to identify key water management and monitoring tools and technologies for the effective detection/prevention of infrastructure failure and/or to prioritize rebuilding projects. New Orleans has an agreement with Shanghai to work on municipal water management systems, but only for wastewater treatment facilities. As future research, Dr. Hsieh suggested that it would be important to find sister sites and conduct research on securing the water supply in the face of aging and /or failing infrastructure.

Tissa H. Illangasekare, Ph.D, *Chair of Civil and Environmental Engineering at the Colorado School of Mines* argued that good modeling requires understanding of fundamental processes through observation. He discussed theory-driven experimentation and "multi-scale testing" for model enhancement, highlighting scale-up challenges that emerge when moving from nano-scale lab experimentation to field scale simulations (e.g., how to deal with dimensionality complexity and/or hydraulic conductivity in sub-surface systems). These challenges point to the need for intermediate-scale case lab testing, and creating synthetic aquifers under controlled conditions to run experiments in order to improve model accuracy.

This type of experimentation is already taking place at a laboratory site in Idaho and at the Colorado School of Mines, at the nano-scale (looking at some of the materials in the subsurface), and non-aqueous-phase liquid (NAPL) scale. Models grounded on such experimentation are relevant for long-term monitoring, intelligent remediation of hazardous-waste sites, enhanced hydraulic-fracturing management, among other applications. Dr. Illangasekare also mentioned that these simulation models may use new technologies such as wireless sensor networks and real-time continuous data feed for improved monitoring, as well as to integrate climate change, atmospheric processes, and other variables for enhanced resource management.

Jian Jian Lu, Ph.D., *Professor of Ecology, East China Normal University in Shanghai, China* presented on a new approach to water purification using artificially created wetlands. He noted that natural wetlands have many functions such as protection of wildlife, water purification and flood protection. In the United States, wetlands have long been used for improving water quality, in particular using the surface layer; however, this approach requires large flooding areas and its effectiveness (compared to water treatment plants) is low. Since the 1970s, their effectiveness has improved to a limited degree, due to more attention to processes in the sub-surface floor.

Artificially created wetland systems offer a multi-stage level approach to water purification by introducing several technological innovations. One approach involves bio-blocks that can remove nitrogen ten times more effectively than a water treatment plant. They employ both anaerobic and aerobic microbial communities that can operate during high and low water levels, respectively. Another innovation is the introduction of wood, activated black carbon and shellfish, which in combination remove phosphorus and some heavy metals. Moreover, at high temperatures, these added materials can also treat some organic compounds. Another benefit of such artificially created wetlands is the attenuation of heavy water.

In China, where there are no large free areas available to maintain natural wetlands for water purification, artificial wetlands are being deployed as pilot projects alongside highways to treat contaminated run off from roads, or to treat water downstream from chicken farms, or in small villages. The artificial wetlands used for water purification have low maintenance fees (as compared to treatment plants) and can easily address 70% of the water purification process. Further research, including scaling up current pilot projects under varying conditions could have large positive impacts.

Yi Zheng, Ph.D., *Associate Professor*, *Peking University*, presented on his research on stormwater pollution and water quality modeling and analysis, focusing on Polycyclic Aromatic Carbohydrates (PAHs) in Beijing, which is a hotspot of emissions of the 16 priority PAH compounds. He argued that there is a correlation between energy consumption, climate change and PAH emissions, in particular black carbon. PAHs loads around urban centers come from incomplete combustion, traffic emissions (in particular during traffic congestion) and releases from certain products (e.g., creosote, moth balls, etc.). They are ubiquitous in the environment around megacities such as Beijing, with wet and dry deposition affecting rivers, soils, and food systems.

Dr. Yi Zheng discussed an experimental study to understand the chemical transport of PAHs in the environment. He presented on a dynamic model to simulate the transport of PAHs in both impervious and permeable areas of the Beijing Plains. The model can be used to estimate the spatial distribution of PAHs and loads to a certain area, in particular benzo(a)pyrenes (BaPs), which pose more risks to humans. The enrichment behavior of an area is seen to depend on: land use, soil composition and erosion / run off rates, different carbon materials that play a different role in the transport; the partitioning coefficient of the carbonation materials, as well as meteorological conditions (higher rain impacts soil erosion, wind speed changes deposition ratios); and all these variables alter the transport and sediment loads to a given area.

Preliminary results show long term loads of PAHs (BaPs) in downtown Beijing, where the content is high and population risks are high, and lower loads in rural/suburban areas and crop lands. Seasonal variation of PAH loadings are observed, depending on rain – soil erosion is high and when it rains high loads PAHs are found in surface water runoff. The model provides strong support to assess the pollution risks as well as to making management decisions; however, given the different set of variables that go into the model for a specific site, Dr. Yi Zheng mentioned that it would be important to conduct further field and experimental studies.

SESSION II: WATER SCARCITY AND HYDROLOGIC CHALLENGES

This session explored the fundamental hydrologic and water scarcity challenges affecting China, the United States and other regions of the world. The discussion took into account the impact of climate change on water supply. Participants considered new advances to enhance research, predictive models for water resource availability, and virtual observatories, as well as new technologies and cyber physical systems.

Richard Hooper, Ph.D., *Executive Director, Consortium of Universities for the Advancement of Hydrologic Science, Inc. - CUAHSI*, led this session with introductory remarks about his vision for advancing watershed science, which requires place-based science, multi-disciplinary perspectives and research collaborations. He noted that various scientists (hydrologists, bio-chemists, geo-morphologists, aquatic ecologists) may study the same water system according to their particular conceptual framework and this will influence what they decide to measure, which in turn is limited by the state of the art of measuring technologies. Another level of abstraction is introduced by mathematical representations or modeling and this challenge may be addressed by place-based science and observations that represent actual phenomena at each site. Another challenge is to change the culture of competition to one of collaboration among different disciplines, especially those working on similar water systems.

Dr. Hooper noted that the United States and China have similar water systems that face comparable challenges, and that the emergence of new information technologies which improve data access and modes of collaboration and research. Besides the CUAHSI's Hydrological Information Systems (to which he offered free access), there are new collaborative tools and data in multiple formats, such as in-situ point data, GIS mapping, dynamic grids, "Google fly-over" information, that may offer a virtual field presence to researchers and augment their ability to collaborate remotely. He described his vision of a network of observatories capable of accessing data from all sites regardless of location that may represent a larger scale context for research collaborations. Under this scenario, watershed research will benefit from the integration of monitoring data sharing (primarily from government data), which will enable analysis of water systems / sites, and ultimately improve the predictive capacity of enhanced models.

Darren Ficklin, Ph.D., *Assistant Professor, Dept. of Geography, Indiana University* presented on his research on surface water, in particular how snowmelt-dominated water resources systems in the western United States are being affected by climate change. In high elevation regions snow acts as water storage towers but these are highly seasonal. Higher temperatures means less snow during the winter and early spring months, and/or rapid melting, which translates into less water availability during the hot summer months. In contrast, rain dominated regions depend on direct precipitation and there has been a shift from snow dominated to rain dominated regimes in Western United States (i.e., in the Columbia River basin, the Upper Colorado river basin and the Sierra Nevada).

Dr. Ficklin presented on a hydrological model that integrates climate scenarios, which may be used to estimate the effect of higher temperatures (2-3 degrees Celsius) on stream flows in different river basins. Historical stream flows (monthly, yearly) – have been shifting from snowmelt to precipitation and in the 21st century rapid melting is expected as well as flooding. Such scenarios will have an impact on fish species, and increase the need to allocate water resources between alternative usages (irrigation for farming, thermo-electric plants, or drinking water reservoirs). This model may be applicable to any snow-dominated water regime throughout the world (e.g., western US or China), and thus merits further research.

John S. Gierke, Ph.D.*, P.E., Professor of Geological & Environmental Engineering, Department of Geological Engineering and Sciences, Michigan Technological University* presented on the need to understand the impact of climate change on natural springs, which serve as the main water supply for large tracks of the world population. His research on springs focuses on characterizing and monitoring sub-surface hydrological systems in complex water terrains, ranging from deep aquifers with abundant water supply to shallow systems (above the shell rock), with lower recharge rates and affected by seasonal variations. Climate change will exacerbate drought periods and as migration to urban centers continues throughout the 21st Century, there will be more water shortage episodes in urban areas.

Dr. Gierke highlighted work on villages and small cities whose water supply depends on natural springs, carried out mostly through the Peace Corps program at Michigan Tech. To illustrate the impact of climate change, he presented a four-decade monitoring case study on China, which shows decreased spring discharge over time. Increased demand and associated higher pumping water rates represent only a 10% of the recharge change, with the majority of the decline explained by lower precipitation rates observed over the study period. Similar diminished precipitation and spring recharge rates are observed in villages in Tanzania and in Quito, Ecuador. A simple model his team has developed can be used as a predictive tool to analyze springs discharge over time. Remote sensing can improve observations to monitor how precipitation is changing, and coupled with site-specific geological and geometry characteristics, it will provide a better picture of how complex hydrological systems (e.g. springs) will behave as climate conditions change.

