Universities Council on Water Resources
Journal of Contemporary Water Research & Education
Issue 153, Pages 42-48, April 2014

Landsat Thermal Infrared Imagery and Western Water Management

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Abstract: The Western States Water Council strongly supported the use of thermal infrared sensor (TIRS) data from Landsat 8 (Western States Water Council 2010). TIRS is increasingly important in monitoring consumptive water uses, particularly agricultural uses. Landsat is the only operational satellite system with a spatial resolution (30m) fine enough to map water use field-by-field. TIRS data applications include:

- Administering state water rights
- Planning for present and future water needs
- Implementing interstate compacts, court decrees, and negotiated tribal settlements
- Mapping evapotranspiration and consumptive surface and groundwater use
- Protecting endangered species and estimating water use by invasive species
- Monitoring food supply security
- Forecasting commodity market fluctuations

TIRS is essential to quantify beneficial consumptive use, evaluate water rights transfer requests, monitor interstate water compacts, negotiate tribal water right settlements and interstate agreements, and review water right "calls." The Landsat data archive tracks temporal changes in water uses over decades. A permanent operational land observation program with TIRS is essential.

Keywords: *Remote sensing, thermal imaging, water law and conservation*

Since 2005, the Western State Water Council (WSWC) has provided longstanding bipartisan support for maintaining data continuity and integrity with Landsat thermal-infrared (TIR) and reflected-light imagery (see www.idwr.idaho.gov/GeographicInfo/Landsat/WSN.htm). WSWC has been an active advocate for TIR imaging as an increasingly essential tool for water resource monitoring, planning, and management applications in the western United States. Landsat is the only operational satellite system providing thermal data at a spatial resolution (30m) fine enough to map consumptive water-resources use at the level of agricultural fields. Landsat 8's multispectral measurements – both thermal and reflective – provide the accuracy and quality consistent with previous Landsat missions that are important to western water managers and administrators. The availability of archived data over decades is also critical for water management and administration of western water law.

Western Water Law

Western water law is designed to provide certainty with respect to water use priorities in an arid region with an uncertain climate where the water supply depends on precipitation that varies greatly both temporally and spatially. The recent droughts across much of the West and Midwest are evidence of this uncertainty. Water rights are property rights, the use of which are primarily regulated and administered by western States under principles consistent with the legal Doctrine of Prior Appropriation – water is a public resource allocated or appropriated by the State for private use. With few exceptions, the Prior Appropriation Doctrine governs surface water use, while rights to the use of groundwater are more diverse.

Two of the best known tenants of Prior Appropriation are the "first in time, first in right" and "use it or lose it" principles. The first

use of water for a beneficial purpose is granted priority, and any unused water returns to the public domain. It is also important, however, to recognize principles that require "reasonable beneficial use" and "prohibit waste." The Prior Appropriation Doctrine generally requires that water be diverted or withdrawn from a public water body (river, stream, lake, or groundwater aquifer) and put to a use that, by custom, statute, and sometimes constitutional definition, is considered reasonable and beneficial, both with respect to the quantity of water used and the use to which the water is put. Water rights define domestic, municipal and industrial, agricultural, stock water, mining, and other off-stream consumptive water uses. In many cases they also recognized instream non-consumptive uses for recreation, fish and wildlife, hydropower, and other purposes.

Water rights are ordered and administered by priority date, or the date on which the use was first recognized. Uses with a senior priority date are allowed to exercise their right to the use of water first, before any junior or subsequent use or user. All uses are limited, however, to a decreed or customary amount considered reasonable and beneficial; any more is considered waste. If any portion of a senior user's water right is not put to beneficial use in a timely manner, that unused portion is available for use by other more junior users. The intent is to maximize beneficial use and discourage idle speculation. Therefore, any water returning to a waterbody, through surface runoff or deep percolation to an aquifer from an irrigated field, or discharged from a municipal wastewater treatment plant or other source, may be reused by junior users or becomes waters of the State subject to subsequent allocation and reuse. The measure and limit of a water right is the amount consumptively used beneficially.

Roughly 80 percent of the water diverted or withdrawn from western waterbodies is put to agricultural use, primarily irrigation of fields and pastures (Hutson et al. 2005). Much of that water eventually returns to the hydrologic cycle. Only those amounts lost through plant evapotranspiration, stockwatering, or otherwise actually consumed are exclusively used and unavailable for further appropriation.

