# A Dual-Purpose Evaporimeter

An insulated evaporimeter has been developed which may provide an improved index to lake evaporation and also serve as an integrator of incident minus reflected all-wave radiation. Results of field tests under significantly different climatic regimes indicate a comparatively stable relationship to lake evaporation. Daily incident minus reflected all-wave radiation may be computed by an energy budget approach utilizing the daily values of evaporation, air temperature, surface water temperature, dewpoint temperature and change in heat storage. The computed values are compared with those obtained from observed total incoming all-wave radiation and solar (short-wave) radiation assuming reflectivity coefficients of 0.03 for long-wave and 0.06 for short-wave radiation.

# A DUAL PURPOSE EVAPORIMETER

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The most widely used method for estimating evaporation from lakes and reservoirs is to apply an appropriate coefficient to pan evaporation measurements. During studies at Lake Hefner (USGS 1954) the following pan coefficients were derived for the most commonly used pans in the United States: Class "A", 0.69; Bureau of Plant Industry, 0.91; Colorado, 0.83; and Young Screened, 0.91. The standard pan used in the Soviet Union is the GGI-3000 (surface area of 3000 $cm^2$) sunken pan which has a coefficient of 0.75 to 1.00.

The transfer of heat through the sides and bottom of the standard pans is related to meteorological conditions and thus the pan-to-lake coefficients vary with climate. Pan coefficients required to provide the best estimates of lake evaporation are generally lower in arid climates and higher for humid areas. Those for the Class "A" pan range from 0.60 to 0.80.

Kohler and others (1955) in Weather Bureau Research Paper No. 38 described a method for adjusting Class "A" evaporation measurements to account for the heat transfer through the sides and bottom of the pans. This method requires the basic data for pan evaporation, surface water temperature, air temperature and wind movement. It would be desirable to have a pan that would have a nearly constant pan-to-lake coefficients.

## Experimental Insulated Pan

To help overcome the deficiency of the heat transfer through the pans, the Weather Bureau in 1960 designed and built an experimental insulated evaporimeter. The original pan, designated the X-1 for experimental, was a circular fiberglass pan 36 cm in diameter, 6.4 cm deep and insulated with styrofoam. This pan was equipped with a thin piano wire screen to provide protection from birds, etc. Analysis of the data from the X-1 pan indicated that the depth of water was not adequate to provide sufficient heat storage and the mean daily water

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temperature when used in the mass transfer equation did not provide satisfactory correlation with pan evaporation. Tests began on a revised design, the X-2, in 1965. This pan was larger and deeper than the X-1, being 62 cm in diameter and 61 cm deep, and was insulated with 8.2 cm of freon-blown polyurethane on the sides and bottom. Readings were made by use of a fixed point fiberglass stilling well which was placed in the pan when measurements were made. The bottom and sides of the interior of the pan were painted black below the water level to minimize reflected radiation.

Analysis of data from the X-2 pan showed satisfactory relation when used in the mass transfer equation. Changes were incorporated in the present model, the X-3, to impove observational techniques. The insulated on the upper part of the pan was increased in thickness to accommodate an offset stilling well for ease in reading. All of the experimental pans have been installed with the rim of the pan and an odometer anemometer at one meter above ground level.

The X-2 and X-3 have been field tested under significantly different climatic regimes. The X-2 pan was installed at the WMO, CIMO, evaporation comparison sites at Sterling, Virginia, Davis, California and Lake Mead, Nevada, from the spring of 1965 to midsummer 1968. Testing of the X-3 pan started in 1967 at the same sites, at Danville, Vermont and at four locations near the Salton Sea in the desert area of southern California. Eleven pans are now being installed for further field testing including locations in Hawaii and Alaska. Slide 1 is a picture of the evaporation pans installed at the WMO, CIMO evaporation comparison site at Sterling, Virginia with an X-2 insulated pan in the foreground, a Soviet 20m$^2$ sunken tank in the background and GGI-3000 Soviet sunken pans to the right. Slide 2 shows the X-3 pan with the offset stilling well.

## The Insulated Pan as an Evaporimeter

Ratios of pan evaporation to assumed lake evaporation were computed for the experimental insulated pan, the Class "A" pan and the Soviet GGI-3000 sunken pan (Table 1). The daily evaporation from the Soviet 20 $m^2$ sunken tank, adjusted for heat storage, has been assumed to simulate a lake. These tanks are 5 meters in diameter and 2 meters deep. The computed ratios, or pan coefficients, for the Class "A" pan varied from 0.64 at Lake Mead to 0.74 at Davis, California. Those for the GGI-3000 range from 0.68 to 1.15 and those for the insulated pan only from 0.72 to 0.77. The test periods from 286 to 370 days are considered adequate to provide a good check on the stability of the coefficients.

## The Insulated Pan as a Radiaiton Integrator

A secondary objective of using an insulated pan was to have it serve as a radiation integrator similar to the Cummings Integrator described in the Lake Hefner Report (USGS 1954). The energy balance for an insulated pan is:

$$Q_a + Q_s - Q_{ar} - Q_r = Q_e + Q_h + Q_\theta + Q_v + Q_w + Q_b$$

where,

$Q_a$ = incoming atmospheric (long-wave) radiation.

$Q_s$ = incoming solar (short-wave) radiation.

$Q_{ar}$ = reflected long-wave radiation.

$Q_r$ = reflected solar radiation.

$Q_e$ = energy used for evaporation.

$Q_h$ = energy conducted from body of water as sensible heat.

$Q_b$ = long-wave radiation emitted by body of water.

$Q_\theta$ = change in energy storage.

$Q_v$ = net energy advected into body of water.

