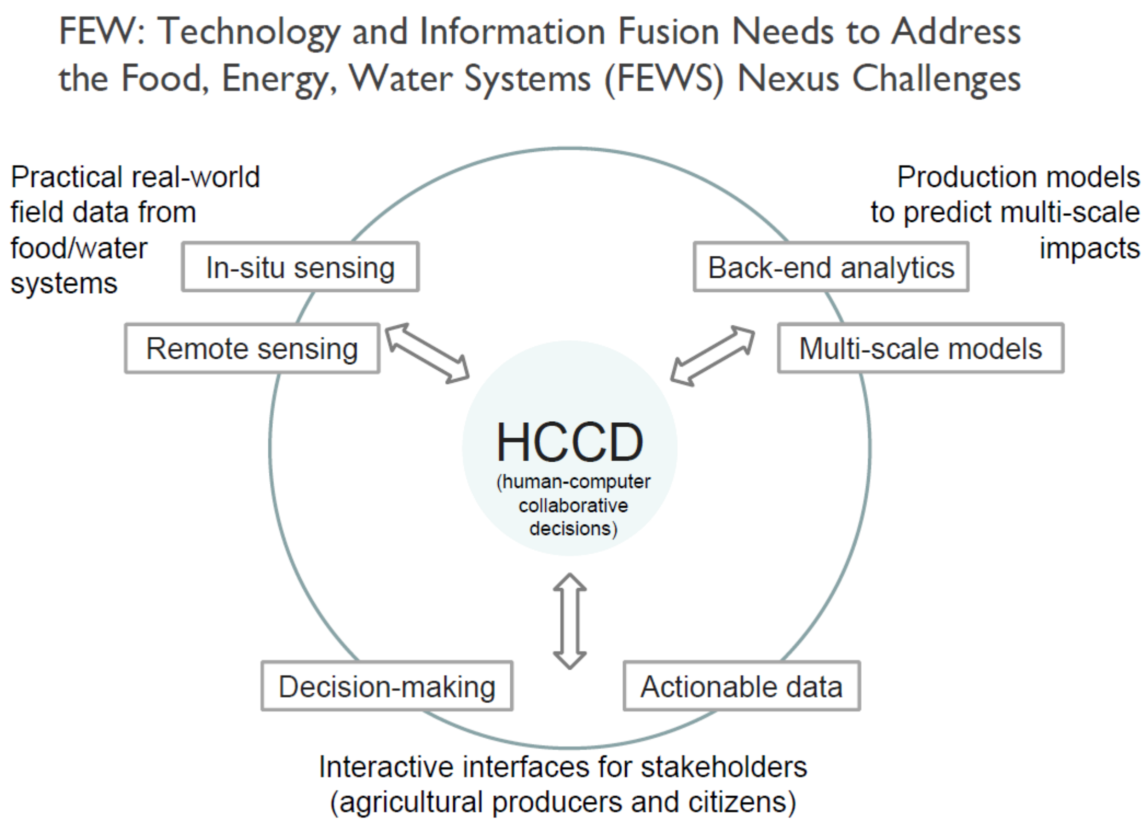
Technology and Information Fusion Needs to Address the Food, Energy, Water Systems (FEWS) Nexus Challenges

Napa, California, November 5-6, 2015

NSF FEWS Nexus Challenges Post-Workshop Event Report



I. OVERVIEW

In response to the Food, Energy, Water Systems (FEWS) Nexus Challenge grant awarded by NSF, the team of investigators led by David Ebert, along with Christian Butzke, Melba Crawford, Phillip Owens, and Dimitrios Peroulis conducted a two-day workshop in Napa, California on November 5th and 6th, 2015.

The workshop addressed the emerging issues in the food/energy/water systems throughout the diverse geography of the United States and over various crops and environmental conditions to better understand and model and ultimately devise a solution for the challenges to the FEWS nexus. One of the intended outcomes of the workshop was to generate a report that will chart the research challenges and opportunities for solving these challenges and have an impact on scientific fields including, sensing technology, hydrology, soil science, climate, data fusion, analysis, visualization, and data driven decision making, as well as agricultural production, local and regional economies, sustainability and planning. The information contained in this post-workshop report serves as that foundation.

II. EXECUTIVE SUMMARY OF KEY FINDINGS

The workshop included leading researchers from a variety of scientific disciplines that underpin this novel and evolving topic, as well as agricultural stakeholders who are experiencing food, water, and energy system challenges created by changing climate and weather conditions. The two-day workshop brought together researchers as well as end-users and defined the scope and relevant research priorities.

This multidisciplinary workshop consisting of academic researchers, corporate technology providers, and agricultural producers defined research challenges and a research road-map to address the following major FEWS challenges:

1) Developing novel targeted remote sensing and in-situ sensing technology that can be practically fielded and used in food and water system management.
2) Developing novel integrated hydrology, soil, microclimate, and plant/agricultural production models that interact accurately and across traditional scales for understanding local, regional, and national impacts.
3) Turning this developing and pending FEWS data deluge into usable, actionable information for agricultural producers, local and regional decision makers, and citizens.