Measuring and monitoring consumptive water use can be a daunting task limited by available data and information, assumptions, and the accuracy of engineering calculations. Agricultural withdrawals and consumptive uses may or may not be carefully regulated, depending on the demand. Often, agricultural water rights are calculated based on a "water duty," specified in acre-feet per acre, an amount of water that is generally considered adequate to irrigate a particular crop over a season, that may be diverted. For example, a water duty of three acre-feet would be the amount of water diverted over an irrigation season sufficient to cover one acre of land three feet deep. In the past, water duties have been determined largely by custom, but increasingly better information is available on diverse cropping needs, agricultural yield statistics, and irrigation best management practices.

Compared to agricultural water use, measuring municipal and industrial water use can be relatively straight-forward because the amount of water delivered to a home or factory is often metered and, after use, largely discharged as wastewater (treated or untreated) at the other end of a pipe.

Thermal Infrared Imagery and Water Management Applications

The availability of Landsat's thermal infrared satellite imagery has led to the development of various techniques that can accurately measure the energy exchanged through the evapotranspiration (ET) process to calculate consumptive crop water use (adjusting for background ET, temperature, precipitation, wind, and other variables). Such remote sensing measurements have been compared favorably with lysimeter measurements (Allen et al. 2005). Typical applications include: (1) mapping irrigated lands as well as crop type; (2) measuring and monitoring consumptive irrigation uses; (3) mapping and determining the extent of surface and groundwater use; (4) allocating and administering rights to the use of water; (5) approving water rights transfers; and (6) consideration of water right "calls," where senior users request junior uses be curtailed to ensure they have sufficient water to exercise their prior rights.

Western water managers and water right administrators are also increasingly using various Landsat-data-driven mapping tools to monitor and manage water rights, both spatially and temporally (seasonal and inter-annual). This allows state and federal agencies to track beneficial consumptive use, administer negotiated tribal agreements and monitor interstate compacts, determine use for agriculture and urban needs, estimate water-use by invasive species, monitor food supply sustainability and security, and provide information to help forecast and moderate commodity market fluctuations. These uses and other applications are expanding (see Table 1; Kustas and Anderson 2012).

None of these applications would be possible without Landsat 7 and 8 as they are presently configured with TIRS. Using different platforms on separate satellites to record multispectral and thermal imagery would degrade the quality of ET calculations when wetting events occur, during periods of rapid vegetation growth, senescence and stress onset, and when crops are harvested or killed by frost, disease, or pests. These situations are all precisely the types of localized conditions that Landsat is uniquely well-suited to monitor.

Some of the state agencies using Landsat data as an element of their water monitoring, planning, and management programs and water rights administration processes include the California Department of Water Resources, Idaho Department of Water Resources, Nevada Department of Water Resources, Colorado Division of Water Resources, New Mexico Office of the State Engineer, Wyoming Office of the State Engineer, Montana Department of Natural Resources and Conservation, and Nebraska Department of Natural Resources, as well as the North Platte Decree Committee and a growing number of other water conservation and irrigation districts (Allen et al. n.d.). There are data also used extensively by federal agencies, including USDA's Agricultural Research Service and Natural Resources Conservation Service, the Bureau of Reclamation, and the U.S. Department of Justice (Miller et al. 2011).

The WSWC strongly supports the establishment of an operational land observation program that maintains the current spatial resolution (30m) essential for land and water management on scales used to build the 40-year global archive of Landsat data. Image procurement every eight days provided by two satellites is critical, and four satellites, one passing every four days would be ideal. This means that multiple future Landsat missions need to be considered, planned, and built simultaneously, and launched expeditiously. There is a need to accelerate policy and funding decisions in order to ensure there are no future data gaps. Landsat 8 has a five-year design life, but its TIRS instrument only has a three-year design life. Any delay while evaluating new technological option puts TIRS data continuity at risk (Environment News Service 2013).

The WSWC worked hard over several years to secure a place for the TIR sensor onto the Landsat Data Continuity Mission (LDCM), which was successfully launched on February 11, 2013. LDCM operational responsibility has been transferred from NASA to the U.S. Geological Survey (USGS), and the satellite is now known as Landsat 8.

The U.S. Department of Interior and NASA partnership that led to the success of LDCM is expected to continue. The President's FY2014 budget request includes USGS funding for Landsat 8 operations as well as NASA funding to explore appropriate next steps forward with future satellites that will provide a permanent operational federal land imaging program. Any uncertainty regarding future funding and Landsat TIR data availability will be an obstacle to building and expanding operational water resources planning, monitoring, and management programs that have begun to flourish with the use of TIR imagery, which is available online free. Further innovations in the use of TIRS data are also expected.

