The Contribution of Satellite Data to Efficient Freshwater Management
A Space Policy Institute Workshop Report

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Introduction:

In order to understand the complexities of managing fresh water resources, and in particular, the current and future use of information from satellites, the Space Policy Institute held a workshop on March 13-14, 2007. Attendees included government research personnel, university researchers, and other informed experts from a variety of fields. Attendees presented information on different aspects of the topic, which stimulated additional discussion. The presentations and additional information evoked by them are summarized below.

The workshop principally focused on deriving estimates of the value of satellite information from forecasts of variables relating to specific components of the management of water resources: e.g., precipitation, snow cover, soil moisture, and river flow rates. These are all of great importance; satellite data are used to augment ground-based traditional measurements.

Satellite data provide the advantages of wide area coverage, access to information from very remote areas, and the ability to take measures of a particular location on a regular and frequent basis. However, satellites lack the ability to make measures over small footprints; are currently unable to have "active" systems that can penetrate the soil, and adding new instruments and satellites to the cadre of existing ones can result in considerable expense and time delays. Most satellite data also suffer from the fact that they derive from research, rather than operational satellites systems.

It is clear that satellites will not replace ground measurements. They can, however, provide important augmentations to other data. Therefore, this compounds the problems of measuring value that this workshop addressed because trying to isolate and estimate the potential marginal improvements from new or improved data, which themselves are still in the experimental and development stage for use in water resource management, is almost impossible.

Further, as described below, because of the very unique market, regulatory, and history of water rights and ownership, normal economic models cannot capture the nuances of forecast improvements for any purposes but some very specific and narrow purposes. Unlike prior analysis done on a similar assignment for the electric energy industry,[1] normal markets do not value the utility of water the way they do for energy or many other price-responsive goods and services.

Therefore, this Workshop reports on some fascinating experimental approaches to using satellite data for water resource management. It highlights not only the problems, but also some future potential solutions, and suggests that as fresh water becomes more scarce, the widely different approaches to the way water is managed and allocated across the country may begin to converge. Along with this economic and social pressure will be a need to find new ways of solving the problem of water distribution, one of which may necessitate adopting market or quasi-market solutions. At some future point, when satellite data are more robust for this purpose and when traditional economic analyses can be applied to a large segment of the water market, we may be able to measure not only the value of water in the marketplace but also the marginal contribution of different data sources to that value much more accurately than we can today.

In the meantime, it is important to note that many people are addressing these issues and that the approaches to using the advantages of satellite data for these purposes show much promise. The greatest value for managers of water resources will be information that is specific to the location, use of water, timeliness, and range of choices available. In this particular utility, aggregate and national data are not nearly as important for specific problems as in other sectors. However, wide-area data, particularly on climate information, will be crucial for modeling water-related conditions relating to long-term changes as well as for prediction of hurricanes, floods, and other disaster-related water issues. (Those are excluded from this report, since they are a different problem from the day-to-day management of normal water resource issues.)

Fresh water is a critical element for the environment and for sustaining human life. Increasingly, as human activity has altered the natural water cycle at all levels, providing sufficient fresh water has required more extensive water management. Better weather and climate information and forecasts about the amount and geospatial distribution of precipitation throughout the year can improve our ability to manage fresh water more efficiently. In particular, improved data, forecast models, and decision support tools can contribute to the improvement of water management practices. They can, for example, help farmers improve the efficiency of irrigation, or reduce the waste of water by municipalities.

Such information holds sizable social and economic value for individuals, families, and for industry. In the United States and many other countries, data from the National Oceanic and Atmospheric Administration's (NOAA)

[1] Henry R. Hertzfeld, Ray A. Williamson, and Avery Sen, "Weather Satellites and the Economic Value of Forecasts: Evidence from the Electric Power Industry," *Acta Astronautica,* 55, pp. 791-802.

environmental satellites and other domestic and non-U.S. satellite systems provide essential inputs to weather and climate forecast models necessary for estimating precipitation and other water-related information. Data from NASA's EO research satellites can contribute to the future development of vital new water management information systems.