There was strong consensus that responding to the challenges facing the sustainable management of the FEWS nexus requires broad transdisciplinary research that connects biological, earth, and environmental sciences, engineering, computer, and social, behavioral, and economic sciences to address both basic knowledge and practical applications covering the food supply from farm to table. Moreover, it is paramount that this transdisciplinary work be undertaken with strong stakeholder engagement (researcher, grower, industry partnerships) to lead to prioritized, fieldable solutions to these FEWS challenges.

Key findings and major recurring themes among the working groups at the event regarding the various research challenges above included the following:

- Develop **novel, multiscale and cross-scale information integration, transformation and analysis environments** that support grower/producer decision making and action leveraging current approaches. From individual plant-level to national-level decision making, as well as farm-to-table decision making across the FEWS landscape can be improved with **cross-scale, interactive, integrated visual analytic environments.**
- Support **public-private partnerships** to develop test beds for sensor systems, models that assimilate data from those systems, and novel visual analytic decision support systems coupled to those models.
- Develop new, **advanced, low-cost, low-power, in-situ and proximal sensing systems, as well as improved multiscale physics and computational science-based modeling techniques** that enable more effective resource management across scales and under uncertainty to increase the resiliency of the individual components as well as the entire FEWS system.
- Pursue **data standardization** efforts to enable developers of decision support systems to access data from sensor systems regardless of vendor, harnessing organizations such as the IEEE Computer Society and Standards Association.

- Pursue development of **modular physical science and agronomic models that are more biologically and geophysically based** and less empirical and which adhere to data standards that allow data assimilation from sensor systems and use by producers of decision support and sensor systems.

Furthermore, the collaborative partnerships between cognitive scientists, natural scientists, computer scientists, and engineers to investigate how producers use the outputs from instruments and models were found to be extremely important. These will facilitate effective production and communication of useful information to growers and to monitor the effectiveness of this communication over time. Scientific studies and engineering efforts to address these issues must connect to and be informed by producer action and adoption.

For more information on the response to the challenges previously identified, please find below an overview of the workshop format that resulted in the detailed recommendations that also appear below.

III. WORKSHOP FORMAT

Targeted participants included researchers, cooperative extension specialists, and farmers with a common goal of defining novel research topics based on the most pressing needs of perennial crop farmers in the Western U.S. A broad section of individuals in these groups was sent the request for proposals to apply for the workshop. The required application materials that were requested to be sent to the organizing committee included:

- 2-page NSF Biographical Sketch
- 1-page position paper on one or more of the topics listed below:
  - Where do water resources face the greatest stress and uncertainty?
  - What impact will a changing climate have on the global and regional precipitation patterns?
  - How can integrated modeling efforts inform decision making with respect to seasonal high-risk-of-failure water quantity and quality?
  - What technological innovations in engineering and agricultural practices will prove most effective in achieving water-food system resiliency and sustainability?

After careful review of the submitted materials, the applicants were selected and notified of the committee’s decision. A travel stipend was given to accepted workshop applicants. There was no registration fee for the workshop itself.

The agenda (see Appendix) outlines the format of the actual two-day workshop in Napa, California. Presentations and panel discussions preceded lengthy team group work where cross-sections of stakeholders related to the FEWS nexus exchanged ideas and identified future areas of research focus. These resulted in a report of recommendations generated by each working group. Their findings are summarized in the following pages.

IV. DETAILED RECOMMENDATIONS FOR RESEARCH CHALLENGES

In this section, we provide the detailed recommendations and considerations provided from our working groups. The high level summary is followed by important, detailed points highlighting and emphasizing key factors and challenges for FEWS Nexus solution success.

1) Develop novel, multiscale and cross-scale information integration, transformation and analysis environments that support grower/producer decision making and action instead of replacing them. Both individual plant-level to national-level decision making, as well as farm-to-table decision making across the FEWS landscape can be improved with **cross-scale, interactive, integrated visual analytic environments.** This topic was the most common theme across all working groups and the specific components can be grouped into the following three topics.

Actionable decision making and information integration:

