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Development of a Methodology that Couples Satellite Remote Sensing Measurements to Spatial-Temporal Distribution of Soil Moisture in the Vadose Zone of the Everglades National Park

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

DEVELOPMENT OF A METHODOLOGY THAT COUPLES SATELLITE
REMOTE SENSING MEASUREMENTS TO SPATIAL-TEMPORAL
DISTRIBUTION OF SOIL MOISTURE IN THE VADOSE ZONE OF THE
EVERGLADES NATIONAL PARK

A dissertation submitted in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

CIVIL ENGINEERING

by

Luis G. Pérez

2014

To: Dean Amir Mirmiran
College of Engineering and Computing

This dissertation, written by Luis G. Pérez, and entitled Development of a Methodology that Couples Satellite Remote Sensing Measurements to Spatial-Temporal Distribution of Soil Moisture in the Vadose Zone of the Everglades National Park, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Florida International University, 2014

DEDICATION

I dedicate this dissertation to Denise for her love and for encouraging me to fulfill my academic dreams, and a special mention to Tairi, Norah Lisa and Andrea, for their unconditional love and support.

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ABSTRACT OF THE DISSERTATION
DEVELOPMENT OF A METHODOLOGY THAT COUPLES SATELLITE
REMOTE SENSING MEASUREMENTS TO SPATIAL-TEMPORAL
DISTRIBUTION OF SOIL MOISTURE IN THE VADOSE ZONE
OF THE EVERGLADES NATIONAL PARK

By

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Florida International University, 2014

Miami, Florida

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Spatial-temporal distribution of soil moisture in the vadose zone is an important aspect of the hydrological cycle that plays a fundamental role in water resources management, including modeling of water flow and mass transport. The vadose zone is a critical transfer and storage compartment, which controls the partitioning of energy and mass linked to surface runoff, evapotranspiration and infiltration. This dissertation focuses on integrating hydraulic characterization methods with remote sensing technologies to estimate the soil moisture distribution by modeling the spatial coverage of soil moisture in the horizontal and vertical dimensions with high temporal resolution.

The methodology consists of using satellite images with an ultrafine 3-m resolution to estimate soil surface moisture content that is used as a top boundary condition in the hydrologic model, SWAP, to simulate transport of water in the vadose zone. To demonstrate the methodology, herein developed, a

number of model simulations were performed to forecast a range of possible moisture distributions in the Everglades National Park (ENP) vadose zone. Intensive field and laboratory experiments were necessary to prepare an area of interest (AOI) and characterize the soils, and a framework was developed on ArcGIS platform for organizing and processing of data applying a simple sequential data approach, in conjunction with SWAP.

An error difference of 3.6% was achieved when comparing radar backscatter coefficient (σ^0) to surface Volumetric Water Content (VWC); this result was superior to the 6.1% obtained by Piles during a 2009 NASA SMAP campaign. A registration error (RMSE) of 4% was obtained between model and observations. These results confirmed the potential use of SWAP to simulate transport of water in the vadose zone of the ENP.

Future work in the ENP must incorporate the use of preferential flow given the great impact of macropore on water and solute transport through the vadose zone. Among other recommendations, there is a need to develop procedures for measuring the ENP peat shrinkage characteristics due to changes in moisture content in support of the enhanced modeling of soil moisture distribution.

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ABBREVIATIONS AND ACRONYMS

Advanced Integrated Equation Model	AIEM
Alternative Area of Interest	AAOI
American Society for Testing and Materials	ASTM
Area of Interest	AOI
Backscattering coefficient	σ^0
Coefficient of determination	R^2
Collected Ground Control Points	CGCPs
Covariance	σ^2
Decibel	dB
Digital Elevation Model	DEM
Ecological Infrastructure	EI
Ensemble Kalman Filter	EnKF
Everglades National Park	ENP
Geographic Information System	GIS
Hydraulic conductivity	K
Integral Equation Model	IEM
Internal Catchment	IC
National Aeronautics and Space Administration	NASA
Next ESA SAR Toolbox	NEST
Normalized radar Backscatter soil Moisture Index	NBMI
North American Vertical Datum of 1988	NAVD88
Personal Digital Assistance	PDA

RADARSAT-2	RSAT-2
Root Mean Square	RMS
Root-Mean-Square Error	RMSE
Shark River Slough	SRS
Soil and Water Assessment Tool “R”	SWATR
South Florida Water Management District	SFWMD
Soil Moisture Active and Passive	SMAP
Soil Moisture Experiment 2002	SMEX02
Soil Moisture Saturation	SSS
Soil-Water-Atmosphere-Plant	SWAP
Soil-Water Characteristic Curve	SWCC
Spatial Averaging	AVG
Synthetic Aperture Radar	SAR
United States Geological Survey	USGS
Universal Transverse Mercator	UTM
Unsaturated Hydraulic Conductivity	K_{θ}
Volumetric Water Content	VWC
Water Retention Curve	WRC
World Geodetic System 1984	WGS_1984

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1. INTRODUCTION

Figure 1 Alternative Area of Interest (AAOI) location. SAR and in situ observations

1.1 Overview of this Dissertation

Spatial-temporal distribution of soil moisture in the vadose zone is an important aspect of the hydrological cycle that plays a fundamental role in water resources management, including modeling of water flow and mass transport (Hanson et al., 1999; and Findell and Elthair, 2002). The vadose zone is a critical transfer and storage compartment, which controls the partitioning of energy and

mass linked to surface runoff, evapotranspiration and infiltration (Rasmussen and Gallo, 2013).

Development and intensive drainage of the Everglades National Park (ENP) has led to alterations in the physical characteristics of its soil. There are two major soil types in the ENP: the wetland soil (peat) formed by slowly decaying plant matter, and the calcitic mud or marl located in the shallower peripheral marshes. The Everglades ecosystem is currently the subject of a major Federal-State ecosystem restoration effort. Understanding the nature of the hydrologic exchange between surface and ground waters in the ecosystem is critical to understanding the movement of water and dissolved nutrients, wastes, metals, etc. (Bruno et al., 2003). Overall, the “Florida Everglades restoration plan is aimed at maintaining and restoring characteristic landscape features, such as soil, vegetation and hydrologic patterns” (Corstanje et al., 2006).

The motivation of this research is to understand the water distribution and movement in the semi-saturated zone of the Everglades with the purpose of contributing to its preservation by developing procedures and finding additional parameters of the soil needed for modeling its spatial-temporal distribution of water.

In support of the Florida Everglades restoration plan, this study is the first attempt to couple satellite remote sensing measurements to a hydrologic transport model for water distribution in the vadose zone of a natural environment, using a 3 X 3-m satellite resolution in a small controlled area for the

purpose of establishing its potential effectiveness and, if promising, extending experimentation to larger scales in further studies.

There have been similar studies in the past (Shoshany et al., 2000; Das et al., 2006; Das et al., 2008; and Piles et al., 2009) for agricultural and ecologic environments, but these studies used satellite resolutions of 400 x 400 m or larger. A key limitation of the resolution of current remote sensing methods with the spatial averaging of the observations (Vereecken, 2008) is, as recently confirmed by Bramer et al. (2013), “the number of point measurements needed to characterize the mean soil moisture of an area in the order of 10’s of square meters and the manner in which these observations should be made remain unknown”.

The study began in November 2010, when an application to the ENP for a scientific research and collecting permit was initiated. The permit was granted on January 16, 2013. An area of interest (AOI) in the Shark River slough (SRS) of the ENP was then chosen for the development of a methodology. The research methodology focuses on the characterization of pixel variability within a satellite-based remotely sensed high resolution soil moisture footprint in a 100-m² scale, to estimate the spatial distribution of the surface soil moisture, used as top boundary condition, in a coupled transport model that simulates transport of water in the semi-saturated soil. The model is a robust physically-based field scale ecohydrological model used to simulate the processes occurring in the Soil-Water-Atmosphere-Plant (SWAP) system.