Jie Liu, Ph.D*., Associate Professor, Peking University and Center for Water Research* discussed her research, together with Chuankun Liu, Yingying Yao, and Dr. Chunmiao Zheng, on temperature as a tracer to identify surface – ground water exchange in the Heihe river basin, the second largest endoheric basin in the northwest of China. The region is facing a severe water scarcity problem, with intense agricultural demand in the middle basin and thus dramatic decreases on the availability of water downstream and fragile ecosystems. The tracer technology used on this site may have applications on other regions facing similar challenges.

Traditionally surface and sub-surface waters have been studied independently but for water management and for the health of water ecosystems it is better to treat them as a single resource. Dr. Liu said that the study focuses on the surface and groundwater interactions in the middle basin and how it changes seasonally, using temperature as a tracer. While groundwater temperatures remain the same throughout the year, surface water exhibits hydrological variation depending on air temperature. Two methods are used: a) distributed temperature sensing (DTS) using optical fibers to measure temperature at very high spatial and temporal resolutions, and b) airborne thermal infrared remote sensing to measure temperature changes at the large scale.

Deploying DTS 2-km long cables along the river's middle basin, the team observed temperatures indicating cold groundwater inflow at certain locations, with high resolution temporal and spatial data. Two patterns were identified: 1) a hyporheic zone where the temperatures are lower than the average registered daily temperature but higher than the average lowest temperature, and 2) a zone with only groundwater inflows, where both river temperatures are lower than the averages. However, because of the river's width and high flow during the summer, the data may be skewed. To tackle this limitation her team used airborne thermal infrared remote sensing and fly-over sensing thru 180 km distance of the river. The data correlates well to the DTS data – groundwater infiltration areas were identified. Moreover, the temperature distribution shows that in the middle basin, the temperatures are higher in the mountainous area, where surface water returns to groundwater, followed by cooler temperatures and groundwater inflows, and then higher temperatures again in the next area.

This side-by-side qualitative comparison indicates that temperature is an important indicator of the spatial and temporal variation and intensity of surface water- groundwater exchanges. Combined with traditional hydrological data (e.g., hydraulic head and flux), temperature can provide an independent calibration of coupled surface water-groundwater models.

Junguo Liu, Ph.D., *Professor, Beijing Forestry University;* noted that most water scarcity models only consider water quantity (blue water), highlighting the significance of studying water scarcity by taking into account both water quantity *and* quality in an integrated manner. Pollution is a key factor leading to pollution-induced water scarcity (gray water) and a significant constraint for China's sustainable development. Another important driver of water scarcity in China, besides the most recognized ones (i.e., increased demand due to economic development, population growth or decreased supply due to climate change) concerns dietary regime shifts. The 2008 China Strategies report stated that the per capita water footprint[7] has increased significantly over this period, and the main reason is changes in dietary patterns to consumption of more animal products.

Dr. Liu has developed a new index to describe the severity of water scarcity in the form of a "water scarcity meter," which may help educate the public about water challenges, including "quality" or pollution-induced water shortages. He applied this index to analyze water scarcity trends since 1995 for the Beijing metropolitan region, which is facing worst water scarcity challenges than Israel.[8] Dr. Liu argued that the City's efforts to curb water consumption and to treat wastewater represent great progress, evident by decreases

[7] The water footprint concept represents the total amount of water used by the human beings, including the use of soil and surface waters as well as groundwater; there is a component called regrowth footprint (related to pollution) that represents the volume of water needed to dilute pollutants to certain quality water standard.

[8] Beijing is a city facing a serious water scarcity problem – per capita available water resources is about 150 cubic meters per person per year, which is much lower than that for Israel and much less than the threshold of 1,000 cubic meter per person per year.

in the blue and grey water *scarcity* indices by 59% and 62%, respectively, in one decade (1999 to 2009). However, as his analysis demonstrates, the Beijing metropolitan area continues to face a grave water scarcity problem because the integrated index has remained high (3.5 in 2009), with the blue and grey water scarcity indices at 1.2 and 2.3 in 2009, much higher than acceptable thresholds of 0.4 and 1, respectively. For Beijing City proper the *quantity induced water scarcity* indicator was about 3, and the *pollution induced water scarcity* indicator 7, which means that in core urban areas the water scarcity problem is more serious than in surrounding areas. This suggests that urbanization is an important driver of water scarcity, in particular due to pollution. The study also found a very good correlation between water scarcity indicators and the groundwater table, which is shallow when unsustainable water use and pollution (which requires more water to treat) are high. As long as the scarcity indicators continue to be above the safe threshold, the groundwater table will be shallow.

Dr. Liu's take-home message was that Beijing should continue to reduce its use of water from groundwater and redouble its efforts to reduce the grey-water footprint below the safe threshold and thus improve the total amount of available water resources. The integrated water scarcity analysis and new index can be used to achieve such goals by helping to engage and educate the public.

AFTERNOON SESSIONS:

In opening the afternoon sessions, **Aibing Hao,** *Vice Director of the Department of Water and Environment, China Geological Survey*, provided introductory remarks. His remarks focused on groundwater work at the agency, in particular the identification of pollution hazards and groundwater monitoring efforts. He also reviewed a number of opportunities for research cooperation between researchers in both nations, including support for U.S. citizens to conduct groundwater research in partnership with researchers in China. He then extended an invitation to participants from the United States to participate in this program.

SESSION III: RESEARCH ADVANCES IN WATER MANAGEMENT FOR HYDRAULIC FRACTURING IN OIL AND GAS PRODUCTION

Hydraulic fracturing, which usually extends the life of existing oil and gas wells, requires the use of fluid and materials (sand, chemical additives) to open small fractures in order to stimulate production. This session explored the use of alternative sources of water, for hydraulic fracturing, improvements in water management and reuse. Participants discussed research directions and models for optimizing the life cycle of produced water, as well as a systems approach to analyzing emissions ensuing from water management decisions, with the goal of identifying best practices.

***Daniel Reible, Ph.D.**, PE, BCEE NAE, Donovan Maddox Distinguished Engineering Chair, Texas Tech University*, led this session, stating that the nexus between energy and water is evidenced in the hydraulic fracturing of shale gas. He noted that worldwide, much of the potential shale production activity is in areas that are water stressed, which is of grave concern because approximately 1,000 gallons of water (on average) are consumed per foot of the hydraulic lateral spread of the wells (or 10,000 cubic liters per meter), and 4-6 million gallons per well.[9] While overall water demand is relatively small compared to other usages, its intensive demand at a particular location affects both the quality and the availability of water in surrounding areas, particularly in times of drought, as is the case in much of the western United States and parts of Asia which have been experiencing substantial drought.[10] Moreover, when the wells are in rural areas with limited infrastructure, the water is typically trucked into a fracturing site, increasing the impacts on these rural communities.

Dr. Reible stated that such water management concerns can be addressed by maximizing the use of local poor quality waters and reuse of flow-back and produced waters, instead of potable water. In the United States there are active shale plates with near surface brackish groundwater supplies; however, increased understanding is needed about their exact chemistry[11] and potential productivity before determining if they may meet hydraulic fracturing requirements. Another alternative is to maximize the reuse and recycling of flow-back and produced waters. The early flow-back water tends to be similar to the water that was first pumped down into the wells but over time its quality degrades, with high or very high dissolved solids. Reuse of these waters requires substantial blending with freshwater or treatment but it is obvious that it cannot be recycled or reused over time – not even with treatment. Full treatment to near-freshwater standards is rarely cost-effective and is energy intensive. Dr. Reible also noted that a fairly small amount of water comes back up in wells in eastern United States but there are limited disposal options (there are only seven saltwater disposal wells in Pennsylvania while there are ~12,000 in Texas). The lack of disposal facilities, combined with the small amount of produced water means that a very high fraction of these northeastern wells gets reused. In Texas only 10% of the water gets reused because there are so many disposal options. There is a significant use of brackish water, whenever alternative water sources are not available.

Minimal treatment that takes advantage of the unique chemistry of the waters and is designed to reduce the fouling characteristics of these waters, is likely a more efficient approach that may be able to compete with deep well disposal options. The combination of brackish poor quality waters unfit for other uses plus expanding reuse and recycling can considerably reduce the water demands of hydraulic fracturing while increasing its acceptance as a viable energy source now and in the future.

[9] This is directly related to how much of the horizontal leg of the hydraulic fracturing well.

[10] Dr. Reible added that in 2011 Texas experienced the worst single-year draught on record and the hydraulic activity there is the greatest, but draught is certainly affecting other mid-west and western States over the past few years.

[11] Brackish waters are often just evaluated by measuring total dissolved solids, but knowledge about their detailed chemistry is usually lacking. In order to be able to use brackish water instead of potable water more information is needed about content (sulfites versus chlorides), viscosity, etc.

Megan Mauter, Ph.D., *Assistant Professor, Chemical Engineering and Engineering and Public Policy, Department of Chemical Engineering, Carnegie Mellon University,* presented on water management practices and the environmental consequences of shale gas development in the *Marcellus Shale gas play*. Her ES&T article published with Danny Reible in April 2014 indicates that the impacts of hydraulic fracturing are very regionally dependent. Drilling a well by hydraulic fracturing is quite similar from region to region, from a process perspective, but impacts depend very intimately on regional conditions. In Texas where shale plays are in arid regions, water management is a significant issue, while in the Marcellus play, with plenty of surface water, but high salinity flowback waters, the risks of surface water contamination are higher. The main water management options are water reuse, disposal in wastewater treatment facilities that can't really handle these brines, and increasingly water recycling facilities that do preliminary treatment before sending such water back to wells.