- There was a strong consensus that solutions to the FEWS challenges needs to be a collaborative human-computer decision making environment that provides actionable information to the user/producer to optimize their decision making and enable harnessing their historical information and also their situational awareness that may not be captured in the digital data. A interactive visual analysis and decision making environment is crucial for the most effective solution in these complex, multiscale, unsure decision making environments and big data analytics approaches alone won't solve these problems [Robertson 2009, Brooks 2013]. The field of visual analytics [Thomas 2005] directly addresses these problems (e.g., [Robertson 2009], [Ko 2014], [Jang 2014] and novel, improved visual analytic environments for FEWS decision making environments are needed to specifically address these multi- and cross-scale, interacting system issues and complex human-computer collaborative decision making environments. Novel visual analytic
- There was wide support for FEWS efforts to be measured against actionable decisions. Modeling, sensing, and data analysis should be focused on scales in time and space which reflect what is controllable. The workshop participants believed that part of the complexity of the FEWS effort related to behavior across scales. The behavior of one year's crop may depend on longer-scale behavior of the plant, which in turn may depend on even longer-scale behavior of the soil. Moreover, the local water usage of one producer has impacts on statewide water usage as well as energy consumption through cascading actions
- There was support for clearer understanding of randomness and uncertainty and how it is modelled and quantified. Systemic failures are hopefully rare, so control of FEWS systems should clearly appreciate the structure of these rare events. For example, sample mean-variance calculations do not do justice to critical tradeoffs.
- In the fields of energy and water conservation, and also in risk communication and decision support, it is well-established that translating scientific research findings and technological innovations into useful action requires more than simply supplying information and technology, but benefits enormously from engagement by cognitive and behavioral scientists in studying how stakeholders think about problems, uncertainties, and risks. [Morgan, 2002; Hansen et al., 2004; Fischhoff, 2006; Dietz et al., 2009; Stern et al., 2010]
- An active and fruitful area at the frontier of Bayesian statistical analysis is research on how to incorporate qualitative knowledge, either expert or informal, as informative priors. [Gelman et al., 2008; Albert et al., 2012; Seaman et al., 2012; Truong et al., 2014; Morris et al., 2015] Moreover, research on vulnerabilities and adaptation to environmental stress, including but not limited to the impacts of climate change, is increasingly recognizing the value of indigenous

expertise and informal knowledge. Where growers often have generations worth of experience and science has large uncertainties, we felt that it would be very timely and fruitful to support research on incorporating this expertise into formal analyses and forecasts as prior distributions.

- Long-range regional climate projections are fraught with uncertainty. Despite this, they are still important sources of information. Using uncertain forecasts effectively for decision support will require engagement between climate scientists, agronomists, social and behavioral scientists, and stakeholders. [Hansen et al., 2004; Fischhoff, 2006; FISCHHOFF, 2007; Swim et al., 2011; Fischhoff, 2013; Wong-Parodi et al., 2014] We felt that a particularly important area for research is where uncertain forecasts can be particularly useful when they identify opportunities for growers and others to engage in risk-hedging when they take long-term decisions, such as planting long-lived crops (e.g., vine rootstock or nut trees) or install durable infrastructure. At these junctures, awareness of a full range of potential futures allows the decision-maker to look for opportunities where a small increment in spending during installation or planting can significantly reduce the risk that they will need to rip out and replace infrastructure or crops ten or twenty years hence.
- Research on data collection, mining, and reporting of farmers' field observations, notes, and logs, to facilitate identification of patterns over time, and recall of information about past experiences.

User-driven collaborative decision making:

- In assessing and setting priorities among the research opportunities, it is valuable to give central consideration to the knowledge, often informal, that practitioners possess due to their accumulated experience. Steve Jobs once said that the condor's flight is the most energy-efficient locomotion in the animal kingdom, but that it doesn't come close to a human on a bicycle. He declared that his vision for computing is that it should be a bicycle for the mind. [Anon, 1990] Similarly, we see the greatest potential for autonomous sensing (remote and in-situ) and computational modeling as tools to enhance the eyes and the brain of the grower, not as substitutes. Models and autonomous sensing should not be seen as substitutes for a grower walking the fields, but as tools to help the grower prioritize where to walk and what to look for.
- Keeping the eyes, mind, and experience of the grower as a central focus suggests several research opportunities: Within statistics, there is considerable interest and research activity on formalizing the use of informative priors for Bayesian analysis, and we see potential to apply the results of that research usefully to agriculture, both to advance basic science and to apply that science usefully in practice.
- Growers' experience in the field can also serve as a useful tool for validating new approaches to measurement and modeling, and to help guide the production of basic knowledge to ensure that it will be relevant to practitioners.
- Producers are clearly not looking to technology to replace their personal experience and the informal expertise that allows them to assess a great deal about crop health by walking through vineyard and orchards and observing crops with their eyes. Rather, they felt that technology would be most useful if it supplemented their direct observation and personal experience, by helping to set priorities about where and when to make observations, and to supplement direct observations with information not readily apparent to the eye. In fact, hand-held sensors were deemed a potential area of research that could supplement current efforts to use remote sensing and automated in-situ sensing. Further, many farmers maintain detailed handwritten notes on what they see when they walk their fields, orchards, and vineyards, and data-management tools to facilitate assimilating these notes into digital format and organizing and

mining them for information and to facilitate recall would be very useful, especially if these tools would be easy to use and would not entail a difficult learning curve on the part of growers.

