Exhibit No.:	
Issues:	Weather Normalization
Witness:	Dennis L. Patterson
Sponsoring Party:	Mo PSC Staff
Type of Exhibit:	Rebuttal Testimony
Case No.:	WR-2007-0216
Date Testimony Prepared:	July 13, 2007

MISSOURI PUBLIC SERVICE COMMISSION

UTILITY OPERATIONS DIVISION

REBUTTAL TESTIMONY

OF

DENNIS L. PATTERSON

MISSOURI-AMERICAN WATER COMPANY

CASE NO. WR-2007-0216

Jefferson City, Missouri
July 2007

BEFORE THE PUBLIC SERVICE COMMISSION

OF THE STATE OF MISSOURI

In the Matter of Missouri-American Water Company's request for Authority to Implement a General Rate Increase for Water Service provided in Missouri Service Areas	)))))	Case No. WR-2007-0216

AFFIDAVIT OF DENNIS L. PATTERSON

STATE OF MISSOURI)
) **ss**
COUNTY OF COLE)

Dennis L. Patterson, of lawful age, on his oath states: that he has participated in the preparation of the following Rebuttal Testimony in question and answer form, consisting of 10 pages of Rebuttal Testimony to be presented in the above case, that the answers in the following Rebuttal Testimony were given by him; that he has knowledge of the matters set forth in such answers; and that such matters are true to the best of his knowledge and belief.

Dennis L. Patterson

Subscribed and sworn to before me this 6th day of July, 2007.

NOTARY PUBLIC NOTARY SEAL STATE OF MISSOURI

SUSAN L. SUNDERMEYER
My Commission Expires
September 21, 2010
Callaway County
Commission #06942086

Susan L. Sundermeyer
Notary Public

My commission expires 9-21-10

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OF

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REBUTTAL TESTIMONY

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DENNIS L. PATTERSON

MISSOURI-AMERICAN WATER COMPANY

CASE NO. WR-2007-0216

Q. Are you the same Dennis L. Patterson who has submitted written direct and supplemental direct testimony in this case?

A. Yes, I am.

Q. Have you any errata to correct in your direct or supplementary direct testimony?

A. Yes. The sentence beginning at Line 20 on Page 2 of my written direct testimony should now read: "For example, St. Louis County Water Quarterly Residential Customer counts from 2002-2005 were 317,639; 313,914; 320,881; and 321,347 (calculated from Dr. Spitznagel's Direct Testimony in this case)."

Q What is the purpose of your Rebuttal Testimony?

A. I will address the written Direct Testimony of Company witness Edward L. Spitznagel, Jr., PhD.

SUMMARY

Q. Please summarize your rebuttal of Dr. Spitznagel's written Direct Testimony.

A. First, I will point out that the billing data that the Company furnished to Dr. Spitznagel are deficient, so that the best possible analysis of these data would be suspect. I will then point out that Dr. Spitznagel's method of analysis causes downward bias in his estimate of weather normalized Gallons per Customer per Day (GCD) for the Company's St.

Louis County Water operational division. Finally, I will show that Dr. Spitznagel's analysis for residential customers in individual service areas of the Company, such as SLCW, is based on an inappropriate weather variable for the wrong geographical areas. In doing so, I will also note that Dr. Spitznagel's weather history was not adjusted for measurement changes to make it consistent throughout, so that averages or normals of his weather variable are unreliable. This omission violates the intent of the Commission's findings in the Commission's Report and Order in the Missouri Gas Energy rate case, Case Number GR-96-285.

THE COMPANY'S BILLING DATA ARE DEFICIENT

Q. What is your basis for stating that the Company's billing data are deficient?

A. Please refer to the question and answer that begin at Line 17, Page 2 of my written direct testimony in this case, as modified above in my errata. The unreliability of these customer counts is illustrated at Revised Schedule 1-1 and Supplemental Schedule 2, both attached to my Supplemental Direct Testimony. The nature of the variance in customer counts indicates that in the years since 2001, numerous customers were not captured in the billing data, and that the Mgallon sales associated with these customers were not captured as well. In short, both quantities are unreliable.

Q. What would be the consequence of these omissions?

A. Since customers are not uniform in usage patterns, any weather normalized GCD quantities calculated from the deficient data would be unreliable. In addition, setting rates with information based on insufficient customer numbers and volumes would unavoidably result in inflated rates.

