Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and David E. Knapp, Editors

Volume 20
BOREAS HYD-1 Soil Hydraulic Properties

S.F. Kelly and R.H. Cuenca

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

July 2000
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July 2000
BOREAS HYD-1 Soil Hydraulic Properties
Shaun F. Kelly, Richard H. Cuenca

Summary

The BOREAS HYD-1 team coordinated a program of data collection to measure and monitor soil properties in collaboration with other science team measurement needs. This data set contains soil hydraulic properties determined at the NSA and SSA flux tower sites based on analysis of in situ tension infiltrometer tests and laboratory-determined water retention from soil cores collected during the 1994-95 field campaigns. Results from this analysis are saturated hydraulic conductivity, and fitting parameters for the van Genuchten-Mualem soil hydraulic conductivity and water retention function at flux tower sites. The data are contained in tabular ASCII files.

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1. Data Set Overview

1.1 Data Set Identification
BOREAS HYD-01 Soil Hydraulic Properties

1.2 Data Set Introduction
Soil hydraulic properties were determined at the flux tower sites based on analysis of in situ tension infiltrometer tests and laboratory-determined water retention from soil cores collected during the 1994-95 field campaigns. Results from this analysis are saturated hydraulic conductivity, and fitting parameters for the van Genuchten-Mualem soil hydraulic conductivity and water retention function at flux tower sites.

1.3 Objective/Purpose
The objective of this study was to determine the soil hydraulic properties needed for physical simulation modeling of soil-vegetation-atmosphere-transfer processes.
1.4 Summary of Parameters

The properties determined for each site were saturated hydraulic conductivity, KSAT; soil water retention using the van Genuchten (1980) function, THETA \( H, N, \alpha, \text{SAT, RESID, M} \) where \( M = 1-(1/N) \); and unsaturated hydraulic conductivity using the Mualem (1976)-van Genuchten (1980) function, \( K \ (H, N, \alpha, KSAT, M) \) where \( M = 1-(1/N) \).

1.5 Discussion

In situ tension infiltrometer tests and laboratory soil core water retention data were combined to determine soil hydraulic properties at the sites of the flux towers operating during the 1994-95 BOREal Ecosystem-Atmosphere Study (BOREAS) field campaigns. At each flux tower site, between 6 and 20 tension disk infiltrometer tests were performed at the soil surface (A-horizon). Laboratory soil core water retention data from the soil surface (A-horizon) were obtained from soil surveys conducted during 1993-94 by Darwin Anderson (southern sites) and Hugo Veldhuis (northern sites).

Saturated hydraulic conductivity at each site was estimated by extrapolating the low tension conductivities of all tests to zero tension to obtain a site average saturated hydraulic conductivity. The unsaturated hydraulic conductivity function and soil water retention function were determined using the combined infiltrometer data of each site and the soil core water retention data. The tension infiltrometer data were determined at low tensions between 0 and 20 cm, and the soil core water retention data were determined at high tensions between 100 cm and 15,000 cm. Combining these two data sets using soil physics theory provides more information across the whole range of tensions from saturation at 0-cm tension to the permanent wilting point at 15,000-cm tension.

The soil hydraulic properties were measured on a scale ranging from 5 to 20 cm, but distributed simulation models more often require these properties on a scale ranging from tens of meters to kilometers. Spatial variations in soil hydraulic properties of this data set were minimized by performing multiple tests at each site. The quality of this data set will be checked by using these parameters in a physics-based model (SWMS-2D finite element model of soil water movement) and comparing with soil moisture profiles collected at the sites during the BOREAS experiment.

