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9 **IN THE SUPERIOR COURT OF THE STATE OF ARIZONA**  
10 **IN AND FOR THE COUNTY OF APACHE**

11 **IN RE THE GENERAL ADJUDICATION**  
12 **OF ALL RIGHTS TO USE WATER IN**  
13 **THE LITTLE COLORADO RIVER**  
14 **SYSTEM AND SOURCE**

15 Contested Case Nos. CV 6417-33-6735  
16 CV6417-33-6893

17 **ARIZONA DEPARTMENT OF**  
18 **WATER RESOURCES' NOTICE OF**  
19 **FILING REPORT &**  
20 **RECOMMENDATION REGARDING**  
21 **THE PENMAN-MONTEITH**  
22 **METHODOLOGY**

23 Special Master Sherri Zendri

24 **CONTESTED CASE NAME:** *In re Jack G. and V. Scott Peterson and In re Kenneth L. and Joy Abrams*

25 **DESCRIPTIVE SUMMARY:** The Arizona Department of Water Resources' ("ADWR")  
26 provides notice of filing its Report & Recommendation Regarding the Penman-Monteith  
Methodology, as requested in the Court's Minute Entry order filed on July 8<sup>th</sup>, 2025.

**NUMBER OF PAGES:** Two and five-page attachment

**DATE OF FILING:** September 9, 2025

In the Court's July 8, 2025 Minute Entry, it requested for ADWR to "provide its  
recommendation on or before September 15, 2025, as to whether the Penman-Monteith

1 methodology is appropriate to use in this contested case and potentially for the entire Little  
2 Colorado River basin.”<sup>1</sup> Accordingly, ADWR provides its Report & Recommendation  
3 Regarding the Penman-Monteith Methodology (Attachment A).

4 **DATED** this 9th day of September 2025.

5 ARIZONA DEPARTMENT OF WATER  
6 RESOURCES

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9 Karen J. Nielsen, Deputy Counsel

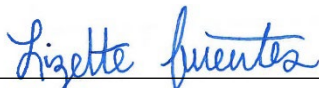
10 **ORIGINAL** of the foregoing sent by  
11 first-class mail on September 9, 2025, to:

12 Clerk of Apache County Superior Court  
13 70 West Third South  
14 St. Johns, Arizona 85936

15 **COPY** of the foregoing sent by  
16 Electronic mail on September 9, 2025, to:

17 Special Master Sherri Zendri  
18 [water@jbazmc.maricopa.gov](mailto:water@jbazmc.maricopa.gov)

19 **COPIES** of the foregoing sent by  
20 first-class mail on September 9, 2025, to  
21 all parties on the court-approved mailing list  
22 for Contested Case Nos. CV6417-33-6735  
23 & CV6417-33-6893.

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25 <sup>1</sup> [Minute Entry for July 1, 2025 Status Conference](#), *In re Jack G. and V. Scott Peterson and*  
26 *In re Kenneth L. and Joy Abrams*, Contested Case Nos. CV6417-33-6735 and CV 6417-33-  
6893, filed July 8, 2025 at PDF p.3.

# **ATTACHMENT A**

**CV6417-33-6735 & CV6417-33-6893 *In re Jack G. and In re V. Scott Peterson & Kenneth L. and Joy Abrams***

**Report & Recommendation Regarding the Penman-Monteith Methodology**

**Introduction**

The Arizona Department of Water Resources (ADWR) prepared this report pursuant to the Court’s Minute Entry order filed on July 8th, 2025. The Court requested:

“ADWR shall provide its recommendation on or before September 15, 2025, as to whether the Penman-Monteith methodology is appropriate to use in this contested case and potentially for the entire Little Colorado River basin.”<sup>1</sup>

The following report summarizes ADWR’s determination if the Penman-Monteith method is appropriate for this contested case, as well as ADWR’s assessment regarding its appropriateness for its use across the entire Little Colorado River basin.

