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## The Need to Continue High Resolution **Thermal Imagery** (i.e., Land Surface Temperature) on the next Landsat Satellite System for Water Resources Management

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***Western water resources of the United States are dominated by diversions and consumption by irrigated agriculture. Management of these diversions requires quantification of water consumption (evapotranspiration) by irrigated crops that is possible only from satellite imagery. The resolution of the quantification must be fine enough to enable 'seeing' water consumption by individual fields and land holdings.***

***The high resolution Landsat system<sup>2</sup> has historically provided this capability.***

***However, the high resolution thermal imager of past Landsat systems necessary for accurate accounting of water consumption from agriculture may not be included on any proposed future Landsat replacement. If proposed satellite coverage at the high resolution (30 m) of Landsat does not incorporate coincidentally collected images of surface temperature, then the current and extensive high resolution mapping programs by state and federal agencies that quantify water consumption from irrigated and other agricultural and natural systems will be substantially impaired.***

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<sup>2</sup> The Landsat satellite orbits the earth from pole to pole at an altitude of 700 km. The satellite passes over every point on earth at least once each 16 days at about 1100 hours. The resolution of the visible and near-infrared imager on Landsat is 30 m (100 feet) and the resolution of the thermal imager on Landsat (for surface temperature measurement) has been 60 m (200 feet) on Landsat 7 and 120 m (400 feet) on Landsat 5. More information is available at <http://landsat7.usgs.gov/>

## Justification

Accurate and detailed information on water consumption has been a long-standing critical need in river and water resources management. Quantification of consumption is increasingly needed as water resources come under more and more tension by more and more users and interests and as water is transferred to cities and environment. The scientific community has long been researching the use of dependable satellite information to fulfill this quantification need, and now image processing programs designed to utilize the long record of Landsat imagery are finally in place for application to extensive areas of the United States. These processing programs locate and quantify the consumption of diverted water resources that occurs via the process of evapotranspiration (ET)<sup>3</sup>. These programs require and have taken strong advantage of the thermal imager of the Landsat system.

**Unfortunately, the longstanding Landsat satellite system that is critical to serving these critical water resources needs is in jeopardy of phase-out and abandonment by the US government. Only two Landsat's are in orbit and one, Landsat 5 (1984 launch), is experiencing a problem with the solar energy array<sup>4</sup> and the other, Landsat 7 (1999 launch), was damaged in 2003 and its usability for high resolution ET quantification is greatly impaired<sup>5</sup>. In addition, very recent plans to launch a temporary replacement Landsat satellite<sup>6</sup> do not include the all-important thermal imager of past Landsat systems that is required for determination of evapotranspiration.**

In the **short term, what is critically needed** to service water management and administrative needs in water resources management is the following:

- An array of new Landsat or similar satellites (preferably a minimum of two) as a stand-alone system or in conjunction with some other satellite platform
- Each Landsat sensor system equipped with at least one thermal imager (for the calculation of surface temperature) having at 60 m resolution or better.
- The satellite array operated to provide images every 4 to 8 days over the entire United States.

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<sup>3</sup> Evapotranspiration is synonymous with the term "consumptive use" and refers to the conversion of liquid water at or below the surface into the vapor form through the process of evaporation and transpiration (through vegetation). ET by irrigated agriculture is by far the largest consumer of western rivers and ground water.

<sup>4</sup> [http://landsat7.usgs.gov/project\\_facts/project\\_news/December\\_Special\\_2005.php#topic\\_322](http://landsat7.usgs.gov/project_facts/project_news/December_Special_2005.php#topic_322)

<sup>5</sup> The capability of Landsat 7 to produce complete images each 16 days for use in creating ET maps based on energy balance has been lost. However, Landsat 7 is considered to still have value for other uses including the high resolution monitoring of vegetation and for producing ET information where only statistically sampled spatial samples are required.

<sup>6</sup> Memo from John Marburger, Director of Office of Science and Technology Policy, Dec. 23, 2005: "Landsat Data Continuity Strategy Adjustment"

## Background

The Landsat satellite system was inaugurated in 1972 and has provided routine high resolution imagery of the earth's surface ever since. Landsat number 4, launched in 1982, was the first to include a special thermal imager for measuring temperature of the earth's surface at high spatial resolution. This thermal imager has enabled the calculation of evapotranspiration at the Earth's surface via complex surface energy balances. Landsat 4 was followed in 1984 with Landsat 5 and in 1999 with Landsat 7 (the Landsat 6 satellite did not reach operational orbit following launch). Landsat 5 and Landsat 7 are still functioning today, although Landsat 7 was partially damaged by unknown causes on May 31, 2003 and since that time its images have not been useful for routine high resolution ET calculation (one or more calculations per month for complete images). In late 2005, Landsat 5 began to experience solar array problems and may be very near the end of its operational life.

The nearly explosive **increase in the use** of image data from **Landsat** for computing evapotranspiration since year 2000 is an outgrowth of:

- 1) the significant lowering of costs for Landsat images (by a factor of 10) since 1999;
- 2) successful research in developing dependable processes for computing ET from satellite images,
- 3) advances in computer data storage and data handling abilities within water resources administrative units and the ability to process and integrate water consumption maps;
- 4) increased litigation and mitigation between environmental needs, endangered species concerns, and historical water use, and
- 5) pressure from state water resources entities such as Idaho Department of Water Resources (IDWR) for such an operational product.