1.6 Related Data Sets

- BOREAS TE-20 Soils Data over the NSA-MSA and Tower Sites in Raster Format
- BOREAS TE-20 Soils Data over the NSA-MSA and Tower Sites in Vector Format
- BOREAS TE-20 NSA Soil Lab Data
- BOREAS TE-01 Soils Data over the SSA Tower Sites in Raster Format
- BOREAS TE-01 SSA Soil Lab Data

2. Investigator(s)

2.1 Investigator(s) Name and Title

Richard H. Cuenca, Professor
Department of Bioresource Engineering
Oregon State University

2.2 Title of Investigation

Coupled Atmosphere-Forest Canopy-Soil Profile Monitoring and Simulation
2.3 Contact Information

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David.Knapp@gsfc.nasa.gov

3. Theory of Measurements

Disk tension infiltrometers are designed to measure soil water infiltration rates at a controlled negative water pressure or tension within a circular interface at the soil surface. The analysis of data in this data set is based on the approximation of flow from a circular source based on Wooding, 1968. From each test the steady-state infiltration rate is used to calculate a conductivity, K, at the specified tension, H. The paired K, H data obtained from each test site run across tensions ranging from 3 cm to 20 cm using two different disk radii. Saturated hydraulic conductivity and the unsaturated hydraulic conductivity at each site were summarized using the Mualem-van Genuchten model (Mualem, 1976; van Genuchten, 1980). Water retention function was simultaneously fitted to the data from the laboratory soil cores.
4. Equipment

4.1 Sensor/Instrument Description

Disk tension infiltrometer:
The disk tension infiltrometer is designed to measure unsaturated flow of water into soil. It consists of: 1) a bubble tower that controls tension at the soil surface, 2) a water reservoir from which water flows into the soil, and 3) a baseplate with a membrane to establish hydraulic continuity with the soil. The water level in the reservoir is monitored using pressure transducers and a datalogger to record infiltration rates during the tests. Infiltrometers with baseplate disk diameters of 8 and 20 cm were used.

4.1.1 Collection Environment
The tension infiltrometer tests were performed throughout the 1994-95 BOREAS Intensive Field Campaigns (IFCs) in both the Northern Study Area (NSA) and the Southern Study Area (SSA) from May to September.

4.1.2 Source/Platform
The ground surface.

4.1.3 Source/Platform Mission Objectives
The objective was to measure hydraulic properties of the soil.

4.1.4 Key Variables
Saturated conductivity, hydraulic conductivity function, and water retention function.

4.1.5 Principles of Operation
The tension infiltrometer applies water to the soil surface at a constant tension and records the resulting infiltration rate in time. Hydraulic conductivities may be calculated using theoretical approximations of steady-state unconfined infiltration rates into the soil from circular sources. Hydraulic conductivities are determined at a number of tensions, and the hydraulic conductivity function is determined by fitting the appropriate function through the measured hydraulic conductivity versus tension data.

4.1.6 Sensor/Instrument Measurement Geometry
The tension infiltrometer is set on the soil surface; therefore, only the hydraulic properties of the soil surface (A-horizon) are determined.

4.1.7 Manufacturer of Sensor/Instrument
Tension infiltrometer
Soil Measurement Systems
7266 N. Oracle Road
Suite 170
Tucson, AZ 85704
(602) 742-4471
(602) 742-4379 or (602) 797-0356 (fax)

The tension infiltrometer was automated by Shaun Kelly using pressure transducers and a recording datalogger.
Pressure transducers
Honeywell 136PC05G2, 5 PSI transducers available from Soil Measurement Systems
Datalogger-Campbell Scientific CR10
Campbell Scientific, Inc.
815 W 1800 N
Logan, UT 84321-1784
(801) 753-2342
(801) 750-9540 (fax)

4.2 Calibration
Pressure transducers are calibrated in the lab using a standing water column. Transducer output in mV is linearly related to pressure. The infiltrometer is calibrated for the desired operating tensions before taking the unit to the field. Tension at the membrane on the baseplate in contact with the soil surface is controlled by the air entry ports in the bubble tower using one of three air entry tubes set at each desired tension. The air entry tubes are adjusted in the lab following the calibrating instructions in the manual.