**Background on Penman-Monteith**

The methodology developed by Howard Penman and John Monteith referred to as the Penman-Monteith (PM) method was developed in 1948 by Howard Penman<sup>2</sup> and revised in 1965 by John Monteith<sup>3</sup> to produce the PM method in use today. The PM method uses both physical climatological variables, such as vapor pressure and wind speed, and energy flux variables, such as net radiative flux and soil heat flux, as inputs to the formula. This method is a widely accepted methodology for calculating reference evapotranspiration<sup>4</sup> (ET<sub>o</sub>) rates

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<sup>1</sup> Minute Entry filed on July 8, 2025, Contested Case No. CV6417-33-6735, *In re Jack G. and V. Scott Peterson*.

<sup>2</sup> Howard Latimer Penman, *Natural Evaporation from Open Water, Bare Soil and Grass, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, April 22, 1948, <https://royalsocietypublishing.org/doi/epdf/10.1098/rspa.1948.0037>.

<sup>3</sup> J. L. Monteith, *Evaporation and Surface Temperature, Quarterly Journal of the Royal Meteorological Society* 107, No. 451 (1981): 1-27, <https://bit.ly/46eEuly>.

<sup>4</sup> Evapotranspiration (ET) is the transfer of water to the atmosphere through evaporation and transpiration from plants. Reference ET (ET<sub>o</sub>) is a calculated quantity used to represent the ET of a reference crop, typically grass or alfalfa. Crop ET (ET<sub>c</sub>) is a calculated quantity used to represent the ET of a crop of interest, derived by multiplying ET<sub>o</sub> by a crop coefficient (K<sub>c</sub>). Actual ET (E<sub>a</sub>) is a measurement of ET from all sources, representing the water lost from a surface under real world conditions.



of irrigated crops and is recommended by the Food and Agriculture Organization<sup>5</sup> (FAO). ETo is used to approximate the water requirements to support a crop during its growing stages. ETo is an incomplete picture of Evapotranspiration (ET) as a whole, since ETo is limited to the ET of a grass (or alfalfa) reference crop. If another crop's water requirements are being assessed, ETo must be multiplied by a crop coefficient (Kc), which may vary throughout the growing season. ETo multiplied by Kc yields the crop's specific evapotranspiration (ETc)<sup>6</sup>. Use of the PM method only calculates the ET rate of the crop being assessed. The ETc calculation is not the final calculation of consumptive use or quantity. The final calculation of consumptive use and quantity should also include other factors such as effective precipitation, net irrigation requirement, application efficiencies and conveyance efficiencies. Consumptive use quantifies the amount of water needed to be applied to a field to grow a specific crop.

### **Is Penman-Monteith appropriate for this case?**

ADWR has determined that the PM method is an appropriate method for this case if it has the necessary data inputs available, as it is the widely accepted method for calculating ET and recommended by the FAO<sup>7</sup>. However, the following criteria and necessary data inputs representative of the area where the field is located are required to quantify the ET rate accurately:

- A climate station representative of the area of interest that records windspeed, net radiation, actual and saturated vapor pressure, mean air temperature, and precipitation.
- Crop data for the field of interest over the time period of interest.

Measuring instruments should be calibrated to ensure accurate measurements. Windspeed must also be corrected to two meters above surface (if recorded at any other height).

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<sup>5</sup> Richard G. Allen et al., *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*, FOA Irrigation Drainage Paper 56 (Rome: Food and Agriculture Organization of the United Nations, 1998), <https://www.fao.org/4/x0490e/x0490e00.htm#Contents>.

<sup>6</sup> Richard G. Allen et al., *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*, FOA Irrigation Drainage Paper 56 (Rome: Food and Agriculture Organization of the United Nations, 1998), <https://www.fao.org/4/x0490e/x0490e00.htm#Contents>.

<sup>7</sup> Richard G. Allen et al., *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*, FOA Irrigation Drainage Paper 56 (Rome: Food and Agriculture Organization of the United Nations, 1998), <https://www.fao.org/4/x0490e/x0490e00.htm#Contents>.