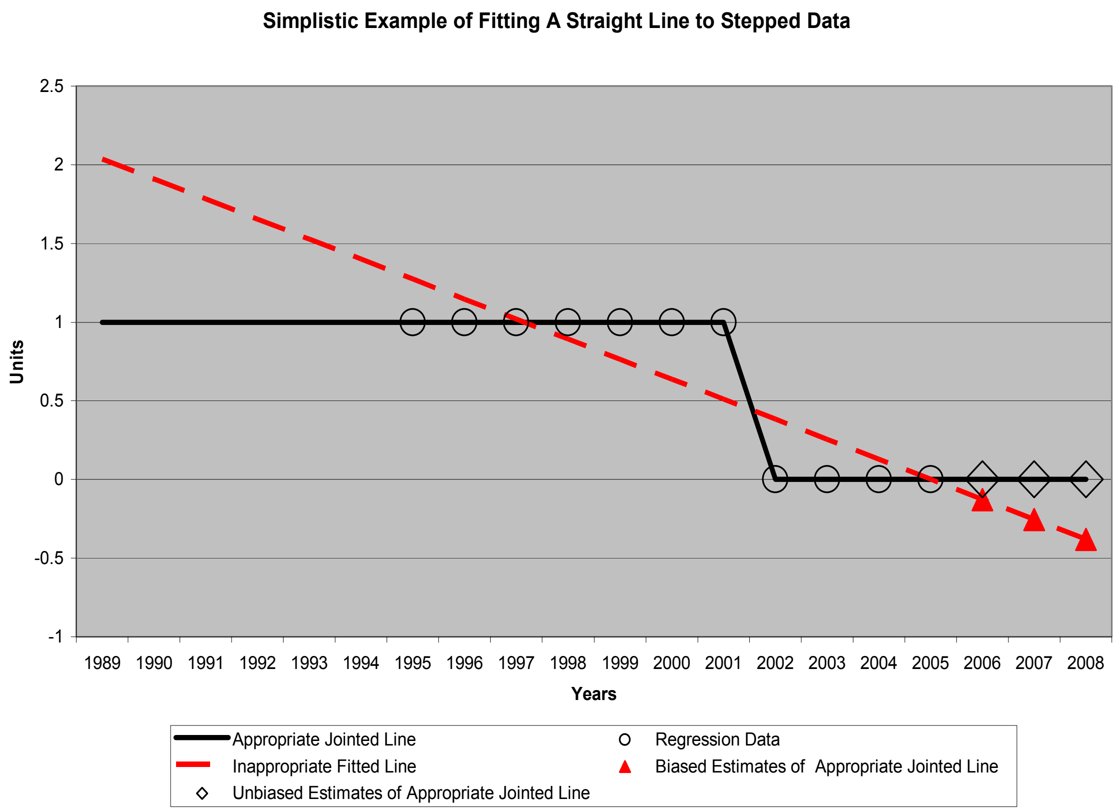
<u>COMPANY'S WEATHER NORMALIZED GCD ARE BIASED</u>

Q. Why do you believe Dr. Spitznagel's estimates of weather normalized GCD for SLCW are biased downward?

A. The bias exists because Dr. Spitznagel uses an inappropriate straight line time trend to model the gradual decline in annual GCD since 1995 at SLCW. However, a stepped time trend would have been the appropriate choice, where the step occurs between 2001 and 2002.

Q. Why would a stepped time function be more appropriate?

A. Dr. Spitznagel filed Supplemental Rebuttal Testimony in the most recent rate case, Case No. WR-2003-0500. In that testimony, in the question and answer beginning at Line 12, Page 2, Dr. Spitznagel states in part: "Yes, based on the individual route data for the added customers from Webster Groves and Florissant, it can be seen that both sets of customers use much less water per day than the rest of the St. Louis District quarterly residential customers." The addition of such customers causes an unavoidable shift from one time trend to another for SLCW quarterly residential customers. Dr. Spitznagel neglected to address this known difference in his regression model, thus causing a serious downward bias in his results. The chart below illustrates the consequences for years after 2005 in a simplistic example, where an inappropriate straight fitted line continues to fall below an appropriate jointed line.



INAPPROPRIATE WEATHER VARIABLE

Q. What weather variable did Dr. Spitznagel use in his analysis?

A. He used the Palmer Drought Severity Index (PDSI), a quantity that is published for Climatological Divisions rather than for localities. For example, in his analysis for SLCW, Dr. Spitznagel used PDSI for Missouri's Climatological Division number 2, the Northeast Prairie division. The PDSI is also called the Palmer Drought Index (PDI). PDSI records are maintained by the National Oceanographic and Atmospheric Administration (NOAA).

Q. What is the PDSI?

A. "The Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI) are indices of the relative dryness or wetness effecting (*sic*) water sensitive economies." (Explanation of the Palmer Drought Index, Midwestern Regional Climate Center, 11/6/2003, p. 1) (Written by NOAA's Climate Analysis Center) (Schedule 1). The document is available at the Midwestern Regional Climate Center web site.

Q. How is the PDSI calculated?

A. "The PDSI is based around a supply and demand model of the soil moisture at a location. The supply is the amount of moisture in the soil plus the amount that is absorbed into the soil from rainfall. The demand, however, is not so as (*sic*) easy to see, because the amount of water lost from the soil is (*sic*) depends on several factors, such as temperature and the amount of moisture in the soil." (Documentation for the Original and Self-Calibrating Palmer Drought Severity Index used in the National Agriculture Decision Supporting System, Nathan Wells, Computer Science & Engineering, University of Nebraska-Lincoln, March 24, 2003, p. 2) (Nathan Wells) (Extract) (Schedule 2). The complete document is included in my working papers and may be found at http://nadss.unl.edu/.

THE PDSI IS INAPPROPRIATE FOR ANALYZING UTILITY WATER USAGE

Q. Why is the PDSI an inappropriate weather variable for the analysis of utility water usage?

A. The PDSI was not designed for the purpose.

Q. What was the PDSI designed for?

A. "The PDSI is an important climatological tool for evaluating the scope, severity, and frequency of prolonged periods of abnormally dry or wet weather. It can be used to help delineate disaster areas and indicate the availability of irrigation water supplies, reservoir levels, range conditions, amount of stock water, and potential intensity of forest fires." (Climate Analysis Center, p. 1).

Q. Why is the PDSI not appropriate for the analysis of utility water usage?

A. The PDSI is a monthly index, and was formulated for highlighting and evaluating "prolonged" conditions. It is therefore not useful for evaluating day-to-day changes. However, residential utility water usage varies from day to day, increasing from base household requirements to elevated lawn sprinkling levels as the soil dries in hot dry weather, and decreasing toward base usage again as the soil moisture improves in cooler and wetter weather.