4.2.1 Specifications
4.2.1.1 Tolerance
None given.

4.2.2 Frequency of Calibration
Pressure transducers have a tendency to drift and were calibrated before each IFC. Air entry tubes were calibrated once and required no further calibration unless it was desired to change the targeted tensions of 3, 5, and 15 cm tension.

4.2.3 Other Calibration Information
Actual tensions applied were determined using the bottom transducer or the transducer mounted closest to the baseplate. The actual tension applied varied depending on the vertical distance between the baseplate and the bubble tower.

5. Data Acquisition Methods
Operation of the tension infiltrometer is described in the user's manual supplied with each tension infiltrometer. The tension infiltrometer was modified to record the water level automatically with two pressure transducers and a datalogger. Each test was run at three target tensions: 3 cm, 6 cm, and 15 cm. Disk radii of 4 cm and 10 cm were used. Actual field operating tensions were calculated using the pressure recorded by the bottom transducer.

6. Observations

6.1 Data Notes
None given.

6.2 Field Notes
None given.
7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage
The data represent determinations of the soil hydraulic properties based on multiple measurements made in the vicinity of the flux tower. The North American Datum of 1983 (NAD83) coordinates for the tower locations are:

<table>
<thead>
<tr>
<th>SITE</th>
<th>LONGITUDE</th>
<th>LATITUDE</th>
<th>BOREAS_X</th>
<th>BOREAS_Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSA Young Aspen (YA)</td>
<td>105.32314°W</td>
<td>53.65601°N</td>
<td>374.607</td>
<td>310.761</td>
</tr>
<tr>
<td>SSA Old Black Spruce (OBS)</td>
<td>105.11779°W</td>
<td>53.98717°N</td>
<td>385.012</td>
<td>348.646</td>
</tr>
<tr>
<td>NSA OBS</td>
<td>98.48139°W</td>
<td>55.88007°N</td>
<td>778.216</td>
<td>613.516</td>
</tr>
<tr>
<td>NSA Old Jack Pine (OJP)</td>
<td>98.62396°W</td>
<td>55.92842°N</td>
<td>768.494</td>
<td>617.236</td>
</tr>
<tr>
<td>NSA Young Jack Pine (YJP)</td>
<td>98.28706°W</td>
<td>55.89575°N</td>
<td>789.845</td>
<td>617.424</td>
</tr>
<tr>
<td>SSA Old Aspen (OA)</td>
<td>106.19779°W</td>
<td>53.62889°N</td>
<td>317.198</td>
<td>303.403</td>
</tr>
<tr>
<td>SSA OJP</td>
<td>104.69203°W</td>
<td>53.91634°N</td>
<td>413.52</td>
<td>343.226</td>
</tr>
<tr>
<td>SSA YJP</td>
<td>104.64529°W</td>
<td>53.87581°N</td>
<td>416.988</td>
<td>339.008</td>
</tr>
</tbody>
</table>

7.1.2 Spatial Coverage Map
None.

7.1.3 Spatial Resolution
These data values were determined from a series of point measurements.

7.1.4 Projection
Not applicable for point data.

7.1.5 Grid Description
Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage
In situ measurements were taken in conjunction with soil moisture monitoring during the growing seasons of 1994 and 1996.

7.2.2 Temporal Coverage Map
None.

7.2.3 Temporal Resolution
Although these soil properties were determined from data collected in 1994 and 1996, the values do not change significantly with time.
### 7.3 Data Characteristics

#### 7.3.1 Parameter/Variable

The parameters contained in the data files on the CD-ROM are:

