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Comparison of Potential Evapotranspiration Calculated by the LXPET (Lamoreux Potential Evapotranspiration) Program and by the WDMUtil (Watershed Data Management Utility) Program

Open-File Report 2005-1020

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
	Energy	
Langleys per day (Lg/d)	279.12	Joules per square meter (W/m^3)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Comparison of Potential Evapotranspiration Calculated by the LXPET (Lamoreux Potential Evapotranspiration) Program and by the WDMUtil (Watershed Data Management Utility) Program

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Abstract

Potential evapotranspiration can be estimated using observed meteorological data, and many methods have been developed to accomplish this estimation. This report, prepared by the U.S. Geological Survey in cooperation with DuPage County Department of Engineering, Stormwater Management Division, describes the LXPET (Lamoreux Potential Evapotranspiration) program and compares the daily and hourly values calculated by LXPET with the values calculated by WDMUtil (Watershed Data Management Utility). The inputs to both LXPET and WDMUtil are total daily solar radiation in Langleys per day, total daily wind movement in miles, and average daily dewpoint temperature in degrees Fahrenheit. Average air temperature in degrees Fahrenheit is used in LXPET, whereas either maximum and minimum daily air temperature or average daily air temperature in degrees Fahrenheit is used in WDMUtil. The latitude (degree, minute, second) where evaporation is calculated is a required WDMUtil input.

The daily evaporation time-series data generated by LXPET are smaller by a factor of 0.7 than the daily time-series data generated by WDMUtil. The 0.7 factor is the same as the 0.7 correction factor commonly applied to pan evaporation data to approximate lake evaporation. The time series from either program can be used in hydrologic modeling depending on the expected model input. The Hydrologic Simulation Program-Fortran (HSPF), the hydrologic model used in this study, uses potential evapotranspiration as input. Because lake evaporation is used as potential evapotranspiration in hydrologic modeling, LXPET time-series values should be used as HSPF input or the WDMUtil time-series values should be multiplied by 0.7 before being input into HSPF. However, because the WDMUtil time series is adjusted for season of the year, this time series may give more realistic evaporation values when HSPF is run over multiple seasons.

Introduction

The U.S. Geological Survey (USGS), in cooperation with DuPage County Department of Engineering, Stormwater Management Division, has been conducting hydrologic and hydraulic modeling studies in DuPage County, Ill. since 1997 using Hydrologic Simulation Program-Fortran (HSPF) as the hydrologic model. Potential evapotranspiration is an important parameter in hydrologic modeling, and it can be estimated using observed meteorological data. A study was begun in 2003 to compare the potential evapotranspiration time series calculated by LXPET (Lamoreux Potential Evapotranspiration) and WDMUtil (Watershed Data Management Utility), a program packaged with HSPF as part of the BASINS (Better Assessment Science Integrating point and Nonpoint Sources) software system (U.S. Environmental Protection Agency, 2001). The purpose of this report is to compare the evapotranspiration time series generated by LXPET with that generated by WDMUtil. The differences between the two time series are discussed, as well as the time series used for HSPF model simulation. The differences between the two time series are also shown graphically using meteorological inputs from the Argonne National Laboratory in Illinois. This meteorology station has been operated since 1948 and data from January 1, 1990, to September 30, 2003, are used in this study (Argonne National Laboratory, 2005).

The USGS was given a program for calculating potential evapotranspiration based on the method of Kohler and others (1955) as adapted to digital computers by Lamoreux (1962) by the Northeastern Illinois Planning Commission (NIPC). The USGS also was given a program for distributing the calculated daily time series to hourly values (Tom Price, Northeastern Illinois Planning Commission, presently with Conservation Design Forum, written commun., 1997). The program code probably originated as part of the LANDS module of the HSP (Hydrocomp Simulation Program) hydrologic model (Hydrocomp International, Inc., 1970) and was coded in PL/1 before it was ported to FORTRAN (FORmula TRANslation) in the early 1980s. The program was coded in FORTRAN by Hey and Associates under contract to NIPC (Tom Price, Northeastern Illinois Planning Commission, presently with Conservation Design Forum, written commun., 2005). Kohler and others (1955) developed graphs to determine lake evaporation from air temperature, dewpoint temperature, solar radiation, and wind movement. Lamoreux (1962) developed equations from the graphs, so a computer can be used to calculate the evaporation. The USGS modified and combined the two programs to automatically distribute the daily time series to an hourly time series and to accept average daily air temperature as an input time series rather than a maximum daily air temperature and a minimum daily air temperature. The USGS named the program LXPET to reflect the use of the Lamoreux methods and calculation of potential evapotranspiration. No complete documentation is available for LXPET; however, this report will describe the equations and methods used by LXPET to calculate potential evapotranspiration and provide instructions for using LXPET in appendix A. The FORTRAN source code for the LXPET program has been included in appendix B. A digital version of the FORTRAN source code and the compiled LXPET program can be requested from the USGS Illinois Water Science Center.

Comparison of Potential Evapotranspiration Equations

LXPET and WDMUtil can both be used to calculate evaporation. LXPET is based on the method of Kohler and others (1955) as adapted to digital computers by Lamoreux (1962). LXPET calculates lake evaporation. The Penman pan evaporation calculations used in WDMUtil are based on the Penman (1948) formula and the method of Kohler and others (1955).

The inputs to LXPET are total daily solar radiation in Langleys per day (Lg/d), total daily wind movement in miles (mi), average daily dewpoint temperature in degrees Fahrenheit (°F), and average daily air temperature (°F). Average air temperature (°F) is required in LXPET, whereas WDMUtil requires either maximum and minimum daily air temperatures, or average daily air temperature (°F). WDMUtil also requires the latitude (degree, minute, second) where evaporation is calculated. The output of LXPET is an hourly lake evaporation time series (thousandths of an inch). The output of WDMUtil is an hourly pan evaporation time series (inches).

