A Survey of Drought Indices: Input, Output, and Available Data Sets

Bisher Imam

Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Water Resources in Developing Countries: Planning and Management in Climate Change Scenarios
ICTP, Trieste, Italy, April 27 through May 8, 2009
Aridity

Concept

Applies to normal conditions (Climatology)
The Degree to which climate lacks effective, life promoting moisture
Used to classify climate zones

Aridity

Index

Koppen/Geiger Climate Classification (1918)
C. W. Thornthwaite (1948)
M. I. Budyko (1958)

UNEP

\[ P = \text{PET} \]

\[ I_a = 100 \times \frac{\text{demand}}{\text{deficit}} \]

\[ I_h = 100 \times \frac{\text{surplus}}{\text{demand}} \]

\[ I_m = I_h - I_a \]

\[ AI = \frac{P}{PET} \]
Aridity Indices: Examples

**Thonthwaite**

\[ I_a = 100 \times \frac{\text{deficit}}{\text{demand}} \]

for deficit months

\[ I_h = 100 \times \frac{\text{surplus}}{\text{demand}} \]

for surplus months

\[ I_m = I_h - I_a \]

**UNEPE**

\[ AI = \frac{P}{PET} \]

<table>
<thead>
<tr>
<th>( Im )</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Im &lt; -66.7 )</td>
<td>Arid</td>
</tr>
<tr>
<td>-66.7 &lt; ( Im &lt; -33.6 )</td>
<td>Semi-Arid</td>
</tr>
<tr>
<td>-33.6 &lt; ( Im &lt; 0.0 )</td>
<td>Dry Sub-humid</td>
</tr>
<tr>
<td>0.0 &lt; ( Im &lt; 20.0 )</td>
<td>Moist Sub-humid</td>
</tr>
<tr>
<td>20.0 &lt; ( Im &lt; 100.0 )</td>
<td>Humid</td>
</tr>
<tr>
<td>( Im &gt; 10.00 )</td>
<td>Per-humid</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( AI )</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Ai &gt; 1.00 )</td>
<td>Humid</td>
</tr>
<tr>
<td>1.00 &gt; ( Ai &gt; 0.90 )</td>
<td>Moist sub-humid</td>
</tr>
<tr>
<td>0.90 &gt; ( Ai &gt; 0.65 )</td>
<td>Dry sub-humid</td>
</tr>
<tr>
<td>0.50 &gt; ( Ai &gt; 0.20 )</td>
<td>Semi-Arid</td>
</tr>
<tr>
<td>0.20 &gt; ( Ai &gt; 0.05 )</td>
<td>Arid</td>
</tr>
<tr>
<td>( A &lt; 0.05 )</td>
<td>Hyperarid</td>
</tr>
</tbody>
</table>
“The country has reason to make careful note of either extreme. When the water rises to only twelve cubits, it experiences the horrors of famine; when it attains thirteen, hunger is still the result; a rise of fourteen cubits is productive of gladness; a rise of fifteen sets all anxieties at rest; while an increase of sixteen is productive of unbounded transports of joy. The greatest increase known, up to the present time, is that of eighteen cubits, which took place in the time of the Emperor Claudius; the smallest rise was that of five, in the year of the battle of Pharsalia, the river by this prodigy testifying its horror.”

Pliny the Elder, Naturalis Historia, Book V, First Century AD
Some (Visible) Impacts
Some (Visible) Impacts

2006 apparently produced the lowest amount of rainfall in Riverside County since annual rainfall had been recorded, at just 1.93 inches. That beat out the previous low of 2.94 inches in 1883.
Recent Extreme Drought Conditions in the U.S. Southwest

Normal Years

Sever Multi-year Drought through 2004

Lake Powell, Colorado River, USA

Source: J. Kane  SRP 2004
Water Resources: (Hydrologic Drought)

August Elevation 1939-2003

- Maximum Elevation (1237 feet)
- Average August Elevation, 1939-2003 (1175 feet)
- 2003 Elevation (1143 feet)