The capabilities of Earth observing satellites to aid in this process have improved greatly in recent years. Improved weather and climate information and forecasts about the geospatial distribution of precipitation is one example. Broad scale satellite measures of evapotranspiration and water usage that assist in managing water losses are another.

Despite broad agreement that such forecast and modeling improvements can provide substantial benefits by helping to reduce risk for information users, such benefits are poorly understood, either qualitatively or quantitatively. We convened this workshop in order to assist in improving the understanding of the role and possible benefits of using satellite systems for freshwater resource management. This workshop was part of a broad based study funded by NASA and NOAA to explore the economic and social benefits of satellite data for water resource management.

Participants were chosen from the academic community, government, and non-governmental organizations. In order to promote discussion and information sharing, we limited the size of the workshop to about 25 participants (Appendix A). The agenda can be found in Appendix B.

This report summarizes the proceedings of the workshop and also includes material gleaned from follow-up research on some of the points raised in the workshop. Discussions at the workshop fell into three general categories: the sources of data (including in-situ and satellite sources, as well as models), the use and value of data, and economic and institutional considerations; although the agenda was not organized in this fashion. The following sections reflect the subjects and, if not the exact, order of the workshop discussion.

Sources of Water Information in the United States: In-Situ Observations

Steve Blanchard of the United State Geological Survey (USGS) introduced the workshop to the U.S. network of stream gauges, explaining their distribution and how they measure stream flow in the thousands of streams and rivers throughout the country. He noted, for example, that operations of many of the gauges are funded jointly by USGS and the state and local governments that have requested gauges be placed in their locales. USGS operates a network of approximately 7000 stream gauges, many of which have a 30 year or greater continuous data record associated with them.   Blanchard also gave an overview of the range of applications in which USGS stream flow information is used, a list that includes reservoir operations, recreation, flood management and control and water infrastructure design. Looking to the future of the stream gauge program, Blanchard noted some limitations of the current gauging technique, including the inability to measure accurately certain difficult flows (such as floods, delta, or ice-bound streams). He also outlined USGS's efforts to develop new approaches to reduce the cost of current methods, and to improve measurement safety, accuracy and precision, noting, for instance, experiments with radar based measurement techniques.

Claudia Hoeft of the USDA's Natural Resources Conservation Service (NRCS) introduced the group to the water resources information collected by NRCS. Hoeft described two data collection networks, SNOTEL (SNOpack TELemetry) and SCAN (Soil Climate Analysis Network). SNOTEL is an operational network of 730+ sites in the Western United States that provides daily data on snow depth, snow water equivalent, temperature and other observables. SCAN is a network of 120 sites, primarily in the Midwest and East, which provides real time monitoring of soil moisture conditions, along with other observables. Hoeft noted that SCAN is one of very few real-time soil moisture and soil temperature monitoring networks in existence in the United States. She also mentioned that although the current footprint of the SCAN network is small, NRCS is actively trying to expand its coverage. During discussion, it was also pointed out that both the SNOTEL and SCAN systems could provide ground truth/validation for remotely sensed snow and soil moisture observations, respectively.

Chandra Kondragunta summarized NOAA's contribution to water resources information from both in-situ gauges and satellite information, with a focus on precipitation (rainfall) estimation and measurement. NOAA currently gathers information on precipitation from three types of sources: rain gauges, Doppler radar, and satellite sensors. Each type of source has its own limitations. NOAA receives precipitation data from an extensive network of rain gauges, although the density of these gauges across the country is uneven and the data collected from them represents only point sources rather than measurements over a complete spatial domain. The National Weather Service operates 160 radar sites across the country that provide precipitation estimates to NOAA with relatively high spatial and temporal resolution. However, in many areas (in particular in the Western U.S.) the effective coverage of the radars is limited (often blocked by terrain). Data from a variety of satellite sources (GOES, DMSP, AMSU-B) provide additional precipitation estimates, but Kondragunta said that the accuracy of these estimates is not high enough for certain applications (for instance flood forecasting). Kondragunta reported that, because of the limitations of all three data sources, NOAA is moving to a multi-sensor precipitation estimator (MPE) approach. The MPE, which is in operational use at NOAA's River Forecast Centers and Weather Forecast Offices, integrates data from gauges, radars, and satellites to provide an hourly precipitation estimation product at a spatial resolution of 4km. It was noted that in this way satellite-derived precipitation data when used in conjunction with other data sources, improve quantitative precipitation estimates.