Dr. Mauter asked, *"how much of the water related environmental impact is intrinsic to the process of hydraulic fracturing and how much of that impact is a function of the way companies chose to implement this process?"* She then discussed the influence of company attributes, experience, and behavior on the environmental consequences of shale gas development in the Marcellus play. Companies exhibit significant variation in their waste management practices, with most of the variance attributed to waste disposal method, company operating experience in the Marcellus, and drilling practices. There is also significant variation in the frequency and severity of oil and gas drilling violations, explained by a combination of enforcement discrepancies and company commitment to a safety culture. Her work suggests that minimizing impacts depends on company and regulatory agency decision-making at a highly localized scale.

Noting that the bulk of the environmental impacts of wastewater management is associated with transport of produced wastewater, she noted that in 2011 waste management practices resulted in 26 million miles of truck traffic and associated emissions (mostly to transport waste to deep-water wells in Ohio or wastewater treatment facilities in Pennsylvania). Two important variables to consider are: a) average distance that waste is transported from the wells to the disposal site, and b) the sum of the distance times of quantity of the waste transported – a better metric for intensity of waste transported. One of the most important predictors of low waste transport impacts, are companies that drill their wells in spatial and temporal clusters. When wells are drilled within 5 miles of each other within 30 days, a company has more opportunity to reuse the water when there are clusters. As more water is reused, there is less wastewater that needs to be transported when you are reusing water in clustered wells. In contrast, injecting, recycling, and treating or discharging the wastewater results in higher transport distances. Dr. Mauter noted that this research is just one small part of her work, with the rest focusing on water desalination, water treatment technologies and trying to reduce the energy intensity of such technologies.

Vincent C. Tidwell, Ph.D., *Distinguished Member of the Technical Staff, Sandia National Laboratories,* summarized research by NRL based on a life cycle analysis that compares the water demand of hydraulic fracturing against different ways of generating electric power, (PV, geothermal, solar thermal, nuclear, natural gas combined cycle and coal). This comparative assessment considers the amount of water per megawatt of electricity generated during the construction of the plant, the fuel cycle (for either processing or extracting the fuel), as well as the steam cycle, which is the most important water withdrawal of all. He noted that in terms of the MG/hr generated, hydraulic fracturing is the least significant one. Location, however, is an important factor to consider. There are a number of new shale plays located in the arid Western U.S. where access to available fresh water supplies is problematic,[12] and the options coincide with those reviewed by previous speakers. Moreover, because hydraulic fracturing is commonly a new use, it would be necessary to find new sources of water.

Toward this end, Dr. Tidwell presented on his work at Sandia National Laboratories that maps over 1200 watersheds throughout the 17-conterminuous states in the western U.S. to assess water availability, cost and new consumptive use to the year 2030. Four unique characteristics of the data make it particularly useful for energy development. First, multiple sources of water were mapped, including un-appropriated surface water, un-appropriated groundwater, appropriated water, municipal wastewater, and shallow brackish groundwater. Second, water availability metrics are matched to institutional controls (e.g., water rights, administrative controls, interstate compacts) to the extent available data permitted. Third, water availability estimates and corresponding cost estimates were linked to access to convey which sectors may be competing for the same supply. Fourth, water metrics were developed with the direct assistance of state water managers in framing, identifying, understanding and vetting other social and ecological metrics. Their assessment provides environmental risk metrics, considering what may happen to various endangered species (riparian, aquatic) and other measures as water is removed from the system.

Dr. Tidwell concluded his remarks by stating that in terms of new hydraulic fracturing development, location is a significant variable, in particular because shale gas and oil are commonly considered as new sources of water. Having a comparable basis for understanding the different water source options, mapping available water resources, competing usages, and costs, along with environmental risks, will help developers understand what the best options are.

Yongpan Liu*, Division Leader for Water Resources at the Ministry of Hydrology* presented in Chinese, with Dr. Cui translating. He stated that in certain areas of China, in particular the northwest, water resources are quite scarce. There is a great water imbalance between the northwest where only 50mm of rain fall per year versus 3000mm of rain fall in the southern region. To compound the problem, most of the rain in the north falls in short time spans causing flooding (e.g., in the northeast 70 to 80% of the rainfall falls in fourth months, and in the northwest close to 90% falls within two months). One third of the coal mining takes place in these northern provinces, which

[12] Water required to drill and hydraulic fracture a shale gas/oil well, may range from 7,500 to 20,000 m^3 of water depending on the characteristics of the "play" where the well is located.

represent 45% of the national GDP and 47% of the total population, but water resource availability is only 19% of the total, nationwide. This water supply imbalance is a large problem; and water usage per capita is low (0.5 versus 0.7 for the rest of the world).

There are several regulations that have been issued to address this imbalance. The main ones were issued in 1998 (then modified in 2002), and 1993 (modified in 2006) both ruling on water quantity usage. There are also anti-pollution laws by the Chinese EPA to address water *quality* problems along with other regulations for water resource planning and management, water use charges, allocations (e.g., for drinking, agriculture, industry, etc.) and over-planning penalties, as well as climate change laws. Considering population trends and projected increases by 2030 when total water shortages will be felt, these regulations, which may seem excessive, are seen as quite necessary. In addition, the Chinese Central government has set up water rights for 53 rivers in different provinces (e.g., those sharing water resources in the Yellow River), and now each province knows exactly how much water it can use from those rivers. Moreover, a trading mechanism has been set, allowing provinces experiencing increased demand to purchase rights from provinces that have surpluses, either because they are able to save water or because they have had more rain and thus decrease withdrawals for agricultural uses. The water price is very low at this time, but it may be increased, depending on total water availability.

SESSION IV: INFORMATION SYSTEMS FOR REAL-TIME WATER QUALITY MONITORING AND ANALYSIS

This session focused on sensors, sensor networks and advances that integrate IT and cyber-physical systems for real-time water quality monitoring and analysis. Research on real-time smart micro-sensors and detection systems can effectively be used for detection, mapping, monitoring, and remediation of contaminated aquifers. Participants discussed best approaches for data collection and analysis, as well as optimal network configurations and methodologies to assess sensors networks performance in the field, as well as to how to reduce errors, such as geo-statistical variance reduction analysis and simulations.

Xiaohui Cui, Ph.D., *Dean, International School of Software, Wuhan University* presented on the problem of creating a data-integration and processing framework, at scales ranging from small mobile devices to large-scale cloud computing platforms. He started research on this issue while at the U.S. National Renewable Energy Laboratory, to model water scarcity and population migration under different long-term (100-150 years) climate change scenarios (e.g., migration caused by drought in African villages, or floods in Bangladesh).

Such frameworks require multiple data collection sets, including long-term monitoring from sensors and satellites as well as "human sensors" and/or social sciences type data. However, in China there is no large database that integrates all types of data; satellite imagery and other information are not integrated, and such data would be needed for water resource management and improved prediction and monitoring systems.

China now has an ambitious plan (the Golden Project) to launch over the next ten years a system of seven high-resolution satellites, each with different functions and capabilities that may be used to collect global information on water resources, air quality, and other environmental variables. Additional data may be collected (e.g., GIS, airplane reading systems, optical imagery and other methods to collect data on underground water resources). The first high-resolution data collection satellite effort since 2013 (phase 1) has been monitoring air quality of the Beijing metropolitan area and other provinces. Results are promising, for example, values on PM 2.5, for example, exactly matches that detected by ground sensors.

Dr. Cui will continue to work on developing such integrated framework, which will be useful to help "tame the sea of data" required to analyze complex issues such as Climate Change. This framework will be useful to the U.S.-China Eco-Partnership team. For example, a planned water monitoring project in the northwest region of China, could help identify optimal locations for water wells, by helping to process, understand and use multiple data points for timely and effective decision making at all levels.

Paul Anid, Sc.D., *Vice President, Water Quality Management Services, HDR Inc.* presented on his experience designing, deploying, commissioning and maintaining a real-time monitoring system with sensors across the coast of Dubai, to track coastline erosion. The project involves 25 stations for real-time monitoring in highly saline, warm marine waters. After designing the sensor network, setting up the specs, and programming all monitoring instruments, data acquisition and processing systems, the system is deployed and all information transmitted via telemetry to a web client server that streams all of the information collected "live." All 25 stations need to be constantly maintained, and this requires divers to repair the instrumentation. The heart of the system is a data logger that stores the information and sends it to the center via telemetry. Data transmission is carried out in a number of ways, via mobile phone calls (e.g. every 15 minutes) satellite information, or radio (cheapest). Higher frequency transmission rates cost more, so the type and frequency must be taken into account when designing the system, besides the number of required parameters. The power source is also another important factor – whether it is through batteries, or cables.

The real-time monitoring system collects data on different parameters; meteorological stations measure temperature, wind speed, wind direction, relative humidity, wind-gusts, etc. using high quality sensors that can withstand harsh marine conditions; for hydrographic data, the parameters measured are water invasion, water currents and waves, and surfaces currents; for water quality: dissolved oxygen (DO), temperature, conductivity, salinity, blue green algae turbidity, TDS; and for coast erosion: cameras are used to stream pictures every half hour, and the pictures are then analyzed for changes over time.