Q. Are there other variables that might be more appropriate for the analysis of utility water usage?

A. Yes. Variables resembling the weekly Crop Moisture Index (CMI) might be more appropriate. "The CMI can be used to measure the status of dryness or wetness affecting warm season crops and field activities." (Climate Analysis Center, p. 1).

Q. Did Dr. Spitznagel attempt to use the Northeast Prairie CMI to perform his analysis?

A. Yes, it appears that he did. Dr. Spitznagel attempted to use the "available soil moisture index in Missouri at that time." (Spitznagel direct , page 4, line1).

Q. Was he successful?

A. No. It "did not correlate nearly as well." (*Ibid*.).

Q. Why do you believe this occurred?

A. I believe that the generalized Northeast Prairie CMI might not correlate well with water usage in a more specific area within St. Louis County.

THE NORTHEAST PRAIRIE PDSI AND CMI DO NOT APPLY TO THE ST LOUIS BILLING DISTRICT

Q. Why don't the Northeast Prairie PDSI and CMI apply to the St. Louis billing district of Missouri American Water Company?

A. Neither the PDSI nor the CMI apply to specific locations. This caveat is also found in the document cited above: "Both indices indicate general conditions and not local variations caused by isolated rain." (Climate Analysis Center, p. 1).

Q. Do special characteristics of the St. Louis district make it different from the Northeast Prairie in general?

A. Yes. Much of St. Louis County is located in the Mississippi and Missouri River valleys, and is densely populated. St. Louis is also located at the extreme southeast corner of the Northeast Prairie division. These characteristics cause the local microclimate to be generally warmer and wetter that the higher, dryer and much more sparsely populated Northeast Prairie. The local microclimate might be distinctly different on many days because, for example, a mass of colder air from Minnesota might stall within an area as large as the Northeast Prairie, but fail to reach the remote corner where St. Louis is located.

Q. What could be the consequences of these differences on a specific summer day with precipitation?

A. Depending on temperatures and moisture levels in local air masses, conditions in the greater Northeast Prairie and in St. Louis could be quite different. On one day, thunderstorms could be prevalent in a moving Northeast Prairie squall line, while St. Louis County stayed dry. On another day, the St. Louis area could be experiencing drizzle beneath a layer of Mississippi Valley stratus clouds, while the Northeast Prairie was clear, sunny and dry.

Q. Would the precipitation from such events not average out over time?

A. No. The generalized thunderstorms in the example could dump whole inches of rain in the countryside, while the local drizzle might deliver a couple of hundredths of an inch to St. Louis County. There is no reason to hope that only a few events of this diversity could compensate for each other in a period as short as a single billing year.

THIRTY-YEAR AVERAGES OF PDSI ARE NOT CONSISTENT WITH CURRENT MEASUREMENTS

Q. How did Dr. Spitznagel calculate normal PDSI?

A. He "inserted the thirty-year averages (from 1973 to 2002) of the Palmer Drought Severity Index for each of the months of April through December…" (Spitznagel direct testimony, page 8, line 7). That is, he did not refer to a published NOAA normal but calculated his own.

Q. What would be the consequences of calculating normal PDSI himself?

A. By his own admission, Dr. Spitznagel calculated his normal from historical PDSI as it was recorded. If there had been changes in the way PDSI was calculated or measured, Dr. Spitznagel's average or normal would not be consistent with measurements in the current year.

Q. Have there been any such changes?

A. Yes. Please recall that the PDSI is based on precipitation and temperature (Nathan Wells, p. 2). Although the PDSI has been calculated the same way since its inception, and although precipitation records aren't often adjusted, there have been many changes in the way temperature measurements were recorded at the various weather stations in the Northeast Prairie division. The temperature record at each of these stations must be adjusted to match current measurement conditions before the 30 years of monthly PDSI and its 12 monthly normals might be calculated. These safeguards would ensure that the PDSI normals were consistent with the test year PDSI. It should be noted, however, that even these safeguards would not make the Northeast Prairie PDSI consistent with the St. Louis County Water service area.

Q. Where are the measurement changes and temperature adjustments described?

A. The measurement changes, need for adjustments, and the way they are calculated are described in detail in <u>CLIM81 1971-2000 NORMALS, MONTHLY STATION NORMALS OF TEMPERATURE, PRECIPITATION, AND DEGREE DAYS, TD-9641C, National Climatic Data Center, Federal Building, Asheville, North Carolina, August 31, 2001.</u> (Monthly Station Normals). The title page of this document, and an extract that includes Topic 58 are attached to my written Rebuttal Testimony as Schedule 3.

Q. Where are measurement changes mentioned specifically?

A. These are first mentioned at Topic 58, page 27, of the Monthly Station Normals document: "Several adjustments were made to the data before the normals were calculated. These adjustments include estimating missing data, adjusting for time of observation bias, and adjusting for exposure changes." Exposure changes would include changing the temperature observation schedule, moving the thermometers, changing the altitude of the thermometers, and changes in the type of thermometers that were used.

Q. Has the Public Service Commission made any findings with regard to the use of adjusted temperature data?

A. Yes. The use of historical temperature data that has been adjusted for exposure changes complies with the Commission's Report and Order in the Missouri Gas Energy rate case, Case Number GR-96-285. In that case, Missouri Gas Energy (MGE) had calculated normal heating degree-days based on temperatures that had not been adjusted for exposure changes, while the Staff had applied NOAA's adjustments. At Page 18 of the Report and Order, the Commission states, "In addition, the data upon which Staff's recommendation is based has gone through the processes established by NOAA to ensure the best data possible. This safeguard is not present in MGE's approach."