The LXPET program contains the following equations for the calculation of lake evaporation (*EVAP*).

$$EVAP = B * A * 1{,}000\,, \tag{1}$$

where

$$B = \left[0.015 + ((T_a + 398.36)^{-2}) * 68{,}554{,}000{,}000 * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right)\right]^{-1},$$

$$A = \exp\left((T_a - 212) * (0.1024 - 0.01066 * \ln(R))\right) - 0.0001 + 0.0105 * C^{0.88} * (0.37 + 0.0041 * U_p)\,,$$

where

$$C = 6{,}413{,}300 * \left[\exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right) - \exp\left(\frac{-7{,}482.6}{(DEWP + 398.36)}\right)\right],$$

where T_a is the air temperature in °F, R is the total daily solar radiation in Langleys, U_p is total daily wind movement in miles, and *DEWP* is the dewpoint temperature in °F.

The WDMUtil Version 2.0 Users' Manual (2001) states the Penman daily pan evaporation formula as

$$E = \frac{(Q * DEL + E_a * GAM)}{(DEL + GAM)}, \quad (2)$$

where E is pan evaporation in inches, Q is net radiation exchange, *DEL* is the slope of the saturation vapor-pressure curve at the given air temperature, *GAM* is 0.0105 inch Hg/°F (defined by Bowen's ratio), and E_a is pan evaporation when air temperature equals water temperature.

The empirical equation for $Q * DEL$ is

$$Q * DEL = \exp[(T_a - 212)(0.1024 - 0.01066 * \ln(R))] - 0.0001.$$

(The last term in the equation above is actually listed as 0.000 in the WDMUtil documentation (WDMUtil Version 2.0 Users' Manual, 2001), but that was confirmed to be an error (Paul Cocca, U.S. Environmental Protection Agency, written commun., 2004.))

The equation for E_a is

$$E_a = (0.37 + 0.0041 * U_p) * (e_s - e_a)^{0.88},$$

where $(e_s - e_a)$ is the vapor-pressure deficit between the surface and dewpoint temperatures.

As is shown in table 1 and discussed below, the key difference between the LXPET and WDMUtil programs is the slope of the saturation vapor-pressure curve, *DEL*.

DEL is calculated in LXPET with the equation

$$DEL = (T_a + 398.36)^{-2} * 68{,}554{,}000{,}000 * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right). \quad (3)$$

DEL is calculated in WDMUtil with the equation

$$DEL = \left(\frac{7{,}482.6}{(T_a + 398.36)^2}\right) \exp\left(15.674 - \frac{7{,}482.6}{(T_a + 398.36)}\right). \quad (4)$$

A side-by-side comparison of the LXPET and WDMUtil evaporation equations is provided in table 1. This table illustrates that the programs are based on the same set of equations. The only difference between pan evaporation and lake evaporation is in the equation for *DEL*.

Table 1. Comparison of the LXPET (Lamoreux Potential Evapotranspiration) and WDMUtil (Watershed Data Management Utility) equations used to generate the evaporation time series for this study.

[*EVAP*, lake evaporation in thousandths of an inch,; T_a, air temperature in degrees Fahrenheit (°F); *R*, total daily solar radiation in Langleys; U_p, total daily wind movement in miles; *DEWP*, dewpoint temperature in °F; *E*, pan evaporation in inches; *Q*, net radiation exchange; *DEL*, slope of the saturation vapor pressure curve at the given air temperature; *GAM*, 0.0105 inch Hg/°F (defined by Bowen's ratio); E_a, pan evaporation when air temperature equals water temperature; (e_s-e_a), vapor-pressure deficit between the surface and dewpoint temperatures]

LXPET	WDMUtil
$EVAP = 1{,}000\left(\frac{A}{B'}\right) = \frac{(Q * DEL + GAM * E_a)}{(GAM + DEL)}$, where $A = Q * DEL + GAM * E_a$ and $B' = B^{-1} = GAM + DEL$	$E = \frac{(Q * DEL + E_a * GAM)}{(DEL + GAM)}$
Numerator	
$A = \exp[(T_a - 212)(0.1024 - 0.01066 * \ln(R))] - 0.0001 + 0.0105 * (0.37 + 0.0041 * U_p) * C^{0.88}$, where $C = e_s - e_a$	$Q * DEL = \exp[(T_a - 212)(0.1024 - 0.01066 * \ln(R))] - 0.0001$ $E_a = (0.37 + 0.0041 * U_p) * (e_s - e_a)^{0.88}$ $GAM = 0.0105$
Denominator	
$B' = \left[0.015 + ((T_a + 398.36)^{-2}) * 68{,}554{,}000{,}000 * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right)\right]$	$DEL + GAM = \left(\frac{7{,}482.6}{(T_a + 398.36)^2}\right) \exp\left(15.674 - \frac{7{,}482.6}{(T_a + 398.36)}\right) + 0.0105$
$DEL = (T_a + 398.36)^{-2} * 68{,}554{,}000{,}000 * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right)$ $= (T_a + 398.36)^{-2} * \frac{4.7988 * 10^{10}}{0.7} * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right)$	$DEL = \left(\frac{7{,}482.6}{(T_a + 398.36)^2}\right) \exp\left(15.674 - \frac{7{,}482.6}{(T_a + 398.36)}\right)$ $= (T_a + 398.36)^{-2} * 7{,}482.6 * \exp(15.674) * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right)$ $= (T_a + 398.36)^{-2} * 4.799 * 10^{10} * \exp\left(\frac{-7{,}482.6}{(T_a + 398.36)}\right)$