Year

Average Monthly Elevation 1993-2003

- Maximum Elevation (1239 feet)
- Average Elevation, 1993-2003 (1173 feet)

Year

May 3, 2003

May 28, 2003
Water Resources Issues: Spatial & Temporal Scales

- Precipitation, Temperature, and Pressure
  - Weather Forecasts
  - Extended Weather Predictions
  - Climate Outlooks
  - Climate Variability
  - Climate Change

- Spatial Scale (km^2)
  - Flash Flood
  - General Flood
  - Reservoir Operation, Well-Field, Watershed Resources
  - Drought, Conjunctive Management, Ecosystems Policy, and Development
  - Sustainable Development

- Temporal Scale
  - day
  - week
  - month
  - season
  - year
  - decade
  - century

- Emissions
- LU/LC Change
- SST
- Soil Moisture, ET

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Water Resources in Developing Countries, Trieste, Italy, 2009
Drought: Definition

- Many Possible Definitions
- It is a normal and recurring feature of climate
- It occurs in all climatic zones
- Varies in characteristics from one region to another

Drought originates from **deficiency of precipitation** over an **extended** period of time, usually a season or more resulting in water **shortage** for some **activities**

Drought is a **persistent and abnormal** moisture deficiency having **adverse impacts** on vegetation, animals, or people

Drought is a **creeping disaster**
- develops slowly and can last long
- difficult to quantify
- long lasting impacts
Drought: Temporal Scales

Kurdufan, Sudan

![Graph showing drought index over time with different temporal scales: months, seasons, years, decades. The graph highlights significant drought events from 1920 to 2000.](image)
Drought: Temporal Scales (Paleo-climate)

A 2129-Year Reconstruction of Precipitation for Northwest New Mexico

Multi-decades
Century?

1950s drought

from Grissino-Mayer 1996
Drought: Spatial Scale

Drought Wet Spell

Sub-Regional
Regional
Local
Wide-Spread

Drought
Wet Spell

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Monthly Water Balance

Changnon, 1987
Precipitation
Runoff
Soil Moisture
Groundwater
Pet
AET
Moisture Deficit
Soil Moisture Recharge
Soil Moisture Utilization

Changnon, 1987
Types of Droughts

Natural Climate Variability

Precipitation deficiency (amount, intensity, timing)
- High temp, wind, low relative humidity, greater sunshine, less cloud cover
- Increased evaporation and transpiration
- Reduced infiltration, runoff, deep percolation, and ground water recharge
- Reduced streamflow, inflow to reservoirs and lakes, shrinking wetlands, reduced wildlife habitat

Soil Water Deficiency
- Plant water stress, reduced biomass and yield

Reduced streamflow, inflow to reservoirs and lakes, shrinking wetlands, reduced wildlife habitat

Economic Impacts

Social Impacts

Environmental Impacts

Duration

Meteorological

Agricultural

Hydrologic
Desirable Characteristics of Drought Indices

Must:
- Easy to Interpret, Independent of assumptions, limitation, and computations
- Reasonable complexity: Not too complex and not too simple
- Informational: Must add information to raw data
- Open ended: Unprecedented behavior yields unprecedented values
- Sensitivities and statistical properties must be well understood before operational usage

Desired:
- Sub-indices should provide understanding of behavior
- Proportional to impacts
- Reliant on available historical data
- New data can easily be incorporated
- Normalized to background climates to facilitate spatial comparison
- Can be placed within historical context