In December 2012, the WSWC and Western Governors' Association completed a report on the use of water rights transfers to meet present and future water supply needs (Iseman et al. 2012). In particular, it addressed transfers from agriculture to other uses, while at the same time highlighting mechanisms available to minimize the impact on small, rural agricultural communities and economies, as well as the environment and ecological systems dependent on current patterns of use. The use of TIRS data to accurately measure consumptive use and evaluate the impacts of specific transfer proposals provides a sound scientific basis for related water management decisions. The USGS archive of Landsat and TIRS data provides an invaluable means to identify

historical consumptive water use patterns, determine how much water diverted under existing rights has actually been used, and quantify the amount available for transfer. Market forces are driving the value of water upwards and also provide a strong incentive for conservation and more efficient use of limited western water supplies.

Ensuring that quality TIRS data remains available as part of future Landsat missions will further facilitate innovative water resources monitoring, planning, and management.

The Economic Value of Landsat Data

Landsat imagery in general and TIRS data in particular provide the nation and the world with continuous, consistent monitoring of critically important natural resources and water use information. There are thousands of users and hundreds of applications of Landsat data in the United States, with strong use internationally as well. An unprecedented archive of four decades of Landsat data provides a record of changes in land cover and water uses over time. Landsat has made and continues to make critical "contributions to U.S. economic, environmental, and national security interests" (Marburger 2005). The dollar value of Landsat imagery can be difficult to estimate as it is primarily used by academic and non-commercial entities and government agencies. The Department of Interior recently requested that the Landsat Advisory Group of the National Geospatial Advisory Committee provide advice to the Department "concerning the economic benefits of Landsat data." A white paper prepared by the Advisory Group provided estimates of the economic value of ten uses of Landsat data. It also summarized recent estimates of the economic value of Landsat data from two large-scale surveys, which showed the annual economic value of Landsat data exceeds the cost of building, launching, and managing Landsat satellites and sensors (NGAC 2012a,b).

The use of Landsat data is growing given the opportunities for cost savings and innovative ways of providing decision support. The Landsat Advisory Group looked at several proven uses of Landsat technology and compared them to the costs of using other alternative technologies, methods, and data. It found these alternatives to be significantly more expensive than funding an operational Landsat program. Many Landsat data applications are associated with the U.S. government and save significant amounts of federal money compared to other methods of accomplishing the same objective. Productivity savings also benefit non-governmental science applications where scarce academic research dollars cannot be wasted on inefficient measurement technologies. The estimated annual Landsat data efficiency savings are conservative and substantial. Ten Landsat applications, highlighted in Table 1, produce estimated savings of $180 million to over $266 million per year for federal and state government agencies.

Notably, the WSWC estimated savings from the use of Landsat TIRS data to measure consumptive agricultural groundwater use from wells. Center-pivot irrigated fields are easily identified as crop circles (Figure 1), and proved to be a relatively easily quantifiable application. A more comprehensive estimate of the value of Landsat TIRS data, however, would require monitoring other agricultural and outdoor water uses, such as furrow irrigated fields, golf courses, public parks, and other areas supplied with surface and ground water.

The WSWC and Idaho Department of Water Resources (IDWR) collaborated in estimating only the value of using Landsat's thermal infrared imagery to measure and monitor consumptive water use by agricultural irrigation wells. However, TIRS data is also used by the State of Idaho in hydrologic modeling, water planning, water use comparisons when cropland is converted to urban uses, monitoring aquifer depletion, administering water rights (legal findings of fact, ensuring compliance with administrative orders, court decrees, and interstate compacts, as well as water right buy-back programs), endangered species protection, invasive species monitoring, and Indian water rights settlements (see www.idwr.idaho.gov/GeographicInfo/METRIC/et.htm).

IDWR and the University of Idaho have partnered to pioneer TIRS data uses, and have been recognized with an award from the Harvard Kennedy School of Government. The award recognized IDWR's use of TIRS data

Table 1. Estimated productivity from ten uses of Landsat imagery.

Landsat Application	Estimated Annual Efficiency Savings
Monitoring consumptive outdoor water usage	$20-73 million
U.S. government mapping	over $100 million
Forest health monitoring	$12 million
National agricultural commodities mapping	over $4 million
Flood mitigation mapping	over $4.5 million
Forest fragmentation detection	over $5 million
Forest change detection	over $5 million
World agricultural supply and demand estimates	over $3-5 million
Support for fire management	$28-30 million
Coastal change analysis program	$1.5 million