Q. Is the safeguard present in Dr. Spitznagel's approach?

A. No, it is not.

Q. Does this complete your written Rebuttal Testimony?

A. Yes, it does.

From Midwestern Regional Climate Center

Explanation of the weekly Palmer drought and crop moisture data products. (Written by the Climate Analysis Center, NOAA)

The Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI) are indices of the relative dryness or wetness effecting water sensitive economies. The PDSI indicates the prolonged and abnormal moisture deficiency or excess. The CMI gives the short-term or current status of purely agricultural drought or moisture surplus and can change rapidly from week to week. Both indicies indicate general conditions and not local variations caused by isolated rain. Calculation of the PDSI and CMI are made for 350 climatic divisions in the United States and Puerto Rico. Input to the calculations include the weekly precipitation total and average temperature, division constants (water capacity of the soil, etc.) and previous history of the indices.

The PDSI is an important climatoligical tool for evaluating the scope, severity, and frequency of prolonged periods of abnormally dry or wet weather. It can be used to help delineate disaster areas and indicate the availability of irrigation water supplies, reservior levels, range conditions, amount of stock water, and potential intensity of forest fires. The CMI can be used to measure the status of dryness or wetness affecting warm season crops and field activities.

The equation for the index was empirically derived from the monthly temperature and precipitation scenarios of 13 instances of extreme drought in western Kansas and central Iowa and by assigning an index value of -4 for these cases. Conversely, a +4 represents extremely wet conditions. From these values, 11 categories of wet and dry conditions are defined (Table 1). The index is a sum of the current moisture anomaly and a portion of the previous index to include the effect of the duration of the drought or wet spell. The moisture anomaly is the product of a climate weighting factor and the moisture departure. The weighting factor allows the index to have a reasonably comparable local significance in space and time. A value for a division in Florida would have the same local implication as a similiar value in a more arid division in western Kansas. The moisture departure is the difference of water supply and demand. Supply is precipitation and stored soil moisture and demand is the potential evapotranspiration, the amount needed to recharge the soil, and runoff needed to keep the rivers, lakes, and resevoirs at a normal level.

The duration of the drought (or wet spell) is determined by calculating indices for different weather spells (incipient and established wet and dry spells). A week of normal or better rainfall is welcome in an area that has experienced a long drought but may be only a brief respite and not the end of the drought. Once a weather spell is established (by computing a 100% "probability" that an opposite weather spell has ended), the final value is assigned. In order for the program to have a real-time significance, a value is assigned based on a greater than 50% "probability" that the opposite weather spell has ended. This is not entirely satisfactoty, but it does allow the index to have a value when there is a doubt as to whether it should be positive or negative. A "F" is placed after the PDSI when a weather spell is established and a "P" when a weather spell is not established.

Schedule 1-1

The CMI was developed from some of the moisture accounting procedures used in computing the PDSI. This index is the sum of the evapotranspiration anomaly (which is generally negative or slightly positive) and the moisture excess (either zero or positive). Both terms are a function of the previous week and a measure of the current week. The evapotranspiration anomaly is weighted to make it comparable in space and time. If the potential moisture demand exceeds available moisture supplies, the CMI is negative. However, if moisture meets or exceeds demand the index is positive. It is necessary to use two separate legends because the resulting effects are different when the moisture supply is improving than when it is deteriorating (Table 2). The stage of crop development and soil type should be considered when using this index. In irrigated regions, only departures from ordinary irrigation requirements are reflected.

A parameter obtained from the calculations is the monthly moisture anomaly (Z) index which is the product of the moisture departure of the most recent 4 weeks and a climate weighting factor. This index can be used as an indicator of forest fire ignition. The classes of dry and wet periods for the different index values are given in table 3.

Another parameter derived from the calculations is the additional precipitation in inches needed to bring the PDSI to near zero. This parameter is computed for all values of the current week's PDSI less than -.5 and left blank for all values greater than or equal to -.5. The precipitation values are the theoretical, additional amounts required to end the drought in each climatic division. In using this parameter to make projections, it must be realized that these values are instantaneous, valid only for the current week. To end the drought in a given climatic division for the oncoming period, the amount listed plus near-normal rainfall must occur.

The following is a listing of the parameters in the files and their meaning. Temperature and precipitation are data received from the field and the other parameter are results of the Palmer drought and crop moisture data calculations. The week number in the heading is the week of the growing season where week one is the week with the first Wednesday in March. The computations are reinitated each year for week one using the output of the February Palmer data run. All initial data are replaced with the historical data received from the National Climatic Data Center in Asheville when available and the calculations rerun.

Columns of the Weekly Palmer Drought
and Crop Moisture Data Files

ST - State (states are grouped in each file by NWS region).

CD - Climate division (CD) number in the state.

TMP - Average weekly temperature (F) in the CD.

PRCP - Total weekly precipitation (inches) in the CD.

SOIL MOIST UPPR LAYR - Soil moisture in the upper layer at the end of the week (water capacity is one inch).

SOIL MOIST LOWR LAYR - Soil moisture in the lower layer at the end of the week (water capacity in inches is a function of the average

Schedule 1-2

soil type in the CD).

PCT FLD CPC END WEEK - The percent of field capacity of moisture in the soil at the end of the week. This value is the ratio of the soil moisture in the upper and lower layers to the available water capacity expressed in percent.

POT EVAP - Potential evapotranspiration using Thornwaites method (based on temperature, solar declination angle, and division constants such as mean latitude).