- In the face of continued global environmental change (e.g., water scarcity, elevated atmospheric nutrient deposition, and land use/land cover change), measurement of water quantity (supply and demand) and quality in irrigated agricultural systems has emerged as a critical tool to increase agricultural resiliency. Recognizing that scientific studies and engineering efforts to address these issues must connect to and be informed by producer action and adoption, a core motivating question is: How does one provide an integrated, actionable information package to the grower that demonstrates how to incorporate these results into management decisions, as well as potential economic outcomes? Responders to this proposal call should address farmers' use of predictive information to make decisions (human response to uncertainty and risk), and seek to understand how information delivery (content, visualization, and medium) relates to action or adoption.
- Turning this developing and pending FEWS data deluge into usable, actionable information for agricultural producers, local and regional decision makers, and citizens
- Develop formal tools to use informal producer experience and expertise as informative priors for Bayesian analysis of empirical measurements and model development.
- Responding to challenges facing the sustainable management of the food-energy-water nexus require broadly transdisciplinary research that connects biological, earth, and environmental sciences, engineering, and social, behavioral, and economic sciences to address both basic knowledge and practical applications covering the food supply from farm to table.

Transdisciplinary research, cross-disciplinary models and cross-scale solutions:

- The biggest challenges for research that we identified call for deeply transdisciplinary and collaborative projects, but with a broad range of the ways in which transdisciplinarity could contribute.
- There was a strong feeling that integrating genomics and the study of plant phenotype expression with research on environmental conditions, including climate and soil conditions, could address major gaps in our understanding of how, exactly, changing environmental conditions affect not just crop yield (quantity) but crop quality, which is a far more pressing concern for viticulture.
- Managing aquifers and surface water is a classic common-pool resource problem. Elinor Ostrom's Nobel-Prize winning research [Ostrom, 1965, 2010] on common-pool resource management, socio-ecological systems, and polycentric governance began with her research, in collaboration with Vincent Ostrom, on water management in California and research remains relevant and important today as water scarcity requires farmers to think not only of their individual withdrawals, but of the challenges to collectively manage shared water resources. Environmental science and engineering approaches to the food-energy-water nexus can benefit enormously if they integrate social-science research on socioecological systems.
- While this workshop focused on specialty crops, we strongly believe that cross-cutting research connecting specialty crops to commodity crops and more broadly to the entire food-energy-water nexus would be valuable. The size of markets for individual specialty crops is often too small to justify large investments either by the federal government or by the private sector, but where cross-cutting research identifies synergies between problems faced by different specialty crops or by specialty and commodity crops alike, opportunities may arise to build tools that can address similar problems across multiple domains of agriculture, and full life-cycle analysis of

food from farm table may identify important opportunities for vertically integrated problem solving that address multiple stages of the food production and consumption process.

- Collaborative research between genomics/phenotype dynamics, soil and environmental science, and instrument engineers to understand how environmental conditions influence phenotype expression and plant health, what kinds of measurements would be most useful for predicting crop quality and yield, and development of durable, accurate, and inexpensive sensors for performing those measurements.
- Improve communication between producers and researchers, both to make more effective use of informal producer expertise as a source of information for basic research and to communicate the results of basic research more effectively and practically to stakeholders.
- Collaborative research between social scientists, crop scientists, and climate modelers on using regional climate projections for risk communication and decision-support to guide long-term decision-making and risk-hedging (e.g., selection of drought-resistant crops or installation of durable equipment and infrastructure).
- The national problems at the nexus of food, energy, and water require new and novel syntheses of ideas. Soil and plant scientists are needed to understand the biological foundations of crops. Civil and mechanical engineers are needed to construct the physical systems needed to implement physical Infrastructure. Electrical engineers provide expertise in energy and sensing. Industrial engineers are needed to optimize and assess how food moves through the supply chain. Computer scientists, mathematicians, and statisticians are crucial in modelling and interpreting data needed to close the loop and make decisions. Many of the academic stakeholders are by nature interdisciplinary; the FEWS focus, however, is new and provides foci not previously considered. The resulting research will lead to new intellectual insights and challenges.
- Research is needed on the Computer and Information Science and Engineering (CISE) aspects of broad data integration for FEWS research on specialty crops, so that actionable information can be accessed by the user in a timely manner based on the structure of raw data, model inputs, and model outputs identified by researchers (ENG, BIO, GEO) to address topics in in situ sensors and model development. CISE researchers should work to develop an open data model and guidance for data standardization (with emphasis on machine readable formats) for FEWs analysis and information use. Along with the data model framework, the CISE researchers need to identify and develop methods that preserve the granularity (spatial and temporal) of the raw data while enabling broad integration from multiple scales (i.e. single-plant data can be rolled into sub-regional soil data and broader watershed data.)
- Research is needed on the Social, Behavioral, and Economic (SBE) aspects of information use and model deployment. Proposed models need to have a formal stakeholder engagement process throughout the design, development, deployment, and testing phases. Researchers need to design and deploy stakeholder participation to ensure that the research is directed toward resolving real problems in the field, and that the models and tools developed will be relevant and desired for actual adoption. Further, even if the tool is desired, researchers can mine the institutional knowledge of stakeholders to identify other potential barriers to adoption, such as data privacy or product cost. Additional research initiatives can explore both technical (CISE, ENG) and behavioral (SBE) solutions to these barriers. Finally, the performance and use of the tools should be monitored and evaluated once they are adopted and deployed

2) Support public-private partnerships to develop test beds for sensor systems, models that assimilate data from those systems, and novel visual analytic decision support systems coupled to those models.