## **Is Penman-Monteith appropriate for use in the entire Little Colorado River basin (LCR)?**

The remote location of irrigation uses within the LCR may result in gaps in the representative climate data necessary for the PM method to accurately quantify ETc. ADWR acknowledges that some irrigation uses within the LCR basin may have the necessary climate data available and the PM method would be appropriate for those uses. However, due to the variability in available climate data throughout the LCR, ADWR recommends that another method, OpenET, be used as it is consistently available throughout the entire LCR and does not have the same pitfalls as the PM method, described below. The PM method has significant drawbacks including the lack of continuous climate data, variability in the methods used to record climate data, and requiring field visits to verify crop types. Climate stations across Arizona are managed by differing entities such as municipalities, airports, and cooperative organizations, among others. This variability in climate station management leads to differences in the way climate data is collected. For example, windspeed might be measured at ten meters above ground level at airports and measured at two meters above ground level at cooperative stations. A variability in input data for the PM method across the LCR basin leads to variability in the quantification of ET rates across the basin. The PM method also requires that the person completing the calculation knows the crop type being grown on the field of interest. This information is often not supplied by the claimant in their Statement of Claimant or pre-adjudication filing, or, even if the information was supplied, may have changed over time. Without access to that necessary data, any person using the PM method would need to conduct extensive field work or contract with other entities to acquire field by field crop type information. This would be costly and time intensive for ADWR to perform basin-wide. Because of the disadvantages associated with the PM method, ADWR does not recommend the PM method to be used to calculate *all* irrigation uses within the Little Colorado River (LCR) basin.

### **OpenET: An alternate method of quantifying ET rates**

OpenET began development around 2018 through a collaborative initiative led by the Environmental Defense Fund, National Aeronautics Space Agency (NASA), United States Geological Survey (USGS), Desert Research Institute, Google, and many more



collaborators<sup>8</sup>. The goal of the project was to provide ET data to the public to assist farmers and water managers to accurately track water consumption. Three years later, in 2021, OpenET data was made publicly available for 17 states across the western United States, including Arizona. OpenET<sup>9</sup> is an open-sourced data platform to access ET rates at a 30x30 meter resolution calculated via a surface energy balance model(s). The OpenET method has many similarities to the PM method as both methods use energy fluxes to quantify ET rates, but OpenET does not require the difficult-to-obtain physical climatological variables like the PM method. Due to the lack of physical climatological data required for the OpenET method, remote sensing techniques are used to acquire the necessary inputs to the model across the entire area of interest consistently. An accuracy assessment of OpenET reported a mean absolute error of 15.55 mm/month (16.6% average error) at monthly timesteps for 45 cropland sites over 1,682 months<sup>10</sup>. The Upper Colorado River Commission found that the PM method routinely overestimated ET values, with a maximum error of approximately 125%, when compared to direct measurements of ET<sup>11</sup>. Entities and governmental agencies across the Western United States have rapidly adopted OpenET as a standardized methodology to calculate ET since its release in 2021. Among these entities and agencies are: the Upper Colorado River Commission and Bureau of Reclamation<sup>12</sup>,

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<sup>8</sup> OpenET, *EDF, NASA, DRI and Google Announce Web Application to Transform Water Management in the Western United States*, 2020, <https://etdata.org/press-release-09-2020/#:~:text=OpenET%20will%20fill%20a%20critical,surface%20and%20transpires%20from%20plants>.

<sup>9</sup> OpenET, *OpenET - Filing the Biggest Gap in Water Data*, 2025, <https://etdata.org/>.

<sup>10</sup> OpenET, *Intercomparison and Accuracy Assessment Report* (OpenET, 2021), [https://openetdata.org/wp-content/uploads/2021/10/Intercomparison-and-Accuracy-Assessment-Report.pdf?sa=D&source=docs&ust=1756138896217878&usg=AOv-Vaw3kfpHCwM\\_0uBgJ9kbP-7CO](https://openetdata.org/wp-content/uploads/2021/10/Intercomparison-and-Accuracy-Assessment-Report.pdf?sa=D&source=docs&ust=1756138896217878&usg=AOv-Vaw3kfpHCwM_0uBgJ9kbP-7CO).