<table>
<thead>
<tr>
<th>Column Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SITE_NAME</td>
</tr>
<tr>
<td>SUB_SITE</td>
</tr>
<tr>
<td>START_DATE</td>
</tr>
<tr>
<td>END_DATE</td>
</tr>
<tr>
<td>SAT_HYD_CONDUCTIVITY</td>
</tr>
<tr>
<td>N_FITTING_PARAM</td>
</tr>
<tr>
<td>ALPHA_FITTING_PARAM</td>
</tr>
<tr>
<td>SAT_VOL_WATER_CONTENT</td>
</tr>
<tr>
<td>RESID_VOL_WATER_CONTENT</td>
</tr>
<tr>
<td>BULK_DENSITY</td>
</tr>
<tr>
<td>SOIL_TEXTURE</td>
</tr>
<tr>
<td>CRTFCN_CODE</td>
</tr>
<tr>
<td>REVISION_DATE</td>
</tr>
</tbody>
</table>

#### 7.3.2 Variable Description/Definition

The descriptions of the parameters contained in the data files on the CD-ROM are:

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SITE_NAME</td>
<td>The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.</td>
</tr>
<tr>
<td>SUB_SITE</td>
<td>The identifier assigned to the sub-site by BOREAS, in the format GGGG-GIIIII, where GGGGG is the group associated with the sub-site instrument, e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.</td>
</tr>
<tr>
<td>START_DATE</td>
<td>The date on which the collection of the reference data commenced.</td>
</tr>
<tr>
<td>END_DATE</td>
<td>The date on which the collection of the referenced data was terminated.</td>
</tr>
<tr>
<td>SAT_HYD_CONDUCTIVITY</td>
<td>Saturated hydraulic conductivity of the soil.</td>
</tr>
<tr>
<td>ALPHA_FITTING_PARAM</td>
<td>The ALPHA fitting parameter of the van Genuchten (1980) function.</td>
</tr>
<tr>
<td>SAT_VOL_WATER_CONTENT</td>
<td>Saturated volumetric water content of the soil.</td>
</tr>
<tr>
<td>RESID_VOL_WATER_CONTENT</td>
<td>Residual volumetric water content of the soil.</td>
</tr>
<tr>
<td>BULK_DENSITY</td>
<td>Bulk density of the soil.</td>
</tr>
<tr>
<td>SOIL_TEXTURE</td>
<td>The soil texture (e.g. sand, clay).</td>
</tr>
<tr>
<td>CRTFCN_CODE</td>
<td>The BOREAS certification level of the data.</td>
</tr>
<tr>
<td>REVISION_DATE</td>
<td>Examples are CPI (Checked by PI), CGR (Certified</td>
</tr>
</tbody>
</table>

\[Page 7\]
7.3.3 Unit of Measurement
The measurement units for the parameters contained in the data files on the CD-ROM are:

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Units</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>SUB_SITE</td>
<td>[none]</td>
</tr>
<tr>
<td>START_DATE</td>
<td>[DD-MON-YY]</td>
</tr>
<tr>
<td>END_DATE</td>
<td>[DD-MON-YY]</td>
</tr>
<tr>
<td>SAT_HYD_CONDUCTIVITY</td>
<td>[meters][day^-1]</td>
</tr>
<tr>
<td>N_FITTING_PARAM</td>
<td>[unitless]</td>
</tr>
<tr>
<td>ALPHA_FITTING_PARAM</td>
<td>[meter^-1]</td>
</tr>
<tr>
<td>SAT_VOL_WATER_CONTENT</td>
<td>[meters^3 H2O][meters^-3 soil]</td>
</tr>
<tr>
<td>RESID_VOL_WATER_CONTENT</td>
<td>[meters^3 H2O][meters^-3 soil]</td>
</tr>
<tr>
<td>BULK_DENSITY</td>
<td>[kilograms][meter^-3]</td>
</tr>
<tr>
<td>SOIL_TEXTURE</td>
<td>[none]</td>
</tr>
<tr>
<td>CRTFCN_CODE</td>
<td>[none]</td>
</tr>
<tr>
<td>REVISION_DATE</td>
<td>[DD-MON-YY]</td>
</tr>
</tbody>
</table>