- Support public-private partnerships to develop test beds for sensor systems, models that assimilate data from those systems and decision support systems coupled to those models. Research and development is needed to close the loop on delivery of integrated sensing, modeling and decision support systems to agricultural producers. Fewer people are involved in production agriculture, but their educational level and ability to use modern electronic media is high. Agricultural producers need decision support systems that reduce complex data streams to actionable intelligence. The technology exists but has not been harnessed to provide on-farm decision support that allows easy understanding of decision alternatives and allows drilling down through multiple layers in an easy 3-D visualization manner to provide confidence in the recommended action. This research effort would bring together state, federal and private scientists and engineers with industrial partners to integrate the pieces and test the integrated decision support systems (sensor networks through to DSS) in real-world test beds. Because "data consumes the attention of its consumers", the data must be reduced to visual and easily understood spatially and temporally represented action recommendations.
- There is great potential for basic research to enhance fundamental scientific understanding of questions that are important to agriculture for specialty crops, such as grapes and nuts. In guiding such research, it will enhance both the basic science and the broader impacts if such research is conducted in a fundamentally transdisciplinary manner and with close communication between researchers, growers, and industry groups, such as growers' associations, which serve as a primary source from which growers learn about new developments in knowledge and best-practices.
- Collaborative partnerships between cognitive scientists, natural scientists, and engineers to investigate how producers use the outputs from instruments and models in order to facilitate effective production and communication of useful information to growers, and to monitor the effectiveness of this communication over time.
- Much of the urgency driving the FEWS collaborations will come from direct national need. Many of the stakeholders from the agricultural community regularly depend on scientific advances to improve crops and maintain economic feasibility. They would welcome FEWS research and experimentation which would help their industry to meet the coming needs. The FEWS effort can have direct and immediate impact on practitioners. The NSF-funded FEWS efforts should have clear collaborations with practitioners. This will provide good science with demonstrable impact.
- Viable testbeds will be an important part of measuring FEWS success. In order to accurately measure the success of various decisions and controls, several testbeds need to be available. Longitudinal studies necessitate that testbeds be available for periods long enough to validate results. There also need to be several testbeds, to avoid locational idiosyncrasies.

3) Develop new, **advanced, low-cost, low-power, in-situ and proximal sensing systems, as well as improved multiscale physics and computational science-based modeling techniques** that enable more effective resource management across scales and under uncertainty to increase the resiliency of the individual components as well as the entire FEWS system.

- Research on wireless sensors and sensor network systems is needed to enable automatic data acquisition, analysis and transformation of data to decision support recommendations for crop irrigation, fertilization and disease and pest control. Data of particular interest include soil water content and energy potential, plant water status, canopy cover fraction, canopy temperature and spectral reflectance (active and passive sensors). Rationale: Decision support systems are hobbled by lack of automatic data acquisition and wireless transmission to embedded computing systems that analyze multiple data streams to generate decision support recommendations.

- Enabling technology will be integrated sensor systems that can acquire, store, and communicate a large number of physiological parameters of the entire plant and its close environment (from root zone to leaf level). The frequency, resolution, and number of measurements should be definable by the user interface or set automatically, based on the combination on a number of parameters (temperature, humidity, sunlight intensity, etc.). Ideally, the system's footprint will be small, such that potential impact on the plant condition is eliminated. In addition, due to the potentially large number of sensors and the need for frequent data communication, alternative power solutions will be required to ensure prolonged and uninterrupted system operation. Furthermore, low-cost fabrication should be pursued, in order to allow for the system deployment and a large number of sensor modules in the system. Data analysis can take place locally, in each system before communication, but preferably data will be accumulated and analyzed at a central node in order to reduce power consumption. Data compression should be pursued for minimizing the wireless communication time and therefore attain lower power consumption.
- Technologies are rapidly developing to provide high-resolution data from a variety of remote platforms. These platforms, however, provide a wide range of observational systems that sense from a range of wavelengths, incidence angles, and approaches (i.e. passive vs active sensing). Integrating these disparate observations into a cohesive set of data products that are useful for agricultural producers remains a major challenge, and will determine the extent to which these technologies are assimilated by the agricultural production community.
- Development of hand-held monitoring devices for assessing crop health.
- Research on socio-ecological systems dynamics in management of common-pool water resources among communities of growers. Focus on informal norm-establishment and conflict resolution where formal regulations are incomplete.
- We suggest that proposals address identify and collect the key measurement streams and modeling tools to develop a whole-farm water budget that quantifies the major water pools and fluxes (precipitation, irrigation (surface and groundwater use, reclaimed water), evapotranspiration, soil water storage, runoff), and water use in processing and production. This analysis not only incorporates the terms of a physical water balance, but also water use in the process of providing agricultural goods (i.e., a whole life cycle analysis of water). These may include remote and proximal water and crop sensing technologies. Modeling efforts should focus on synthesizing data to predict water supply and demand, as well as crop growth, yield, and quality. To the extent that resulting simulations point to the need for new information, development of new technologies may be required to act on that information.
- Under the broad umbrella of water management, there is a particular need for precision approaches in both commodity and specialty crops throughout the United States and globally. To this end, we need a particular focus on engineering irrigation systems for zonal management that rely on granular microclimate, plant variety, and subsurface characteristics (e.g., soil types and hydrological flow paths). In addition, proposals to create technologies that address irrigation with low-quality water (e.g., measurement of quality from diverse sources, models of optimal use from diverse sources) are welcome.