As an example of benefits derived from the Landsat thermal band, in **Idaho**, the Idaho Department of Water Resources uses water consumption maps based on ET derived from Landsat images, including thermal data, for:

- 1) water rights management and regulation;
- 2) purchase of water rights for endangered species and agreements with native American entities;
- 3) hydrologic modeling;
- 4) prediction of incidental ground-water recharge from surface irrigation;
- 5) quantification of water consumption during water rights litigation;
- 6) management of stream diversions for endangered species; and
- 7) prediction of water consumption changes due to the transition of land use from agriculture to city.

Other uses of water consumption prediction by satellite include:

- 1) impacts of deficit irrigation of orchards and vineyards to conserve water (**California**),
- 2) crop water demands for river management (**New Mexico**),
- 3) areal extent and amount of water consumption by riparian vegetation (**New Mexico** and **California**),
- 4) transferable water from land fallowing (**California**),
- 5) state wide consumption as part of a state water plan (**California**)
- 6) helping farmers determine actual irrigation water needs during state mandated conservation programs (**Kansas**),
- 7) compliance with limits on water consumption under interstate compacts (**Wyoming, Nebraska, Utah, Idaho**), and
- 8) impact of ground-water pumping by cities on surface hydrology and native vegetation (**Florida**).

With the 2003 malfunction of Landsat 7, useful satellite images for high resolution mapping of ET by energy balance (requiring every pixel every overpass) were available only from Landsat 5 and therefore only every 16 days. Now, with Landsat 5's pending failure, a replacement Landsat system is desperately needed. It is **critical** that the replacement system contain the **thermal imager** or equivalent of past Landsat missions for measuring surface temperature. Clouds preclude the processing of images for evapotranspiration, so that water consumption maps can now be guaranteed only about once every 2 months if only a single Landsat satellite is functioning. This frequency is insufficient for closely following the seasonal changes of ET that result from plant growth and water availability. Therefore, two replacement Landsat satellites, each with a thermal imager, are recommended.

### Specific Concerns

Specific concerns with the current Landsat satellite system and with the Landsat Data Continuity Mission (LDCM)<sup>7</sup> are the following:

- a) Landsat 7 malfunctioned in 2003 and no longer provides complete image information for all of its coverage (however, Landsat 7 is still useful for less periodic vegetation monitoring and for those areas lying along the center line of the flight path)
- b) Landsat 5 became crippled in late 2005<sup>8</sup> and may have only one to two years of service life remaining before it fails completely.

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<sup>7</sup> <http://ldcm.nasa.gov/>

<sup>8</sup> [http://landsat7.usgs.gov/project\\_facts/project\\_news/December\\_Special\\_2005.php#topic\\_322](http://landsat7.usgs.gov/project_facts/project_news/December_Special_2005.php#topic_322)

- c) NASA may plan for a future Landsat satellite under the Landsat Data Continuity Mission and the NPOESS<sup>9</sup> missions, but plans **do not contain the high resolution thermal band sensor** (i.e., for computing surface temperatures ). The high resolution **thermal band sensor is critical** for applying the SEBAL and METRIC evapotranspiration mapping procedures at sufficient resolution to quantify water consumption by individual farms (fields) and water rights holdings.
- d) **The cancelled NASA solicitation** for the Landsat Data Continuity Mission (LDCM) implementation phase as of September 26, 2003 that was to launch Landsat 8 **did not include** a **thermal band sensor** that is **critical** to consumptive water use mapping.
- e) **NASA has been reluctant to consider and understand the importance of the Landsat mission (including its thermal mapping) in water resources management.**

### Current Image Processing

Two of the primary processing programs used to predict high resolution ET from satellite images are the **SEBAL** procedure (Surface Energy Balance Algorithms for Land) of SEBAL North America, Inc.<sup>10</sup> and the University of Idaho **METRIC** procedure<sup>11</sup> (Mapping EvapoTranspiration at High Resolution with Internalized Calibration). These relatively sophisticated, energy-balance based programs produce **maps of ET** having **30 m by 30 m** (100 ft by 100 ft) resolution when used with **Landsat** images. This high resolution allows water resources managers and administrators to identify the water consumed from individual fields and within individual water rights. The combined use of images from both Landsat 5 and Landsat 7 satellites prior to the May, 2003 malfunction of Landsat 7 provided high resolution images that were updated every 8 days. The **METRIC** processing has continued to be implemented in Idaho's consumptive use quantification programs.

Table 1 summarizes recent applications of SEBAL and METRIC processing. Water resources are becoming critically strained and the future management and planning analyses need the accurate and detailed information on water consumption afforded by satellite data. The use of such information is spreading across the United States. State and federal water resources agencies are discovering the immense value of evapotranspiration information produced by the SEBAL and METRIC processes and are incorporating this information into routine operations, as evidenced by a