One of the biggest challenges of operating in very warm, high salt marine waters is bio-fouling with algae and other micro-organisms, which causes the sensors to underperform and provide incorrect measurements, thus requiring frequent and unscheduled interventions to ensure the overall operation and reading of key performance indicators (KPI) and variables. Another challenge faced when designing the systems is anticipating its power demand, sources and how to connect the system between land, sensors and a satellite. To avoid escalating costs, the designing team may ask what is the optimal data collection frequency, keeping in mind the law of diminishing returns. The data collected is streamed in real-time and is also used to make 3-day predictions via complex water quality and hydrodynamic models.

Fang Li, Ph.D.*, Assistant Professor, Mechanical Engineering, School of Engineering and Computing Sciences, New York Institute of Technology*
Ziqian Dong, Ph.D.*, Assistant Professor, Electrical and Computer Engineering, School of Engineering and Computing Sciences, New York Institute of Technology*

This combined presentation highlighted the importance of real-time continuous monitoring and having reliable and high-resolution monitoring information on water quality, which is essential for water management and for maintaining or improving the quality of water resources. A recent incident in Lanzhou province demonstrated that current water quality assessment methods (based on laboratory analysis, or measurements every six months) were not efficient in warning people about benzene contamination in drinking water. In contrast, real-time water quality monitoring networks offer a quick and good overall water toxicity assessment, cover a greater geographical spread, with low cost.

Dr. Li reviewed state-of-the-art sensor technologies for real-time water quality monitoring. While several technologies are available, (e.g., including fiber optic sensors, bio-sensors – both bacteria-based, and cell based ones –, microelectrode-based sensors, lab-on-a-chip system, electromagnetic wave sensors) her research focuses on cell based-bio-sensors. She then noted several advantages of such sensors. First, the cells can respond to the toxicants in a manner that is highly related to their pathology and physiology, therefore they can be used to distinguish between active and inactive toxicants and their bioavailability. Second, the sensor signal results from the interaction of the cell and toxicants; thus the device can detect a broad range of toxicants, including unexpected and unknown pollutants.

Dr. Li also discussed current challenges that limit field applications of cell-based biosensors such as the need to preserve the cell's bioavailability, which requires that the cell environment be highly controlled, mostly because the lifetime of the cell on the sensor platform is limited. Another challenge is that the cell behavior is very complicated; there are a number of ways for cells to respond to a pollutant, therefore it is hard to use a single cell mechanism to evaluate comprehensive cell behaviors when exposed to toxicants.

To address these challenges, and using micro-fabrication techniques, Dr. Li is working on developing multi-parameter sensor platforms, combined with acoustic waves sensors and electric impedance sensors that prop the cells and provide information about cell properties and adherence). She is also working to integrate a multi-fluidic device to the sensor platform, to provide higher sensitivity range while reducing the cell's medium consumption, thus also decreasing costs. Results from demonstration tests, where stable cells are given various concentrations of toxicants in water, indicated that the cells can be maintained automatically for more than one month, and the sensors are capable of detecting several toxicants. In the future, Dr. Li hopes to reduce the size of the sensor platforms, costs, and conduct real-time monitoring for longer time frames and a range of toxicants. Another important consideration is how to connect to, and transmit data from the sensors, which was then discussed by Dr. Dong.

Dr. Ziqian Dong noted that a large challenge in the area of sensor networks is the energy needed to transmit data via wireless technology. Another challenge is how to design protocols that can significantly reduce communication overhead. In real-time systems there is a lot of environmental noise and if maintenance cannot be carried out on time, this may result in data being lost. Dr. Dong proposed to recover such data using "Matrix Completion," a mathematical method that may be used to "recover" unkowns or measurements using a limited number of sensors and signals that render sparse representations in the transform domain. As long as there is coherence in measurements of the signal, it is possible to extract information to recover the original signal with good confidence using vector analysis. This will reduce the communication overhead in the whole system.

To illustrate, she described her research project based on Planet Lab, with online data from sensor nodes in America, Europe and Africa, but unfortunately scant data from China, where only 300 out of 1,000 sensor nodes rendered reliable data streams. Ideally, all the measurements would be available, but an alternative is to strategically locate the nodes, with sensor clusters that can improve data collection even if some specific nodes fail. One of her projects focusing on the northeast of the United States, selected 28 sensor nodes, and obtained signals with high concentration in the low frequency domain, and very sparse in the high frequency domain. She then applied compressed sensing and a "Matrix Completion" method to recover data, and results compared quite well to the "on the ground-data." The approach described reduces the number of devices needed, as well as costs when expensive sensor networks are involved; moreover, it decreases the overall energy consumption of the sensor network systems.

Xin-Zhong Zhao, Ph.D., *Professor and Head of Laboratory, Department of Physics, Wuhan University,* presented on his research on micro-fluidics, which are very small sensors commonly applied in the field of biomedical engineering, with potential applicability to water quality monitoring. The sensors are so small that they can be implemented for medical analysis. The idea is to monitor very small droplets of cells, bacteria, and any other microorganism that need to be studied. The special chips may be simple or complex. The technique involves changing the electric voltage to alter the size of the droplets along with their speed – to monitor how fast the droplet goes through micro-channels, which carry the chemicals to be analyzed – plus a control channel. One can also change the density of the droplet, as well as the chemical reaction start time.

Micro-fluidics devices have several applications. They may be used to analyze toxicant content, such as elemental mercury in water or air. Similar devices target E-coli bacteria, by embedding the anti-E-coli bacteria peptide on a special bead, and based on an anti-body special recognition protocol it is possible to identify the presence of E-coli. Another technique tries to isolate special cells (circulating tumor cells) in human blood by using microfluidic devices to recognize their immune-fluorescent characterization, and then release them from the substrate to complete the analysis. Dr. Zhao is also working on applying microfluidic devices to isolate fetal nucleated red blood cells from maternal blood, in order to conduct genetic analysis. Future research directions refer to the application of microfluidic devices to real-time continuous water monitoring.

Alan Mickelson, Ph.D., *Associate Professor, ECEE Department, University of Colorado at Boulder*, presented on delayed tolerant water quality monitoring, deploying a multitude of sensors linked to cell phone networks. He has conducted water quality monitoring in rivers across the world, gathering information on a number of parameters, such as measurements of dissolved oxygen, pH, oxygen reduction potential, conductivity and temperature. With sufficient number of measurements along a river, it is possible to obtain information about likely plumes or flooding, or other severe episodes (e.g., run off from mines; or bio-amplification from remobilization of water that was sitting on pools) and conduct monitoring in a spatial-temporal manner. However, their monitoring to-date is time consuming, in terms of having to go back to and for between the river and the lab.

An alternative is using wireless personal network systems with inexpensive components that are easy to put together, such as five monitors connected to a simple board, with Internet /Bluetooth capabilities, and 10 gigabit ST cards or XP cards, plus added sensors. These cards can store data for months without much energy consumption, keep the data until it is downloaded (e.g., via a cell phone), and then easily transmit the collected data. This easy procedure permits having as many stations as are needed.

The main problem problems are maintenance and power requirements. Dr. Mickelson's team has addressed the energy challenge at a project in the Ecuadorian Amazon, where there are no roads. They deployed 17 stations along the Napa River, each with a 12-watt transmitter, powered by a small solar panel (175 watt) and a deep cycle battery (6 volt – 200 amp power). The network has been operating continuously since 2007. Each system also has a 2.5gigabit server that monitors and stores data and transmits once a day, since 2010. The amount of power required by the sensors is very small compared to the transceivers. To address the maintenance challenge, the team plans to deploy future sensor network systems between the intake and outtake of 50 water filtration stations in the Napa River, which are usually maintained because they are the water supply for small villages throughout the river; thus the sensor networks maintenance may be carried out at the same time. In short, these delayed tolerant individual wireless network systems can store and then transmit data that may be used to track hydrological, biological, and chemical river changes and feed hydrological models and GIS databases.

SESSION V: WRAP-UP SESSION AND WORKSHOP RECOMMENDATIONS

This session synthesized the main roundtable discussion points and pinpointed research gaps and areas for future research directions, as well as identified joint research agendas for collaborative projects engaging researchers from China and the United States.

Dr. Nada Marie Anid, Dean of the School of Engineering and Computing Sciences at NYIT led this session. Prior session leaders, including Drs. Chunmiao Zheng (PKU), Richard Hooper (CUASI), Danny Rieble (Texas Tech U.), and Xiaohui Cui (Wuhan U.), reviewed each session's main findings. All participants then engaged in developing the recommendations outlined below.

Session on Water quality modeling for megacities and rural areas

<u>Storm water / Runoff:</u>

Participants agreed that further experimental studies are needed to understand the chemical transport of pollutants (e.g., PAHs) in the environment, in order to build dynamic models that can simulate pollutant transport in both impervious and pervious areas, and incorporate seasonal / meteorological data as well.

The relevance of a systems-based approach was noted. For example, an Industrial Ecology approach should be explored to identify primary sources of pollutants, which can assist in designing efficient interventions to curb environmental releases and thus improve water quality.