- Coupled to these efforts, we suggest a focus on exploring means for assigning an economic value of water at the farm scale, as well as investigation into water governance and markets at local to regional scales.

4) Pursue data standardization efforts to enable developers of decision support systems to access data from sensor systems regardless of vendor, harnessing organizations such as the IEEE Computer Society and Standards Association.

- Research and develop of data standards that are acceptable to a wide spectrum of data users and sensor systems manufacturers is needed to remove barriers to development of advanced decision support systems for agricultural production and quality control. Rationale: Decision support systems (DSS) are hobbled by inaccessibility of data from proprietary sensor systems, slowing the development of badly needed DSS.
- There was wide support for FEWS efforts for development of data standardization. Commercial stakeholders keenly believed that, while they compete with each other on many levels, they are also faced by common constraints on water and energy. Can a data standard be developed which would inform best practices while still providing proprietary information. This was noticeable in the viticulture industry, where roots can have long lifespans and experimental procedures can have long-lasting impact.
- We believed that data standardization which met commercial and scientific demands was definitely possible. Disciplines like electrical engineering and computer science have a deep understanding of the theory of privacy and information and standardization. We also believed that recent developments in using unstructured data could readily allow for data standards which evolve to meet developing demands.

5) Pursue development of modular physical science and agronomic models that are more biologically and geophysically based and less empirical and which adhere to data standards that allow data assimilation from sensor systems and use by producers of decision support and sensor systems.

- Pursue development of modular physical science and agronomic models that are more biologically and geophysically based and less empirical, and which adhere to data standards that allow data assimilation from sensor systems and use by producers of decision support and sensor systems. Research is needed to improve biophysical models of the soil-plant-atmosphere continuum so that model components can be easily shared and adapted to crop-specific model development, including tree and vine crops, vegetable crops, forage crops, fiber crops and pulse and grain crops. Decision support systems rely on accurate models that can easily assimilate data from multiple sensor streams and perform the analyses that result in actionable recommendations. Existing models are not set up or designed for data assimilation and use in real time or near real time to support DSS. Data standardization will increasingly allow development of real-time data assimilation and analysis.
- Research is needed to develop simulation models of agricultural systems that can both take advantage of the high-resolution observations becoming more widely available through advanced sensor systems, and guide precision agricultural practices at the plant level. Modern simulation capabilities of agricultural systems allow for the resolution of diurnal function and stress over growing seasons, along with considerations of the vertical structural variability of agricultural canopies [Drewry et al., 2010a, b]. These models have allowed for detailed analysis and understanding of seasonal water use under current and future climate conditions [Drewry

et al., 2010a; Le et al. 2011], as well as potential pathways to enhance productivity and water use efficiency [Drewry et al., 2014]. These capabilities, however, lack the spatial resolution to take advantage of the observations of individual plant function now available through modern in-situ and remote sensing systems, and likewise lack the ability to guide plant-scale management now possible through emerging precision agricultural techniques. These next-generation simulation models will synthesize our knowledge of plant-level processes controlling growth and phenology, and canopy-level interactions that control the micro-environment, producing a unified framework for predicting crop growth, yield and quality at unprecedented resolution.

- Integrate biofuels production systems and battery technology to power farm machinery for enhancing energy efficiency of specialty crops and perennial production systems.
- Integrating research on specialty crops into broader cross-cutting research on both specialty and commodity crops, food processing, and distribution that incorporates full life-cycle analyses of farm-to-table energy and water use and environmental impact, and that seeks simultaneously optimize water consumption and product quality.
- Cross-cutting life-cycle analyses to understand water-energy-food dynamics across the entire farm-to-table chain for individual crops, and across different crops (different specialty crops as well as common ground between specialty and commodity crops)
- Identification of inefficiencies and opportunities for economically efficient conservation and efficiency measures in energy and water use in growing, processing, and shipping.
- Identification of effective measures to communicate and encourage adoption of best practices for energy and water efficient growing, processing, and transportation of food.
- Identification of long-term environmental impacts of organic versus conventional production.
- Developing broadly applicable approaches to multicriteria optimization of water use, crop yield, and crop quality.
- While one aspect of the FEWS effort is clearly at the level of agricultural food production, an equally important concern is energy usage post-harvest. Energy usage in industrial processes and buildings can significantly affect the overall energy footprint of an industry. Energy-usage programs like LEED certification could be adapted to the food industry.