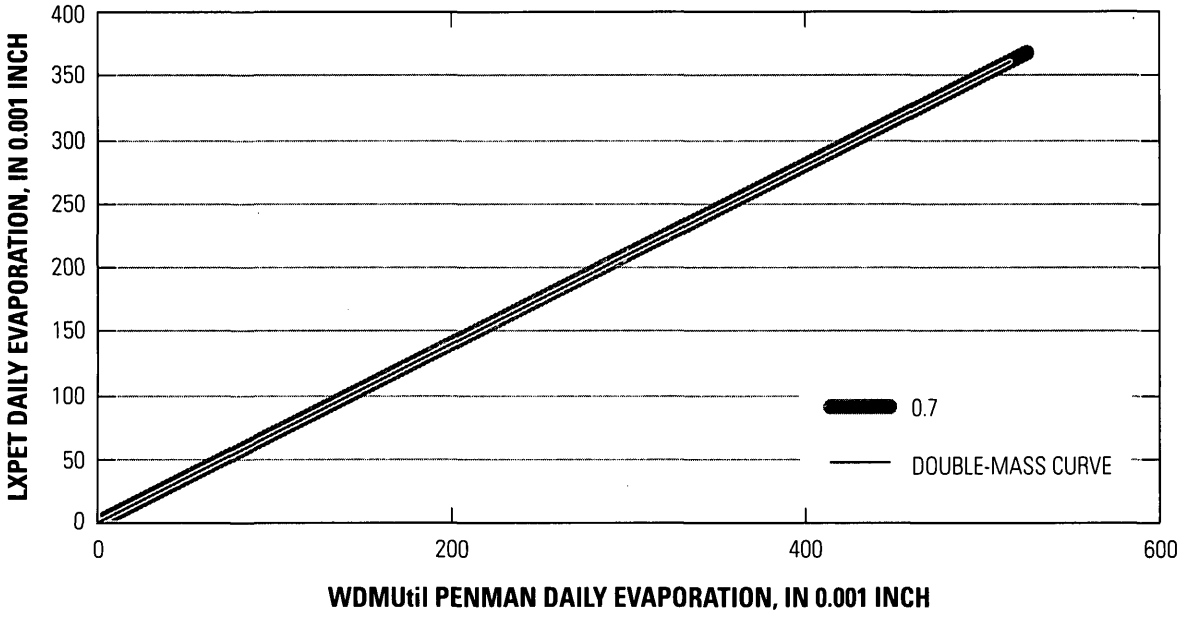

Figure 1. LXPET (Lamoreux Potential Evapotranspiration) and WDMUtil (Watershed Data Management Utility) double-mass curve and the 0.7 factor for daily evaporation calculated at Argonne National Laboratory in Illinois for the period January 1, 1990,–September 30, 2003.

The Lake-Correction Factor

When the daily-evaporation time series from these two programs were compared, the LXPET values were smaller than the values calculated with the WDMUtil program. When the LXPET values were divided by the WDMUtil values, the result always was approximately 0.7. A double-mass curve with a constant line of 0.7 is depicted in figure 1 to show the consistency of the 0.7 factor over the period January 1990-September 2003.

The *DEL* equation in the LXPET calculations can be rewritten to reveal a 0.7 term not present in the WDMUtil *DEL* equation (table 1). This 0.7 factor is described as a lake correction by Kohler and others (1955) and is used to convert from Class A pan evaporation to lake evaporation. According to Viessman and others (1989, p. 102), "most investigators have assumed that potential evapotranspiration is equal to lake evaporation as determined from National Weather Service Class A pan records." However, Viessman and others (1989) also explain that the potential evapotranspiration is a function of soil type and vegetation, so the simple use of lake evaporation is not theoretically correct.

Hourly Distribution

The LXPET program calculates daily lake evaporation values and distributes the daily values to hourly values. The distribution process is incorporated into the program and is not seen by the user as a separate step. In contrast to the WDMUtil method described below, the LXPET distribution process does not change seasonally. The LXPET program always distributes daily evaporation over the hours from 6:00 to 18:00.

The WDMUtil hourly pan evaporation time-series calculation takes two steps. The daily evaporation time series is calculated, then must be disaggregated to an hourly time series as a second step. WDMUtil requires the latitude of the site as an input for the disaggregation process. The seasons at the site are determined based on the latitude. WDMUtil disaggregates the evaporation differently depending on season. The winter evaporation is spread over fewer hours (for example, 7:00-15:00) than the spring or fall (for example, 5:00-17:00) with evaporation occurring over the most hours in the summer (for example, 4:00-18:00). This disaggregation method more realistically divides the daily evaporation over the hours of the day than the LXPET method, which does not change seasonally.

The difference in the disaggregation on a winter day and a summer day at the meteorological observation station at Argonne National Laboratory in northeastern Illinois is illustrated in figure 2. In winter, LXPET peak evaporation is lower than WDMUtil, whereas in summer, LXPET peak evaporation is higher than WDMUtil. LXPET distributes

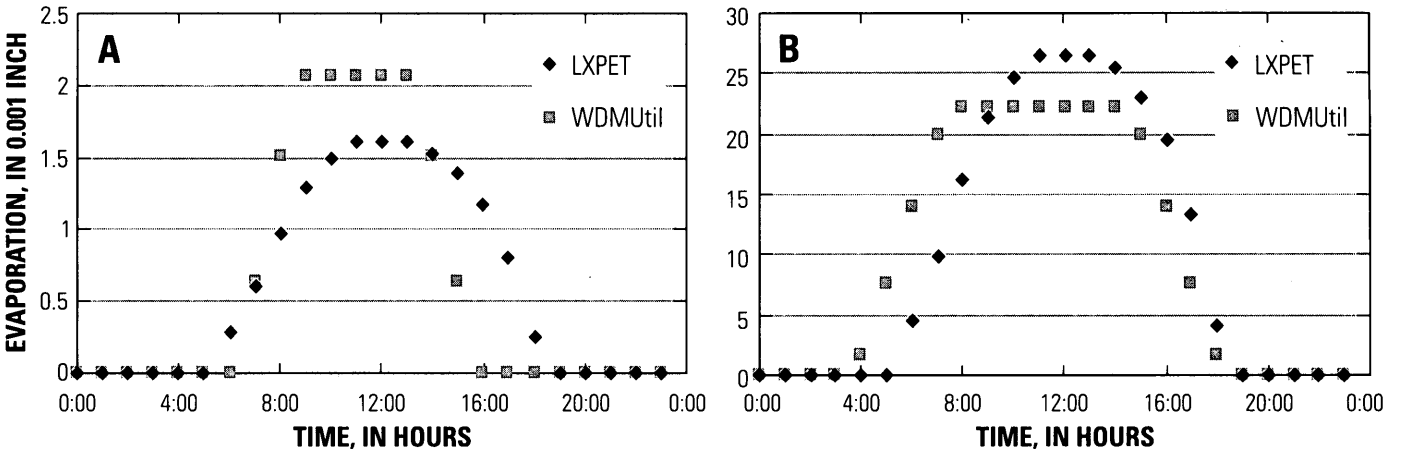

Figure 2. Evaporation distribution by LXPET (Lamoreux Potential Evapotranspiration) and WDMUtil (Watershed Data Management Utility) at Argonne National Laboratory in Illinois on A) January 15, 1995 (winter), and B) July 15, 1995 (summer).