$Q_w$ = energy advected by evaporated water.

When only rainless days are included the net energy advected into the body of water, $Q_v$, may be neglected. If the magnitude of the advection losses due to evaporation is very small with respect to the other terms, the energy advected by evaporated water, $Q_w$, may also be neglected.

By defining $Q_{ir}$ as the incident minus reflected total radiation, equation 1 can be expressed as:

$$Q_{ir} = Q_a + Q_s - Q_{ar} - Q_r = Q_e + Q_h + Q_b + Q_v \qquad (2)$$

Using Bowens ratio and further simplifying:

$$Q_{ir} = EL\,(1 + R) + \varepsilon\sigma\, T_o^{\,4} + D\,(T_o - T_{oy}) \qquad (3)$$

where,

$$R = \text{Bowens Ratio} = \frac{Q_h}{Q_e} = \gamma\,\frac{T_o - T_a}{e_o - e_a}$$

$\gamma$ = constant derived from standard psychometric equation (assumed 0.000367 times the station pressure in this comparison).

$T_o$ = water-surface temperature.

$T_a$ = air temperature.

$e_o$ = water vapor pressure at the water surface temperature.

$e_a$ = atmospheric water vapor pressure.

E = observed evaporation.

L = latent heat of vaporization.

$\varepsilon$ = emissivity of the water surface.

$\sigma$ = Stefan-Boltzman constant for black body radiation

D = depth of water (in cm.).

$(T_o - T_{oy})$ = Temperature increase from last time of observation (in ° C).

Pan evaporation and mean air, dew-point and surface water temperatures are used to compute the energy loss by evaporation and sensible heat (the first term on the right hand side of the second equation slide 5). The mean daily surface water temperature was used to evaluate the energy emitted by long-wave radiation from the body of water ( the second term of equation 3) and the change in water temperature (after stirring) for the observational period was used to account for the change in heat storage (the last term of equation 3).

Incident minus reflected total radiation values ($Q_{ir}$) from the above equation were compared with values obtained from observed radiation measurements of total hemispherical and solar radiation. The reflected coefficients for long and short-wave radiation were assumed to be 0.03 and 0.06 respectively as:

$$Q_a = Q_{total} - Q_s$$

$$Q_{ir} = 0.97\ Q_a + 0.94\ Q_s$$

Observed and computed daily values of $Q_{ir}$ are shown in Table 2. At Sterling, Virginia, for a 195 day period, the regression correlation was 0.94 with an average daily error of 5% and a bias of only 0.6 percent. At the Salton Sea Test Base, which was the location of the radiation equipment at Salton Sea, the regression correlation was 0.87, the average daily error 6% and the bias 1.3 percent.

## Other Uses for $Q_{ir}$

In addition to the use of a pan-to-lake coefficient to compute lake evaporation, the computed $Q_{ir}$ values could be utilized in evaporation formulae requiring total absorbed radiation. Computed $Q_{ir}$ values were used in the Kohler-Parmele equation (1967) and compared with the lake evaporation based on the observations from the 20 $m^2$ Soviet tanks. These results are shown in Table 3. The technique appears to be very good since the bias values for all sites are within plus or minus 1.0%.

## Future Evaluation

A screen to protect the water from birds and animals is being tested on the X-3 pan so that the pan could be used in any areas where such losses are significant. Initial analysis from these tests indicates that the use of a screen requires a correction to the pan-to-lake coefficient but the computed values of $Q_{ir}$ are as reliable as those obtained from unscreened pans. Studies are also being proposed to determine the value of the pan as a radiation integrator during periods of freezing weather conditions by use of antifreeze solutions or other heatsinks.

The preliminary analysis on the use of the insulated pan as an evaporimeter and as a radiation integrator has been very encouraging. However, considerable additional field testing is considered necessary before a recommendation could be made to adopt the insulated pan as a standard for evaporation measurements.

TABLE 1

OBSERVED PAN COEFFICIENTS

| Location | No. of Days | Pan Coefficients | | |
|---|---|---|---|---|
| | | Class A | GGI-3000 | X-3 |
| Sterling, Va. | 286 | 0.70 | 1.15 | 0.77 |
| Lake Mead, Nev. | 290 | 0.64 | 0.68 | 0.72 |
| Davis Calif. | 370 | 0.74 | 0.95 | 0.72 |

TABLE 2

COMPARISON OF OBSERVED AND COMPUTED VALUES OF INCIDENT MINUS REFLECTED TOTAL RADIATION

| Location | No. of Days | Regression Coefficient | Average Daily Error Percent | Bias Percent |
|---|---|---|---|---|
| Salton Sea Test Base | 124 | 0.87 | 6.1 | -1.3 |
| Salton Sea National Refuge | 88 | 0.80 | 6.8 | -2.1 |
| Salton Sea Niland | 158 | 0.84 | 7.1 | +0.9 |
| Salton Sea State Park | 168 | 0.90 | 5.8 | -0.3 |
| Sterling, Virginia X-2 | 195 | 0.94 | 4.8 | -0.6 |
| Sterling, Virginia X-3, No. 1 | 125 | 0.89 | 6.0 | +4.3 |
| Sterling, Virginia X-3, No. 2 | 127 | 0.90 | 5.7 | +4.7 |

TABLE 3

COMPARISON OF LAKE EVAPORATION COMPUTED
BY KOHLER PARMELE AND OBSERVED 20 $m^2$ EVAPORATION PAN

| Location | No. of Days | Bias Percent |
|---|---|---|
| Sterling, Virginia | 286 | -1.0 |
| Lake Mead, Nevada | 290 | +1.3 |
| Davis, California | 370 | +1.0 |