Sources of Water Information in the United States: Satellite Observations

Presentations by Jared Entin and Christa Peters-Lidard of NASA, although made at different sessions of the workshop, both discussed NASA's research activities and satellites in the water-cycle arena. Entin introduced NASA's Energy and Water Cycle Focus Area Road Maps. In doing so he highlighted two particular areas of research; first, the GRACE mission (for water storage observations) and second, snow and cold processes observations. GRACE was described as providing the only opportunity for monitoring groundwater variability in most of the world. In describing NASA's research into estimating snow water equivalent Entin, highlighted the need for a multiple sensor, multi-scale approach to observations. During the course of his presentation, he also noted that the lack of accurate soil moisture observations constitutes a critical gap in the current space based observations suite at NASA, NOAA or USGS. Entin made the point, echoed by other participants, that in many areas of observation, satellite sensor or technology might be available but appropriate data processing techniques may not, limiting the utility of space derived data.

Christa Peters-Lidard also gave an overview of NASA water cycle research, highlighting collaborative efforts underway with NOAA. Her discussion focused largely on precipitation, snow cover and snow water equivalent, and terrestrial water storage (GRACE). Peters-Lidard described an ongoing project to improve NOAA's river flow forecasts by integrating NASA satellite-derived data and modeling products into NWS stream flow forecast products.

A glimpse of potential future water cycle observations was given by Gerry Dittberner of NOAA. He introduced the findings and recommendations of the recent National Academy of Sciences Decadal Survey on Earth Observations, highlighting the report's recommendations regarding observations in water resources and the hydrologic cycle.

Bob Adler, of NASA, introduced the group to the current and future capability of NASA satellite precipitation measurement with a discussion of the current Tropical Rainfall Measuring Mission (TRMM) and the planned Global Precipitation Measurement Mission (GPM). He described the details of the TRMM mission, which forms the basis for the future GPM program, and outlined some applications products that NASA is developing based upon TRMM data. Adler concluded that space based, real-time, multi-satellite precipitation observations (like those provided by TRMM and, in the future, GPM) provide opportunities to develop global hydrological applications, for example flood and landslide alerts. However, as a caveat, the spatial resolution of current products produced from TRMM data is only 25km.

Martha Anderson presented the group with an overview of remote sensing of evapotranspiration and soil moisture. Current thermal imaging sensors on board several satellites, in particular the ETM instrument on Landsat-7, have been shown in experimental and pilot scale projects to be particularly useful for the indirect estimation of evapotranspiration and soil moisture. Anderson reported on a number of applications of Landsat-derived evapotranspiration maps, including monitoring of water consumption, managing and regulating water rights, and predicting changes in water consumption as related to changes in land use. However, she warned of an impending data and capabilities gap in fine resolution (90-120m meters) thermal imaging sensors when Landsat-7 reaches the end of its operational life.[2]

Use and Value of Water Information

Satellite and other data related to water resources are of little use in and of themselves until they are integrated successfully into predictive models that can be used to forecast future conditions with some accuracy. Paul Houser gave a detailed discussion on the assimilation and integration of data, both in-situ and satellite derived, into climate and forecast models. Houser stated that while the amount of remotely sensed hydrology data available is expected to increase dramatically in the coming years, the usefulness of these data will be limited by our ability to organize and integrate a range of different data sources and types. Difficulties and tradeoffs are encountered in assimilating data on various different aspects of the water cycle into forecast models. For example there is a tradeoff between obtaining fine resolution out of a given model and the ability to implement that model over a large geographic area. Houser concluded that our capacity to measure, monitor, and model the water cycle is significant but not fully realized.