the evaporation over more hours in winter than WDMUtil. In summer, LXPET distributes the evaporation over 1 hour less than WDMUtil.

Hydrological Simulation Program-Fortran (HSPF)

The HSPF program uses potential evapotranspiration as a model input. The following discussion of the appropriate HSPF input time series is taken from the HSPF manual (Bicknell and others, 1997) regarding the input of potential evapotranspiration to the model.

"ET potential or demand is supplied as an input times series, typically using U.S. Weather Bureau Class A pan records plus an adjustment factor. The data are further adjusted for cover in the parent subroutine PWATER."

This data description indicates that pan evaporation time series should be adjusted before it is input to HSPF. A conclusion of the present study is that either the LXPET time series should be used or the WDMUtil time series should be multiplied by 0.7 before it is input into HSPF.

Summary

The U.S. Geological Survey, in cooperation with DuPage Department of Engineering, Stormwater Management Division, has compared the evaporation time series calculated by LXPET and WDMUtil. Either program can be used to calculate an evaporation time series for hydrologic modeling. The programs use similar equations and require similar input data. The LXPET program generates a lake evaporation time series, whereas WDMUtil generates a pan evaporation time series. The difference between the programs is the equation used for *DEL*, the equation of the saturation vapor-pressure curve. The LXPET daily values are adjusted by a lake correction factor of approximately 0.7 compared to the WDMUtil daily values of pan evaporation.

The LXPET daily evaporation values are disaggregated to hourly values in a uniform manner that does not change based on season of the year or latitude. WDMUtil uses latitude to alter the disaggregation from daily to hourly values based on seasonal and regional differences.

HSPF is a hydrologic model used to simulate the amount of runoff during storms in watersheds. The HSPF program requires potential evapotranspiration as an input time series. Because lake evaporation is used by HSPF modelers as potential evapotranspiration, either LXPET time-series values should be used as HSPF input or the WDMUtil pan evaporation time-series values should be multiplied by 0.7 before being input into HSPF. However, because the WDMUtil time series is adjusted for season of the year and latitude, multiplying it by 0.7 may give more realistic potential evapotranspiration values than the LXPET output time series when the HSPF model is run over multiple seasons.

The FORTRAN source code for the LXPET program has been included in this report. A digital version of the FORTRAN source code and the compiled LXPET program can be requested from the USGS Illinois Water Science Center.

References Cited

Argonne National Laboratory, 2005, Argonne Data: accessed February 14, 2005, at URL http://www.atmos.anl.gov/ANLMET/

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Donigan, A.S., and Johanson, R.C., 1997, Hydrologic Simulation Program-Fortran, User's Manual for Version 11: U.S. Environmental Protection Agency, EPA/600/R-97/-90, 755 p.

Hydrocomp International, Inc., 1970, The LANDS Module of the Hydrocomp Program: Palo Alto, California.

Kohler, M.A., Nordensen, T.J., and Fox, W.E., 1955, Evaporation from Pans and Lakes: U.S. Weather Bureau Research Paper, no. 38, 21 p.

Lamoreux, W.W., 1962, Modern Evaporation Formulae Adapted to Computer Use: Monthly Weather Review, v. 90, p. 26-28.

Penman, H.L., 1948, Natural evaporation from open water, bare soil, and grass: Proceedings of the Royal Society of London, Series A, Mathematical and Physical Sciences, v. 193, p. 120-146.

U.S. Environmental Protection Agency, 2001, Better Assessment Science Integrating point and Nonpoint Sources, BASINS, Version 3.0: EPA-823-B-01-001, 337 p.

Viessman, W., Lewis, L., and Knapp, J., 1989, Introduction to Hydrology (3d ed.): New York, Harper & Row, 780 p.

WDMUtil Version 2.0 Users' Manual, 2001: accessed November 8, 2004, at URL http://www.epa.gov/waterscience/basins/bsnsdocs.html.

APPENDIXES

Appendix A: Computing evapotranspiration time series using LXPET (Lamoreux Potential Evaporation)

LXPET is a program that computes an hourly potential evapotranspiration (lake evaporation) time series (EVAP) using daily average dewpoint temperature (DEWP), daily average temperature (TEMP), daily total wind movement (WIND), and daily total solar radiation (SRAD) data files as input. The use of LXPET with input data files created in the GenScn (Generation and Analysis of Model Simulation Scenarios) program (Kittle and others, 1998) is described below, but the input data files can be from any source as long as they are properly formatted. Instructions for generating input data files using GenScn, correctly formatting these data files, and using LXPET as a DOS application are given in the steps below. Tips on troubleshooting common problems also are included.

Obtaining the data from the WDM (Watershed Data Management) with the Generation and Analysis of Model Simulation Scenarios (GenScn) Program

Note: These instructions are based on GenScn version 2.3 (Kittle and others, 1998). Certain details may vary in other versions.

(1) Open GenScn and the WDM file with the DEWP, SRAD, TEMP, and WIND data.

(2) Select OBSERVED, the constituent (for example, DEWP), and the location (for example, Argonne). Add this combination to your Time Series frame (see figure A1 below).

(3) Enter the beginning and ending dates needed for the computed EVAP.

(4) From the T step, Units menu, select the appropriate units for the data. "Sum" should be selected for SRAD and WIND, "Average" for DEWP and TEMP.