After, Redmond 1991, and 2002
### Historical Evolution

#### Statistical
- Rainy days
- Percent of normal
- Deciles
- Standardized Precipitation Index (SPI)

#### Deficit-based
- Palmer Drought Severity Index (PDSI)
- Crop Moisture Index (CMI)
- Soil Moisture Index (SMI)

#### Satellite-based
- Vegetation Condition Index
- Normalized Difference Vegetation Index
- Maximum Snowpack Extent

#### Composite Impact-based
- US-Drought Monitor
- Total Water Deficit

### In-situ data
- Precipitation
- Temperature
- Streamflow
- Reservoir Storage

### Models
- Simple Water Balance
- Land Surface Models (VIC)
- Data assimilation systems

### Remote Sensing
- Snow
- Vegetation
- LS temperature
- Topography
- Reservoir Levels (Future)

### Impact Models

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**Water Resources in Developing Countries, Trieste, Italy, 2009**
| Metric                        | Data | Calculation                                                                 | Drought definition and severity scale                                                                                                                                                                                                                                                                                                                                 | Strengths                                                                                           | Weaknesses                                                                                                                                                                                                 |
|-------------------------------|------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Days of rain                  | R    | Consecutive days with little or no R, or total R during a specified period of time | Drought if days with no rain > place-specific maximum or R for given period < place-specific minimum R                                                                                                                                                                                                                                                                                  | Intuitive and communicative Easy to measure                                                                                                     | Not comparable. Valid only for specific application in specific region (11) Does not assess increasing or decreasing severity Abrupt termination of drought                                                                         |
| Percent of average rainfall   | R    | Divide actual R (or RF, SF) for a given period by multiyear average for this period | Drought if percent < place-specific minimum The lower the percent, the more intense the drought                                                                                                                                                                                                                                                                                         | Intuitive and communicative Easy to measure Useful for reservoir management                                                                  | Average is not the same as normal in variable climates (mean ≠ median) (145) Cannot compare departure from average for locations with different climates                                                                 |
| (runoff or streamflow)        |      |                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                 |                                                                                                                                                                                                                                                                   |
| Deciles (146)                 | R    | Divide distribution of occurrences over a long-term R record into tenths of distribution (deciles) | Scale: deciles 1–10 Drought if R in third through fourth decile Extreme drought in deciles 1–2 (i.e., R not exceeding 10%–20% of record)                                                                                                                                                                                                                                                                                                         | Easy to measure Accurate statistical measurement of departure from normal, comparable across contexts | Impacts from statistical departures vary depending on local conditions Accurate calculations require a long data record                                                                                                                                            |
Statistical Indices: Standardized Precipitation Index (SPI)

1. Select data from Calibration Period
2. Fit (Gamma or Weibul) to data
3. Identify Probability value for P
4. Identify N(0,1) associated with probability
5. N(0,1) Deviate SPI for month P

T.B. McKee, N.J. Doesken, and J. Kleist (1992)
For the selected accumulation period and duration
Select data from the calibration period
Fit Probability distribution (Gamma or Weibul)
For the Entire Period
   Identify value of CDF corresponding to p
   Identify SPI as the N(0,1) deviate corresponding to CDF(P)
Step 1: Extract timeseries for accumulation period: January 1 Months accumulation

Step 2: Fit pdf/cdf to I-Gamm

Step 3: Convert Gamma probabilities into N(0,1) Deviates

Step 4: N(0,1) deviates is the accumulation period's SPI

Repeat for all accumulation periods to construct SPI series

Legend:
- near normal
- anomalously moist
- moderately moist
- very moist
- extremely moist
- exceptionally moist

- exceptionally dry
- extremely dry
- severely dry
- moderately dry
- abnormally dry
- near normal

-2.00 to -1.60
-1.99 to -1.59
-1.59 to -1.29
-1.29 to -0.80
-0.80 to -0.51
-0.51 to 0.00
+0.00 to +0.50
+0.51 to +1.00
+1.00 to +1.59
+1.59 to +2.00
+2.00 and above
Characteristics of SPI

- Can be computed for any duration, generally (1, 3, 6, 9, 12, and 24) months
- Can account for long term precipitation deficit (9 months +)
- Requires long term precipitation data
- Best possible distribution is still subject of research
- Has high correlation with PDSI (at longer duration)
- Mean SPI for any location is 0
- Applicable to station and gridded data (Satellite data)
Available Global Monitoring of SPI