7.3.4 Data Source
The source of the parameter values contained in the data files on the CD-ROM are:

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
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<td>[Assigned by BORIS]</td>
</tr>
<tr>
<td>SUB_SITE</td>
<td>[Assigned by BORIS]</td>
</tr>
<tr>
<td>START_DATE</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>END_DATE</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>SAT_HYD_CONDUCTIVITY</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>N_FITTING_PARAM</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>ALPHA_FITTING_PARAM</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>SAT_VOL_WATER_CONTENT</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>RESID_VOL_WATER_CONTENT</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>BULK_DENSITY</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>SOIL_TEXTURE</td>
<td>[Supplied by Investigator]</td>
</tr>
<tr>
<td>CRTFCN_CODE</td>
<td>[Assigned by BORIS]</td>
</tr>
<tr>
<td>REVISION_DATE</td>
<td>[Assigned by BORIS]</td>
</tr>
</tbody>
</table>

7.3.5 Data Range
The following table gives information about the parameter values found in the data files on the CD-ROM:

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Minimum Data Value</th>
<th>Maximum Data Value</th>
<th>Missing Data Value</th>
<th>Unrel Data Value</th>
<th>Below Data Value</th>
<th>Detect Limit</th>
<th>Not Detect Not Limit Clldctd</th>
</tr>
</thead>
<tbody>
<tr>
<td>SITE_NAME</td>
<td>NSA-OBS-FLXTR</td>
<td>SSA-YJP-FLXTR</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>SUB_SITE</td>
<td>HYD01-SHP01</td>
<td>HYD01-SHP01</td>
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</tr>
<tr>
<td>START_DATE</td>
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<td>END_DATE</td>
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<td>31-DEC-94</td>
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<td>None</td>
<td>None</td>
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<td>None</td>
</tr>
<tr>
<td></td>
<td>Sat_Hyd_Conductivity</td>
<td>N_Fitting_Param</td>
<td>Alpha_Fitting_Param</td>
<td>Sat_Vol_Water_Content</td>
<td>Resid_Vol_Water_Content</td>
<td>Bulk_Density</td>
<td>Soil_Texture</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------------</td>
<td>----------------</td>
<td>---------------------</td>
<td>-----------------------</td>
<td>-------------------------</td>
<td>--------------</td>
<td>--------------</td>
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<tr>
<td>Minimum Value</td>
<td>0.25</td>
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<td>Maximum Value</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Unreliable Value</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Below Limit</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Data Not Collected</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

**Minimum Data Value** -- The minimum value found in the column.  
**Maximum Data Value** -- The maximum value found in the column.  
**Missing Data Value** -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the parameter value, but the attempt was unsuccessful.  
**Unreliable Data Value** -- The value that indicates unreliable data. This is used to indicate that an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel.  
**Below Limit** -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation.  
**Data Not Collected** -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but not identical data sets into the same data base table but this particular science team did not measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.  
N/A -- Indicates that the value is not applicable to the respective column.  
None -- Indicates that no values of that sort were found in the column.

---

### 7.4 Sample Data Record

The following are wrapped versions of data records from a sample data file on the CD-ROM.

```
SITE_NAME, SUB_SITE, START_DATE, END_DATE, SAT_HYD_CONDUCTIVITY, N_FITTING_PARAM, ALPHA_FITTING_PARAM, SAT_VOL_WATER_CONTENT, RESID_VOL_WATER_CONTENT, BULK_DENSITY, SOIL_TEXTURE, CRTFCN_CODE, REVISION_DATE
'NSA-OBS-FLXTR', 'HYD01-SHP01', 01-JAN-94, 31-DEC-94, .46, 1.15, 1.5, .65, .17, 1300, 'Clay', 'CPI', 04-JUN-98
'NSA-OJP-FLXTR', 'HYD01-SHP01', 01-JAN-94, 31-DEC-94, .77, 1.35, 8.7, .21, .01, 1450, 'Sand', 'CPI', 04-JUN-98
```
8. Data Organization

8.1 Data Granularity
The smallest unit of data tracked by the BOREAS Information System (BORIS) was the entire data set.

8.2 Data Format(s)
The Compact Disk-Read-Only Memory (CD-ROM) files contain American Standard Code for Information Interchange (ASCII) numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

Each data file on the CD-ROM has four header lines of Hyper-Text Markup Language (HTML) code at the top. When viewed with a Web browser, this code displays header information (data set title, location, date, acknowledgments, etc.) and a series of HTML links to associated data files and related data sets. Line 5 of each data file is a list of the column names, and line 6 and following lines contain the actual data.