RUN OFF - Run off in inches at the end of the week.

CROP MOIST INDEX - Crop moisture index (CMI). Values indicate dry or wet conditions in the short term.

CHNG FROM PREV WEEK - The difference of the previous week's CMI from the current CMI (negative values indicate a drying of the soil).

MONTH MOIST ANOML (Z) INDEX - The monthly moisture anomaly (Z) index.

PRELIM FINAL PALMER DROUTH INDEX - Either a preliminary or a final Palmer Drought Severity Index (PDSI). Values indicate long term conditions.

- P - Preliminary. The listed PDSI could revert to a different value if the current weather trend (dry or wet) reverses to an opposite trend before it becomes established.

- F - Final. A weather spell is established and the PDSI is final.

PRCIP NEED TO END DROUTH - The additional precipitation in inches needed for the given week and CD to bring the PDSI up to a -.5 (the upper limit of a incipient drought). For any PDSI greater than or equal to -.5, this parameter is left blank.

TABLE 1

PDSI values for the 11 drought (or wet) categories.

4.0 and above	Extreme moist spell
3.0 to 3.99	Very moist spell
2.0 to 2.99	Unusual moist spell
1.0 to 1.99	Moist spell
.5 to .99	Incipient moist spell
.49 to -.49	Near normal
-.50 to -.99	Incipient drought
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought

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-4.0 and below	Extreme drought

TABLE 2

CMI values when the index increased or did not change from the previous week.

3.0 and above	Excessively wet, some fields flooded
2.0 to 2.99	Too wet, some standing water
1.0 to 1.99	Prospects above normal, some fields too wet
0 to .99	Moisture adequate for present needs
0 to -.99	Prospects improved but rain still needed
1.0 to -1.99	Some improvement but still too dry
-2.0 to -2.99	Drought eased but sill serious
-3.0 to -3.99	Drought continues, rain urgently needed
-4.0 and below	Not enough rain, still extremely dry

CMI values when the index decreased

3.0 and above	Some drying but still excessively wet
2.0 to 3.99	More dry weather needed, work delayed
1.0 to 1.99	Favorable, except still too wet in spots
0 to .99	Favorable for normal growth and fieldwork
0 to -.99	Topsoil moisture short, germination slow
-1.0 to -1.99	Abnormally dry, prospects deteriorating
-2.0 to -2.99	Too dry, yield prospects reduced
-3.0 to -3.99	Potential yields severly cut by drought
-4.0 and below	Extremely dry, most crops ruined

TABLE 3

Z index values for dry and wet periods

3.50 and above	Extreme wetness
2.50 to 3.49	Severe wetness
1.00 to 2.49	Mild to moderate wetness
-1.24 to .99	Near normal
-1.99 to -1.25	Mild to moderate drought
-2.74 to -2.00	Severe drought
-2.75 and below	extreme drought

Schedule 1-4

Last Modified: May 30, 1997

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Schedule 1-5

Documentation for the Original and Self-Calibrating Palmer Drought Severity Index used in the National Agriculture Decision Support System

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Abstract

The National Agriculture Decision Support System (NADSS) is a collection of decision support tools. Drought indices can be very important tools for agricultural planning. NADSS offers users information from the Palmer Drought Severity Index (PDSI). The original PDSI was designed in 1965, and has several well-known shortcomings. An improved implementation of the PDSI is the Self-Calibrated PDSI, which is also offered as part of NADSS.

There are several subtle characteristics of the calculation and behavior of the PDSI that are many time overlooked by users of the PDSI. This documentation was created to (1) inform users of NADSS of these subtleties and (2) introduce the concepts used in the Self-Calibrated PDSI, allowing them to more accurately interpret the information supply through NADSS.

Note on this document:
The information provided in this document was designed first and foremost for publication on the web, and it can be viewed at http://nadss.unl.edu/ . This document is simply a collection of the information into a single document for easier distribution. Readers should refer to the web page for the most up-to-date information, as well as for higher quality images.

-- March 24, 2003

SCHEDULE 2-1

Contents

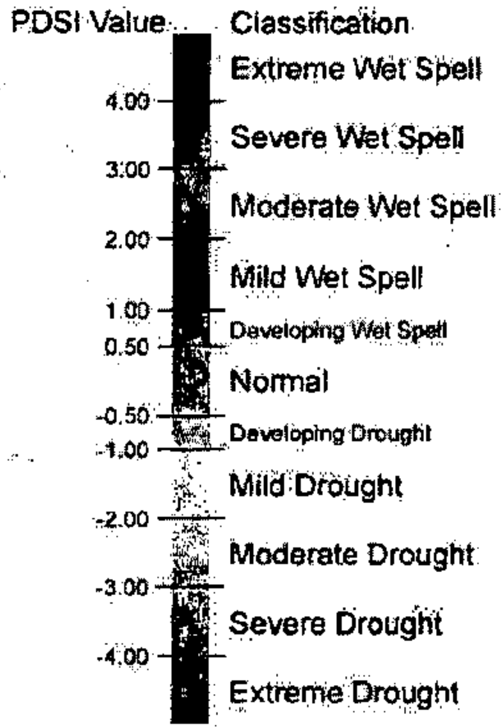
SCHEDULE 2-2

What is the Palmer Drought Severity Index?

The Palmer Drought Severity Index is usually abbreviated to PDSI, but sometimes the "Severity" part is left out and it is called the PDI. Throughout the course of this documentation, it will be referred to as PDSI.