V. APPENDICES

AGENDA

ORGANIZING COMMITTEE

ATTENDEES

REFERENCES

FEWS 2015 - AGENDA

Thursday, November 5th, 2015

8:00 AM Introduction and Welcome

8:30 AM Panel 1: Struggles of Agricultural Producers
Moderator:
Jean-Mari Peltier, *President, National Grape and Wine Initiative*
Panelists:
Tres Goetting, *Director of Winemaking, Robert Biale Vineyards*
Robert Curtis, *Director Agricultural Affairs, Almond Board of California*
Karen Lapsley, *Chief Scientific Officer, Almond Board of California*
Lise Asimont, *Director of Grower Relations, Francis Ford Coppola Winery*
Jerry Lohr, *President, J. Lohr Vineyards & Wines*
Daniel Bosch, *Senior Viticulturalist & Vineyard Director, Constellation Wines*

10:00 AM Break and optional Historic Oakville Research Vineyard Tour

10:30 AM Panel 2: Novel Technological Approaches for FEWS
Moderator:
David Ebert, *Professor of Electrical and Computer Engineering, Purdue University*
Panelists:
Kelly Gaither, *Director of Visualization, Texas Advanced Computing Center*
Phillip Owens, *Associate Professor of Agronomy, Purdue University*
Melba Crawford, *Associate Dean of Engineering, Purdue University*
Richard Woolley, *COO and Chief Forecaster, Weathertrends360*
Harris Mousoulis, *Senior Research Scientist, Purdue University*
Jonathan Gilligan, *Associate Professor of Earth and Environmental Sciences, Vanderbilt University*

11:45 AM Talk by Dr. David Block, *Ernest Gallo Endowed Chair in Viticulture and Enology, UC Davis*

12:00 PM Introduction to Group Assignments and Revision of Questions:
Address 3 Major FEWS Challenges

12:15 PM Lunch

1:00 PM Work Groups (group of no more than 6)

2:30 PM Break

2:45 PM Working Group II

4:00 PM Brief Report Back/Status Update

6:30 PM Reception

FEWS 2015-AGENDA

Friday, November 6th 2015

8:00 AM Summary from Day 1

8:15 AM Group Presentations (Five minutes per group)

9:00 AM Drafting Challenges and Roadmap Statements

10:00 AM Break

10:30 AM Keynote Speaker: Karen Ross, *Secretary-California Department of Agriculture*

11:30 AM Working Lunch & Final Report

1:00 PM Adjourn

WORKSHOP ORGANIZING COMMITTEE

David Ebert, Purdue University, visual and predictive analytics (Chair)

Doug Adams, Vanderbilt University, sensing technology and environmental engineering

Christian Butzke, Purdue University, enology, viticulture, and food science

Melba Crawford, Purdue University, remote sensing technology

Kelly Gaither, University of Texas at Austin, advanced computational infrastructure and large-scale data visualization

Terry Nipp, Aegis, crop science and biofuels

Phillip Owens, Purdue University, soil pedology

Dimitrios Peroulis, Purdue University, wireless sensor technology

Jonathan Gilligan, Vanderbilt University, climate change

Attendees / NSF FEWS Workshop / November 5th-6th, 2015		
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References

[Albert 2012] Albert, I., S. Donnet, C. Guihenneuc-Jouyaux, S. Low-Choy, K. Mengersen, and J. Rousseau (2012), Combining Expert Opinions in Prior Elicitation, *Bayesian Anal.*, *7*(3), 503–532, doi:10.1214/12-BA717.

[Anon 1990] Anon (1990), *Steve Jobs Interview*, WGBH TV, Boston, MA.

[Brooks 2013] Brooks, D. "What Big Data Analytics Can't Do (editorial)", New York Times, February 18, 2013.

[Dietz 2009] Dietz, T., G. T. Gardner, J. Gilligan, P. C. Stern, and M. P. Vandenbergh (2009), Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions, *Proc. Natl. Acad. Sci.*, *106*(44), 18452–18456, doi:10.1073/pnas.0908738106.

[Drewry 2010a] Drewry, D.T., P. Kumar, S.P. Long, C. Bernacchi, X. Liang and M. Sivapalan. Ecohydrological Responses of Dense Canopies to Environmental Variability, Part 1: Interplay Between Vertical Structure and Photosynthetic Pathway. Journal of Geophysical Research – Biogeosciences, 115, G04022, doi:10.1029/2010JG001340.

[Drewry 2010b] Drewry, D.T., P. Kumar, S.P. Long, C. Bernacchi, X. Liang and M. Sivapala. Ecohydrological Responses of Dense Canopies to Environmental Variability, Part 2: Role of Acclimation Under Elevated CO2. Journal of Geophysical Research – Biogeosciences, 115, G04023, doi:10.1029/2010JG001341.