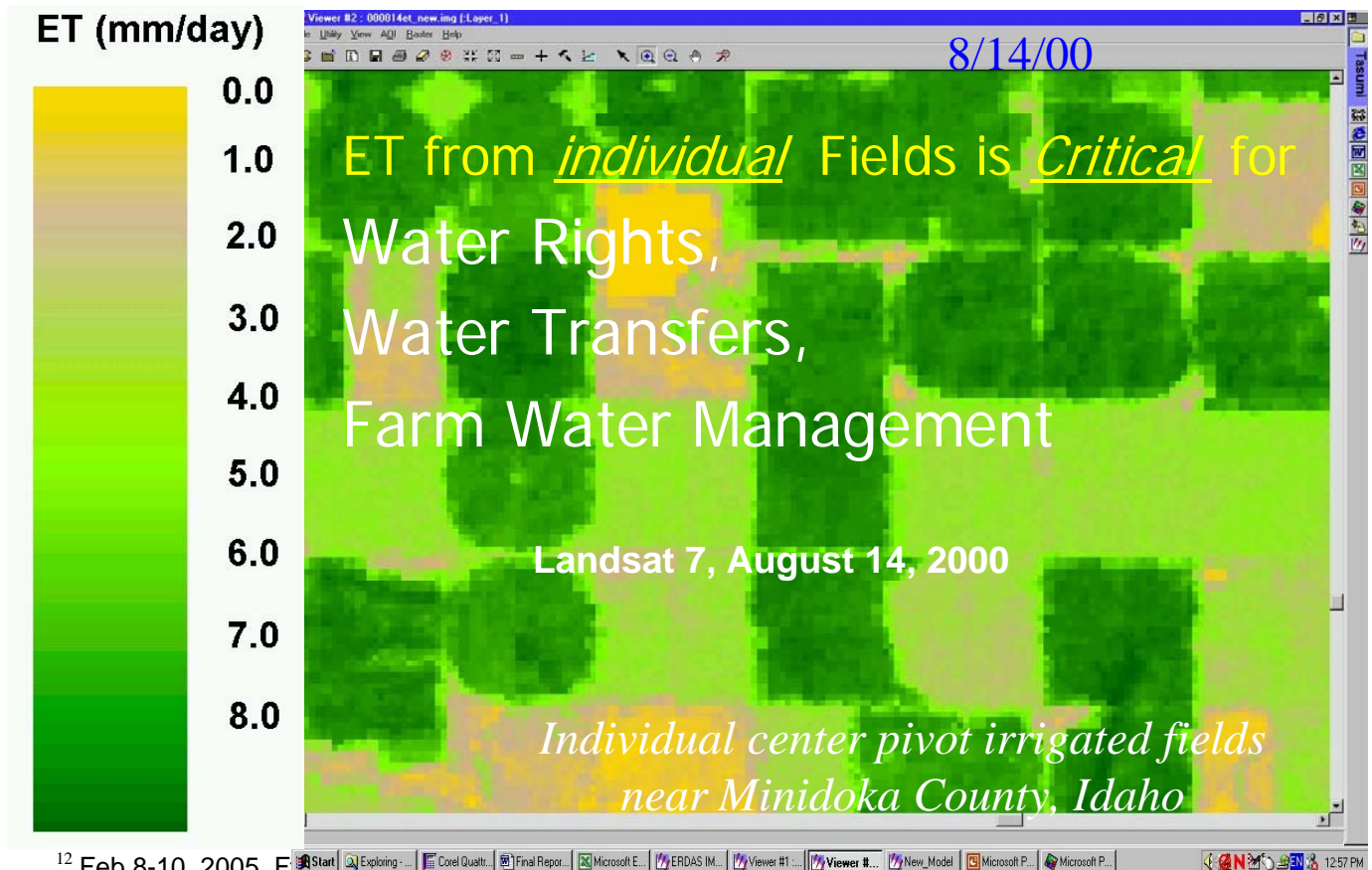
<sup>9</sup> National Polar-orbiting Operational Environmental Satellite System (<http://www.ipo.noaa.gov/>). The NPOESS VIIRS sensors have only 400 m resolution, which is too coarse for irrigated agriculture and water resources management ([http://www.ipo.noaa.gov/Technology/viirs\\_summary.html](http://www.ipo.noaa.gov/Technology/viirs_summary.html)). The NPOESS may be expanded to contain Landsat-scale (resolution) sensors (Memo from John Marburger, Director of Office of Science and Technology Policy, Aug. 13, 2004). **However, the all-important thermal band is not planned for inclusion.** Therefore, the expanded NPOESS - LDCM combination would not be useable for quantifying water consumption from individual irrigated and agricultural fields necessary for future management levels.

<sup>10</sup> [www.sebal.us](http://www.sebal.us)

<sup>11</sup> <http://www.kimberly.uidaho.edu/water/metric/index.html>

recent national conference on Evapotranspiration by Remote Sensing sponsored by the U.S. Bureau of Reclamation<sup>12</sup>.

SEBAL and METRIC are currently preferred over other satellite-based ET process models in the western United States because of the use of internalized calibration procedures<sup>13</sup>. These procedures index sensible heat fluxes from land surfaces (one of the major energy balance components) to satellite measured surface temperatures at specific surface boundary conditions. The indexing of the heat flux to available ground weather data eliminates the need for atmospheric correction of short-wave and thermal information in images and greatly reduces accuracy requirements of thermal images<sup>14</sup>.



<sup>12</sup> Feb 8-10, 2005, F

<sup>13</sup> Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag, 1998. A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. *Journal of Hydrology* 212-213:198-212.

Allen, R.G., A. Morse, and M. Tasumi. 2003. Application of SEBAL for Western US Water Rights Regulation and Planning. Proc. Int. Workshop on Use of Remote Sensing of Crop Evapotranspiration for Large Regions. 54th IEC Meeting of the International Commission on Irrigation and Drainage (ICID), Montpellier, France, Wednesday, 17 September, 2003. 13 pages. On web at:

[http://www.kimberly.uidaho.edu/water/montpellier/p10/Allen\\_P.pdf](http://www.kimberly.uidaho.edu/water/montpellier/p10/Allen_P.pdf)

with presentation at <http://www.kimberly.uidaho.edu/water/montpellier/p10/index.html>

<sup>14</sup> Tasumi, M. 2003. Progress in operational estimation of regional evapotranspiration using satellite imagery. Ph.D. Dissertation, University of Idaho, Moscow, Idaho.