Geographic Information Systems (GIS) is considered a highly effective tool for organizing and processing data at the watershed scale. A GIS stores spatial data, determines model parameters, and visualizes modeling results (Thicken et al., 1999). Consequently, a python computer script has been developed, for ArcGIS platform, by integrating the one-dimensional vadose zone hydrology model SWAP to each one of the grid cells of the AOI; the model produces graphic outputs representing the spatial-temporal behavior of the root zone soil moisture content at different depths.

Surface soil moisture retrieval from Synthetic Aperture Radar (SAR) using backscatter models depends on vegetation, soil surface roughness, and soil moisture content. This research used a modified approach, based on change detection techniques, making vegetation and soil roughness index information irrelevant to estimate the surface soil moisture content.

High resolution images from the Canadian RADARSAT-2 (RSAT-2) satellite were scheduled to cover the AOI. In preparation of the area, twenty five acrylic tubes for the insertion of profile hydro-probes were installed and geo-located, triple sets of core samples were taken from two of nine point-base scheduled locations, an observation well was installed, vegetation samples were taken, and surface roughness was measured. However, three days before the scheduled satellite pass, a heavy rainfall event flooded the area which then remained flooded for the rest of the season, forcing postponement of all data collection. As a result, all equipment was removed from the AOI and two new

smaller locations (herein referred to as the Alternative Area of Interest (AAOI), with more appropriate dryness, were selected within the buffer zone around the Shark River Visitor Center.

In the new locations, a total of twenty-three surface soil samples were obtained, simultaneously with the RSAT-2 images, and their Volumetric Water Content (VWC) was measured. Of the twenty-three geo-located soil samples, eight were used to develop a linear algorithm based on radar change detection techniques; the remaining fifteen were used for algorithm validation. The coefficient of determination (R^2) obtained for the linear algorithms was 0.90 using two consecutive images recorded with different incidence angles, coefficient that well exceeds the 0.67 obtained by NASA (Piles et al., 2009) using six consecutive images recorded with same incident angle.

The linear algorithm was then used to estimate VWC at the remaining fifteen locations, and they were compared with the surface moisture measured in situ. An error difference of 3.6% was measured in comparison with the 6.1% obtained by Piles (Piles et al., 2009). This result, close enough to allow for a surface boundary to initiate the modeling of the root zone, supports our main research objective that a method that links high resolution satellite images to vadose zone modeling can effectively forecast spatial-temporal water distribution in the unsaturated zone of the Everglades National Park slough ecosystem.

One of the two new smaller areas was also selected for its subsurface to be characterized; its area was subdivided in 117 1m-gridded cells. The area was

core sampled at three sites, X1, X2, and X3, and a rain station and four acrylic tubes for profile hydra probe were installed. Surface soil measurements, using a calibrated POGO piece of equipment, as well as four profile hydra probes for moisture reading at different depths, were taken during five consecutive days. One of the five days of surface data was used for the estimation of the initial pressure top boundary condition, while the remaining data was used as observations for comparison with model predictions.

Five months of continuous laboratory experiments were required to characterize the soil at X1, X2, and X3. Triple core soil samples were taken from each one of the three layers, and processed in the laboratory to determine their needed hydraulic parameters for input to SWAP in the development of the model.

Root zone soil moisture was modeled in a watershed ecosystem environment located in the SRS of the ENP from June 3 to June 7, 2013, and spatial-temporal reports were generated at 0.8, 2.5, and 6.5 cm depths.

A sensitivity analysis between soils X1, X2, X3, and its average were modeled at node 56 of the 117 gridded cells, comparing the degree of saturation of the top two layers of the profile soil (layer A at 0.2, 0.8, 2.5 cm depth, and layer B at 6.5 cm depth) and analyzing the effect of the capillary rise on the degree of saturation.

To show the use of the new developed computer script between SWAP and GIS to changes in soil parameters and time scale, a comparative simulated modeling in the AAOI was performed between mineral soil and peat soil and

changing the time scale from 4 days of hourly modeling to daily modeling of 144 days (January 9 to June 1, 2002), representing the driest period registered in the ENP during the past 10 years.

Preferential flow was investigated and a simulation was completed in the AAOI changing the soil parameters from the current mineral soil to organic soil. Due to the lack of existent macropore soil parameters needed for modeling purposes, the parameters were assumed from the SWAP manual for peat soil and adapted to AAOI. Comparative analysis, of using preferential flow concept versus uniform flow, proves the need to use preferential flow to model water and solute transport when organic soil is present, and also the need to develop soil shrinkage parameters due to changes in moisture content in order to be able to model water content in the vadose zone of the ENP.

The Ensemble Kalman filter (EnKF), a data assimilation that uses Monte Carlo methods was investigated but discarded after learning that it is a method that provides a framework for the conversion of different spatial scales data (coarse to fine scales). This technique (EnKF) is not suitable to our research objective because the spatial scale used by the hydrological model SWAP (3 x 3-m) is at the same spatial scale as the resolution used by the radar image (3 x 3-m).

2. LITERATURE REVIEW

A very small proportion (0.15%) of fresh water on Earth is present as soil moisture (Dingman 1994). Soil moisture is an important parameter that integrates the land-surface hydrology and relates the Earth's surface with the atmosphere through its effect on surface energy and moisture fluxes. "Soil moisture is a key variable of the hydrologic cycle" (Kurum et al., 2009).

The Ramsar convention defines wetlands as "all areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt" (More 2007). The convention set a depth of 20 feet as the limit for any water body to be included in the term *wetland*. In addition to the production of energy-rich materials, the wetlands of the ENP contain reserves of freshwater for human consumption. They also wetlands can act as flood controls as well as providing a sustainable supply of food to animals and plants that inhabitant the ENP.

In this study hydro-geophysical and remote sensing technologies were integrated to quantify the subsurface soil moisture dynamics providing spatial coverage of soil moisture in the horizontal and vertical dimensions with a high temporal resolution.

Soils are often mismanaged because we pay little attention to their role as key components of Ecological Infrastructure (EI). EI is defined as the underlying framework of natural elements, ecosystems, functions and processes that are spatially and temporally interconnected to maintain the continued regeneration

and evolution of life on Earth (Bristow et al., 2010). Explicitly, EI is how natural capital stocks are organized to produce ecosystem goods and services (Šimůnek et al., 2011).

Near-surface soil moisture conditions are a primary determinant of watershed modeling. “Direct observations of soil moisture are currently restricted to discrete measurements at specific locations, and such point-based measurements do not represent the spatial distribution because soil moisture is highly variable both spatially and temporally” (Das and Mohanty, 2008).

Kostov and Jackson (1993) concluded that the most promising approach to the problem of profile soil moisture estimation was the integration of remote sensing and computational modeling.

2.1 Remote sensing

According to Lillesand and Kiefer (2000) “remote sensing is the science and art of obtaining useful information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation”. Based on the wavelength in which the system works, remote sensing is categorized into two different groups, optical and microwave. Optical remote sensing uses visible and infrared waves while microwave remote sensing uses radio waves (Lillesand 2000).

2.1.1 Synthetic Aperture Radar (SAR)

SAR data has unique capabilities because the long microwave wavelengths penetrate vegetation cover and are sensitive to wet soil that exists

beneath a canopy. “The microwave scattering received by a SAR sensor from a wetland is dependent upon the wavelength, polarization, and incidence angle at which the energy was transmitted, the surface roughness, vegetative biomass, dielectric properties of the vegetation and soils (moisture in the plant canopy and on the ground), and the presence or absence of a flooded surface” (Bourgeau-Chavez, et al. 2009).