Cherie Schultz of the Interstate Commission on the Potomac River Basin (ICPRB) gave the workshop participants a user's perspective on the role of water resources information. The ICPRB is charged with coordinating the use of Potomac River water among various users, including the metropolitan Washington, DC area. Schultz stated that among the organization's primary operational data needs are one- and nine-day stream flow forecasts at a certain point along the course of the Potomac River. The ICPRB uses a variety of data sources to meet this need, including USGS and local river gauges, weather and temperature forecasts and the National Weather Service's Multi-sensor Precipitation Estimates. The ICPRB is also in the process of developing, at the local level, a watershed runoff model (the SWAT model) to assist in real-time

[2] Note: These measurements are considered fine scale because these measurements are among the highest resolution achieved by a thermal satellite sensor.

operational forecasts of river flow. Schultz also discussed the ICPRB's planning data needs, which include the SWAT runoff model as well as another simulation model that aims to assess the ability of the Potomac River system to meet current and projected future water demand. These planning models use USGS gauge data as well as daily precipitation and temperature data.

Laurie Houston discussed estimates of the value of water resources information to various user communities or interests. She presented a range of estimated values across a variety of economic sectors, including agriculture, transportation and utilities. Findings indicate that weather and climate data does have substantial value in a variety of sectors and geographic areas if available and if used. However, Houston noted that the operational water management community tends to underutilize climate forecasts and data.[3]

The workshop concluded with a discussion of economic and institutional considerations related to using satellite data for water resources management. Holly Hartmann and Katherine Jacobs presented some of the institutional factors that might be acting to prevent greater use of climate and weather data by water resource managers. Several participants observed that operational water managers tend to be conservative in nature, risk averse and resistant to change. Management decisions are made in a context rooted in a local perspective and political and legal complexities may present additional institutional obstacles to using weather and climate data. In some case managers may simply not be aware of the types of data and forecasts available to assist their work. It was suggested that data and forecast providers should pay more attention to communication and dissemination efforts, especially given the uncertainty inherent in some of the data.

Molly Macauley of Resources for the Future addressed some of the economic factors relating to the use of the types of data discussed during the workshop. She argued that the Earth Science community has failed to make the case that these data are useful and that there is a need to need to demonstrate the quantitative value of the data. Macauley noted that there are difficulties in demonstrating this value, those being that neither investment costs in water nor "prices" are real indicators of value and that data only have value where actions can be taken in response to the data. She then suggested that value of information approaches exist that are relevant and practical to this problem, and highlighted as an example payments being made for environmental services in the Everglades. Macauley also noted that water markets have developed in some places, specifically for watershed protection.

[3] See also, Steve Rayner, et al., "Weather Forecasts are for Wimps: Why Water Resource Managers Don't Use Climate Forecasts,"

Themes

Several pervasive themes emerged from the workshop. The following paragraphs (not in rank order) summarize conclusions from the workshop presentations and discussions.

Future progress in using satellite data effectively will depend on integrating several data sources into comprehensive regional models of water availability. This will necessarily involve a multi-source/multi-sensor approach. Participants made clear that no one data source will suffice to gain an overall view of water availability, inputs, and outputs in a drainage system. Although satellite data can improve the coverage and quality of data, especially in sparsely settled areas where ground and aerial sensors are less well distributed, multiple-source data assimilation is generally still in the research stages, although, as Kondragunta noted, some multi-sensor methods are in operational use in NOAA's precipitation monitoring operations. As reported by Peters-Lidard, NASA and NOAA are conducting further work on such issues in order to improve water resources applications.

Although participants generally agreed that satellite data, when fused with other water resource data can improve water resources management, several remarked that the satellite community still has to "sell the value of satellite-derived information" to the user community, which has had management systems in place for many years with which they are comfortable. A history of overselling the potential value of satellite data to the user community combined with a risk-averse user community that has well-established systems already in place, makes it very difficult to make inroads into the water resources management community. Water resources managers are understandably very reluctant to change processes that work, unless such new processes can demonstrate that they will lower, rather than increase, the risk of making incorrect decisions about water availability. Government, industry, and private citizens depend on a secure and stable supply of water for their needs.