The PDSI was developed during the early 1960's by W. C. Palmer as a standard way to quantify the severity of drought conditions. Palmer published his method in the 1965 paper, "Meteorological Drought" for the Office of Climatology of the U.S. Weather Bureau. Since then, the PDSI has become one of the most widely used drought assessment tools. The federal government and many state governments rely on the PDSI to trigger drought relief programs.

Unlike the Standardized Precipitation Index (SPI), which is another popular drought index, the PDSI is based on more than just precipitation. The PDSI actually uses a supply and demand model for the amount of moisture in the soil. The value of the PDSI is reflective of the how the soil moisture compares with normal conditions. A given PDSI value is usually a combination of the current conditions and the previous PDSI value, so the PDSI also reflects the progression of trends, whether it is a drought or a wet spell. That means that a single PDSI value is not representative of just the current conditions, but also of recent conditions to a certain extent.



Palmer defined the scale at the left for the PDSI. The categories run from "mild" to "moderate" to "severe" to "extreme". The normal range of PDSI values is from -0.50 to +0.50. Any PDSI values above +4.00 or below -4.00 fall into the "extreme" category of wet spell or drought. This scale was arrived at somewhat arbitrarily, which has been one of the criticisms of the PDSI.

The motive behind the development of the PDSI was to create a standard tool for quantifying severity of the effects of droughts. Exactly what is meant by "the effects of droughts" is a little vague, since droughts have wide ranging consequences. However, Palmer decided that the severity of a drought's effects is proportional to the relative change in climate. For example, if a climate that usually has very slight deviations from the normal experiences a moderate dry period, the effects would be quite dramatic. On the other hand, a very dry period would be needed in a climate that is used to large variations to produce equally dramatic effects. So the effects of a drought can be approximated by simply quantifying the unusualness of the climate conditions.

Palmer wanted a single methodology that could be used in any climate that was accurately representative of how the drought conditions affect that local climate. In other words, a PDSI of -4.0 in Western Texas should be similar to a PDSI of -4.0 in coastal Washington, even though coastal Washington will, even in its driest years, receive several times more rain than Western Texas. The procedure he developed involves calculating the moisture deficit or surplus and then weighting that value according to several factors of the historical behavior of the local climate. Successfully weighting the value should mean that it is representative of the severity of the conditions for the local climate.

How the PDSI is calculated

The PDSI is based around a supply and demand model of the soil moisture at a location. The supply is the amount of moisture in the soil plus the amount that is absorbed into the soil from rainfall. The demand, however, is not so as easy to see, because the amount of water lost from the soil is depends on several factors, such as temperature and the amount of moisture in the soil.

Potential Evapotranspiration

Abbreviations

PET	Potential Evapotranspiration
PR	Potential Recharge
PRO	Potential Runoff
PL	Potential Loss
ET	Evapotranspiration
R	Recharge
RO	Runoff
L	Loss
AWC	Available Water Holding Capacity
Ss	Surface Soil Moisture Content
Su	Underlying Soil Moisture Content

The basis of the soil modeling is the calculation of the **potential evapotranspiration** (PET). **Evapotranspiration** (ET) is, as one would guess, the combination of evaporation and transpiration, and in this context, refers to the amount of water lost from the environment through vegetation and evaporation. PET is calculated using **Thornthwaite's** method. Thornthwaite's method of calculating PET is much too complicated to explain on a web page, but here is some code, written in C, to look at if the desire is there to know exactly how it is done. It is suffice to say that the monthly PET depends on that month's average temperature, average temperature of that month over all historical record, and the latitude of the weather station.

One important thing to note is that Thornthwaite's method is an approximation of PET. It has been around for quite a long time, and is generally considered the accepted method to calculated PET, but it has seen some disagreement over how accurate it is. There has also been some criticism that the PDSI relies too heavily on Thornthwaite's. It is true that the PDSI relies heavily on the calculation of PET, but the PDSI could easily use another method to approximate PET.

Besides PET, there is also **potential recharge** (PR), **potential runoff** (PRO), and **potential loss** (PL). Before getting into how these are calculated, another definition is needed. The **Available Water Holding Capacity** (AWC) is the amount of water the soil is capable of holding. The

CLIM81 1971-2000 NORMALS

MONTHLY STATION NORMALS OF TEMPERATURE, PRECIPITATION, AND DEGREE DAYS

TD-9641C

National Climatic Data Center
Federal Building
Asheville, North Carolina

August 31, 2001

This document was prepared by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Data and Information Service, National Climatic Data Center, Asheville, North Carolina.

This document is designed to provide general information on the current, origin, format, integrity and the availability of this data file.

Errors found in this document should be brought to the attention of the Active Archive Branch Administrator, NCDC. See topic 58 for a summary of this data set.

SCHEDULE 3-1

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58. Summary

When historical climate data are accumulated and examined, they generally follow a certain pattern called a statistical distribution. For example, if 30 years of June temperature data were assembled and examined, the data would have a pattern that consisted of most of the Junes having temperatures close to the normal or average value, a few Junes having very warm temperatures, and a few Junes having very cold temperatures. This kind of statistical pattern is called a "Gaussian" distribution. Temperature data typically follow a Gaussian distribution, but precipitation frequently does not. This is because precipitation is zero bounded. When historical precipitation data are examined, most of the values will be close to the middle of the distribution, and some values will be considerably higher than the middle range. But on the low end of the scale, the smallest values will never be less than zero, since there can't be a negative precipitation. In particularly dry (e.g., desert) regions, the pattern can be drastically skewed to the left-hand side of the scale, with most of the values being near zero and a few very wet values spread far to the right. This kind of pattern is called a "Gamma" distribution. Once the statistical distribution is identified, the statistical properties of the distribution can be used to estimate the probabilities that certain values will occur, and which values can be expected at certain probability levels. The probability levels desired can be preselected at certain individual levels or at regular intervals. The 0-20%, 20-40%, 40-60%, 60-80%, and 80-100% intervals are called the quintile levels.