9. Data Manipulations

9.1 Formulae
Wooding's equation (1958):

\[ Q = \pi r^2 K \left( 1 + \frac{4 lc}{\pi r} \right) \]

where
- \( Q \) is water infiltration \([\text{vol/time}]\).
- \( K \) is hydraulic conductivity \([\text{length/time}]\).
- \( r \) is disk radius \([\text{length}]\).
- \( lc \) is the macroscopic capillary length \([\text{length}]\).

Gardner's hydraulic conductivity function (1958):

\[ K(H) = K_{SAT} \exp(ALPHAG*H) \]

where
- \( ALPHAG \) is a fitted parameter.
- \( H \) is the soil water tension.
- \( K_{SAT} \) is the saturated conductivity.
- \( K \) is the hydraulic conductivity.

van Genuchten soil water retention equation (1980):

\[ \Theta(H) = RESID + \frac{(SAT-RESID)}{\left[1 + \left(\frac{ALPHA*H}{N}\right)^{1-(1/N)}\right]} \]

where
- \( \Theta \) is the volumetric water content \([\text{vol/vol}]\).
- \( RESID \) is the residual water content at some large negative tension \([\text{vol/vol}]\).
- \( SAT \) is the saturated water content \([\text{vol/vol}]\).
- \( ALPHA \) is an empirical fitting parameter or \((1/lc)[1/\text{length}]\).
- \( N \) is a fitting parameter.
- \( H \) is the soil water tension.
Mualem (1976)-van Genuchten (1980) unsaturated hydraulic conductivity function:

\[
K(H) = \frac{K_{DAT} \times (1 - |\alpha| \times H^{(N-1)}) \times (1 + |\alpha| \times H^{N})^{((1/N)-1)2}}{(1 + |\alpha| \times H^{N})^{((N-1)/2+N)}}
\]

where \( K_{SAT} \) is the saturated hydraulic conductivity [length/time].

The vertical bars \(|\cdot|\) represent "absolute value".

All other variables are the same as those in the water retention equation.

9.1.1 Derivation Techniques and Algorithms
An average value for \( K_{SAT} \) was determined by extrapolating a fitted Gardner (1958) exponential function to zero tension using the low tensions from each sequence of infiltration runs. The parameters for the water retention and hydraulic conductivity were then simultaneously fitted using a nonlinear fitting routine. The variables optimized were the sum of the squared difference between the natural log of the calculated and the measured steady state infiltration rates for the hydraulic conductivity and the weighted volumetric water contents for the water retention function. The fitting parameters \( N, \alpha, SAT \) (saturated volumetric water content), and RESID (residual water content) are subject to the following constraints: \( 0 < N < 1, 1 < \alpha < 2, SAT < \) observed maximum soil moisture, and \( RESID > 0.01 \).

9.2 Data Processing Sequence

9.2.1 Processing Steps
None given.

9.2.2 Processing Changes
None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments
None given.

9.3.2 Calculated Variables
Saturated hydraulic conductivity, hydraulic conductivity, water infiltration, and volumetric water content.