“Soil moisture retrieval from SAR using state-of-the-art backscatter models is not fully operational at present, mainly due to difficulties involved in the parameterization of soil surface roughness” (Lievens et al., 2011). The backscattering of microwaves from soil surface depends on the soil moisture content, the vegetation biomass, and the soil surface roughness.

The heterogeneity of fine-scale soil moisture footprint is masked by the area-integrated properties within the sensor footprint. Therefore, the soil moisture values derived from these measurements are an area average. The variability in soil moisture within the footprint is introduced by inherent spatial variability present in geophysical parameters (vegetation, topography, and soil).

2.1.1.1 Speckles

SAR images have inherent salt and pepper like texture called speckles which degrade the quality of the image and its interpretation. “Reduction of speckle noise is one of the most important processes to increase the quality of radar coherent images. Before using active radar and SAR imageries, the very first step is to reduce the effect of speckle noise” (Mansourpour , 2006).

“Lee filter assumes a Gaussian distribution for the noise in the image data. The Lee filter is based on the assumption that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving kernel” (Lee 1980). Lee filter 3 x 3 is used to reduce speckle noise.

2.1.1.2 Backscattering Coefficient

Satellite images are generated by active microwave remote sensing launching a pulse of electromagnetic energy, traveling in the form of a wave to the earth's surface and measuring the amount of radiation scattered back at the same position as where the waves were originally transmitted. Then, the power returned to the radar antenna is a function of transmitted power corrected for the two-way spreading loss and losses caused by the target.

The Integral Equation Model (IEM) is a theoretical backscattering model applicable to a wide range of roughness values (Fung et al., 1992). The Advanced Integrated Equation Model (AIEM) improves the calculation accuracy of scattering coefficient by keeping the absolute phase term in Greens function which was neglected by IEM (Wang et al., 2011).

The AIEM calculates the backscattering coefficient as a function of the sensor configuration s (i.e., radar frequency, polarization, and incidence angle) and land surface parameters (e.g., soil dielectric constant and surface roughness). In SAR remote sensing applications, sensor configurations are known, while surface roughness and dielectric constants are unknown.

In AIEM, the single scattering term is given by

$$\sigma_{pq}^S = \frac{k^2}{2} \exp[-(\sigma)^2(k_z^2 + k_{sz}^2)] \sum_{n=1}^{\infty} (\sigma)^{2n} |I_{pq}^n|^2 \frac{W^n(k_{sx} + k_x, k_{sy} - k_y)}{n!} \quad (1)$$

$$I_{pq}^n = (k_{sz} + k_z)^n f_{pq} \exp[-(\sigma)^2 k_z k_{sz}] + \frac{(k_{sz})^n F_{pq}(-k_x, -k_y) + (k_z)^n F_{pq}(-k_{sx}, -k_{sy})}{2}$$

with

- $k_x = k \sin \theta \cos \phi$
- $k_y = k \sin \theta \sin \phi$
- $k_z = k \cos \theta$
- $k_{sx} = k \sin \theta_s \cos \phi_s$
- $k_{sy} = k \sin \theta_s \sin \phi_s$
- $k_{sz} = k \cos \theta_s$

where k is the wave number, I_{pq}^n is a function of θ , ϕ , σ and ϵ_r (soil dielectric constant), F_{pq} denotes the complementary field coefficient. $W^{(n)}$ is the Fourier transform of the n^{th} power of the surface correlation function. The subscripts p and q indicate polarization state. θ and ϕ are zenith angle and azimuth angle of the sensor, θ_s and ϕ_s are zenith and azimuth of scattering angle, respectively. Soil texture and land surface correlation function type can be measured in field and assumed as a priori information. Thereby, the remaining unknown surface parameter is soil moisture mv .

2.1.1.3 Dielectric constant

Radar remote sensing presents advantages for monitoring near-surface soil moisture (0–5 cm), including timely coverage with repeat passes, and day or night operational capability. Response of radar backscatter to changes in soil moisture resulting from the difference in real dielectric constant, ϵ , for oven-dried soil ($\epsilon = 2$) and water ($\epsilon = 80$) offers an opportunity to measure near-surface soil moisture (Henderson and Lewis, 1998).

Dobson found that the dielectric constant of dry soil is independent of frequency over the microwave region and is primarily dependent upon soil bulk density, and because the dielectric constant of moist soils is proportional to the number of water dipoles per unit volume, the preferred measure for soil moisture is volumetric (Dobson and Ulaby, 1986).

2.1.1.4 Surface and vegetation geometry

Surface roughness is a relative concept depending upon wavelength and incidence angle. A surface is considered "rough" if its surface structure has dimensions that are comparable to the incident wavelength.

According to the Rayleigh criterion, a surface is considered smooth if:

$$h < \frac{\lambda}{8 \cos \theta} \quad (2)$$

and considered rough if:

$$h > \frac{\lambda}{8 \cos \theta} \quad (3)$$

where

- h mean height of surface variations
- λ wavelength
- θ incidence angle

In Figure 2, theoretical scattering of C-band sensor from forested versus herbaceous landscapes in various dry to flooded conditions is shown. Observed in the herbaceous canopy are some double-bounce effects; however, as the saturation increases, the backscattering initially gets stronger and then lessens until it reaches a low specular reflection case from the water surface in the highly inundated situation (Bourgeau-Chavez, et al. 2009).

Figure 2 Diagram showing theoretical scattering of C-band energy from forested and herbaceous ecosystems in dry, wet and flooded conditions, with open and closed forest canopies (Bourgeau-Chavez, et al. 2009).

The backscatter coefficient above the canopy for vegetated rough surface ($\sigma_{can}^o(\theta)$, $\text{m}^2 \text{m}^{-2}$) for a given incidence angle θ , can be expressed as

$$\sigma_{can}^o(\theta) = \sigma_{veg}^o(\theta) + \sigma_{veg+soil}^o(\theta) + \gamma^2(\theta)\sigma_{soil}^o(\theta) \quad (4)$$

where,

- $\sigma_{veg}^o(\theta)$ represents the backscattering from the vegetation canopy
- $\sigma_{veg+soil}^o(\theta)$ represents the interaction between vegetation layer and the soil underneath and account for multiple scattering effects
- $\gamma^2(\theta)\sigma_{soil}^o(\theta)$ represents the backscattering from the soil layer that is attenuated by the canopy
- $\gamma^2(\theta)$ is the two-way vegetation transmissivity

Because the microwave dielectric constant of dry vegetative matter is much smaller (by an order of magnitude or more) than the dielectric constant of water, and because a vegetation canopy is usually composed of more than 99% air by volume, it is proposed that the canopy can be modeled as a water cloud whose droplets are held in place by the vegetative matter (E. P. Ulaby 1978); consequently, it is assumed that the vegetation-soil interactions can be neglected, and therefore,

$$\sigma_{can}^o(\theta) = \sigma_{veg}^o(\theta) + \gamma^2(\theta)\sigma_{soil}^o(\theta) \quad (5)$$

with

$$\sigma_{veg}^o = A v w c \cos \theta [1 - \gamma^2(\theta)] \quad (6)$$

$$\gamma^2(\theta) = \exp[-2bvwc/\cos(\theta)] \quad (7)$$

where vw represents the vegetation water content (kg m^{-2}). Parameters A and b depend on the vegetation type, growth condition, and radar frequency.

SAR data penetrates vegetation cover and are sensitive to soil moisture; however, since the presence of standing water causes the SAR energy to interact differently depending on the dominant vegetation type, several researchers have evaluated SAR and Optical/IR fusion for wetland mapping to measure different features of wetlands (Bourgeau-Chavez, et al. 2009). Images provided by optical sensors contain information about the surface layer of the imaged objects (i.e. color), while microwave images provide information about the geometric and dielectric properties of the surface or volume studied (i.e., roughness).