Potential Collaborations: Drs. Yi Zheng (Peking University) and Danny Reible (Texas U.) discussed potential collaboration around PAHs in runoff and stormwater and a dynamic model to simulate the transport of PAHs in both impervious and permeable areas.

<u>Artificially Created Wetlands:</u>

Additional research was recommended regarding artificially created wetlands (ACW), used for water purification and treatment of pollutants in runoff. Participants highlighted the significance and potential large positive impacts of efforts to scale up from current pilot projects, and explore how the ACW projects may work under varying conditions. They recommended a multidisciplinary, cross-cutting approach to develop models at various scales.

Potential Collaborations: Dr. Tissa Illangasekare (Colorado School of Mines) would like to work with Drs. Jian Jian Lu (East China Normal University) and Shieh-Tsing Hsieh

(Tulane University), to develop a simulation, multi-scale model of biological systems functions to assess how ACW may very under different conditions.

Session on Water Scarcity and Hydrological Challenges

Dr. Hooper highlighted the similarities between China and the United States, in terms of water scarcity patterns (e.g., northwest China and western US,); large rivers (Yangtze, Mississippi) and wetland systems in both countries, which offer a fertile ground for conducting joint research and paired site projects with substantive follow up. The joint research may be formally structured as part of an NSF Research Coordinating Network (RCNs), in particular one with global reach.

Participants also noted different practices in data sharing and called for greater transparency. Dr. Hooper offered access to the CUASHI network to all participants, in support of potential joint projects.

Water sustainability and Climate Change, and how water balances will be affected by climate trends continues to be an area requiring further research. Studies may focus on improving resolution for hydrological models that integrate climate scenarios to estimate the effect of higher temperatures (2-3 degrees Celsius) on groundwater, springs, streams, and/or different river basins, as well as surface water- groundwater exchange and related models. Alternatively, research could also center on understanding how climate change will affect areas (and species) dependent on snowmelt (western China and US) versus precipitation.

The area of climate change adaptation research was also highlighted, including measures and regimes to allocate water resources between alternative usages (irrigation for farming, thermo-electrical plants, or drinking water reservoirs).

Potential Collaborations:

Drs. Zheng (PKU) and Tidwell (Sandia National Lab) will continue to explore potential collaboration to better characterize climate change impacts on water resources. Potential collaborations may be structured around NSF Sustainability Research Networks (SRNs).

Water supply pressures (quantity & quality factors):
An integrated approach to researching the main drivers affecting water supply was called for, going beyond well-known factors (e.g., climate change, population growth, and economic growth) to focus on how urbanization processes and pollution may be affecting available supplies. Water footprint studies, which incorporate the concept of gray-water were deemed of interest, along with the development and adoption of simple water scarcity indices to communicate to the public the urgency of conserving and protecting resources.

Potential collaborations:

Dr. Junguo Liu (Beijing Forestry University) and several US parties, including NYIT will explore integrated quantity /quality assessments, developing enhanced blue / gray-water footprint models, while attempting to identify best tools or metrics to communicate water shortages to the public.

Session on Research advances in water management for hydraulic fracturing in oil and gas production

<u>Water supply for hydraulic fracturing (HR):</u>
A key research area is evaluating water requirements and underground water resources for HF in different regions, as these are is seen to be regionally dependent, according to the characteristics of each gas / oil "play." Collaborations among researchers in southwestern China and those focusing on various shell plays in the United States should be encouraged.

There was also interest in exploring the water (and energy) implications of transitioning from coal to gas and oil, which will extend overall water supplies and lower energy costs as well as treatment technologies to reuse / recycling water. There is interest from industry (e.g., EQT) to have a whole systems perspective for optimizing industrial water management for hydraulic fracturing (HF) and reduce impacts, but universities need to lead this research.

Potential collaborations:
The water-energy implications of transitioning from burning coal is an area of interest to Dr. Tidwell (Sandia National Lab), as well as Tissa Illagansekare, who suggested an integrated approach to estimating energy-water- and atmospheric impacts. Aibing Hao, *Vice Director of the Department of Water and Environment, China Geological Survey*, invited US participants to visit China to conduct groundwater research in partnership with researchers in China. Research may be coordinated through NSF SRNs, and perhaps fundamental research may be supported by DoE, Industry Office of Sciences (fossil fuels), which may have a $100M budget for this research area.

<u>Alternative sources of Water for hydraulic fracturing:</u>
Use of brackish water (often available near certain underground gas /oils deposits) should be explored, in particular with respect to their specific chemistry. Participants agreed that research to develop the theoretical framework to evaluate aqueous chemistry of brackish water is needed.

Potential collaborations:
Danny Rieble (Texas Tech U.) and Meagan Mauter (Carnegie Mellon) are exploring collaboration, which may be extended through the AIChE network, as well as the Chinese USGS (through the program mentioned by Dr. Aibing Hao).

Session 4 — Information Systems for real-time water quality monitoring and analysis

The need for further research on real-life water quality monitoring was recognized by several participants, including Robert Tansey (Nature Conservancy), who noted that the Chinese population is aware of pollution in air, food, water and soils (in that order of awareness).

<u>Technologies for water quality monitoring:</u>
Participants were interested in further understanding satellite imagery data and networks for real world applications, as well as less costly systems of sensors capable of improving water quality monitoring. Two specific applications were recommended: a) broad deployment of low-cost sensors for groundwater wells monitoring; b) biosensors integrated to microfluidic devices that may be used as early warning systems for toxicants in water.

Potential Collaborations:

Dr. Cui (Wuhan University's International School of Software) invited US researchers to a newly created center and invited US, including Dr. Ziqian (Cecilia) Dong at New York Institute of Technology (NYIT), to visit and work on joint sensor networks projects.

Dr. Chunmiao Zheng (PKU) stated that he would be interested in better water quality sensors and real-time instrumentation for ground water. Dr. Fang Li (NYIT) and Dr. Zhao (Wuhan U., School of Physics) are exploring collaboration around bio-sensors and microfluidic devices for real time monitoring and analysis.

CONCLUSIONS:

The "Clean Water Matters" workshop was successful in identifying a few opportunities for joint research collaborations among scholars in China and the United States in order to address pressing water challenges affecting both nations, which are also potentially applicable to other regions of the world. This synthesis report summarizes the scientific, engineering and information systems and data challenges and opportunities identified by the 32 active participants in four key areas: *a) Groundwater quality modeling for mega-cities and rural Areas; b) Water scarcity and hydrologic challenge, c) Research advances in water management for hydraulic fracturing in oil and gas production, and d) Information Systems for real-time water quality monitoring and analysis.*

To build a research agenda for collaboration across the US and China that supports joint approaches to clean water challenges and barriers to sustainability facing both nations, participants worked diligently as evident in three key outcomes. First, they reviewed the research capacity and resources of all institutions represented. Moreover, through active engagement and discussions, several priority topics for research collaboration were identified. Participants also discussed several models for the promotion of open data and data sharing across the nations, and they gained access to data platforms such as the one managed by the Consortium of Universities for the Advancement of Hydrological Science, Inc., in the United States.

APPENDIX I:

Agenda for the Clean Water Matters: Challenges and Research Perspectives Workshop, April 18, 2014; Beijing, China

Schedule and Organization:

April 18 – Conference Room – Center for Water Research, PKU	
8:30 – 8:45 am	*Goals for the Workshop:* Drs. Nada Anid and Chunmiao Zheng
8:45 – 9:45 am	Session 1*: Groundwater Quality Modeling for Mega-cities and Rural Areas*. Moderated by Dr. Chunmiao Zheng
9:45 – 10:30 am	Session 1*:* Roundtable discussion
10:30 – 10:45 am	Break
10:45 – 11:45 am	Session 2: *Water scarcity and hydrologic challenges.* Moderated by Dr. Richard Hooper
11:45am – 12:30 pm	Session 2: Roundtable discussion
12:30 – 1:15 pm	Lunch
1:15 – 1:45 pm	Session 3: *Research advances in water management for hydraulic fracturing in oil and gas production.* Moderated by Dr. Danny Reible
1:45 – 2:30 pm	Session 3: Roundtable discussion
2:30 – 2:45 pm	Break
2:45 – 3:45 pm	Session 4: *Information Systems for real-time water quality monitoring and analysis.* Moderated by Dr. Xiaohui Cui
3:45 – 4:30 pm	Session 4: Roundtable discussion
4:30 – 4:45 pm	Break
4:45 – 5:45 pm	Closing Session (5) to explore future research directions. Moderated by Dr. Nada Anid.
5:45pm	Meeting adjourned

APPENDIX II:

Participants and Affiliated Organizations

Nada Marie ANID, Ph.D., Professor and Dean, School of Engineering & Computing Sciences (SoECS), NYIT.

Paul J. ANID., Dr. Sc., Vice-President, HDR Inc.

Paul BIRETA, Doctoral candidate in Environmental and Water Resources Engineering at the University of Texas at Austin.

Xiaoli CHAI, Ph.D., Professor, Department of Environmental Engineering, Tongji University.

Xiaohui CUI, Ph.D., Dean, International School of Software, Wuhan University. Assistant Professor, Computer Sciences, NYIT, and Research Scientist, ORNL.

Ziqian DONG, Ph.D., Assistant Professor, Electrical and Computer Engineering, School of Engineering and Computing Sciences, New York Institute of Technology.