9.4 Graphs and Plots
See Sections 10 and 11 for graphs and plots that are applicable to those sections.

10. Errors

10.1 Sources of Error
Possible sources of error are poor contact of the infiltrometer disk with the soil surface, which reduces the actual effective disk radius (up to 1 cm), and pressure transducer drift in the offset, which may affect the actual tension applied to the soil (+/-2 cm). There is no additional information available to provide a quantitative error analysis of this data.
10.2 Quality Assessment

Soil bulk density was not measured in the field and is an estimated value. It is not a parameter used
in the retention or conductivity functions and is provided for reference only. It is the value given in the
laboratory soil core data performed independently by other BOREAS researchers (see Section 1.6,
Related Data Sets). Where bulk density was not provided in other data sets, a value was estimated
from known values of soils with similar texture.

Saturated and residual volumetric water content, SAT and RESID, were not directly measured in
the field. These values were treated as fitting parameters when calculating retention and conductivity
functions. Appropriate limits were placed on these parameters based on observed minimum and
maximum water contents observed in the field measured with a neutron probe and Time Domain
Reflectometry (TDR). These values may not be the same as would be found during soil core analysis
because of entrapped air, existence of macropores, etc. Nevertheless, these values gave the best fit to
the limited set of retention data collected.

10.2.1 Data Validation by Source

Data were validated by comparing calculated parameters with soils of similar texture from the
UNSODA data base (United States Department of Agriculture (USDA) Salinity Lab). Parameters are
currently being used in physics-based soil water transport models (HYDRUS and WAVE) to simulate
soil water movement and for comparing to site measurements of soil water content observed at the
BOREAS sites from 1994-96.

10.2.2 Confidence Level/Accuracy Judgment

The authors feel that the quality of the data is very good for use at the tower flux sites because of
the numerous measurements made at the sites.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

Quality assessments of the goodness of fit are shown in the following graphs of the hydraulic
conductivity function and the soil water retention function for the north OJP site and the south OA site.
Actual field data are plotted with the calculated values using the parameters determined.

![NSA-OJP Hydraulic Conductivity Function](image1)

![SSA-OA Hydraulic Conductivity Function](image2)
10.2.5 Data Verification by Data Center
The data were loaded into a data base table and reviewed to ensure that no errors occurred in loading the data.

11. Notes

11.1 Limitations of the Data
As one moves farther from the site, the variability of soils due to natural geologic soil genesis processes will limit the spatial extent of the data. Although these are point measurements, it is expected that these parameters will be used for modeling of soil water processes at sites with soils similar to those at the tower site.

The parameters were derived from tension infiltrometer data from the surface of the first mineral soil layer at each site (A-horizon). Therefore, these parameters would most accurately represent the soil water properties of the top 15 cm of soil. Although caution should be used when extrapolating the use of these parameters to greater soil depths, it is expected that these parameters will be used to model soil water properties at depths greater than 15 cm.

11.2 Known Problems with the Data
None given.

11.3 Usage Guidance
See Section 12.

11.4 Other Relevant Information
None given.

12. Application of the Data Set
This data set is particularly useful for use in models needing soil water hydraulic properties. The data are derived from in situ measurements and parameters developed from the theories of soil physics. This data set can be used to convert water contents to corresponding soil water tensions and vice versa. This data set can also be used to determine the hydraulic conductivity of the soil when soil water content or tension is known. The data set can be summarized in the following plots of the conductivity and retention functions at each site.
13. Future Modifications and Plans

These data are currently being used for calibration of a finite element model of soil water movement for the BOREAS tower sites. These data are being used for initial calibration of the model. Model verification is being made using the soil water transect data collected during the 1994 IFCs and the data currently being collected at NSA-OBS, NSA-OJP, NSA-YJP, SSA-OBS, and SSA-OA. In the future, it is planned to calculate sorptivity parameters for soils at each site.

14. Software

14.1 Software Description
Microsoft Excel for Windows 95, Version 7.0
HYDRUS - finite element model of soil water movement
WAVE - finite difference model of soil water movement
Mathcad, Version 6.0

14.2 Software Access
Microsoft Excel and Mathcad are proprietary software packages. The availability of HYDRUS and WAVE software is not known.
15. Data Access

The HYD-01 soil hydraulic properties data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornl_daac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics
http://www-eosdis.ornl.gov/ [Internet Link].