For vegetation with above ground biomass less than 0.5 kg m^{-2} and green leaf area index < 0.35 , the effect of vegetation can be ignored (Ulaby, Dubois and van Zyl 1996; and Moran et al., 2000).

2.1.1.5 Change detection approach

All models described to this point are based on soil moisture retrieval from a single image. Image differencing, on the other hand, requires two images obtained with identical radar wavelength, viewing geometry, and beam mode. Image differencing is an empirical model that improves moisture retrieval results

with much improved results over moisture retrieval using single date imagery (Shoshany et al., 2000; and Piles et al., 2009).

The simple ratio between multitemporal backscatter had the form (Shoshany et al., 2000):

$$V_{sm} = \alpha(\sigma_{t_1}/\sigma_{t_2}) + b \quad (8)$$

where V_{sm} is the volumetric soil moisture, $\sigma_{t_{1,2}}$ are backscatter at different times, and a and b are the linear coefficients.

Shoshany related the volumetric soil moisture to backscatter at two different sites using linear regression higher than 85% confidence level, and stated that the relationship measured on Normalized radar Backscatter soil Moisture Index (NBMI), based on independent data from a wide range of climates, was related strongly to volumetric soil moisture concentration for the ranges between 20 and 40%; suggesting a general relationship between radar backscatter and volumetric soil moisture between 0 and 40% soil moisture concentration (Shoshany et al., 2000).

Change detection techniques have been demonstrated to be able to monitor temporal evolution of soil moisture by taking advantage of the approximately linear dependence of radar backscatter and brightness temperature (σ^o) change in soil moisture change (Piles et al., 2009). This approach is based on the assumption that the temporal variability of the surface roughness and vegetation biomass is generally at a much longer time scale than

that of soil moisture, and therefore, the change in SAR σ^0 between repeat passes results from the change in soil moisture.

2.1.1.6 SAR image correction

It is important to note that the pixel of the final SAR image does not have the same dimensions as the resolution cell during the data acquisition, due to the variation of range resolution with incidence angle. Thus it is necessary to perform a pixel resampling with a uniform grid.

Orthorectification is a common geometric correction process that requires the use of a 3D rigorous geometric model computed from Collected Ground Control Points (CGPs), and a Digital Elevation Model (DEM) to correct for elevation distortions. Accurate high resolution radar ortho-images are possible with RADARSAT-2 satellite and a new 3D hybrid satellite model (Toutin 2010). However, our study site located in the ENP did not required elevation correction because it has a uniform elevation; only CGPs correction is needed.

In order to rectify the 2D geometric correction, a minimum of three (3) CGPs are needed. Due to the small amount of 3 x 3-m pixels (20 pixels) contained in the AOI, only one CGP was registered and the images were adjusted using a visual Google earth reference point for consecutive images. This lack of 2D correction caused misalignments introducing an additional source of error. Further studies made into the ENP must contemplate the use of at least three (3) GCPs to be able to accurately apply 2D correction.

2.1.1.7 Lambert's law

In optics, Lambert's cosine law states that the radiant intensity or luminous intensity observed from an ideal diffusely reflecting surface is directly proportional to the cosine of the angle θ between the observer's line of sight and the surface normal. It is named after Johann Heinrich Lambert, from his *Photometria*, published in 1760.

Following is the methodology proposed by Zribi (Zribi et al., 2005) to normalize the radar signal to one angle relative to the incident angles, using the cosine law, based on Lambert's law for optics,

$$\sigma_{\theta_{ref}}^o = \sigma^o \frac{\cos^2 \theta_{ref}}{\cos \theta^2} \quad (9)$$

where: σ^o = linear backscatter observation at incident angle θ

σ_{ref}^o = linear backscatter normalized to a reference incidence angle θ_{ref}

2.2 Modeling of root zone soil moisture

There are two types of modeling approaches that use root data in different ways. One is, bottom-up or microscopic models that contain detail description of the plant, its root and soil texture, and is only considered in steady-state conditions requiring detail plant information that often is not available. The other, top-down or macroscopic models, more hydrologically oriented, that are based on principle of energy and mass transfer through specification of plant-available water capacity of the root zone; it represents the root water uptake as a sink term

that is added to the vertical water flow equation through the soil (Feddes et al., 2001).

Two well-known soil physical models, SWAP (van Dam et al., 2007) and HYDRUS (Šimůnek, 2008), were investigated for the research. Both models apply to the unsaturated zone and solve numerically the Richards equation for water flow. Extra features of HYDRUS 2-D are the two-dimensional version and a graphical user interface. Extra features of SWAP are evapotranspiration of partly covered soils, and flow in water-repellent and macroporous soils.

Feddes (1978) improved the agrohydrological model ARID CROP that simulates transpiration and vegetation growing on homogeneous soil profiles and in the absence of a soil water table, with a new approach Soil and Water Assessment Tool “R” (SWATR) to simulate the water balance describing a field situation in a temperate climate with a heterogeneous soil profile and high water table (Feddes et al., 1978).

SWAP 3.2 model, successor of the agrohydrological model SWATR, is used as the transport model. SWAP (van Dam et al., 2007) is a robust physically-based field scale ecohydrological model used to simulate the processes occurring in the soil-water-atmosphere-plant system. SWAP is an open source hydrological model and is available at <http://www.swap.alterra.nl/>. In the vertical direction, the model domain reaches from a plane just above the canopy to the groundwater plane. In this zone, the transport processes are predominantly vertical; therefore SWAP is a one-dimensional, vertical directed

model. In the horizontal direction, SWAP's main focus is the field scale (Figure 3).

Figure 3 SWAP 3.2 (Soil, Water, Atmosphere and Plant) simulates transport of water, solutes and heat in unsaturated/saturated soils (<http://www.swap.alterra.nl/>)

The model simulates both the soil water quantity and quality with hourly temporal resolution. SWAP can account for several combinations of the top and bottom boundary conditions. Das (2006) have successfully used SWAP in their study for quantifying surface and root-zone soil water contents from low resolution remote sensing data.

2.2.1 Basic equations

Gradients of the soil water potential induce soil water movement. Darcy's equation is commonly used to quantify these soil water fluxes. Darcy's equation, for one-dimensional vertical flow, can be written as:

$$q = -K(h) \frac{\partial(h + z)}{\partial z} \quad (10)$$

where q is soil water flux density (positive upward) (cm d^{-1}), $K(h)$ is hydraulic conductivity (cm d^{-1}), h is soil water pressure head (cm) and z is the vertical coordinate (cm), taken positively upward.

Water balance of an infinitely small soil volume in the unsaturated zone results in the continuity equation for soil water:

$$\frac{\partial \theta}{\partial z} = -\frac{\partial q}{\partial z} - S_a(h) - S_m(h) \quad (11)$$

where θ is VWC ($\text{cm}^3 \text{cm}^{-3}$), t is time (d), $S_a(h)$ is soil water extraction rate by plant roots ($\text{cm}^3 \text{cm}^{-3} \text{d}^{-1}$), and $S_m(h)$ is the exchange rate with macro pores (d^{-1}).

Combination of Eq. (10) and (11) provides the general water flow equation in variably saturated soils, known as Richards' equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial \left[K(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right]}{\partial z} - S_a(h) - S_m(h) \quad (12)$$

2.2.2 Root water extraction

The maximum possible root water extraction rate $S_a(h)$, under optimal moisture conditions, is equal to the potential transpiration rate T_p (cm day^{-1}), which is governed by atmospheric conditions (Feddes et al., 2001).

Stresses due to moisture conditions and/or salinity concentration may reduce $S_a(h)$. Feddes proposed a function to describe the water stress, as shown in Figure 4 (Feddes et al., 1978).