Convincing water resources managers to adopt new methods will require a concerted, long term effort to demonstrate the value of satellite data in their management systems. This an age-old problem, not only in the water resources community, but other communities that are potential users of information derived from satellite sources. Differences in vocabulary, working assumptions, and cultures, impede communication. Such barriers, when combined with the natural conservatism of water resources managers to install new methods into their work stream, make it difficult to adopt new information and ways of doing business. As a result, proponents of new, more efficient and accurate ways of measuring water availability in a region will have to work much harder than they have in order to convince the user community of the worth of their information products.

The increasingly widespread use of geographic information services (GIS) for displaying water resources information and distribution services such as GoogleEarth and Virtual Earth are likely to assist with the integration of new, geospatial methods into water resources management

Better water resources forecasts can reduce risk for information users. However, making accurate estimates of the value of such information for users is fraught with difficulty. As introduced above, normal economic analysis of the value of water resources has only yielded gross approximations—far too variable for any useful purpose on an aggregate scale, and only of a very general use for particular regions and problems. The basic issue is that water is not particularly price-sensitive. In the Eastern United States, riparian rights allow those water users bordering rivers, lakes, and other water sources the right to take what they need without payment. The same is true for ground water. Our consumer water bills from local utilities reflect the costs of the water quality and distribution systems, not the water itself.

In the Western United States, water is “owned” by governments and allocated often based on seniority rights rather than on a rational economic and market criteria. As water becomes scarcer, the rights to purchase and sell water become more important.

The major uses of water in the United States are for thermoelectric purposes (about 40%) and for irrigation of farmland (also about 40%). The rest is used for industrial, commercial, and domestic purposes. Most of the water used in producing electricity is not consumed, but quickly replaced; other valuable uses for fresh water that do not consume it include recreation. Recreational use of water is not even measured by the USGS or other Government data sources since it is ancillary to the issues at hand, but its value is actually high because of the impact on land values and markets for boats, resorts, etc.

Since we cannot at present value water in the aggregate by what people are willing to pay for it (the economist’s normal yardstick), other ways have been devised to reveal what it might be worth. (See the summary of L .Houston’s presentation above.) The one revealing fact from almost all of the existing studies is that the result of each study finds value measured as a median with a range of estimates that often exceed 100% in either direction—not accurate enough to draw any firm conclusions. Therefore, trying to find the value of the contribution of satellite information through these models is virtually impossible, even though the specific case studies clearly point to both the interesting supplements to our understanding of water management that satellite data provide currently as well as to the vast experimental data that are being developed from satellite sources today and those that are planned for the future.

It appears, therefore, that the best use of economic analysis and of satellite data for water resource management will be at the very local level and will entail specific problems and uses of water. The actual value, though will come from the actual use of the information and changes in the allocation and distribution of water. Water is an emotional issue since it is so important for so many people doing so many things. Therefore the potential conflicts that will emerge, even with better information, will require either the enforcement of strong price and market rules, strong leadership, and/or effective conflict resolution systems (and, quite possibly, all of the above together.)

As M. Maculey pointed out in her presentation, there are interesting experiments today in introducing market systems to water allocation. Satellites have the potential to give more timely warnings about future situations (for example, far upstream developments that are not easily analyzed or visible to observers, affecting downstream users at a later time). They also will provide aggregate climate information, and can monitor land use developments that will aid regional planners.

Appendix A

Space Policy Institute Workshop
The Contribution of Satellite Data to Efficient Freshwater Management
Participant List

Dr. Robert Adler
NASA Goddard Space Flight Center

Dr. Martha Anderson
USDA-ARS Hydrology and Remote Sensing Laboratory

Dr. Stephen Blanchard
U.S.G.S. National Streamflow Information Program

Dr. Christopher P. Carlson
National Ground Water Program Leader
USDA Forest Service

Ian Christensen
Space Policy Institute
The George Washington University

Dr. Steven F. Daly
ERDC/CRREL
Army Corps of Engineers

Dr. Gerry Dittberner
NOAA NESDIS
Technology Planning, Requirements, and Integration Group