Darren L FICKLIN, Ph.D., Professor, Department of Geography, Indiana University.

John S GIERKE, Ph.D., Professor of Geological & Environmental Engineering and Interim Chair, Department of Geological & Mining Engineering & Sciences, Michigan Technological University, Houghton, Michigan, USA.

Aibing HAO, Vice Director of the Department of Water and Environment, China Geological Survey from the Chinese Geological Service.

Shieh-Tsing HSIEH, Ph.D., Professor and Chair Electrical Engineering Department, Tulane University.

Richard P HOOPER., Ph.D. Executive Director, Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI).

Tissa H. ILLANGASEKARE, Ph.D., AMAX Distinguished Chair and Professor of Civil and Environmental Engineering, Colorado School of Mines.

Fang LI, Ph.D., Assistant Professor, Mechanical Engineering, School of Engineering and Computing Sciences, New York Institute of Technology.

Jie LIU, Ph.D., Associate Professor, College of Engineering, Peking University and Center for Water Research.

Junguo LIU, Ph.D., Professor of Hydrology and Water Resources, Beijing Forestry University.

Yongpan LIU, Division Leader for Water Resources at the Ministry of Hydrology.

Jian Jian LU, Ph.D., Professor of Ecology, East China Normal University, Shanghai.

Megan MAUTER, Ph.D., Assistant Professor, Chemical Engineering and Engineering and Public Policy, Department of Chemical Engineering, Carnegie Mellon University.

Devinder MAHAJAN Ph.D., SBU/BNL Joint Appointment Professor and Co-Director, Chemical & Molecular Engineering, Stony Brook University, SUNY.

Xiaoliang MENG, Ph.D.,Director of the Joint International Center for Resources, Environment Management and Digital Technology, International School of Software, Wuhan University.

Sarah MEYLAND, JD, Assosiate professor, Environmental Technology Dept., School of Engineering & Computing Sciences, New York Institute of Technology.

Alan MICKELSON, Ph.D., Associate Professor of Electrical Engineering, Department of Electrical and Computer and Energy Engineering, University of Colorado at Boulder

Marta PANERO, Ph.D., Director of Strategic Partnerships , Adjunct Professor, School of Engineering & Computing Sciences, New York Institute of Technology.

Victoria PFEIFFER, Special Assistant to the President, NYIT

Daniel REIBLE, Ph.D., PE, BCEE NAE, Donovan Maddox Distinguished Engineering Chair, Texas Tech University

Vincent C. TIDWELL, Ph.D., Distinguished Member of the Technical Staff, Sandia National Labs

Robert TANSEY, Nature Conservancy Asia-Pasific Region

Xiaoli WANG, MS, Executive Assistant, Center for Water Research, Peking University.

Mona YEW, Deputy Director of Natural Resources Defense Council, China; Pacific, Gas and Electric**.**

Zhao ZENG, School of Nature Conservation, Beijing Forestry University, Beijing.

Chunmiao ZHENG, Ph.D., Professor and Chair, Water Resources and Director of the Center for Water Research, Peking University. Jianguo (Jack) Liu and David Hyndman, Michigan State University

Yi ZHENG, Ph.D., Associate Professor and Associate Director, Center for Water Research, Peking University.

The above lists active participants at the workshop, which also included students who benefited from the presentations, dialogue and asked questions. The following students from NYIT attended: Ashley Degrandis, Geysa Gonzalez, Anthony Reyes and Collins Vinson.

APPENDIX III:

Presentation Abstracts for the Workshop "Clean Water Matters: Challenges and Research Perspectives."

Several participants provided presentation abstracts in anticipation of the April 18 workshop, which was conducted in English. These abstracts are provided below.

Session 1. Water Quality Modeling for Megacities and Rural Areas
This session will contribute to advancing the understanding of hydrologic processes and water quality evolution. Challenges in the modeling of groundwater contaminants transport for improved monitoring, as well as new approaches for identifying contaminant sources (e.g., ModGA code for contaminant source identification, substance flow accounting; industrial ecology) will be described. The presentations and round table discussion will consider both urban and rural aquifers.

Authors: **Chunmiao ZHENG, Ph.D.,** Professor and Chair, Water Resources and Director of the Center for Water Research, Peking University. **Jianguo (Jack) Liu** and **David Hyndman**, Michigan State University

Presentation Title: **"ENSURING WATER SECURITY FOR BEIJING AS AN INTERNATIONAL METROPOLIS: A SYSTEMS-BASED ASSESSMENT"**

Abstract: Global changes pose major threats to water sustainability around the world. These threats are magnified in megacities, most of which are already experiencing water shortages that are likely to be exacerbated by changes in climate, land use, urbanization, population, and economic development. Water shortages and other sustainability issues will extend well beyond the boundaries and catchment areas of individual megacities because of cascading effects on regional water supplies and the profound influence that these cities have globally. Most research on water sustainability for megacities has been fragmented and thus not able to effectively elucidate the interactive and synergetic effects of global change factors. Furthermore, models used hitherto to tackle these issues are either too simple, with insufficient accuracy to be useful for policy formulation and decision-making, or may require detailed data not available for many megacities, limiting their transferability.

This presentation will provide an introduction to a new initiative by a trans-disciplinary and international team to develop, evaluate and apply innovative systems models that integrate subsystems models of hydrology, biology, climate, socioeconomics, and engineering. These models will be developed and evaluated for Beijing, an emerging major international metropolis, which exemplifies the global water sustainability problems of megacities and provides many excellent opportunities for this research. The systems models will help policy makers understand and integrate complex long-term dynamics of water availability and use in Beijing as it strives to become a major

international metropolis (e.g., help policy makers quantify the potential long-term impacts of various policy choices).

Author: **Shieh-Tsing HSIEH, Ph.D.,** Professor and Chair Electrical Engineering Department, Tulane University.

Presentation Title: **"NEW ORLEANS: A UNIQUE CITY WITH UNIQUE CHALLENGES BY WATER"**

Abstract: New Orleans has been the most important city of Louisiana and the Gulf of Mexico's busiest northern port since the early 1700s. In its last hundred years the key struggles of New Orleans have been social (poverty, racial strife) and natural (hurricanes, floods and slowly sinking land). On August 29, 2005, Hurricane Katrina struck. The Category 5 storm's winds tore away roofs and drove a storm surge that breached four levees, flooding 80 percent of the city. The waters receded, but a year later only half the city's residents had returned. Within five years 80 percent were back, but New Orleans—though as diverse, unique and historic as ever—remained far from reclaiming its 1930s nickname, "the city that care forgot." Further, the city's drinking water supply system is deteriorating. We will discuss the main challenges and opportunities of water management in New Orleans.

Author: **Tissa H. Illangasekare**, AMAX Distinguished Chair and Professor of Civil and Environmental Engineering, Colorado School of Mines, Golden CO 80401, USA

Presentation Title: **"IMPROVING GROUND WATER QUALITY MODELS THROUGH LABORATORY STUDIES"**

Abstract: Many advances have been made in the last several decades on modeling flow and fate and transport of chemicals in the subsurface. With available computing power, it has become possible to apply these models to large systems with increased grid resolutions to obtain accurate numerical results. However, many challenging problems still remain where the numerical accuracy of the model is not sufficient to make useful predictions for exposure risk assessment and contaminated site management. Among many factors that contribute to the complexity of these problems, the most challenging is the role of subsurface heterogeneity that is manifested in all scales of observations and how it is conceptualized and represented in models. In this presentation, we make the arguments that laboratory experimentation at multiple scales will allow us to fill many knowledge gaps for better conceptualization and effectively incorporate heterogeneity into groundwater quality models for better predictions and address problems of up-scaling.

Author: **Jian Jian LU, Ph.D.,** Professor of Ecology, East China Normal University, Shanghai, China;

Presentation Title: **"AN EFFECTIVE AND ECONOMICAL SYSTEM TO CLEAN GREY WATER"**

Abstract: A major feature of a *multi-state subsurface ecological water treatment system* is to simulate the alternation of drying and wetting of the natural wetlands, control the transformation conditions of aerobic and anaerobic environment, and develop new and efficient aerobic and anaerobic nitrobacteria as well as high efficient phosphorous removal fillers. This system has many advantages, such as less area demand, high unit treatment efficiency, stable yearly operation, and good landscape effect. It can widely be used in sewage treatment, river and lake management, landscape water treatment, rainwater collection, and agricultural wastewater treatment, etc. Its sewage treatment capacity can be expanded through parallel designation of different scales so that it is able to fully meet the demand for the water purification and reclaimed water reuse for constructions and facilities like villas, villages, tourist determinations, parks, farms, roads and railways, etc. Particularly, when used in the blind spot area from municipal sewage pipe network and remote tourist attractions, the role and advantages of this water treatment System can get maximized.

Author: **Yi Zheng, Ph.D.,** Associate Professor and Associate Director, Center for Water Research, Peking University.