Figure 4 Reduction coefficient for root water uptake, α_{rw} , as function of soil water pressure head h (cm) and potential transpiration rate T_p (cm/day⁻¹) (after Feddes et al. 1978). Water uptake above h_1 (oxygen deficiency) and below h_4 (wilting point) is set to zero. Between h_2 and h_3 (reduction point) water uptake is maximal. The value of h_3 varies with the potential transpiration rate T_p (Feddes et al., 1978).

In order to use experimental data, SWAP calculates the actual root water flux density from:

$$S(h) = \alpha_{rw} \alpha_{rs} S_a(h) \quad (13)$$

where α_{rw} and α_{rs} are the reduction factors due to water and salinity stresses.

Integration of $S(h)$ over the rooting depth yields the actual transpiration rate T_a .

2.2.3 Capillary fringe

The capillary fringe is the subsurface layer in which groundwater seeps up from a water table by capillary action to fill pores. Generally, water in this zone is

under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure.

Figure 5 Soil structure showing the unsaturated zone (vadose), zone of saturation and capillary fringe (<http://geology.er.usgs.gov/eespteam/brass/ground/groundintro.htm>)

A characteristic feature of wetlands is the proximity of the water surface (or water table below the surface) relative to the ground surface. The shallow hydrologic environment of wetlands creates unique biogeochemical conditions that distinguish it from aquatic and terrestrial environments.

Capillary rise results from the natural tendency of water to adhere to soil surfaces and other water molecules. “Because the capillary height of rise can extend for several meters above the water table in fine-grained materials, the soil may be entirely saturated even when water levels are below the ground surface” (T. Rasmussen 2008).

To calculate the capillary rise the Darcy's equation, for one-dimensional vertical flow can be used and the unsaturated hydraulic conductivity, $K(q)$, needs

to be known. The hydraulic conductivity is a function of the moisture content and the moisture content is a function of the pressure head. The soil-water retention curve is the graph representing the relationship between pressure head and water content.

2.2.4 Hydraulic lift

An important effect that can happen in the real world but the models overlook is the influence plant roots can have on the redistribution of soil water via hydraulic lift. “Hydraulic lift is the passive movement of water from roots into soil layers with lower water potential, while other parts of the root system in moister soil layers, usually at depth, are absorbing water” (Caldwell et al., 1997; and Horton and Hart, 1998) (Figure 5).

One prerequisite for hydraulic redistribution is the presence of a large water potential gradient across the soil profile (Richards and Caldwell, 1987). The soil water potential gradient is usually developed during dry periods when surface soil dries out due to evapotranspiration, while deeper soil layers are still wet.

Figure 5 Hydraulic lift in plants (Dawson Todd E. 1996)

The majority of the hydraulic lift cases are documented for semi-arid or arid species; however, recent studies indicate that hydraulic lift occurs in wetter environments, like mangroves in the Biscayne National Park (Hao et al., 2009).

2.2.4 Spatial averaging of hydraulic parameters

To obtain the hydraulic parameters for all of the 117-cell grid (Table 10) that represents our AAOI, we averaged the hydraulic parameters obtained in the laboratory for the three locations following the guidelines suggested by van Genuchten: arithmetic means for K , and n , a value between arithmetic and geometric means for α when K , and α are highly correlated, and a value between geometric and harmonic means for α when K , and α are poorly correlated (Zhu and Mohanty, 2002).

2.2.5 Soil physical relations

Before the Brooks and Corey publication (Brooks and Corey, 1964) describing some hydraulic properties of soil related to drainage problems, involving both partially and fully saturated regions of the soil profile, “the engineers (with rare exceptions) have made the simplifying assumptions that soil is either completely saturated with water or it is, completely unsaturated, and that resistance to flow of air (associated with the movement of water into and out of soil) is negligible” (Corey 1964). Corey’s purpose was to describe these functional relationships and the properties of porous media which affect them. The use of a pressure plate determined the pore-size distribution index, λ , plotting $\log S_e$ (effective saturation) versus $\log P_c$ (capillarity pressure head),

determining the residual saturation θ_{res} . Since the saturation, θ_{sat} , is related to S_e by the relation:

$$S_e = \frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}} \quad (14)$$

The Mualem-van Genuchten function (Van Genuchten, 1980) has been implemented in SWAP. Following is the analytical $\theta(h)$ function proposed by van Genuchten (1980):

$$\theta = \theta_{res} + (\theta_{sat} - \theta_{res})(1 + |\alpha h|^n)^{-m} \quad (15)$$

where α (cm⁻¹), n (-) and m (-) are empirical shape factors. Without losing much flexibility, m can be taken equal to:

$$m = 1 - \frac{1}{n} \quad (16)$$

Using the above $\theta(h)$ relation and applying the theory on unsaturated hydraulic conductivity by Mualem (Mualem 1976), the following $K(\theta)$ function results:

$$K = K_{sat} S_e^\lambda \left[1 - \left(1 - S_e^{\frac{1}{m}} \right)^m \right]^2 \quad (17)$$

where K_{sat} is the saturated conductivity (cm d⁻¹), λ is a shape parameter (-) depending on $\partial K / \partial h$, and S_e is the relative saturation.

2.2.6 Modification for near saturation conditions

“Relative small changes in the shape of the soil water retention curve near saturation can significantly affect the results of numerical simulations of variable

saturated flow, including the performance of the numerical scheme itself in terms of stability and rate of convergence” (Vogel et al., 2001).

Ippisch wrote “...we rigorously specify the conditions for which the classical van Genuchten-Mualem model leads to wrong predictions of relative hydraulic conductivity and, hence, an alternative formulation including an air-entry value should be used” (Ippisch et al., 2006; and Schaap 2006), suggesting to rewrite the model. SWAP implemented Ippisch modification by defining the relative water content as:

$$S_e = \begin{cases} \frac{1}{S_e} [1 + |\alpha h|^n]^{-m} & h \leq h_e \\ 1 & h \geq h_e \end{cases} \quad (18)$$

where S_e is the relative saturation at the cut-off point h_e in the classical Van Genuchten model, given by:

$$S_e = [1 + |\alpha h|^n]^{-m} \quad (19)$$

the hydraulic conductivity is then given by:

$$K = \begin{cases} K_{sat}(S_e)^\lambda \left[\frac{1 - (1 - (S_e S_c)^{1/m})^m}{1 - (1 - (S_c)^{1/m})^m} \right]^2 & S_e < 1 \\ K_{sat} & S_e \geq 1 \end{cases} \quad (20)$$

This model reverts to Eq. (11) for $h_e = 0$; showing that the modification affects the shape of the retention curve only minimally relative to the original function.

2.2.7 Hysteresis

Hysteresis refers to non-uniqueness of the $\theta(h)$ relation and is caused by variations of the pore diameter (inkbottle effect), differences in radius of advancing and receding meniscus, entrapped air, thermal gradients and swelling/shrinking processes (Hillel 1980; Feddes et al., 1988). “Gradual desorption of an initially saturated soil sample gives the main drying curve, while slow absorption of an initially dry sample results in the main wetting curve. In the field, partly wetting and drying occurs in numerous cycles, resulting in so-called drying and wetting scanning curves lying between the main drying and the main wetting curves” (Kroes et al., 2008) (Figure 6).

Figure 6 Water retention function with hysteresis, showing the main wetting, main drying and scanning curves. (Kroes et al., 2008)

In simulation practice, often only the main drying curve is used to describe the $\theta(h)$ relation. This is mainly due to the time and costs involved in

measurement of the complete $\theta(h)$ relationship, including the main wetting, the main drying, and the scanning curves.

2.2.8 Macroporosity

“Water never moves uniformly through soils and landscapes; it always flows through the least resistant path (thus forming preferential flow pathways)” (Lin et al., 2006). Preferential and non-equilibrium flow and transport are considered to hamper accurate predictions of contaminant transport in soils and fractured rocks (Šimůnek et al., 2002).