<table>
<thead>
<tr>
<th>SPI Values</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 2.00</td>
<td>Extremely Wet</td>
</tr>
<tr>
<td>1.50 to 1.99</td>
<td>Severely Wet</td>
</tr>
<tr>
<td>1.00 to 1.49</td>
<td>Moderately Wet</td>
</tr>
<tr>
<td>-0.99 to 0.99</td>
<td>Near Normal</td>
</tr>
<tr>
<td>-1.00 to -1.49</td>
<td>Moderately Dry</td>
</tr>
<tr>
<td>-1.50 to -1.99</td>
<td>Severely Dry</td>
</tr>
<tr>
<td>&lt;= -2.00</td>
<td>Extremely Dry</td>
</tr>
</tbody>
</table>

1, 3, 6, 9, and 12 Months

Interactive tool to plot and visualize
Palmer Indices: brief procedure

Compute monthly water budget using hydrologic accounting for a long series and obtain coefficients.

Determine the amount of moisture required for climatically appropriate existing conditions (CAFEC: Normal) weather during each month.

Compute the precipitation departure from CAFEC value.

Convert the departures to indices of moisture anomaly Palmer Z Index using K (climatic characteristic factor).

Calculate Palmer Drought Severity Index (PDSI) and its derivatives.

Two bucket model

Thornthwaite (PE)

ET, Loss, Recharge, Run-Off

Requires AWC in soil

\[ \hat{P} = \alpha_i \frac{PE_i}{PR} + \beta_i \frac{PR}{PL} + \gamma_i \frac{RO_i}{POR} - \delta_i \frac{L_i}{PL}. \]

\[ d = P - \hat{P} \]

\[ Z = dK. \]

\[ X_i = 0.89X_{i-1} + \left( \frac{1}{3} \right) Z_i. \]

Duration factors
**PDSI: Further Developments**

**Karl, 1986**: PHDI (Palmer Hydrological Drought Index)
Different treatment of the end of a dry spell to reflect water availability (soil moisture, runoff) as opposed to meteorological end based on weather.

**Heim 2005**: Weakly basis calculation of PDSI

**Wells et. al. 2004**, Self calibrating PDSI
Allows for the calculation of climatic characteristic and duration factors using site specific data instead of Palmer’s empirical estimates

**Dai, 2004**: Global PDSI data set for 100+ years.
<table>
<thead>
<tr>
<th>Metric</th>
<th>Data&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Calculation</th>
<th>Drought definition and severity scale</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmer Drought Severity Index (PDSI) (147)</td>
<td>R, T, ET, SM, RF</td>
<td>Calculates a series of water balance terms for a generic two-layer soil model. Fluctuations in the hypothetical moisture supply are compared to a reference set of water balance terms to compute dimensionless cumulative departure of moisture supply.</td>
<td>Scale: -6 to 6 (typically -4 to 4) Drought if &lt;0 -0.5 to -0.99 incipient dry spell -2 to 2.99 moderate drought -4 and less extreme drought</td>
<td>Takes evapotranspiration and soil moisture into account Most effective where impacts sensitive to soil moisture Factors in antecedent conditions Calculable from basic data</td>
<td>Arbitrary algorithms (148) Nonintuitive classification Undefined generic timescale (7); may lag drought termination (8) Complex computation and reduced transparency Calibrated for U.S. Great Plains’ conditions; limited applicability in locations with climatic extremes, mountainous terrain, or snow-pack unless calibrated (but see 18)</td>
</tr>
<tr>
<td>Standardized Precipitation Index (SPI) (7)</td>
<td>R</td>
<td>The long-term R record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for location and desired period is 0.</td>
<td>Scale: -2 and less, to 2 and more Drought when SPI continuously &lt;0 -1 to -1.49 moderate -1.5 to -1.99 severe -2 and less extreme</td>
<td>Can be computed at different timescales as they relate to different types of drought (agricultural, streamflow, groundwater) Uses only one input variable (R) so calculations are simpler than PDSI</td>
<td>Long climatic record needed Changes from month to month as new data is incorporated Does not consider hydroenvironmental factors and seasonal differences in evapotranspiration</td>
</tr>
</tbody>
</table>
Model-Based Drought Monitoring: (E. Wood, 2006)