Presentation Title: "**MODELING THE STORMWATER POLLUTION OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN URBAN AREAS"**

Urban stormwater runoff delivers a variety of pollutants to water bodies. Polycyclic aromatic hydrocarbons (PAHs), a category of persistent organic pollutants (POPs) mostly of atmospheric origin, are ubiquitous in urban soils and road dusts. During rainfall runoff events, a significant amount of PAHs would be delivered from urban surfaces to water bodies and eventually deposit into sediments, which poses serious risk to aquatic life and human health. The stormwater pollution of PAHs is serious in many urban areas, but has been largely overlooked by environmental modeling and management. This study addresses modeling the PAHs pollution on both impervious and pervious urban surfaces. A variable time-step model was developed to simulate the continuous cycles of pollutant buildup and washoff on urban roads. Long-term simulations of the model can be efficiently performed, and probabilistic features of the pollution level and its risk can be easily determined. The transport of PAHs from contaminated soils with runoff was also studied through laboratory experiments, and an approach to estimate the PAHs load was proposed. The modeling approaches developed in this study were integrated with SWAT, a widely applied hydrological and water quality model, and applied to the plain area (most urbanized part) of Beijing. The pollution level and environmental risk of the PAHs pollution were assessed.

Session 2. Water scarcity and hydrologic challenges

Participants in this session will explore the fundamental hydrologic challenges and water scarcity issues affecting countries across the globe. The discussion will take into account the impact of climate change on water supply and critical zone processes, and feedback loops. Participants will consider new advances to enhance water resource availability predictive models, whether they take into account findings from critical zone observatories, cyber physical systems, demand-side management predictions or other variables, as well as systems to signal resource depletion.

Author: **Richard P. Hooper,** Executive Director, CUAHSI (Session Leader)

Presentation Title: **"DATA SHARING AND INFORMATION TECHNOLOGIES FOR MANAGING WATER SCARCITY"**

Abstract: "You can't manage what you don't measure." That bit of wisdom can be amplified by sharing data on water and water quality among stakeholders to better manage water conflicts. The CUAHSI Hydrologic Information System is a federated, services-oriented architecture that allows each data collection entity to manage its own data bit also to share data with others through registering the data service with a central catalog. This system allows users to discover and to download data in a consistent format with metadata including the entity which collects the data. Currently all data registered with the system are freely available, but the system is being extended to permit registration of metadata only which will require potential users to contact the data collection entity for permission to download the data.

Author: **Darren L. Ficklin**, Professor, Department of Geography, Indiana University, Bloomington, Indiana

Presentation Title: **"IMPLICATIONS OF A CHANGING CLIMATE ON WATER RESOURCES IN THE WESTERN UNITED STATES"**

Abstract: The impact of climatic change on the availability of water resources is particularly important in rapidly developing, economically-important regions with arid or semi-arid climates, such as the western United States. Increases in air temperature and associated precipitation regime shifts (snow-dominated to rain-dominated) are expected to result in significant consequences for the large fraction of western United States water resources that are dependent on high-elevation snowpack. While General Circulation Models project surface temperature warming for the western United States, precipitation projections are variable, with no wetter or drier consensus. Based on hydrologic model simulations, it is projected that snowmelt will be reduced throughout the western United States, resulting in shifts toward streamflow occurring earlier in the year, longer summer drought periods, and changes from snowmelt-dominated to rainfall-dominated runoff regimes. Additionally, it can be expected that average annual streamflow will be decreased. Sierra Nevada, Colorado River Basin, and Columbia River Basin, the largest runoff-producing regions in the western United States, will be discussed.

Author: **John S Gierke,** Professor of Geological & Environmental Engineering and Interim Chair, Department of Geological & Mining Engineering & Sciences, Michigan Technological University, Houghton, Michigan, USA

Presentation Title: **"NEEDS AND CHALLENGES FOR CHARACTERIZING AND MONITORING SHALLOW SUBSURFACE HYDROLOGY IN COMPLEX TERRAINS IN REMOTE LOW-RESOURCE SETTINGS"**

Abstract: The importance of shallow groundwater systems for water supplies is not quantified. For example, estimates of the contribution of springs as water supplies are lacking for much of the developing world because of the lack of data on flows and demands. Qualitatively we know that these supplies are critical for many people and it is anticipated that these supplies are likely to be among the first types to be impacted by climate change. Springs often occur in complex geological terrains (steep slopes, shallow and fractured bedrock, etc.) that are inherently challenging to characterize in terms of the catchment area, recharge rates, and flow paths. High-resolution remotely sensed imagery coupled with advanced digital image processing techniques show promise in delineating surface expressions of geological features that affect shallow groundwater flows, but there remains a tremendous gap in technologically advanced approaches for remote characterization of landscapes and site-specific data for validating/calibrating these new advancements. Moreover, flow and climate monitoring are especially needed to develop baseline understanding of these systems in response to current climate so that future changes can be forecast and future impacts identified.

Author: **Jie LIU, Ph.D.,** Associate Professor, College of Engineering, Peking University and Center for Water Research

Co-Author: **Jie Liu, Chuankun Liu, Yingying Yao, Chunmiao Zheng**

Presentation Title: "**TEMPERATURE AS A TRACER TO IDENTIFY SURFACE WATER – GROUNDWATER EXCHANGES IN THE HEIHE RIVER BASIN, NORTHWEST CHINA"**

Abstract: Among the various methods used to study surface water-groundwater interactions, those based on temperature have distinct advantages because of the obvious temperature differences between surface water and groundwater and because of the simplicity and low cost of temperature measurement. Fiber-optic distributed temperature sensing (DTS) can continuously measure temperature at very high spatial and temporal resolutions. Airborne thermal infrared temperature sensing (TIR) can measure temperature of the ground surface at regional scale, provide higher spatial resolution imagery and is more temporal flexible compared to space remote sensing.

Those two methods were applied in a study area at the Heihe River Basin (HRB), which is the second largest inland river basin in the arid region of northwest China. Under natural conditions, the Heihe River recharges to groundwater in the piedmont areas after coming out from the Qilian Mountain. In the front edge of the alluvial and fluvial fans in the middle HRB, groundwater discharges to the river in the form of spring, then flows into the Heihe River and ends up at the terminal lakes in the lower HRB.

The surface water-groundwater interactions are frequent and dynamic along the Heihe River, and the understanding of these interactions is essential for conjunctive use and management of water resources and is fundamental to ensuring ecosystem health of the entire basin. In this study, DTS was applied to observe high-resolution temperature variations in a total distance of 5 km along two sections of the Heihe River. A statistical approach was used to discern the spatial distribution and the size of groundwater discharge zones and hyporheic zones, respectively. The airborne thermal infrared remote sensing method was applied in a total length of 185km of the Heihe River to obtain pattern information of temperature of the river surface. The distribution and variation pattern of temperature anomalies were identified, thus providing an effective means of locating groundwater discharge areas. A new method to quantify groundwater discharge to river using river surface temperature from TIR was also provided.

Author: **Junguo LIU, Ph.D.,** Professor of Hydrology and Water Resources, Beijing Forestry University

Co-Author: Zhao Zeng, School of Nature Conservation, Beijing Forestry University, Beijing

Presentation Title: "**ASSESSING WATER SCARCITY INTEGRATING WATER QUANTITY AND QUALITY**"

Abstract: Water scarcity has become widespread all over the world. Current methods for water scarcity assessment are mainly based on water quantity and seldom consider water quality. Here, we develop an approach for assessing water scarcity considering both water quantity and quality. In this approach, a new water scarcity index is used to describe the severity of water scarcity in the form of a water scarcity meter, which may help to communicate water scarcity to a wider audience. To illustrate the approach, we analyzed the historical trend of water scarcity for Beijing city in China during 1995–2009. The results show that Beijing made a huge progress in mitigating water scarcity, and that from 1999 to 2009 the blue and grey water scarcity index decreased by 59% and 62%, respectively. These achievements were made through great efforts of water-saving measures and wastewater treatment. Despite this progress, we demonstrate that Beijing is still characterized by serious water scarcity due to both water quantity and quality. The water scarcity index remained at a high value of 3.5 with a blue and grey water scarcity index of 1.2 and 2.3 in 2009 (exceeding the thresholds of 0.4 and 1, respectively). As a result of unsustainable water use and pollution, groundwater levels continue to decline, and water quality shows a continuously deteriorating trend. To curb this trend, future water policies should further decrease water withdrawal from local sources (in particular

groundwater) within Beijing, and should limit the grey water footprint below the total amount of water resources.

Reading materials:

1. Zeng Z, **Liu J.***, Savenije H.H.G., 2013. A simple approach to assess water scarcity integrating water quantity and quality. *Ecological Indicators* 34: 441-449.
2. **Liu J.***, Zang C., Tian S., Liu J., Yang H., Jia S., You L., Liu B., Zhang M., 2013. Water conservancy projects in China: achievements, challenges and way forward. *Global Environmental Change* 23(3): 633-643.
3. **Liu J.***, Lundqvist J., Weinberg J., Gustafsson J., 2013. Food losses and waste in China and their implication for water and land. *Environmental Science & Technology* 47(18): 10137-10144.

Session 3. Research advances in water management for hydraulic fracturing in oil and gas production

Hydraulic fracturing, which usually extends the life of existing oil and gas wells, requires the use of fluid and materials (sand, additives) to open small fractures in order to stimulate production. This session will explore advances in water management, reuse, and how they might address the potential contamination of groundwater resources if the fluid enters the water supply. Participants will discuss research directions and models for optimizing the drilling and production water life cycle, as well as potential fixed and mobile solutions.