Figure 7 Preferential flow in the soil matrix (taken from Lin et al., 2006)

In structured soils such as clay and peat, preferential flow occurs through large pores or macropores in the unsaturated soil matrix. Macropores are defined as pores with a diameter or width equal to or larger than 100 μm . “Macroporosity can be caused by shrinking and cracking of soil, by plant roots, by soil fauna, or

by tillage operations” (Kroes et al., 2008), and strongly influence water flow in structured soils (Jarvis et al., 2009).

Although soil water flow is usually described by the equation given by Richards (1931), preferential flow is the generic term to describe this irregular wetting that refers to the process of moving faster than the average water movement through only a fraction of the pore space (Gerke et al., 2010). It covers several processes with different physical causes, but with the common feature that non-uniform wetting leads to an increase of the effective velocity of the water flow through a small portion of the unsaturated zone.

In the SWAP model, macropore water flow comprises uptake of water by macropores at the soil surface, vertical transport to deeper layers or the groundwater bypassing (most of) the soil matrix, lateral infiltration into and exfiltration out of the soil matrix, and rapid drainage to drainage systems (van Dam et al., 2007).

In SWAP the geometry of macropore structure is described by characterizing the macropore volume according to two main properties:

1. Vertical continuity: vertical continuity controls flow of water that is taken up at the soil surface to different depths in the profile, and horizontal continuity controls exchange of water between macropores. It is divided in two domains (**Error! Reference source not found.**):
 - Main Bypass flow domain, which is the network of continuous macropores, and represents the main system of continuous and

- interconnected structural and shrinkage cracks, and roots and worm holes, that penetrate relatively deep into the soil profile; and
- Internal catchment domain, which are the discontinued macropores ending at different depths, and represents macropores ending at different depths in the profile, resulting in forced infiltration of macropore water into the soil matrix.

Figure 8 (Left) Schematic representations of the main bypass flow domain, for transporting water deeper into the profile and rapid drainage, and the internal catchment domain, for infiltration of trapped water into unsaturated matrix at different depths. (Right) Graphical representation of the two domains obtained by the analytical equations. Vertical lines in the internal catchment domain depict subdomains. Z_{Ah} , depth of the A horizon; Z_{ic} , depth of end of internal catchment macropores; Z_{st} , depth of end of Static macropore volume. V_{st} , volume of static macropores at the soil surface; V_{mb} , volume of main bypass flow domain at the soil surface; V_{ic} , volume of internal catchment domain at the soil surface (taken from van Dam et al., 2007).

- Persistency: the model of each of the domains consist of partly:
 - Static macropore volume representing macropores that are permanently present, independent of the soil moisture status, and

- Dynamic macropore volume (shrinkage cracks) depending on the shrinkage characteristics and the current soil moisture content.

Water flowing into the macropore domains accumulates at the bottom of the macropores. The stored water can infiltrate laterally into the soil matrix that is in contact with this water, and, only in the case of the Main Bypass flow domain, drain rapidly to the drainage systems. Water that has not infiltrated or drained within one time step is saved as storage for the next time step. A separate water balance is calculated for each sub-domain” (van Dam et al., 2007).

The most important aspect of macropore flow is that precipitation water is routed into macropores at the soil surface. A relatively small part of precipitation enters the macropore volume directly. Inflow of precipitation excess via overland flow in case of precipitation intensity exceeding matrix infiltration rate, is the dominant source of macropore inflow at soil surface. In order to describe these inflow processes accurately, realistic precipitation intensities and matrix infiltration rates should be simulated.

Figure 9 is a simulation presented by van Dam (van Dam, et al. 2007) regarding the performance of SWAP with respect to simulation of macropore flow at an experimental field on clay; it shows the simulation of daily groundwater levels with and without the macropore flow option in SWAP. Macropores have a damping effect on these oscillations because of the increased storage introduced by the macropore volume. The conclusion of this model exercise is that for

realistic numerical simulation of groundwater levels in clay soils, the incorporation of macropore volume in the model is essential (van Dam et al., 2007).

Figure 9 Simulated daily groundwater levels with and without macropores for the Andelst case (van Dam et al., 2007)

For peat soils **Error! Reference source not found.** three shrinkage stages (Figure 10) can be distinguished (Hendriks et al., 2010):

1. Near-normal shrinkage where volume reduction equals minimal initial moisture loss; little air entering the pores and the peat matrix remains close to saturation;
2. Subnormal shrinkage where drying moisture loss volume reduction is exceeded by air entering the large pores while the small pores remain water-filled; and
3. Supernormal shrinkage where the volume reduction exceeds by far moisture loss; small pores are emptied and the skeleton collapses.

Figure 10 Typical shrinkage characteristic peat (after Hendricks, 2004), expressed as void ratio e as a function of moisture ratio θ , showing the three shrinkage stages (Kroes et al., 2008).

Macropore was not taken into account in the present study due to the change of original location containing organic soils to a new sandy location with lack of soil structure.

2.2.9 Evapotranspiration

Evapotranspiration refers to both transpiration of the plants and evaporation from the soil or of water intercepted by vegetation or ponding on the soil surface. It is only determined by atmospheric conditions and plant characteristics. SWAP assumes the atmospheric conditions to be external conditions, which are representative for the area for which the simulations are performed. SWAP applies Penman-Monteith equation,

$$ET_p = \frac{\frac{\Delta_v}{\lambda_w} (R_n - G) + \frac{P_l \rho_{air} C_{air}}{\lambda_w} \frac{e_{sat} - e_a}{r_{air}}}{\Delta_v + \gamma_{air} \left(1 + \frac{r_{crop}}{r_{air}}\right)} \quad (21)$$

where ET is the transpiration rate of the canopy (mm d^{-1}), Δ_v is the slope of the vapor pressure curve ($\text{kPa } ^\circ\text{C}^{-1}$), λ_w is the latent heat of vaporization (J kg^{-1}), R_n is the net radiation flux at the canopy surface ($\text{J m}^{-2} \text{d}^{-1}$), G is the soil heat flux ($\text{J m}^{-2} \text{d}^{-1}$), P_l accounts for unit conversion ($=86400 \text{ s d}^{-1}$), ρ_{air} is the air density (kg m^{-3}), C_{air} is the heat capacity of moist air ($\text{J kg}^{-1} ^\circ\text{C}^{-1}$), e_{sat} is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), γ_{air} is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), r_{crop} is the crop resistance (s m^{-1}) and r_{air} is the aerodynamic resistance (s m^{-1}) (van Dam et al., 2007).

2.2.10 Numerical implementation

Water flow in the vadose zone is predominantly vertical, and can be simulated as one-dimensional flow in many applications (Romano et al., 1998). Accurate numerical solution of Richards' partial differential moisture capacity, C , is difficult due to its hyperbolic nature, the strong non-linearity of the soil hydraulic functions and the rapid changing boundary conditions near the soil surface; van Dam investigated the effect of the nodal distance and averaging the hydraulic conductivity with SWAP (van Dam and Feddes, 2000).

Calculated soil water fluxes can be significantly affected by the structure of the numerical scheme, the applied time and space discretization, and the procedure for the top boundary condition (van Genuchten and Alves, 1982). The

numerical scheme chosen in SWAP solves the one-dimensional Richards equation (5) with an accurate mass balance, and converges rapidly using known relations between θ , h and K , where analytical solutions do not exist.

Milly (1984) and Celia (1990) eliminated the differential moisture capacity by using the previous soil water pressure head for the next iteration step (Feddes, 1983).

2.3 Ensemble Kalman filter

The Ensemble Kalman filter (EnKF) is a Monte Carlo approach to the nonlinear filtering problem and is based on the approximation of the conditional probability densities of interest by a finite number of randomly generated model trajectories (Figure 11).

EnKF is believed to be a flexible and effective sequential data assimilation method that provides a framework of explicit consideration of the various sources of uncertainty and is suitable for real-time, updated observations (Li and Ren, 2011; Walker and Houser, 2001).