(5) Once the T step unit is chosen, another drop-down box will appear. Make sure "1 Day" appears. If not, select "Day" from the drop-down box.

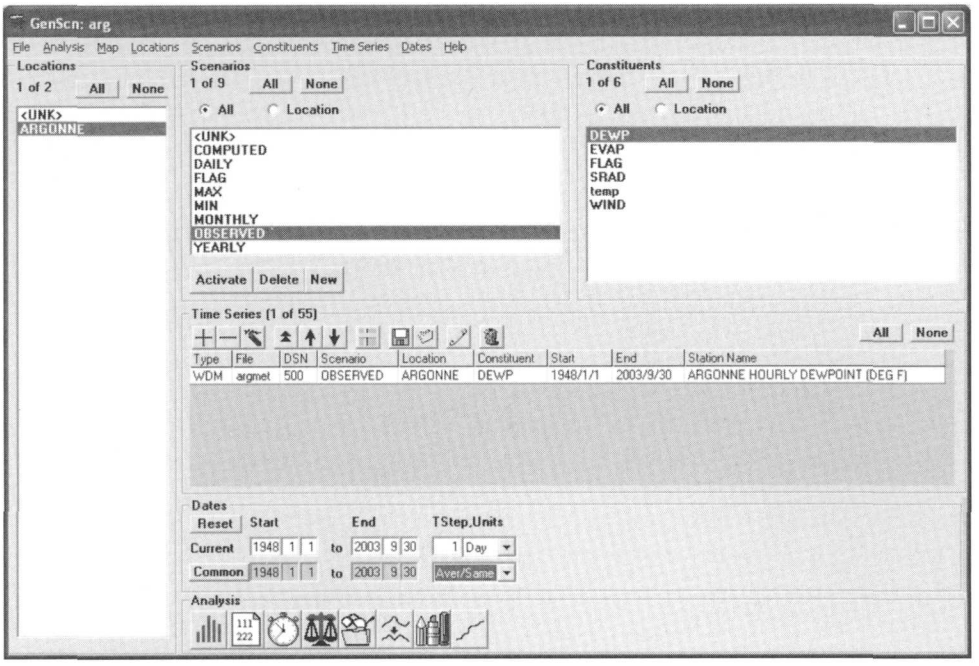

Figure A1. The Generation and Analysis of Model Simulation Scenarios (GenScn) program with the Argonne National Laboratory in Illinois dewpoint time series selected.

(6) Select the List option (second from the left in the Analysis menu at the bottom of the screen).

(7) The date format should be 4-digit year, space, 2-digit month, space, 2-digit day. If the data are not in this for mat, select edit and date format to adjust the format of the date.

(8) Select File and Save to Text File. Save the text file as a space delimited file. Make sure that the data files are saved in the same directory as the LXPET program. Choose a file name with no more than eight characters and an extension with no more than three characters. This file name format is necessary because the data file will be used on a DOS platform.

Repeat steps 4-7 for the other constituents.

Formatting the data for LXPET

(1) Open the data file in a text editor.

(2) Delete the header lines of the file (lines at the top that contain information about the data set). These header lines will cause an error message from LXPET.

(3) Make sure there are 21 spaces between the last character of the date and the first character of the value for that date. The first character of the value may be a minus sign in the case of temperature and dewpoint files. Make sure there are no tabs, only spaces. The LXPET program does not accept tab characters. An example of a properly formatted file (with the spaces visible) is included as figure A2 below.

(4) Save the changes.

Repeat these steps for each of the other data files.

Running LXPET

(1) Make sure that LXPET and the four input data files are in the same directory.

(2) Run LXPET by either double-clicking on LXPET.exe from the Windows Explorer or typing LXPET at the prompt from a DOS screen or window from its directory. In the DOS window, change to the directory where LXPET and the data files are located (see figure A3 below). No parameters need to be added to LXPET at the command line. It is preferable to start from a DOS window, so the error messages are shown in the DOS win dow if LXPET does not work correctly. If the LXPET.exe is opened by double-clicking from Windows, the DOS window will close automatically if an error occurs.

(3) When prompted, enter the name of the solar radiation data file including the extension. Hit enter when fin ished.

(4) Next, the multiplication factor for solar radiation is requested. Type in 1 for this multiplication factor. Use 1 as the multiplication factor for the other data types as well.

(5) Enter the names of the other data files as prompted by the program.

(6) The last step prompts for the name of the evaporation file. This file is where LXPET saves the computed EVAP time series. Choose a name no longer than eight characters and an extension of no more than three char acters. It is recommended that .hsp is used as the extension. The .hsp format is the default output format and will make it easier to input the results to a WDM file using HSPF.

Open the EVAP file in a text editor. If a blank file, all zeros, or some other unexpected output is listed, then refer to the troubleshooting tips below.