1) Retrospective Simulation

- Forcings
- VIC LSM
- Retrospective Soil Moisture

2) Calculate Soil Moisture Index

- L-Moments
- Fit beta distribution
- Calculate Index

\[
L_{\text{mean}}(\mu_s) = \lambda_1 \\
L_{\text{CV}}(\sigma_s / \mu_s) = \frac{\lambda_2}{\lambda_1} \\
L_{\text{skew}}(\gamma_s) = \frac{\lambda_3}{\lambda_2}
\]

3) Drought Analysis

- Historic soil moisture
- Realtime soil moisture

After: E. Wood, 2006 Princeton University
Example: VIC-based Soil Moisture Quantile (Aug, 1984)
Satellite Based Drought Monitoring

NDVI = (NIR - VIS)/(NIR + VIS)

VHI – Vegetation Health Index:
Estimates vegetation health (condition) based on combination of vegetation greenness (Normalized Difference Vegetation Index, NDVI) and temperature (Brightness Temperature, BT).

VCI – TCI - Vegetation & Temperature Condition Indices:

\[
VCI = 100(\text{NDVI} - \text{NDVI}_{\text{min}})/(\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}})
\]

\[
TCI = 100(\text{T}_{\text{max}} - T)/(\text{T}_{\text{max}} - T_{\text{min}})
\]

Estimate moisture and thermal conditions, respectively, based on NDVI and BT.

Fire Risk Index:
Index showing if conditions of vegetation are suitable for fire development.
Example: VHI (Current)

Composite Indices: US-Drought Monitor

U.S. Drought Monitor

April 21, 2009
Valid 8 a.m. EDT

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm

Authors: Richard Haim/Liz Love-Brotak, NOAA/NESDIS/NCDC

Released Thursday, April 23, 2009
# Components

## Blend

### Table 1. The categories of drought magnitude used in the Drought Monitor. Each category is associated with its percentile chance of happening in any given year out of 100 yr.

<table>
<thead>
<tr>
<th>Category</th>
<th>Drought condition</th>
<th>Percentile chance</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0</td>
<td>Abnormally dry</td>
<td>20 to ≤30</td>
</tr>
<tr>
<td>D1</td>
<td>Drought—moderate</td>
<td>10 to ≤20</td>
</tr>
<tr>
<td>D2</td>
<td>Drought—severe</td>
<td>5 to ≤10</td>
</tr>
<tr>
<td>D3</td>
<td>Drought—extreme</td>
<td>2 to ≤5</td>
</tr>
<tr>
<td>D4</td>
<td>Drought—exceptional</td>
<td>≤ 2</td>
</tr>
</tbody>
</table>

### Table 2. The association of the six key objective drought indicators with the magnitude of drought severity in the Drought Monitor.

<table>
<thead>
<tr>
<th>Drought type</th>
<th>Associated ranges of objective indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Palmer drought</td>
</tr>
<tr>
<td>D0</td>
<td>Abnormally dry</td>
</tr>
<tr>
<td>D1</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>D2</td>
<td>Severe drought</td>
</tr>
<tr>
<td>D3</td>
<td>Extreme drought</td>
</tr>
<tr>
<td>D4</td>
<td>Exceptional drought</td>
</tr>
</tbody>
</table>

Source: Svoboda, et. al., BAMS, Aug 2002
## Sectoral Impact

<table>
<thead>
<tr>
<th>Category</th>
<th>Agriculture (A)</th>
<th>Water (W)</th>
<th>Fire (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0</td>
<td>Slows farm activity, and crop and pasture growth</td>
<td>Steamflow below average</td>
<td>Fire risk above average</td>
</tr>
<tr>
<td>D1</td>
<td>Some damage to crops and pastures</td>
<td>Streamflow, reservoir, and well levels are low; some water shortages develop</td>
<td>Fire risk high</td>
</tr>
<tr>
<td>D2</td>
<td>Crop and pasture losses likely</td>
<td>Water shortages common; water restrictions imposed</td>
<td>Fire risk very high</td>
</tr>
<tr>
<td>D3</td>
<td>Major crop/pasture losses</td>
<td>Widespread water shortages and restrictions</td>
<td>Fire risk extreme</td>
</tr>
<tr>
<td>D4</td>
<td>Exceptional and widespread crop/pasture losses</td>
<td>Shortages of water in stream, reservoirs, and wells creating emergencies</td>
<td>Fire risk exceptionally dangerous</td>
</tr>
</tbody>
</table>