Reichle proved the concept of optimal downscaling for the case where soil moisture estimates are required at scales smaller than the scale of the microwave observations (Reichle and Entekhabi, 2001a). Das implemented “a multiscale ensemble EnKF that assimilates remotely sensed coarse scale soil moisture footprint, and coarse/fine scale simulation into a spatial characterization of soil moisture evolution at the finer scales” (Das et al., 2008; Das and Mohanty, 2006).

Figure 11 Schematic of the ensemble Kalman filter (EnKF) (Reichle and Koster 2003)

Our research study does not require such data assimilation to assimilate from coarse to fine spatial scale, since our radar footprint, as well as soil moisture modeling, are of the same fine spatial scale.

3. RESEARCH OBJECTIVE

The importance of knowing the semisaturated soil characteristics in the ENP consists of understanding the effect that the man-regulated water table level has in the soil properties. These properties regulate the production of energy-rich materials, and also provide freshwater for human consumption and a sustainable supply of food to animals and plants that inhabit the ENP.

The motivation for this research is to understand the water distribution and movement in the semi-saturated zone of the Everglades with the purpose of contributing to its preservation by developing procedures and finding the additional soil parameters needed for modeling its spatial-temporal distribution of water.

The main research objective is to test the feasibility of monitoring soil moisture spatial temporal distribution in the vadose zone of a natural ecosystem of ENP, by developing a methodology that integrates the following components:

- Microwave remote sensing (radar),
- Laboratory and field experiments,
- SWAP water transport model, with enhancements with data management, and
- Measure of error difference between modeled and observed volumetric water content.

Specific Objectives:

1. Design a methodology that better represents the surface soil moisture using satellite images.
2. Design a protocol where both techniques, field soil moisture reading and remote sensing radar, are reporting data at the same time and location.
3. Obtain in laboratory soil parameters (θ , α , m , n and K), and ρ_b , G_s , and hydraulic conductivity ($K_{(h)}$) for each element of the profile soil in the vadose zone.
4. Develop a computer program to read information from each pixel of the grids and to interface with SWAP to report graphically their spatial temporal states of moisture content.

4. METHODOLOGY

4.1 Introduction

Subsequent to ENP granting the Scientific Research and Collecting Permit #EVER-2013-SCI-0004 #EVR-00486, which authorized access to an area within the Shark River Slough (SRS) in ENP, field observations started in December 2012.

Figure 12 Shark River Slough delineated in the Everglades National Park. The freshwater section is shown in orange while the estuarine section adjacent to the Gulf of Mexico is shown in green. Red dots indicate sampling locations for water level. Arrow indicates direction of water flow. Also shown in the map is Taylor Slough (USGS-SOFIA).

The experimental site is located east of the Shark Valley Visitor Center (parallel to the road) (Figure 12, red arrow). Tamiami Trail, U.S. 41 is the main highway to get to the Shark Valley Visitor Center. SRS is a natural wetland

depression that contains organic sediments made up of both shallow and deep peats. SRS provides the primary source of water to ENP.

4.2 Field work

In preparation for the satellite recording images at the AOI on Wednesday, April 10 and Saturday, April 13, 2013 at 6 am, the geographic coordinates of the 100 m x 100 m AOI were established (Figure 13). Core soil samples were taken at two scheduled locations. Twenty-five acrylic tubes were installed in pre-determined stations inside the AOI, to allow the insertion of the profile hydra-probe to read the volumetric water content at different depths. Two observation wells were installed, and vegetation mass was estimated. Days before the scheduled satellite pass, an intense precipitation occurred, flooding the AOI. The water table never recovered its depth since then.

Two non-flooded locations, of 15 m x 10 m (location 1) and 15 m x 9 m (location 2), 1,300 meters apart, herein referred to as AAOI, were selected to measure surface soil moisture from satellite images, and location 1 for the modeling of water content in the vadose zone.

Fifteen flags in location 1 and eight flags in location 2, of the AAOI, were installed and their geographic coordinates recorded (Figure 14). A calibrated low resolution global position equipment (i.e., Magellan Explorist 510) was used to obtain the Universal Transverse Mercator (UTM) coordinates.

Figure 13 Area of Interest (AOI) showing locations of 25 acrylic tubes (red), 9 soil samples (yellow) and 2 observation wells (blue) (lat 25.757182° lon -80.762291°)

Surface core samples were taken from location 1 at 6:00 AM, concurrently with satellite passes capturing the images on Saturday, May 4, and on Tuesday, May 7. Samples were sealed and transported to the laboratory at Florida International University where the volumetric moisture content of each sample was obtained and recorded to estimate their volumetric water content by drying the sample at 105 °C (Table 1) and (Table 2).

Four sets of core soil samples (Figure 14**Error! Reference source not found.**), from each layer of the soil profile, were taken at 3 different points. The

samples were kept refrigerated at 0 °C until they were used for the determination of soil property characterization.

Figure 14 Flag location of surface soil samples retrieved during remote sensing

Figure 15 Profile soil core sample

Table 1 Surface volumetric water content taken on May 4, 2013

Volume (cm ³): 51.36		Weight			Volumetric Water Content (%)
Flag #	Location	Wet (g)	Dry (g)	Diff./Water (g)	
1	1	107.41	91.25	16.16	31%
2	1	82.03	63.64	18.39	36%
3	1	101.38	85.27	16.11	31%
4	1	94.02	69.71	24.31	47%
5	1	101.85	77.54	24.31	47%
6	1	85.62	65.57	20.05	39%
7	1	91.92	71.87	20.05	39%
8	1	88.11	63.80	24.31	47%
9	1	82.05	57.74	24.31	47%
10	1	92.06	74.47	17.59	34%
11	1	88.11	71.54	16.57	32%
12	1	88.41	71.80	16.61	32%
13	1	93.46	78.88	14.58	28%
14	1	103.26	88.68	14.58	28%
15	1	93.54	78.92	14.62	28%
16	2	99.06	69.44	29.62	58%
17	2	100.8	68.50	32.3	63%
18	2	81.29	41.40	39.89	78%
19	2	84.96	46.44	38.52	75%
20	2	106.16	79.47	26.69	52%
21	2	68.47	22.00	46.47	90%
22	2	104.49	76.98	27.51	54%
23	2	105.58	75.42	30.16	59%

Table 2 Surface volumetric water content taken on May 7, 2013

Volume (cm ³): 51.36		Weight			Volumetric Water Content (%)
Flag #	Location	Wet (g)	Dry (g)	Diff./Water (g)	
1	1	78.99	60.76	18.23	35%
2	1	111.99	91.3	20.69	40%
3	1	105.03	84.3	20.73	40%
4	1	89.61	64.52	25.09	49%
5	1	74.76	46.42	28.34	55%
6	1	92.06	77.52	14.54	28%
7	1	91.49	78.6	12.89	25%
8	1	75.53	60.61	14.92	29%
9	1	90.97	70.81	20.16	39%
10	1	78.97	59.89	19.08	37%
11	1	90.28	70.43	19.85	39%
12	1	104.56	78.62	25.94	51%
13	1	97.08	76.01	21.07	41%
14	1	112.9	93.36	19.54	38%
15	1	90.02	66.28	23.74	46%
16	2	94.62	61.68	32.94	64%
17	2	98.69	68.19	30.5	59%
18	2	104.18	71.77	32.41	63%
19	2	102.6	73.23	29.37	57%
20	2	95.97	74.89	21.08	41%
21	2	69.78	27.49	42.29	82%
22	2	96.95	73.2	23.75	46%
23	2	91.16	61.74	29.42	57%

Location 1 of the AAOI was used to model the water content in the vadose zone. It was gridded in 1m x 1m sections (Figure 16, and

Figure A71). Surface elevation was recorded for each gridded cell (Table A15). Surface soil moisture at 2.5 cm depth was also recorded (Table A16) using a calibrated POGO portable soil sensor (Figure 17) with Personal Digital Assistance (PDA) for 5 consecutive days at noon. These data are important as they define the top initial boundary condition for modeling moisture distribution in the vadose zone with SWAP; additional data were collected in 4 additional days to assess the uncertainty of the model predictions.