Trezza, R. 2002. Evapotranspiration using a satellite-based surface energy balance with standardized ground control. Ph.D. Dissertation, Utah State University, Logan, Utah.

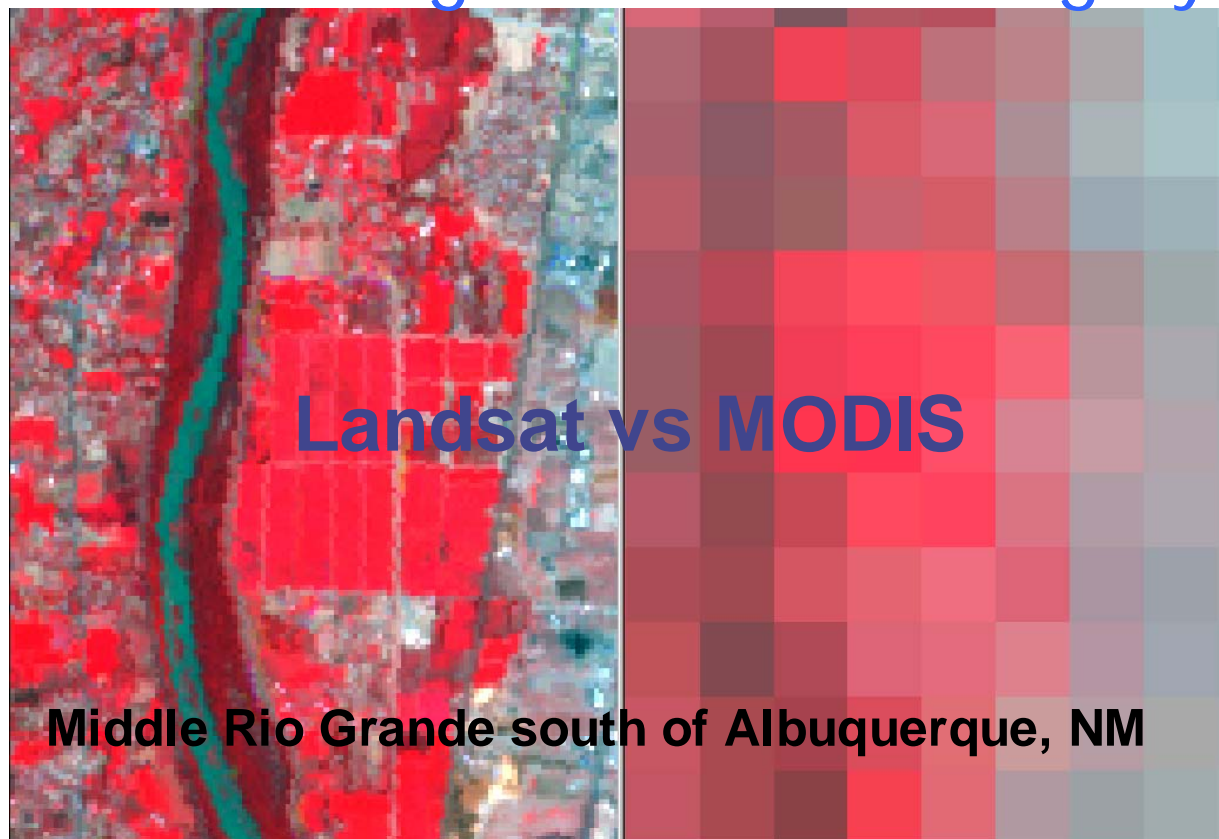
Table 1. Applications of **SEBAL** or **METRIC** in the United States that have relied on **Landsat satellite imagery** (including the **thermal band**) to produce maps of water consumption (evapotranspiration).

State(s)	River Basin	Year(s) of Study	Year(s) of Images	No. Studies	Applier	Client	Use of Water Consumption maps
Idaho, Utah, Wyoming	Bear River	2000	1985	1	Univ. Idaho, Idaho Dept. Water Resources <a href="http://www.kimberly.uidaho.edu/water/metric/1_02ERDAS.pdf">http://www.kimberly.uidaho.edu/water/metric/1_02ERDAS.pdf</a>	Idaho Dept. Water Resources	Bear River Compact Compliance
New Mexico	Middle Rio Grande	2000, 2003	2000, 2002	4	WaterWatch, New Mexico Tech, SEBAL North America, Univ. Idaho	New Mexico Tech, USBR, Keller-Bliesner Engineering, U.S. Dept. Justice	Endangered Species Issues, Impacts of water table on water consumption
Florida	Tampa Bay	2000	2000	1	Allen Engineering, Waterstone, Inc.	Tampa Bay Water	Impacts of ground-water pumping on ET of natural vegetation
Idaho, Montana, Utah, Nevada	Snake River	2001, 2002, 2003	1986, 1988, 1989, 1990, 1991, 2000, 2002	3	University of Idaho <a href="http://www.kimberly.uidaho.edu/water/montpellier/p10/Allen_P.pdf">http://www.kimberly.uidaho.edu/water/montpellier/p10/Allen_P.pdf</a>	Idaho Dept. Water Resources	Prediction of ground-water recharge and spring flow, Regulation of ground-water permits
Idaho, Oregon	Boise River	2002	1997, 2001	1	Idaho Dept. Water Resources	USBR, Idaho Dept. Water Resources	Transition of agriculture to residential, planning reservoir operations
Texas	East Texas	2002	2000	1	Interra	State of Texas	Multi-basin water balance
New Mexico	San Juan	2002	2002	1	WaterWatch, Keller-Bliesner Engineering	Navajo Agricultural Products Industry (NAPI)	Management of center pivot irrigation
California	Lower Colorado River	2003	2002, 2003	1	Univ. Idaho	Metropolitan Water District	Spatial and seasonal trends in agricultural water use

Table 1 Continued. Applications of **SEBAL** or **METRIC** in the United States that have relied on **Landsat** imagery (including the thermal band) to produce maps of water consumption.