Jared Entin
Hydrology Program
NASA Earth Sciences Program

Dr. Holly Hartmann
Department of Hydrology and Water Resources
University of Arizona

Sherry Hazelhurst
USDA Forest Service

Dr. Henry R. Hertzfeld
Research Professor
Space Policy Institute
The George Washington University

Claudia Hoeft
Acting Director, National Climate and Water Center, NRCS-DC

Dr. Paul R. Houser
Center for Research on Environment and Water (CREW), and George Mason University, Climate Dynamics Department

Laurie Houston
Water Resource Economics Consultant
Portland, Oregon

Dr. Katherine Jacobs
Executive Director, Arizona Water Institute

Chandra Kondragunta
NOAA NESDIS

Dr. Roger Lang
Electrical and Computer Engineering
The George Washington University

Dr. Christa Peters Lidard
NASA Goddard Space Flight Center

Dr. Molly Macauley
Senior Fellow
Resources for the Future

Dr. Douglas Parker
Associate Professor
Agriculture and Resource Economics Department
University of Maryland, College Park

Avery Sen
NOAA National Weather Service

Dr. Cherie Schultz
Potomac River Commission

Dr. Ray A. Williamson
Research Professor
Space Policy Institute
The George Washington University

Space Policy Institute Workshop
The Contribution of Satellite Data to Efficient Freshwater Management

Tuesday & Wednesday, 13 & 14 March 2007
1957 E St, NW, Room 602

8:30 Coffee & Pastry

9:00 Welcome, Introductions

9:15 The Space Policy Institute Study—*Ray Williamson*

9:30 **Measuring Water Supply—What Information is Available and Why Is It Gathered?**

The US Stream Gauge Network—*Steve Blanchard, USGS Office of Surface Water*

NOAA's Water Resource Information—*Chandra Kondragunta, NOAA NESDIS*

NRCS's Water Resource Information Systems—*Claudia Hoeft, National Climate and Water Center, NRCS.*

10:45 Break

11:00 Discussion

11:30 The Structure and Nature of U.S. Water Markets—*Henry Hertzfeld & Ian Christensen, Space Policy Institute*

Water Supply, Distribution, and Use in the East—*Cherie Schultz & Erik Hagen, Potomac River Commission*

12:00 Discussion

12:15 Lunch

1:15 **The Contribution of Satellite Data to Water Resources Information**

NOAA's Satellite Data and Information—*Gerry Dittberner, NOAA NESDIS*

NASA's Satellite Water Information Research—*Jared Entin, NASA Earth Sciences*

Data Assimilation and Modeling—*Paul Houser, CREW & George Mason Univ.*

2:30 Discussion

3:00 Break

3:15 **Economic and Social Benefits of Information—*Douglas Parker, Univ. Maryland***

Economic and Cultural Issues in Valuing Water—*Henry Hertzfeld, Space Policy Institute*

Measuring Benefits of Water Resources Information—*Laurie Houston, Consultant*

Remote Sensing of Evapotranspiration and Soil Moisture—*Martha Anderson, USDA-ARS Hydrology and Remote Sensing Laboratory*

4:30 Discussion

5:00 Adjourn (Reception to follow in Suite 403)

14 March

8:30 Coffee & Pastry

9:00 Recap of Day One & Discussion

9:30 **Improving Satellite Water Resources Information**

Satellite Precipitation Measurements: Results from TRMM & the Promise of GPM—*Robert Adler, NASA Goddard Space Flight Center*

NASA-NOAA Collaborative Water Resources Information Research—*Christa Peters Lidard, NASA Goddard Space Flight Center*

Technical Considerations—*Roger Lang, The George Washington University*

10:30 **Challenges and Opportunities of Using Satellite Data for Water Resources**

Helping Decision Makers Connect the Dots: Linking Satellite Data with Water Resources Management—*Holly Hartmann, University of Arizona*

Institutional Issues—*Katherine Jacobs, University of Arizona (by phone)*

Economic and Policy Issues—*Molly Macauley, Resources for the Future*

12:00 Discussion

12:30 Adjourn