<sup>11</sup> Upper Colorado River Commission, *Assessing Agricultural Consumptive Use: Including Remote Sensing of Actual Evapotranspiration in the Upper Colorado River Basin*, 2016, [http://www.ucrcommission.com/RepDoc/Studies/Assessing%20Ag\\_CU\\_PhaseII.pdf](http://www.ucrcommission.com/RepDoc/Studies/Assessing%20Ag_CU_PhaseII.pdf).

<sup>12</sup> Upper Colorado River Commission, *OpenET: Upper Colorado River Commission and Bureau of Reclamation Move to Satellite-Based ET for Consistent Consumptive Water Use Measurements*, 2022, [http://www.ucrcommission.com/openet-upper-colorado-river-commission-and-bureau-of-reclamation-move-to-satellite-based-et-for-consistent-consumptive-water-use-measurments/&sa=D&source=docs&ust=1756138896220455&usg=AOv-Vaw09oZ0UaYulPwMdgPP764v\\_](http://www.ucrcommission.com/openet-upper-colorado-river-commission-and-bureau-of-reclamation-move-to-satellite-based-et-for-consistent-consumptive-water-use-measurments/&sa=D&source=docs&ust=1756138896220455&usg=AOv-Vaw09oZ0UaYulPwMdgPP764v_).



Idaho Department of Water Resources<sup>13</sup>, Montana Climate Office<sup>14</sup>, California Department of Water Resources<sup>15</sup>, Colorado River Authority of Utah<sup>16</sup>, and the Salt River Project<sup>17</sup>.

ADWR prefers the OpenET methodology to quantify irrigation uses for the following reasons:

- Provides a consistent method readily available to calculate ET across an entire watershed
- Uses open-source data available to the public free of charge,
- Provides pre-calculated ET rates, allowing claimants and parties to the Adjudication easier access to quantify themselves, and
- Is significantly more efficient in terms of time and money spent quantifying irrigation uses<sup>18</sup>.

## Summary

ADWR finds that the PM method may be applicable for quantifying the irrigation uses for this case if the necessary climate data is available and that data is representative of the area of interest. However, ADWR does not recommend using the PM method to quantify all irrigation uses across the LCR due to lack of climate data availability, inconsistent recording methods of available climate data, and an inefficient use of ADWR staff time.

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<sup>13</sup> Idaho Department of Water Resources, *Director's Annual Report: 2023*, 2023, <https://idwr.idaho.gov/wp-content/uploads/sites/2/general/2023-Directors-Annual-Report-FINAL.pdf>.

<sup>14</sup> Ketchum, David, Kelsey Jencso, Marco P. Maneta, Forrest Melton, Matthew O. Jones and Justin Huntington. *IrrMapper: A Machine Learning Approach for High Resolution Mapping of Irrigated Agriculture Across the Western U.S. Remote Sensing* 12, No. 14: 2328. 2020. <https://doi.org/10.3390/rs12142328>.

<sup>15</sup> California Natural Resources Agency, California Environmental Protection Agency, and California Department of Food and Agriculture. *Water Resilience Portfolio*, 2023, [https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/WRP\\_PR23\\_Progress\\_Report\\_2023.pdf](https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/WRP_PR23_Progress_Report_2023.pdf).

<sup>16</sup> Colorado River Authority of Utah, *OpenET*, Accessed August 25, 2025, <https://cra.utah.gov/openet/>.

<sup>17</sup> OpenET, *Use Cases: Salt River Project*, Accessed August 25, 2025, <https://openet-data.org/openet-use-cases/#srp>.

<sup>18</sup> ADWR recorded a 95% increase in efficiency when quantifying irrigation uses using OpenET.