State(s)	River Basin	Year(s) of Study	Year(s) of Images	No. Studies	Applier	Client	Use of Water Consumption maps
Idaho	Lemhi River Basin	2002	2000	1	IDWR, Univ. of Idaho	IDWR	Water balance for hydrologic modeling and water rights management
Idaho	Salmon River Basin	2003	2003	1	IDWR, Univ. of Idaho	IDWR	Improving streamflow for fish listed under the Endangered Species Act
Washington	Yakima River	2003	2001	1	SEBAL North America	Benton Irrigation District/USBOR	Quantification of ET for negotiation of diversion reduction agreement
California	Russian River				SEBAL North America	Sonoma County Water Agency	Hydrologic modeling leading to assessment of compliance with water rights
California	State-wide	2004	2002	1	SEBAL North America (see <a href="http://www.sebal.us">www.sebal.us</a> ) (using MODIS satellite with validation via Landsat)	Proof of Concept	State-wide ET by month for use in the State water plan, etc.

# Need for High Resolution Imagery



Landsat False Color (MRG)  
8/26/2002 10:33am

MODIS False Color (MRG)  
8/26/2002 11:02am

## The Specific Need for Landsat and its high resolution Thermal band

A typical irrigated field in the western U.S. has dimensions of 800 x 800 m or less. Generally, with Landsat 7's 60 m thermal pixel, we can obtain up to 100 thermal pixels that are completely contained within an individual field (after buffering in from edges). With Landsat 5's 120 m thermal pixel, we can find about 15 thermal pixels within a single field. These numbers of pixels provide extremely valuable information regarding spatial variability of evapotranspiration within fields and uniformity of water use. They also 'insure' our capability to estimate accurately total water consumption by that individual field.

In the case of MODIS's 1000 m thermal pixels (at nadir view) one average-sized field is 'swallowed' by a single thermal pixel, or worse yet, is split between two large thermal pixels, with specific thermal information for the field lost.

Other low (i.e., coarse) resolution satellites can be used to create maps of evapotranspiration. However, these do not have the same, necessary moderately high (30 to 120 m) resolution of Landsat, or they lack the consistent return time of Landsat:

- Although the **MODIS** satellite (first launched in 1999) has a daily return time (one overpass per day) and provides adequate spectral and thermal information for ET mapping, **its thermal resolution is only 1000 m** (0.6 mile) actual and 2000 m useable (based on average view angles), which makes the identification of water consumption from individual fields (generally having dimensions of 200 to 800 m) and for individual crops impossible. (see figure above).
- The **ASTER** satellite sensor (1999 launch) has a potential 8 day return time, which is adequate for ET mapping, but **communication downlink constraints** prohibit continuous collection of image data. Therefore, the actual image return time for all areas of the western U.S. is on the order of months, rather than days. Thus, continuous coverage of large areas of the United States or even irrigated areas of the west is not possible.
- The **AVHRR** satellite of NOAA has similar resolution as MODIS and similar constraints. Although AVHRR and MODIS can be used to provide ET maps for large areas that are useful for hydrologic and global climate change studies, the **resolution is not sufficient** to provide the evapotranspiration information required for precision management of our seriously stretched water resources, especially in the irrigated areas of the west.
- The **GOES** satellite system provides continuous, near real-time coverage of all points of the United States. However, this satellite **lacks the spatial resolution** necessary for the accurate and detailed computation of water consumption by agriculture.
- The future "next generation" **NPOESS** (National Polar-orbiting Operational Environmental Satellite System) (earliest launch in 2009), while having superior spectral and thermal sensors and information, will suffer the same deficiencies of MODIS and AVHRR for energy balance and evapotranspiration determination, in that the image resolution will only be about 700 m in the bands required for ET modeling. NPOESS may be expanded to contain Landsat-scale (resolution) sensors (Memo from John Marburger, Director of Office of Science and Technology Policy, Aug. 13, 2004). However, **the all-important thermal band is not planned for inclusion at the current Landsat resolution**. Therefore, the expanded NPOESS - LCDM combination will not be useable for quantifying water consumption by individual stakeholders in irrigated agriculture.
- Other high resolution satellites such as the French **SPOT** and Indian **ISIS** satellites **do not contain thermal imagers to measure surface temperature** and are therefore **unusable** with the energy-balance based SEBAL and METRIC processes for ET mapping

In NASA's own words: "No other current or planned remote sensing system, public or private, fills the role of Landsat in global change research or in civil and commercial applications."<sup>15</sup>

It was the intention of NASA and Congress since 1992<sup>16</sup> to continue support for this critical Earth-imaging program that includes monitoring of land surface temperature (critical to the calculation of evapotranspiration). The noted NASA publication on Landsat goes on to state: "**Landsat 7 will fulfill its mission** by providing repetitive, synoptic coverage of continental surfaces; spectral bands in the visible, near-infrared, short-wave, and **thermal infrared** regions of the electromagnetic spectrum; spatial resolution of 30 meters (98-feet); and absolute radiometric calibration. **No other current or planned remote sensing system matches this combination of capabilities.**" Unfortunately, Landsat 7 is damaged and any follow-on system may not contain the high resolution **thermal** imager of previous Landsat systems.