In this data set, the Gamma distribution was used to estimate the precipitation values at 15 probability levels (0.005, 0.01, 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 0.99, and 0.995). The expected precipitation values at the quintile levels are also included.

The climatological normals presented in this publication are based on monthly mean maximum and minimum temperature and monthly total precipitation records for each year in the 30-year period 1971-2000, inclusive. Data are assembled by individual states. Most stations were operating as of December 2000. Some stations were closed prior to 2000, but were identified as "normals stations" for special applications.

Several adjustments were made to the data before the normals were calculated. These adjustments include estimating missing data, adjusting for time of observation bias, and adjusting for exposure changes.

Data are presented in the order shown in the title. Units used in this publication are degrees F for temperature and inches for precipitation. Heating and cooling degree day (base: 65 degrees F) normals are derived from the monthly normal temperatures using the technique developed by Thom (1954a, 1954b, 1966). Degree day normals have also been computed to other bases and may be obtained from the National Climatic Data Center, Federal Building, 151 Patton Avenue, Asheville, NC 28801-5001, or by calling (828)271-4800.

NORMALS FOR FIRST ORDER AND COOPERATIVE STATIONS
TEMPERATURE AND PRECIPITATION NORMALS

First Order (Principal Climatological) Stations: First Order Stations record hourly observations and are usually staffed by professional observers. They can often be identified as having WSO, WSFO, WSMO, WSCMO, or FAA in their name. For all First order stations, any missing data for the 1971-2000 period were estimated from the monthly values of neighboring stations. Time of observation adjustments were made, as necessary, to the data from the neighboring stations before these data were used to estimate the missing first order station data (Karl, et al., 1986). Exposure change adjustments (Karl and Williams, 1987) were made to First order stations in the contiguous 48 States, but not to the stations in Alaska, Hawaii, or U.S. possessions because of the lack of a sufficient number of neighboring stations. The neighboring stations used in the adjustment procedure included stations from the Cooperative Station Network.

Cooperative Stations: Cooperative Stations usually record daily data only and are usually operated by volunteer observers. For all Cooperative Stations, any missing data for the 1971-2000 period were estimated from the monthly values of neighboring First Order and Cooperative stations. Time of observation adjustments were made to those stations in the contiguous 48 States that required the adjustment. No adjustment s were made to stations in Alaska, Hawaii, or U.S. possessions because of the lack of a sufficient number of neighboring stations. No exposure change adjustments were made to the station history information, but also because a Cooperative Station's identity changes (according to National Weather Service standards) when significant moves occur (generally at least 5 miles or 100 feet in elevation, subject to the judgment of the National Weather Service Cooperative Program Manager).

Methodology: A climate normal is defined, by convention, as the arithmetic mean of a climatological element computed over three consecutive decades (WMO, 1989). Ideally, the data record for such a 30-year period should be free of any inconsistencies in observational practices (e.g., changes in station location, instrumentation, time of observation, etc.) and be serially complete (i.e. no missing values). When present, inconsistencies can lead to a non-climatic bias in one period of a station's record relative to another. In that case, the data record is said to be "inhomogeneous". Since records are frequently characterized by data inhomogeneities, statistical methods have been developed to identify and account for these data inhomogeneities. In the application of these methods, adjustments are made so that earlier periods in the data record more closely conform to the most recent period. Likewise, techniques have been developed to estimate values for missing observations. After such adjustments are made, the climate record is said to be "homogeneous" and serially complete. The climate normal can then be calculated simply as the average of the 30 values for each month observed over a normals period like 1971 to 2000. By using appropriately adjusted data records, where necessary, the 30-year mean value will more closely reflect the actual average climatic conditions at all stations.

The methodology used to address inhomogeneity and missing data value problems stations is described in Figure 2. As with all automated quality control and statistical adjustment techniques, only those data errors and inhomogeneities falling outside defined statistical limits can be identified and appropriately addressed. In addition, even the best procedures can occasionally apply corrections where none are required or misidentify the exact year of a discontinuity. In the 1971-2000 monthly normals calculations, the sequential year-month data were adjusted to conform to a common midnight-to-midnight observation schedule. This is necessary since changes in observation time also can lead to non-climatic biases in a station's record. The data were then quality controlled to identify suspect observations and missing or erroneous values were estimated. Finally, the serially complete data series were adjusted for non-climatic inhomogeneities. In the 1971-2000 normals, all stations were processed through the same procedures, whereas in the 1961-1990 normals only NWS First Order stations were evaluated for inhomogeneities.

In order to effectively compare records among various stations, the time of observation bias, if present, must be removed. While the practice at all NWS First Order stations is to use the calendar day (midnight recording time) for daily summaries, Cooperative Network Station observers record observations once per day summarizing the preceding 24-hour period ending generally in the local morning or evening hours. Observations based on observation times other than midnight can exhibit a bias relative to those based on a midnight observation time (see e.g., Baker, 1975). Moreover, observation times at any one station may change during a station's history resulting in a potential inhomogeneity at that station. To produce records that reflect a consistent observational schedule, the technique developed by Karl et al. (1986) was used to adjust the monthly maximum and minimum temperature observations to conform to observations recorded on a midnight-to-midnight schedule. However, no time of observation bias adjustments were applied to stations in Alaska, Hawaii, or the U.S. possessions since no model for adjustment presently exists for these regions.