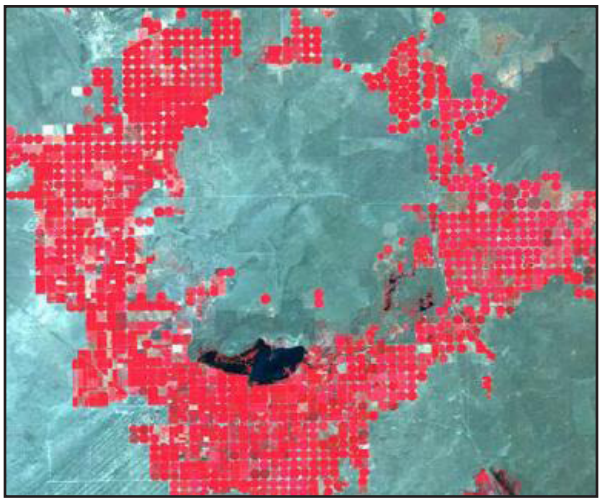

Figure 1. Landsat TIRS imagery showing easily identifiable crop circles from center-pivot irrigated fields.

in adjudicating, measuring, and monitoring consumptive irrigation use by wells on the Snake River Plain Aquifer (see www.ash.harvard.edu/Home/News-Events/Press-Releases/Mapping-Evapotranspiration-Wins-Innovations-Award).

IDWR previously used a power consumption coefficient measurement method to estimate groundwater extraction and use at an annual cost of about $500,000 for some 5,000 Snake Plain wells or about $100 per well. IDWR began using Landsat TIRS data through a process called METRIC (Mapping EvapoTranspiration with high Resolution and Internalized Calibration) to measure actual crop evapotranspiration on a field-by-field base. IDWR's annual costs dropped to approximately $53,500 per year for the same 5,000 wells or less than $11 per well. These two measurement options were also compared with requiring installation of flow meters on every well at an estimated capital cost of several hundred to thousands of dollars per well.

Given IDWR's cost experience and extrapolating the use of the power consumption coefficient method (or installing flow meters) on unmetered irrigation wells in the 17 western waters states, the potential annual cost savings were estimated to range from nearly $20 million to over $73 million annually (again for measuring agricultural groundwater well extraction alone). These figures represent a conservative estimate using unpublished IDWR cost figures (Morse 2012) and west-wide unmetered irrigation well numbers from USDA's 2002 Census of Agriculture (USDA 2002).

Conclusion

The water resources of the United States are a $200 billion per year economic engine that supports hundreds of thousands of jobs. In the West, water is in short supply, often requiring reductions in consumptive uses. Water and water rights are increasingly valuable commodities being bought and sold. Remotely sensed TIRS imagery collected by Landsat satellites is essential for determining past and present water use and evapotranspiration at scales (30m) that reveal patterns of land use and water consumption to inform future decision-making. Evapotranspiration maps derived from Landsat TIRS imagery are used operationally by water managers to monitor and manage myriad water uses. Landsat is the only operational satellite system that combines thermal data with multispectral data at the spatial resolution (30m) needed to administer water use and water rights at the level of the individual agricultural fields.

As water becomes an increasingly valuable commodity, the use of which will be subject to greater public scrutiny, the innovative use of Landsat TIRS data to measure and monitor consumptive water use will help further revolutionize water management and state water rights administration, leading to greater efficiency and better planning and decision-making. It is therefore essential that the nation maintain this capability and expeditiously move to establish a permanent operational land observation program, including the accelerated development and launch of a Landsat 9 satellite with TIRS capabilities.

Acknowledgements

The help of Anthony (Tony) Morse, retired, formerly with the Idaho Department of Water Resources, is gratefully acknowledged in preparing the cost estimates and comparisons for monitoring groundwater wells in the Snake Plain Aquifer and identifying other IDWR uses. He can be reached at tmorsell@yahoo.com.

Biographical Information

Anthony G. Willardson was named Executive Director of the Western States Water Council (WSWC) in July 2009. Formerly the Deputy Director, he has been with the Council since 1979. The Council is affiliated with the Western Governors' Association (WGA). Its members are appointed by the governors of eighteen states. He holds a BA in political science from Brigham Young University, and a MS in public administration from the University of Utah and is a member of the National Honor Society for Public Affairs and Administration (Pi Alpha Alpha). He oversees publication of a weekly newsletter, Western States Water, which he edited for many years. He is the author of numerous articles and reports covering a wide range of water resource issues, including water project financing and cost sharing, groundwater management and recharge, water conservation, drought, and interregional water transfers. He is also one of the principal authors of the WGA's 2006 Report, *Water Needs and Strategies for a Sustainable Future* and 2008 *Next Steps Report*, as well as a 2010 *Progress Report*. He actively contributed to the WGA/WSWC's December 2012 *Water Transfers in the West* report. He can be reached at Western States Water Council, 5296 S. Commerce Drive, Suite 202, Murray, Utah 84123, phone: (801) 685-2555, e-mail: twillardson@wswc.utah.gov. For additional information see: http://www.westernstatewater.org.

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