Source: Svoboda, et. al., BAMS, Aug 2002
<table>
<thead>
<tr>
<th>Metric</th>
<th>Data⁸</th>
<th>Calculation</th>
<th>Drought definition and severity scale</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation Condition Index (VCI)</td>
<td>GVI</td>
<td>Satellite measures visible and near-IR radiance as a proxy for health of vegetation. Vegetation associated to drought severity, adjusted for land climate, ecology, and weather conditions</td>
<td>Scale: 0–100</td>
<td>Real-time monitoring of onset and progression of drought. Good for early warnings. Useful for areas not covered well by precipitation or hydrological stations (Africa)</td>
<td>Limited utility during cold seasons when vegetation is dormant. Ground conditions other than drought affect vegetation index</td>
</tr>
<tr>
<td>Total water deficit (149)</td>
<td>SF</td>
<td>Sum of flows below some truncation level (mean or impact-related minimum) Product of time during which flows are below truncation level and average departure of streamflow</td>
<td>Drought if deficit &gt; 0</td>
<td>Intuitive and communicative. Easy to measure.</td>
<td>Long streamflow record needed. River regulation and other human impacts distort streamflow record. Problems in scaling up from individual streams to region/river basin.</td>
</tr>
<tr>
<td>Days of supply remaining (150)</td>
<td>RS, D</td>
<td>Calculates the days a reservoir (or system) can satisfy demand using storage capacity, forecasted future inflows, and predicted demands</td>
<td>Drought if days &lt; system-specific threshold</td>
<td>Communicative. Takes demand into account</td>
<td>System-specific thresholds; limited comparability Sensitive to models’ assumptions about demand and inflows</td>
</tr>
</tbody>
</table>
Drought Prediction and Outlook

Source: http://www.nws.noaa.gov/ost/climate/STIP/33CDPW/Luof1.jpg

Fig. 1. Schematic diagram of the drought monitoring and prediction system (DMAPS) implemented for the US.

Increased GHG Concentration leads to heating of the atmosphere

Higher temperature leads to higher rates of evaporation and evapotranspiration, leading to faster depletion of soil moisture (Drought conditions).

Hotter atmosphere has a higher water holding capacity. More moisture remains in the atmosphere, and the rate of recycling through precipitation slows down. Increased evaporation rate leads to even higher amounts of atmospheric moisture, and water vapor, being a GHG, can contribute to further heating.

More vapor is available for precipitation, but at lesser frequency of events. Rainfall variability increases and the probability of extreme events may increase despite little or no change in total annual precipitation. Water vapor is a GHG and its increase may exasperate the problem.

On the earth’s surface, more extreme events are likely. Snow seasons shorten, and the intense precipitation causes flood. The lower frequency of rain days and increased evapotranspiration contribute to drought conditions.
Figure 13. The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. PDSI is the most commonly used drought index. Red and orange areas are drier when the values in the lower panel are positive (red) and wetter during the time when the values in the lower panel are negative (red). Conversely, green and blue areas are wetter when the values in the lower panel are positive (red) and dryer when the values of the lower panel are negative (blue). Adapted from Dai et al. (2004) and IPCC 2007.
Potential Impacts

Changnon, 1987

Water Depth (mm)

Oct  Nov  Dec  Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep

0  50  100  150  200  250

AET  PET  Moisture Deficit  Soil Moisture Utilization  Soil Moisture Recharge
Potential Impacts

Changnon, 1987

Water Depth (mm)

Oct  Nov  Dec  Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep

Month

P
Soil Moisture Recharge
AET
PET
Moisture Deficit
Soil Moisture Utilization

Changnon, 1987
Changes in Drought Severity.

HadCM3 A2 scenario (Burke and Brown, 2006)
Global Drought Information