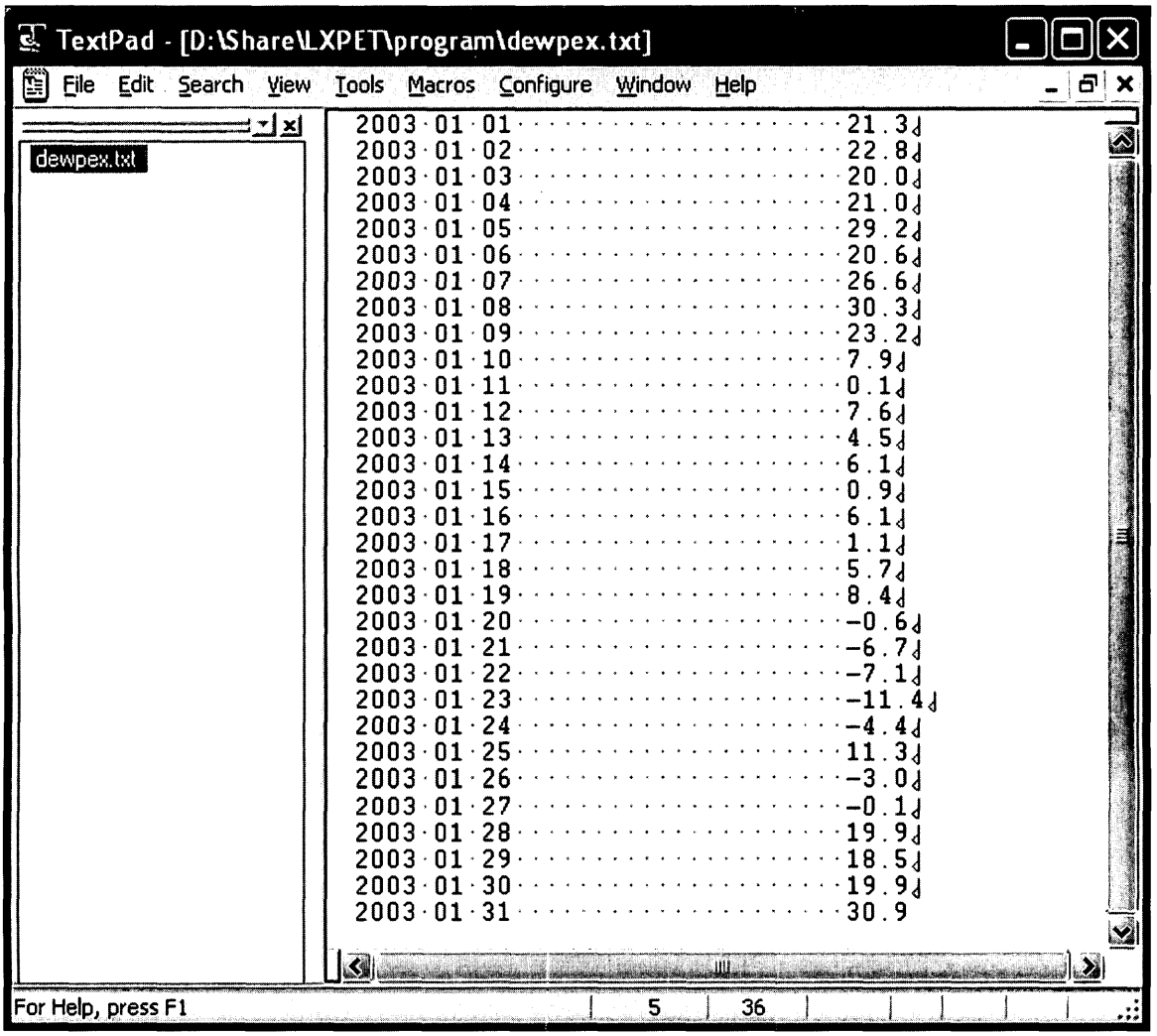

Figure A2. An example of a properly formatted input file of the dewpoint data for LXPET (Lamoreux Potential Evapotranspiration).

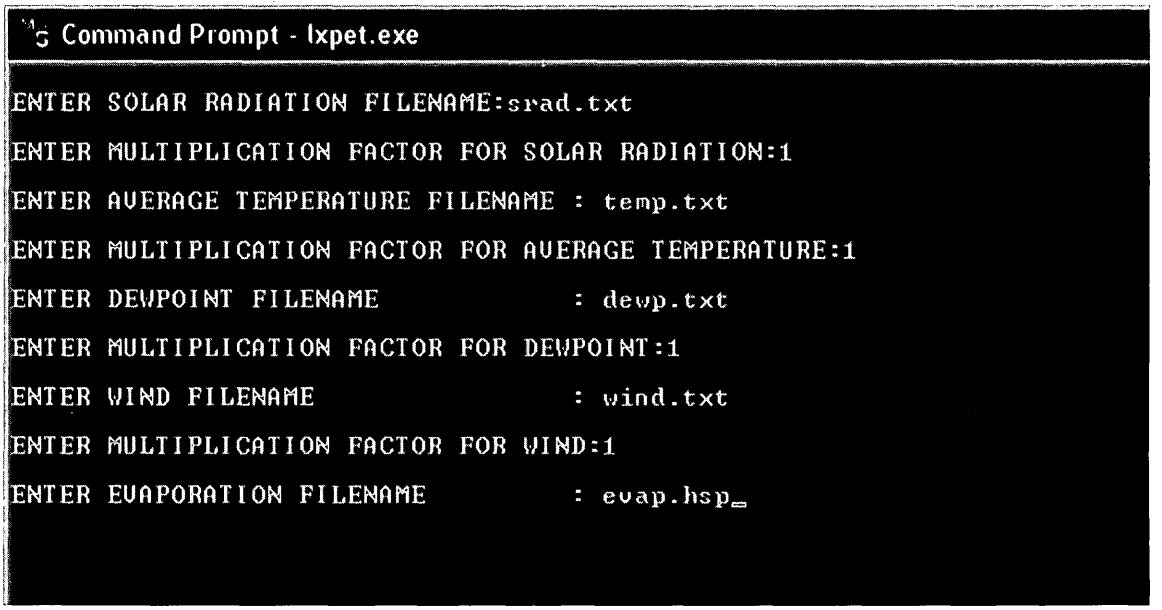

Figure A3. The LXPET (Lamoreux Potential Evapotranspiration) program, in a DOS window, with all the prompts displayed.

Troubleshooting Tips

Problem: The output file shows 24 sets of 24 values for each day.

Cause: This problem is caused by using hourly data instead of daily data. LXPET treats each hour as a day. To fix this problem, go back into GenScn and retrieve daily data. Rerun LXPET with daily data.

Problem: The output file shows 0.00 for all the values.

Cause: This type of error could be caused by entering the wrong file name for each data type (for example, the file name of the wind data was entered when the program prompted for solar radiation data). Rerun LXPET and make sure the right filename is entered for each data type. If this solution doesn't work, check that the data files are named correctly. Another potential cause of this problem is that one or more of the data files were not formatted correctly. As mentioned earlier, there should be 21 spaces between the last character of the date and the first character of the value.

Problem: Evaporation values that look appreciably low.