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.
17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

17.2 Journal Articles and Study Reports


17.3 Archive/DBMS Usage Documentation
None.

18. Glossary of Terms

ALPHA is an empirical fitting parameter, or (1/lc)[-1/length]. ALPHAG is a fitted parameter in the Gardner equation, or (1/lc)[-1/length]. H is the soil water tension [length]. K is hydraulic conductivity [length/time]. KSAT is the saturated conductivity [length/time]. lc is the macroscopic capillary length [length]. N is a fitting parameter. Q is water infiltration [vol/time]. r is disk radius [length]. RESID is the residual water content at some large negative tension [vol/vol]. SAT is the saturated water content [vol/vol]. THETA is the volumetric water content [vol/vol].

19. List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td>BOREAS</td>
<td>BOReal Ecosystem-Atmosphere Study</td>
</tr>
<tr>
<td>BORIS</td>
<td>BOREAS Information System</td>
</tr>
<tr>
<td>CD-ROM</td>
<td>Compact Disk-Read-Only Memory</td>
</tr>
<tr>
<td>DAAC</td>
<td>Distributed Active Archive Center</td>
</tr>
<tr>
<td>EOS</td>
<td>Earth Observing System</td>
</tr>
<tr>
<td>EOSDIS</td>
<td>EOS Data and Information System</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
</tr>
<tr>
<td>HTML</td>
<td>HyperText Markup Language</td>
</tr>
<tr>
<td>HYD</td>
<td>Hydrology</td>
</tr>
<tr>
<td>IFC</td>
<td>Intensive Field Campaign</td>
</tr>
<tr>
<td>NAD83</td>
<td>North American Datum of 1983</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NSA</td>
<td>Northern Study Area</td>
</tr>
<tr>
<td>OA</td>
<td>Old Aspen</td>
</tr>
<tr>
<td>OBS</td>
<td>Old Black Spruce</td>
</tr>
<tr>
<td>OJP</td>
<td>Old Jack Pine</td>
</tr>
<tr>
<td>ORNL</td>
<td>Oak Ridge National Laboratory</td>
</tr>
<tr>
<td>PANP</td>
<td>Prince Albert National Park</td>
</tr>
<tr>
<td>SSA</td>
<td>Southern Study Area</td>
</tr>
<tr>
<td>TDR</td>
<td>Time Domain Reflectometry</td>
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</table>
20. Document Information

20.1 Document Revision Date
Written: 18-Sep-1996
Revised: 26-Jul-1999

20.2 Document Review Date(s)
BORIS Review: 05-Jun-1998
Science Review:

20.3 Document ID

20.4 Citation
When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:
These data were collected by Richard Cuenca, Shaun Kelly, and David Stangel as part of the HYD-01 investigation of the BOREAS Project.

If using data from the BOREAS CD-ROM series, also reference the data as:

Also, cite the BOREAS CD-ROM set as:

20.5 Document Curator

20.6 Document URL
**Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)**

**BOREAS HYD-1 Soil Hydraulic Properties**

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- Richard H. Cuenca
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**Sponsoring / Monitoring Agency Name(s) and Address(es):**
National Aeronautics and Space Administration
Washington, DC 20546-0001

**Abstract:**
The BOREAS HYD-1 team coordinated a program of data collection to measure and monitor soil properties in collaboration with other science team measurement needs. This data set contains soil hydraulic properties determined at the NSA and SSA flux tower sites based on analysis of in situ tension infiltrometer tests and laboratory-determined water retention from soil cores collected during the 1994-95 field campaigns. Results from this analysis are saturated hydraulic conductivity, and fitting parameters for the van Genuchten-Mualem soil hydraulic conductivity and water retention function at flux tower sites. The data are contained in tabular ASCII files.