All monthly temperature averages and precipitation totals were cross-checked against archived daily observations to ensure internal consistency. In addition, each monthly observation was evaluated using an adaptation of the quality control procedures described by Peterson et al.(1998). In this approach, observations at each station are expressed as a departure from the long-term monthly mean. Then, monthly anomalies at a candidate station are compared with the anomalies observed at neighboring stations. Where anomalies at the candidate disagree substantially with those of its neighbors, the observations at the candidate are flagged as suspect and an estimate for the candidate is calculated from neighboring observations (see below). If the original observation and the estimate differ by a wide margin (standardized using the observed frequency distribution at the station), the original is discarded in favor of the estimate. Very few observations were eliminated based on the quality control evaluation.

To produce a serially complete data set, missing or discarded temperature and precipitation observations were replaced using the observed relationship between a candidate's monthly observations and those of up to 20 neighboring stations whose observations exhibited the highest correlation with those at the candidate site. Monthly estimates are calculated using the climatological relationship between candidate and neighbor as well as a weighting function based on the neighbor's correlation with the candidate. For temperature estimates, neighboring stations were drawn from the pool of stations found in the U.S. Historical Climatology Network (USHCN; Karl et al. 1990) whereas for precipitation estimates, all available stations were potentially used as neighbors in order to maximize station density for estimating the more spatially variable precipitation values.

Peterson and Easterling (1994) and Easterling and Peterson (1995) outline the method that was used to adjust for temperature inhomogeneities. This technique involves comparing the record of the candidate station with a reference series generated from neighboring data. The reference series is reconstructed using a weighted average of first difference observations (the difference from one year to the next) for neighboring stations with the with the highest correlation with the candidate. The underlying assumption behind this methodology is that temperatures over a region have similar tendencies in variation. For example, a cold winter followed by a warm winter usually occurs simultaneously for a candidate and its neighbors. If this assumption is violated, the potential discontinuity is evaluated for statistical significance. Where significant discontinuities are detected, the difference in average annual temperatures before and after the inhomogeneity is applied to adjust the mean of the earlier block with the mean of the latter block of data. Such an evaluation requires a minimum of five years between discontinuities. Consequently, if multiple changes occur within five years or if a change occurs very near the end of the normals period (e.g. after 1995), the discontinuity may not be detectable using this methodology.

The methodology employed to generate the 1971-2000 normals is not the same as in previous normals calculations. For example, in the calculation of the 1961-1990 normals no attempt was made to adjust Cooperative Network observer data records for inhomogeneities other than those associated with the time of observation bias. Therefore, serial year-monthly data for overlapping periods between normals (e.g., for the 20 years in common between the 1961-90 and 1971-2000 normals) will not necessarily be identical.

Degree Day Normals

Degree day normals were computed in two ways. For 250 selected NWS locations, heating and cooling degree day normals were computed directly from daily values for the 1971-2000 period. For all other stations, the rational conversion formulae developed by Thom (1954, 1966) was modified by using a daily spline-fit assessment of mean and standard deviations of average temperature. The Thom methodology allows the adjusted mean temperature normals and their standard deviations to be converted to degree day normals with uniform consistency. The modification eliminates an artificial month-by-month 'step' in the data output. In some cases this procedure will yield a small number of degree days for months when degree days may not otherwise be expected. This results from statistical considerations of the formulae. The annual degree day normals were calculated by adding the corresponding monthly degree day normals.

Supplementary Data

Individual station values (by-month) of average (maximum, minimum, and mean) temperature and total precipitation used to calculate the normals for the 1971-2000 period are available from the National Climatic Data Center, Asheville, NC, and may be obtained in either microfiche or digital media (TD-9641). In addition, extremes of monthly total precipitation and mean temperature are included, along with the standard deviations of the monthly temperatures. The median (i.e., 50th percentile), 11-year and 21-year means are also provided for both temperature and precipitation.

Precipitation normals less than .005 inch are shown as zero. Precipitation includes rainfall and the liquid water equivalent of frozen precipitation (snow, sleet, hail).

Temperature normals are provided for mean monthly maximum temperature (NORMAL MAX), mean monthly minimum temperature (NORMAL MIN), and mean monthly average temperature (NORMAL). The median (50th percentile) monthly average temperature is shown as MEDIAN. The median is the middlemost value in an ordered series of values. Half of the values are greater than the median and half are less than the median.

Monthly normals for February are based on a 28-day month.

Figures and letters following the station name generally indicate a rural location and refer to the distance and direction of the station from the nearest Post Office. WSO, WSMO, WSCMO and WSFO denote a National Weather Service office, meteorological observatory, contract meteorological observatory and forecast office, respectively. FAA implies a Federal Aviation Administration station with an observing capability coordinated by the National Weather Service. Station elevations are in feet above mean sea level. The December 1990 observation time for temperature is shown on the temperature tables under the station name. LT refers to Local Time (Standard or Daylight, as applicable).

Stations located on islands (U.S. possessions) generally have short records (i.e., less than 30 years) and do not meet the criteria for computation of normals. Short-term or period averages are given for these stations (as shown).

MAX is maximum, MIN is minimum, MID O.S. TIME ADD is the adjustmended factor to convert a normal to midnight observation time, ANN is annual, SEQ NO is sequence number and is used to locate the station on the map. STATION NO. is the Cooperative station number.