Cause: One of the data files was not formatted correctly. The LXPET program does not use improperly formatted data files in its calculations; therefore, the evaporation would be lower than the correct value.

Problem: Output for evaporation has 0.00 for the beginning and end of the day and ****** characters for the rest of the day.

Cause: This problem is caused by the evaporation value being calculated as too high; for example, if 11 were typed instead of 1 for the multiplication factor for DEWP, TEMP or SRAD. Be aware that if this problem occurs from an improperly formatted wind data file, the evaporation values would be larger than the correct values but not high enough to make it obvious that a problem is present.

Problem: After the program is run, an error message results as follows:

Invalid decimal character * was detected (unit=**)
(the relative position causing an error in a record = *)
DAILY ***** OBSERVED *** at ARGONNE
?
Error occurs at or near line *** of (underscore)getday(underscore)
Called from or near line *** of (underscore)MAIN(underscore)

Cause: This message appears if the first three lines from the data file(s) are not removed. Delete the first three lines of the data file(s) and run LXPET again.

Problem: While entering the names of the data files, the following error results:

The value of the STATUS specifier in an OPEN statement does not match the file status (unit=**). Error occurs at or near line ** of (underscore)MAIN(underscore)

Cause: This error occurs when the file name entered is not valid. Check to be sure that all required data files are in the same directory as LXPET. This error also is caused by misspelled file names entered at the LXPET prompt. Also make sure the file name was not misspelled when it was saved in GenScn.

References Cited

Kittle, J.L., Jr., Lumb, A.M., Hummel, P.R., Duda, P.B., and. Gray, M.H., 1998, A Tool for the Generation and Analysis of Model Simulation Scenarios for Watersheds (GenScn): U.S. Geological Survey Water-Resources Investigations Report 98-4134, 152 p.

Appendix B: LXPET Fortran code

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```
C/*                    UTILITY PROCEDURE LXPET                    */
C/*  PURPOSE:                                                     */
C/*    THE LXPET PROCEDURE COMPUTES DAILY EVAPORATION IN 1000THS   */
C/*    OF INCHES FROM DAILY WIND MOVEMENT (MPD), RADIATION        */
C/*    (LANGLEYS/DAY), MAX-MIN AIR TEMPERATURE (DEGREES FAHREN-   */
C/*    HEIT), AND DEWPOINT (DEGREES FAHRENHEIT) USING THE METHOD  */
C/*    OF KOHLER, NORDENSEN, AND FOX (1955) AS ADAPTED TO         */
C/*    COMPUTERS BY LAMOREUX (1962).                              */
C/*
C/*    MODIFIED TO READ AVERAGE AIR TEMP, IT IS READ INTO MAX AIR */
C/*    ARRAY, THE MIN AIR ARRAY ISN'T USED IN THIS VERSION        */
C/*    CALLS DISTRIB.FOR TO DISTRIB THE DAILY DATA INTO HOURLY    */
C/*    DATA                                                       */

      INTEGER YR,MTH,DAY
      INTEGER I,J
      INTEGER RFILE,MXFILE,MNFILE,DFILE,WFILE,EFILE
      INTEGER RESULT
      INTEGER B3,B6

      REAL A,A11,A12,A13,A2,A3,A31,A4,A5
      REAL B,B1,B2,B4,B5
      REAL C,C1,C2,C3
      REAL E,TA

      REAL RAD,TMAX,DEWP,WIND,EVAP
      REAL RFAC,MXFAC,DFAC,WFAC
```

```
      CHARACTER*64 RFNAME,MXFNAME,DFNAME,WFNAME,EFNAME

C*********************************************************************
C*    SETUP CONSTANTS                                                *
C*********************************************************************
      A = 0.0
      A11 = 212.0
      A12 = 0.1024
      A13 = 0.01066
      A2 = 0.0001
      A3 = 0.0105
      A31 = 0.88
      A4 = 0.37
      A5 = 0.0041
      B = 0.0
      B1 = 0.015
      B2 = 398.36
      B3 = -2
      B4 = 68554000000.0
      B5 = -7482.6
      B6 = -1
      C = 0.0
      C1 = 6413300.0
      C2 = 7482.6
      C3 = 398.36
      E = 2.71828
      TA = 0.0

C*********************************************************************
C*     GET INFORMATION FROM USER                                     *
C*********************************************************************

      WRITE (*,'(1X,A)') 'ENTER SOLAR RADIATION FILENAME:'
      READ  (*,'(A)') RFNAME
      RFILE=10
      OPEN  (RFILE,FILE=RFNAME,STATUS='OLD')
      WRITE (*,'(1X,A)')
     $      'ENTER MULTIPLICATION FACTOR FOR SOLAR RADIATION:'
      READ  (*,'(F10.0)') RFAC
      IF (RFAC .EQ. 0) RFAC=1.0

      WRITE (*,'(1X,A)') 'ENTER AVERAGE TEMPERATURE FILENAME : '
      READ  (*,'(A)') MXFNAME
      MXFILE=11
      OPEN  (MXFILE,FILE=MXFNAME,STATUS='OLD')
      WRITE (*,'(1X,A)')
     $      'ENTER MULTIPLICATION FACTOR FOR AVERAGE TEMPERATURE:'
      READ  (*,'(F10.0)') MXFAC
      IF (MXFAC .EQ. 0) MXFAC=1.0


      WRITE (*,'(1X,A)') 'ENTER DEWPOINT FILENAME           : '
      READ  (*,'(A)') DFNAME
      DFILE=13
      OPEN  (DFILE,FILE=DFNAME,STATUS='OLD')
      WRITE (*,'(1X,A)')
```

```
      $       'ENTER MULTIPLICATION FACTOR FOR DEWPOINT:'
       READ   (*,'(F10.0)') DFAC
       IF (DFAC .EQ. 0) DFAC=1.0