Session Leader and Speaker:

Author: **Daniel REIBLE, Ph.D.,** PE, BCEE NAE, Donovan Maddox Distinguished Engineering Chair, Texas Tech University

Presentation Title: "**HYDRAULIC FRACTURING AND WATER MANAGEMENT"**

Abstract: Hydraulic fracturing operations employ significant water to achieve the goals of fracturing shale for the production of oil and gas. Water demand can exceed 4 -6 million gallons of water per well. While the total water needs vary a great deal, the specific water demand, or water usage per foot of horizontal extent is typically approximately 1000 gallons/linear foot. In many areas, this demand for water is not a significant fraction of available water supplies. Increasingly, however, hydraulic fracturing is conducted in areas of water scarcity such as the western United States and parts of Asia where the hydraulic fracturing water needs may negatively impact prior water uses. Since hydraulic fracturing is often conducted in rural areas with limited infrastructure, this water is typically trucked into a fracturing site, increasing the impacts on these rural communities.

Water management concerns can be addressed by maximizing use of local poor quality waters and reuse of flowback and produced waters. Brackish groundwaters are an

underutilized resource throughout the world but are often readily available and directly usable for hydraulic fracturing water needs. A significant barrier to increased use of these waters, however, is the lack of knowledge about the productivity of these aquifers since there has been little incentive to perform the aquifer and pumping testing needed to characterize them. Another alternative is to maximize reuse and recycling of flowback and produced waters. Flowback water reflects the combined influences of injected water and formation waters and can be relatively easily recycled for hydraulic fracturing. Produced water reflects the properties of the formation and can be much more variable and of poorer quality. Reuse of these waters requires substantial blending with freshwater or treatment to reduce dissolved solids content. Full treatment to near-freshwater standards is rarely cost-effective and is energy intensive. Alternatively, minimal treatment that takes advantage of the unique chemistry of the waters in a particular play and designed to reduce the fouling characteristics of these waters may be more a more efficient approach that may be able to compete with deep well disposal options. Together the combination of use of poor quality brackish waters that are unfit for other uses and expanding reuse and recycling can reduce the water demands of hydraulic fracturing and increase its acceptance as a viable energy source now and in the future.

Author: **Megan MAUTER, Ph.D.,** Assistant Professor, Chemical Engineering and Engineering and Public Policy, Department of Chemical Engineering, Carnegie Mellon University

Presentation Title: "**ANTECEDENTS AND EFFECTS OF COMPANY BEHAVIOR IN THE IMPLEMENTATION OF UNCONVENTIONAL NATURAL GAS EXTRACTION"**

Abstract: This work discusses the influence of company attributes, experience, and behavior on the environmental consequences of shale gas development in the Marcellus play. We find significant variation in the waste management practices of Marcellus firms, with a large portion of this variance attributed to waste disposal method, company experience operating in the Marcellus, and drilling practices. We also find significant variation in the frequency and severity of oil and gas drilling violations in the Marcellus, but find that much of this variation is explained a combination of enforcement discrepancies and company commitment to a culture of safety. Taken together, this work suggests that impact minimization is a function of company and regulatory agency decision making on a highly localized scale.

Author: **Vincent C. Tidwell,** Ph.D., Distinguished Member of the Technical Staff, Sandia National Labs

Presentation Title: "**MAPPING AVAILABLE WATER FOR DEVELOPING SHALE PLAYS"**

Abstract: It is estimated that between 7,500 and 20,000 m^3 of water are required to drill and hydraulically fracture a shale gas/oil well. There are a number of new shale plays located in the arid Western U.S. where access to available fresh water supplies is problematic. In these cases information is needed to weigh competing water supply options. Toward this need, water availability, cost and new consumptive use to the year 2030 have been mapped for over 1200 watersheds throughout the 17-conterminuous states in the western U.S. Four unique characteristics of the data make it particularly useful for energy development. First, multiple sources of water were mapped, including un-appropriated surface water, un-appropriated groundwater, appropriated water, municipal wastewater, and brackish groundwater. Second, water availability metrics accommodate institutional controls (e.g., water rights, administrative controls, interstate compacts) to the extent available data permitted. Third, water availability estimates were accompanied by cost estimates to access, treat and convey each unique source of water. Fourth, water metrics were developed with the direct assistance of state water managers in framing, identifying, understanding and vetting the resultant metrics.

Session 4. Information Systems for real-time water quality monitoring and analysis. This session will focus on advances in the integration of IT and cyber-physical systems for real-time water quality monitoring and analysis. Research on real-time smart microsensors and detection systems can effectively be used for detection, mapping, monitoring and remediation of contaminated aquifers. Similar systems may be developed for reservoirs and other surface fresh water resources. Participants will discuss optimal network configurations and methodologies to assess sensors networks performance in the field, as well as to reduce errors, such as geo-statistical variance reduction analysis and simulations.

Session Leader and Speaker

Author: **Xiaohui CUI, Ph.D.,** Dean, International School of Software, Wuhan University. Assistant Professor, Computer Sciences, NYIT, and Research Scientist, ORNL

Presentation Title: "**GIS AND BIG-DATA ANALYTICS IN OUR WATER PROJECT**"

Abstract: We will tackle the problem of creating a data integration and processing framework based upon at scales ranging from small mobile devices to large scale cloud computing platform that will help to "tame the sea of data" in which we will face in the water project in the northwest region of China. The water resource related data about northwest region in our water project has created the pressing problem of how to process, understand and use these data for timely and effective decision making at all levels.

Author**: Paul J. ANID,** Dr. Sc., Vice-President, HDR Inc., New Jersey, USA

Co-Authors: **Alya Abdulrahim Alharmoudi**, Dubai Municipality, Dubai, UAE; **Noora Mohammed Hokal**, Dubai Municipality, Dubai, UAE; **Darren Birmingham**, M.Sc., HDR Inc. Dubai, UAE; **James Reilly**, M.Sc. HDR Inc. Dubai, UAE; **Kelly Knee**, RPS|ASA, Rhode Island, USA.

Presentation Title: "**MULTI PARAMETERS REAL-TIME MONITORING SYSTEMS IN HIGHLY SALINE, WARM MARINE WATERS"**

Abstract: Operating in hot, high salt marine waters carries its toll on data reliability from instruments deployed for real or near real-time data collection. Examples of multi-parameter systems including meteorological, hydrographic and water quality sensors will be described with particular focus on instruments reliability, online tracking, bio-fouling, maintenance requirements and frequency of scheduled and unscheduled interventions and the overall influence of these variables on key performance indicators (KPI).

Author: **Fang LI, Ph.D.,** Assistant Professor, Mechanical Engineering, School of Engineering and Computing Sciences, New York Institute of Technology;

Co-Author: **Ziqian DONG, Ph.D.,** Assistant Professor, Electrical and Computer Engineering, School of Engineering and Computing Sciences, New York Institute of Technology

Presentation Title: "**SENSOR TECHNOLOGIES FOR REAL-TIME WATER QUALITY MONITORING"**

Abstract: There is an increasing demand for monitoring water quality across a broad range of applications, including drinking water, wastewater and environmental waters (i.e.: rivers, lakes, groundwater and marine). Reliable and high-resolution information about water quality is essential for water management and for maintaining or improving the quality of water resources. Most of current water quality assessment methods are based on laboratory analysis, which require fresh supply of chemicals, trained staff and are time-consuming. Real-time water quality monitoring provides quick assessments covering a greater geographical spread with low cost, which is critical to national and international health and safety. In this presentation, state-of-the-art sensor technologies for real-time water quality monitoring will be reviewed. The modern real-time monitoring technologies include fiber optic sensors, biosensors, microelectrode-based sensors, lab-on-a-chip system, electromagnetic wave sensors, etc. Challenges in developing real-time water monitoring platform will be discussed.

Author: **Alan MICKELSON, Ph.D.,** Associate Professor of Electrical Engineering, Department of Electrical and Computer and Energy Engineering, University of Colorado at Boulder

Presentation Title: "**DELAY TOLERANT MONITORING OF WATER QUALITY**"

Abstract: The maintenance of a healthy watershed that supplies treatable water for human use as well as the quality necessary for agriculture and quantity necessary for commerce requires a comprehensive system of water monitoring. Manual measurement is time and manpower intensive. Automatic water monitoring equipment placed in river flows and equipped with electronic transmitters is expensive. Micro-controllers and internet compatible devices have become cost effective and ubiquitous. A five measurement (e. g. Ph, dissolved oxygen, oxidation reduction potential, conductivity and temperature) water quality monitor with data storage and internet compatibility can be constructed for a few hundred dollars.

Our experience in Amazon Peru is that such monitors can be co-located in small scale water treatment facilities that are in use in many of the smallest of river villages. Water quality is sensitive to chemical pollution as well as to bio-amplification of pathogens. A multitude of networked water quality sensors, therefore, provides early warning as well as the analytical data necessary for water management decisions. Micro-controllers allow local sensing systems to be linked to wireless personal access networks (WPANs) such that local storage cards can download stored data to personal computers or handheld devices on demand. Delay tolerant data collection over periods of hours, to days or weeks greater lowers costs without sacrificing real time in the diurnal or climatological sense. We are presently focused on developing such a networked system throughout the Napo River basin in Peru. Such water monitoring approaches should find widespread application.