**Continued Landsat imagery** that includes thermal imagery is imperative to western and southeastern water resources management for the following reasons:

1. **Moderately High resolution.** The 30 m short-wave resolution and 60 to 120 m thermal resolution of Landsat satellites is critical for the computation and mapping of evapotranspiration from individual irrigated fields. Water rights regulation and administration are critically tied to identification and quantification of water consumption on a **field by field basis.** The current ET mapping by the Idaho Department of Water Resources (IDWR) could not have been developed if the high-resolution Landsat images with thermal (temperature) images had not been available. The high-resolution Landsat images provide a means for identifying the crop type for each field that is useful for characterizing trends in evapotranspiration and for establishing relationships between water consumption and crop type (for example work by the U.S. Bureau of Reclamation in California and Arizona). The detailed and accurate computation of evapotranspiration using Landsat satellite data is not possible with the 1 km resolution of MODIS and AVHRR satellites.
2. **Continuous coverage.** Landsat satellite images are available for every portion of the United States for nearly every overpass date. This **continuous coverage is critical for tracking the change of water consumption** over time and space for individual fields, irrigation projects, river basins, and regions. Continuous surface coverage is not possible with the ASTER satellite. ASTER coverage must be ordered ahead of time and there is substantial competition within the scientific community for this information. In water resources management and conflict resolution and in issues involving endangered species, we often must look back in time to quantify historical water consumption and historical trends. Rarely do we have the foresight to "order on" a satellite platform such as ASTER ahead of the

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<sup>15</sup> [http://pao.gsfc.nasa.gov/gsfcservice/gallery/fact\\_sheets/earthsci/landsat/landsat7.htm](http://pao.gsfc.nasa.gov/gsfcservice/gallery/fact_sheets/earthsci/landsat/landsat7.htm)

<sup>16</sup> The 1992 Land Remote Sensing Policy Act

needed date. Recent Idaho applications of SEBAL and METRIC have processed Landsat images as far back as 1985<sup>17</sup>.

3. **Long image history.** Landsat images ( including thermal images) have been available for much of the United States since the early 1980's. This historical data has been extremely valuable for water resources management because it provides information on changes in water consumption over time for specific areas. **Long, continuous records are essential for hydrologic studies** and ecological and endangered species studies on the impacts of land use change. The implementation of the Landsat Data Continuity Mission is crucial to the future of water consumption mapping having adequate resolution, return cycle, and coverage.
4. **Workable return time.** The 16 day return time of Landsat (8 days with both Landsat 5 and 7 satellite) has been sufficient to establish trends in water consumption caused by growth and death of vegetation and change in weather. Shorter return times (i.e., with multiple Landsats) would be even better. However, two Landsat satellites are sufficient to provide three cloud-free high resolution images per month during summer in most western regions. Four Landsat satellites would provide even better temporal data for the western states and would provide some backup capacity in the event of satellite failure.

**We see a tremendous future for the use of high resolution Landsat thermal band information in water resources management in the United States that would justify the cost of a complete, fortified, stand-alone Landsat program.** Morse<sup>18</sup> has conservatively estimated cost savings of ground-water pumping monitoring over a ten year period for the western United States through the use of Landsat to estimate water consumption by agriculture as opposed to expensive and problematic pump flow measurements, site visits, and checking of electrical power consumption records. He has estimated the ten-year value of using Landsat imagery at about 1 billion dollars, which far exceeds the total cost for the Landsat 8 program. The potential savings for this one application, alone, are enormous. Mapping of consumptive use is critical for surface water management.

**The Landsat satellite replacements** or other satellite systems **must measure surface temperature** (i.e., have at least one thermal imager) coincident with the short-wave images for the computation of water consumption maps.

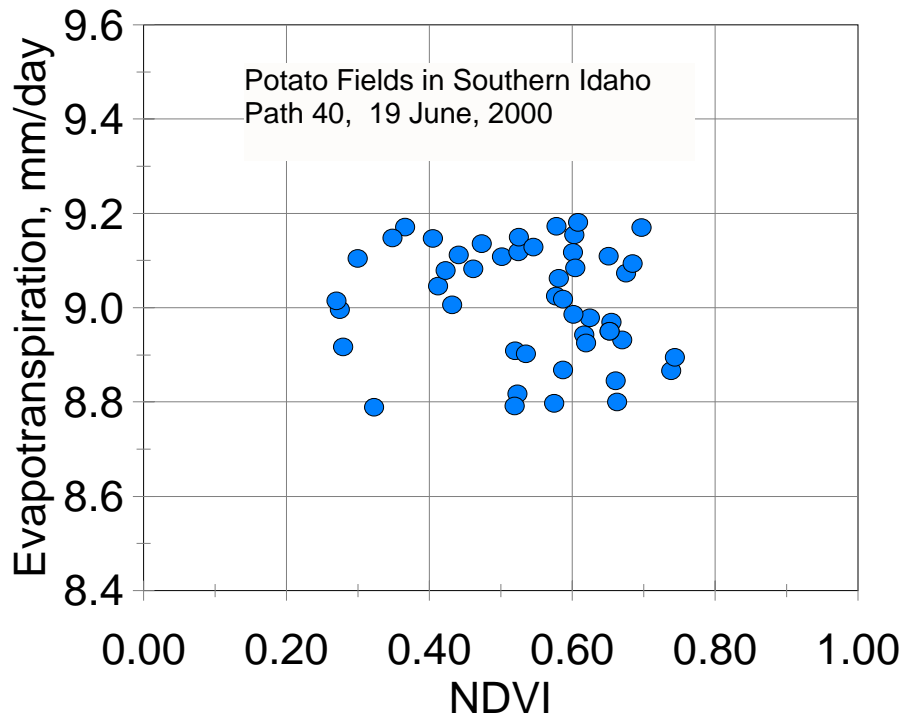
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<sup>17</sup> Morse, A., M. Tasumi, R.G. Allen and W.J. Kramber, 2000. Application of the SEBAL Methodology for Estimating Consumptive Use of Water and Streamflow Depletion in the Bear River Basin of Idaho through Remote Sensing: Final Report. Idaho Department of Water Resources, Idaho