       WRITE (*,'(1X,A)') 'ENTER WIND FILENAME                : '
       READ   (*,'(A)') WFNAME
       WFILE=14
       OPEN   (WFILE,FILE=WFNAME,STATUS='OLD')
       WRITE (*,'(1X,A)')
      $       'ENTER MULTIPLICATION FACTOR FOR WIND:'
       READ   (*,'(F10.0)') WFAC
       IF (WFAC .EQ. 0) WFAC=1.0

       WRITE (*,'(1X,A)') 'ENTER EVAPORATION FILENAME         : '
       READ   (*,'(A)') EFNAME
       EFILE=15
       OPEN   (EFILE,FILE=EFNAME,STATUS='UNKNOWN')

C**********************************************************************
C*     READ IN A DAY OF DATA FROM DATA FILES                          *
C*     SOLAR RADIATION FILE DETERMINES WHICH MONTH/DAY WE'RE ON       *
C**********************************************************************
100    CONTINUE
C +++ RADIATION DATA +++
       YR = 0
       MTH = 0
       DAY = 0
       CALL GETDAY (RFILE,YR,MTH,DAY,RAD,RFAC,RESULT)
       IF (RESULT.EQ.3) GOTO 900
       IF (RESULT.NE.0) THEN
         WRITE (*,'(1X,A)') 'RADIATION FILE : '
         GOTO 800
       ENDIF

C +++ AVERAGE TEMPERATURE DATA +++
       CALL GETDAY (MXFILE,YR,MTH,DAY,TA,MXFAC,RESULT)
       IF (RESULT.NE.0) THEN
         WRITE (*,'(1X,A)') 'AVERAGE TEMPERATURE FILE : '
         GOTO 800
       ENDIF

C +++ DEWPOINT DATA +++
       CALL GETDAY (DFILE,YR,MTH,DAY,DEWP,DFAC,RESULT)
       IF (RESULT.NE.0) THEN
         WRITE (*,'(1X,A)') 'DEWPOINT FILE : '
         GOTO 800
       ENDIF

C +++ WIND DATA +++
       CALL GETDAY (WFILE,YR,MTH,DAY,WIND,WFAC,RESULT)
       IF (RESULT.NE.0) THEN
         WRITE (*,'(1X,A)') 'WIND FILE : '
         GOTO 800
       ENDIF

C**********************************************************************
```

```
C*    CALCULATE EVAP                                                *
C*******************************************************************

        C = C1*(E**(-C2/(TA+C3))-E**(-C2/(DEWP+C3)))
        IF (C .LT. 0.00001) C = 0.00001
        B = (B1+((TA+B2)**B3)*B4*E**(B5/(TA+B2)))**B6
        A = E**((TA-A11)*(A12-A13*LOG(RAD)))
     $       -A2 + A3*(C**A31)*(A4+A5*WIND)
        EVAP=B*A*1000.0
        IF (EVAP .LT. 0.0) EVAP=0.0
       CALL DISTRIB(EFILE,YR,MTH,DAY,EVAP)

       GOTO 100

800    CONTINUE
       WRITE (*,2010) RESULT
2010   FORMAT (' ERROR : ',I2)

900    CONTINUE
       CLOSE (RFILE)
       CLOSE (MXFILE)
       CLOSE (DFILE)
       CLOSE (WFILE)
       CLOSE (EFILE)
       END

C*******************************************************************
C*    SUBROUTINE GETDAY / GET A DAY OF DATA FROM FILE               *
C*******************************************************************
       SUBROUTINE GETDAY(FILE,TY,TM,TD,DATA,MFAC,RESULT)

C +++ ARGUMENT VARIABLES +++
       INTEGER FILE,TY,TM,TD,RESULT
       REAL DATA,MFAC

C +++ LOCAL VARIABLES +++

       INTEGER YR,MTH,DAY,I

1000   FORMAT (I4,1X,I2,1X,I2,20X,F10.2)
       RESULT = 0
100    CONTINUE
       READ (FILE,1000,END=800) YR,MTH,DAY,DATA


C +++ CHECK TO SEE IF WE GOT THE MONTH/DAY WE WANT +++
       IF ((0.EQ.TY) .AND. (0.EQ.TM) .AND. (0.EQ.TD)) THEN
         TY = YR
         TM = MTH
         TD = DAY
         GOTO 900
       ENDIF

       IF (YR.EQ.TY) THEN
         IF (MTH.EQ.TM) THEN
            IF (DAY.EQ.TD) GOTO 900
```

```
        IF (MTH.LT.TM) GOTO 100
        ENDIF
        RESULT=2
        GOTO 900
      ENDIF

      IF (YR .LT. TY) GOTO 100
      RESULT = 2
      GOTO 900

800   CONTINUE
C +++ UNEXPECTED END OF FILE +++
      RESULT = 3

900   CONTINUE
      IF (MFAC .NE. 1.0) THEN
          DATA=MFAC*DATA
      ENDIF
      RETURN
      END

C ***************************************************************
C * SUBROUTINE    DISTRIB                                       *
C *   CONVERT DAILY EVAP DATA TO HOURLY EVAP DATA BASED     *
C *               ON DISTRIBUTION FROM LANDS PROGAM   *
C ***************************************************************
      SUBROUTINE DISTRIB(EFILE,YR,MTH,DAY,DAYDAT)
      REAL HRDAT(24),DAYDAT,EVAPDIST(24)
      INTEGER YR,MTH,DAY,I,J,EFILE

      DATA EVAPDIST / 0.000,0.000,0.000,0.000,0.000,0.000,0.019,0.041,
     $                0.067,0.088,0.102,0.110,0.110,0.110,0.105,0.095,
     $                0.081,0.055,0.017,0.000,0.000,0.000,0.000,0.000/

      DO 200,J=1,24
        HRDAT(J)=DAYDAT*EVAPDIST(J)
200   CONTINUE

      WRITE(EFILE,2000) YR,MTH,DAY,1,(HRDAT(J),J=1,12)
      WRITE(EFILE,2000) YR,MTH,DAY,2,(HRDAT(J),J=13,24)
2000  FORMAT(8X,I4,1X,2(I2,1X),I1,12F5.2)
      RETURN
      END
```

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