[Drewry 2014] Drewry, D.T., P. Kumar, and S. P. Long. Simultaneous Improvement in Productivity, Water Use and Albedo Through Crop Structural Modification. Global Change Biology DOI: 10.1111/gcb.12567.

[Fischoff 2006] Fischhoff, B. (2006), Behaviorally realistic risk management, *Risk Disaster Lessons Hurric. Katrina*, 77–88.

[Fischhoff 2007] Fischhoff, B. (2007), Nonpersuasive Communication about Matters of Greatest Urgency: Climate Change, *Environ. Sci. Technol.*, *41*(21), 7204–7208, doi:10.1021/es0726411.

[Fischhoff 2013] Fischhoff, B. (2013), The sciences of science communication, *Proc. Natl. Acad. Sci.*, *110*(Supplement_3), 14033–14039, doi:10.1073/pnas.1213273110.

[Gelman 2008] Gelman, A., A. Jakulin, M. G. Pittau, and Y.-S. Su (2008), A weakly informative default prior distribution for logistic and other regression models, *Ann. Appl. Stat.*, *2*(4), 1360–1383.

[Hansen 2004] Hansen, J. W., S. M. Marx, and E. U. Weber (2004), The Role of Climate Perceptions, Expectations, and Forecasts in Farmer Decision Making: The Argentine Pampas and South Florida: Final Report of an IRI Seed Grant Project,

[Jang 2014] Jang, Y., Gaither, K., Ebert, D., "Cross-Scale, Multi-Scale, and Multi-Source Data Visualization and Analysis Issues and Opportunities," in *Scientific Visualization,* Chapter 28, Springer, 2014.

[Ko 2014] Ko, S., Zhao, J., Xia, J., Afzal S., Wang X., Abram G., Elmqvist N., Kne L., Riper, D., Gaither K., Kennedy, S., Tolone, W., Ribarsky W., Ebert, D, "VASA: Interactive Computational Steering of Large

Asynchronous Simulation Pipelines for Societal Infrastructure," *IEEE Transactions on Visualization and Computer Graphics* (Proceedings of IEEE VAST), to appear 2014.

[Le 2011] Le, P.V.V., P. Kumar and D.T. Drewry. Implications for the Hydrologic Cycle Under Climate Change Due to the Expansion of Bioenergy Crops in the Midwestern United States. Proceedings of the National Academy of Sciences, 1107177108v1-6.

[Morgan2002] Morgan, M. G. (2002), *Risk Communication: A Mental Models Approach*, Cambridge University Press.

[Morris 2015] Morris, W. K., P. A. Vesk, M. A. McCarthy, S. Bunyavejchewin, and P. J. Baker (2015), The neglected tool in the Bayesian ecologist's shed: a case study testing informative priors' effect on model accuracy, *Ecol. Evol.*, *5*(1), 102–108, doi:10.1002/ece3.1346.

[Ostrom 1965] Ostrom, E. (1965), Public entrepreneurship: a case study in ground water basin management., University of California, Los Angeles.

[Ostrom 2010] Ostrom, E. (2010), A Long Polycentric Journey, *Annu. Rev. Polit. Sci.*, *13*(1), 1–23, doi:10.1146/annurev.polisci.090808.123259.

[Robertson 2009]Robertson, G., Ebert, D., Eick, S., Keim, D., Joy, K., "Scale and Complexity in Visual Analytics," *Information Visualization* 2009.

[Seaman 2012] Seaman, J. W., J. W. Seaman, and J. D. Stamey (2012), Hidden Dangers of Specifying Noninformative Priors, *Am. Stat.*, *66*(2), 77–84, doi:10.1080/00031305.2012.695938.

[Stern 2010] Stern, P. C., G. T. Gardner, M. P. Vandenbergh, T. Dietz, and J. M. Gilligan (2010), Design Principles for Carbon Emissions Reduction Programs, *Environ. Sci. Technol.*, *44*(13), 4847–4848, doi:10.1021/es100896p.

[Swim 2011] Swim, J. K., P. C. Stern, T. J. Doherty, S. Clayton, J. P. Reser, E. U. Weber, R. Gifford, and G. S. Howard (2011), Psychology's contributions to understanding and addressing global climate change., *Am. Psychol.*, *66*(4), 241–250, doi:http://dx.doi.org.proxy.library.vanderbilt.edu/10.1037/a0023220.

[Thomas 2005] Thomas, J., and Cook, K., *Illuminating the Path: The Research and Development Agenda for Visual Analytics,* IEEE Computer Society, 20015.

[Truong 2014] Truong, P. N., G. B. M. Heuvelink, and E. Pebesma (2014), Bayesian area-to-point kriging using expert knowledge as informative priors, *Int. J. Appl. Earth Obs. Geoinformation*, *30*, 128–138, doi:10.1016/j.jag.2014.01.019.

[Wong-Parodi 2014] Wong-Parodi, G., B. Fischhoff, and B. Strauss (2014), A method to evaluate the usability of interactive climate change impact decision aids, *Clim. Change*, *126*(3-4), 485–493, doi:10.1007/s10584-014-1226-9.