<sup>18</sup> Morse, A. 2003. Comparison of Ground Water Monitoring Costs as a Reason to Maintain the Thermal Band on the Landsat Data Continuity Mission: A Quick Look. Internal Report to the Idaho Department of Water Resources, Boise, Idaho. Feb. 18, 2003, 5 p.

## Evapotranspiration from Vegetation Indices Alone

Evapotranspiration has a high correspondence with the amount of vegetation cover. However, ET is also impacted by wetness of soil beneath and around vegetation or even in the absence of vegetation. The following figure of ET on a single day for more than 50 fields of potatoes in southern Idaho demonstrates that high levels of ET (in this case in the range of 8.8 to 9.2 mm per day) can occur over a broad range in a vegetation index (NDVI) due to impacts of soil surface wetness. Thus, using a vegetation index alone is in general incapable of quantifying ET for specific instances. Surface temperature imagery is needed to quantify impacts of surface wetness.



Reasons given in the past by NASA<sup>19</sup> for not including a thermal band sensor in future Landsat missions are:

- 1 The cryogenically-cooled, older technology used on present Landsat satellites is too expensive and heavy to put on the future Landsat Data Continuity Mission (LDCM).
- 2 New **microbolometer** technology for measuring earth surface temperature is still relatively immature and perhaps too risky to incorporate on the LDCM. However, we believe that thermal images acquired with a microbolometer imager would provide sufficient accuracy to be used in METRIC and SEBAL image processing procedures for consumptive use quantification. These processes can tolerate several degrees of measurement bias.

<sup>19</sup> Dr. Ghassem Asrar, NASA Associate Administrator for Earth Science in a letter dated August 7, 2003 to Drs. Paul Pinter and Bruce A. Kimball, USDA-ARS, Phoenix, AZ

3 NASA has not been able to identify a sufficient customer base for thermal (surface temperature) data.

**Other short term pathways:**

In the **short term**, to fill in before new Landsat class satellites with thermal bands can be designed, funded and launched, what might serve as a fill-gap is to utilize the Chinese-Brazilian CBERS satellite system<sup>20</sup>. However a ground-station for North America, operated by the USGS EROS center or other federal center, would need to be constructed to download CBERS images, since these are currently only downloaded over Brazil and China.

The CBERS system is comprised of two (soon to be three) satellites launched in 1999, 2003 and 2006 that have somewhat coarser resolution in the thermal band (80 to 160 m as compared to 60 m for Landsat 7's thermal band). However, this system, that does contain thermal imagers, could help fill in for Landsat while a new Landsat constellation (having a high resolution thermal band) is designed and launched. The CBERS satellites are only designed for mission lifespans of two years, however, so the CBERS system may not be a viable long-term solution. However, CBERS may be the only solution if a high resolution thermal band is not included on future Landsat data continuity missions. Presently, CBERS data are only downloaded over Asia and Brazil. No ground-station exists in North America to download images for the United States.

Some kind of a mutual-use agreement may enable the use of the CBERS program for the short-term. The quality and reliability of the CBERS images are in question and must be investigated.

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<sup>20</sup> <http://www.cresda.cn/> and <http://www.cbbers.inpe.br/en/programas/cbers1-2.htm>

## Summary and Conclusions

The current ET mapping in Idaho, Utah, Wyoming, Montana, Washington, New Mexico, Texas and Nevada and California requires the high resolution of Landsat satellites (as opposed to MODIS or AVHRR) to identify ET from individual fields for purposes of water rights and irrigation water management. The ET mapping process requires the consistent return time and coverage of the Landsat system (as opposed to ASTER, which is intermittent at best). In addition, the process **requires the high resolution thermal imager of past Landsat systems.**

- 1 With the damage to Landsat 7, we are now down to one single high-resolution, continuous coverage, thermal-sensor equipped satellite (Landsat 5) and, since December 2005, its ability to continue to generate operational power is questionable;
- 2 **High-resolution, continuous coverage thermal information** is essential for the mapping of water consumption (evapotranspiration) in the U.S. Mapping of water consumption is imperative for
  - a) quantifying actual depletions to the water resource caused by evapotranspiration of diverted water
  - b) monitoring ground-water pumpage by individual landholders;
  - c) mediating and mitigating water rights conflicts and impacts of water transfers; and
  - d) solving endangered species issues related to water resources;
- 3 Several states besides **Idaho** are beginning or considering a substantial application of SEBAL, METRIC or related procedures for quantifying ET from satellite including **New Mexico, Texas, California, Wyoming, Colorado, Florida, and Nebraska.**
- 4 The western U.S. has suffered an extended drought that has shown that better management of the water resource through more effective and economically efficient water use is essential.
- 5 A **short term solution** could be the establishment of a ground-station for downloading image data from the **Sino-Brazilian CBERS satellite system** that has spatial resolution and thermal band similar to Landsat.

### **We need a working Landsat system that (ideally) is:**

- An array of two to four Landsat satellites
- Each satellite is equipped with at least one **thermal band sensor** (for measurement of surface temperature) at a maximum of 60 m resolution.
- The array is operated to provide images every four days for all points within the United States.

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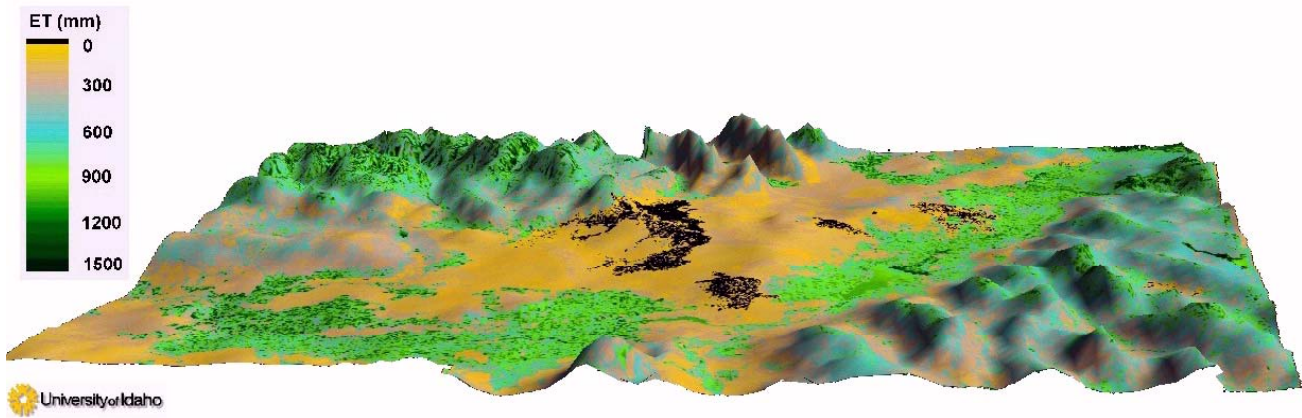
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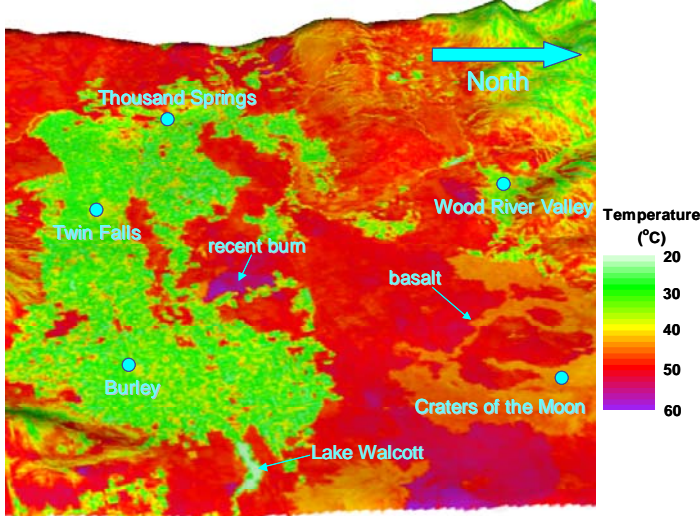
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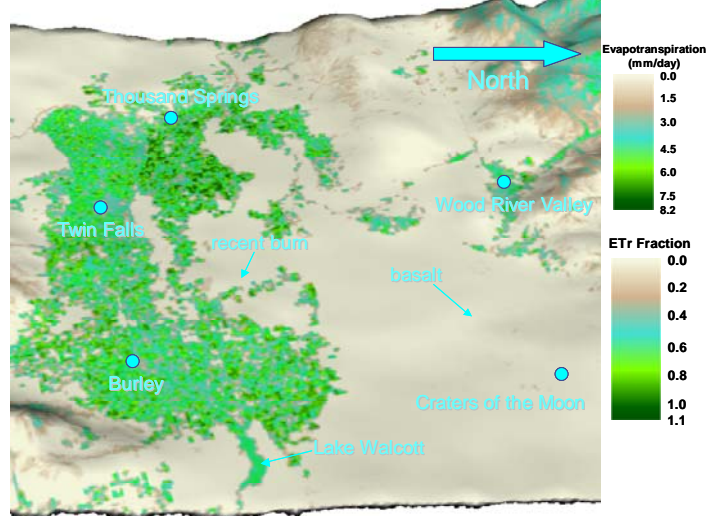


Annual Evapotranspiration for a 200 mile x 100 mile section of southern Idaho during year 2000 as determined from Landsat visible and thermal imagery by the METRIC processing algorithms. Resolution of the ET map is 30 m x 30 m.

Surface Temperature – southcentral Idaho – August 14, 2000



24-hour ET – southcentral Idaho – August 14, 2000



Surface temperature image from Landsat (left) for southcentral Idaho and associated evapotranspiration 'map' (right) derived from the Landsat visible and thermal images.