Figure 16 Alternative Area of Interest (AAOI) gridded 1 m x 1 m

Four acrylic access tubes provided access to the Profile Probe PR4 (Figure 18) to read the volumetric water content at different depths during 5 consecutive days at noon time (Table A17). These data are used as observation points to measure the uncertainty of the model predictions.

Figure 17 POGO portable soil sensor with PDA

Figure 18 Profile Probe PR4 installation and reading

One square meter of vegetation was sampled, covered with paper and sealed in a plastic bag, and then transported to the laboratory to measure its density. A rain gage with a temperature sensor (Oregon RGR-202), with hourly rainfall history, was installed (Figure A72) and data was recorded for five consecutive days (Table A19).

Figure 19 Rainfall gage at AAOI

Two measurements of soil roughness profile were photographed and aligned in the same satellite trajectory using an aluminum pin profilometer (Figure 20) that was manufactured in house. The photographs were later digitized for processing, using the QUIP Matlab program (Script 1, Page 266), to obtain the surface roughness index (Figure A73).

Figure 20 Surface roughness measurement using a pin profilometer

4.3 Active microwave remote sensing

4.3.1 Introduction

The approach presented in this dissertation for a 3-m spatial resolution is based on the change detection method employed by Piles using Soil Moisture Experiment 2002 (SMEX02) data for a 400-m spatial resolution. “Change detection techniques have been demonstrated to be able to potentially monitor temporal evolution of soil moisture by taking advantage of the approximately linear dependence of radar backscatter and brightness temperature change on soil moisture change” (Piles et al., 2009).

4.3.2 Pre-processing

Received SAR images were pre-processed, using Next ESA SAR Toolbox (NEST) version 5.0.16, free software by Array Systems Computing Inc. (<http://www.array.ca/nest>), as follows.

1. Radiometric calibration:
 - a. Pixel Digital Number (Amplitude/Intensity) converted to Sigma Naught (σ^0)
 - b. Backscatter Coefficient in decibels (dB)
2. Single Image Speckle Filtering: Lee Filter (3x3 window)
3. Geocoding (orthorectification) World Geodetic System 1984 (WGS_1984)
4. Re-projection

No topographic correction was applied to SAR imagery because the AAOI was flat.

4.3.3 Georeferencing

SAR projected image (WGS_1984) was out of position with regard to Google Earth (WGS_1984) by 4 to 6 m. GIS was used to georeference the SAR images to Google Earth image, following the procedure:

1. SAR raster image (Sigma-HH-db.img) was projected into ArcMap
2. A GIS basemap layer with same spatial reference WGS_1984 was loaded and used as reference to calibrate the SAR image using a GIS georeference tool

4.3.4 Soil surface roughness index

“Unless accurate surface roughness parameter values are available, retrieving soil moisture from radar backscatter usually provides inaccurate estimates” (Verhoest et al. 2008).

QUIP, a Matlab script, provided by Sherbrooke University, Canada, was used to process the profilometer images to find the soil roughness parameters root mean square (rms) height, s^2 , and the correlation length, l , both needed to obtain the soil roughness index, Z_s ,

$$Z_s = s^2/l \quad (22)$$

The values obtained from three consecutive 1-m transects were (Figure A74):

- $s^2 = 0.62$
- $l = 47.22$

obtaining a soil roughness index, Z_s , of 1.31×10^{-2} .

4.3.5 Data

A total of twenty-three surface soil samples were obtained concurrent with the satellite recorded images, and their volumetric water content was estimated (Table 1 and 2). This data was used for algorithms development to convert radar images to moisture content.

To obtain the radar backscatter value (dB) for each sample location position, the location coordinates of the twenty-three soil sample locations were projected into Google Earth and exported (KMZ file), converted to a GIS layer using a GIS toolbox (Conversion: KMZ file to shp file), and loaded into GIS, where the georeferenced SAR image resides. The pixel values (dB) of the twenty-three locations were extracted using a GIS toolbox “Spatial Analyst Tool” and converted to a point image layer. Then, the Attribute Table of the new layer was opened and its table exported to Excel (Table 3).

Table 3 Flag pixel values (dB)

Name Flag #	04-May-13 RASTERVALUES dB	07-May-13 RASTERVALUES dB
1	-14.7684088	-12.6061650
2	-17.6236401	-9.8034320
3	-22.5684834	-8.8716430
4	-22.5684834	-8.9847700
5	-19.0076809	-6.9674560
6	-19.0076809	-8.4319790
7	-19.0076809	-6.7562900
8	-22.5684834	-6.9674560
9	-20.5270252	-6.6457120
10	-16.9494286	-8.2739920
11	-16.1010933	-7.6385560
12	-16.1289291	-6.1756490
13	-14.4357748	-10.6271790
14	-14.4357748	-7.6385560
15	-14.4713831	-8.5757070
16	-13.5587620	-11.8943920
17	-12.8406330	-14.7458930
18	-13.5956490	-12.1860210
19	-12.6266190	-12.9799760
20	-10.4217320	-12.5491360
21	-12.0594450	-9.5145350
22	-9.0934790	-5.2859740
23	-9.8615660	-4.7929860

Surface volumetric water content was measured in each cell of the 117-cell grid during five consecutive days (Table A15); the first day was used by the transport model as initial boundary condition, and the remaining data is used as observations to compare with the model prediction.

Figure 21 High resolution RADARSAT-2 Canadian satellite (De Lisle 2009)

Two processed satellite images, from May 4, and May 7, 2013, have been used for the research presented in this thesis. The data sets were obtained from RSAT-2 Canadian satellite in descending direction, with antenna C-band, using *hh* polarimetric mode and an ultra-fine resolution of 3 m x 3 m (Tables A22 to A25).

NEST software was used to process the satellite images (Figure A75 to A78). Speckles were removed and kernel filter was applied which averaged 3 x 3 consecutive pixels, and the image was georeferenced. The location flags corresponding to the sampled locations were input into the pixel-image (Figure 22 and Figure 23) and the backscatter value (dB) for each location flag was obtained (Table 4Error! Reference source not found.).

Figure 22 SAR image showing location flags (1-15)

Figure 23 SAR image showing location flags (16-23)

Table 4 Satellite data for flagged soil sample locations taken on May 4th and May 7th, 2014

Flag	Lon	Lat	04-May		07-May		
			$\theta_{\text{reference}}$	σ^{01}	θ_{02}	σ^{02}	$\sigma_{\theta_{\text{ref}}}^{02}$
			incident _ angle	Sigma0_ HH_dB	incident _ angle	Sigma0_ HH_dB	Normalized dB
pin_1	-80.76151	25.70601	47.76	-14.77	31.38	-12.61	-6.68
pin_2	-80.76150	25.70598	47.76	-17.62	31.38	-9.80	-5.19
pin_3	-80.76148	25.70594	47.76	-22.57	31.38	-8.87	-4.70
pin_4	-80.76151	25.70593	47.76	-22.57	31.38	-8.98	-4.76
pin_5	-80.76154	25.70596	47.76	-19.01	31.38	-6.97	-3.69
pin_6	-80.76154	25.70598	47.76	-19.01	31.38	-8.43	-4.47
pin_7	-80.76157	25.70597	47.76	-19.01	31.38	-6.76	-3.58
pin_8	-80.76155	25.70594	47.76	-22.57	31.38	-6.97	-3.69
pin_9	-80.76154	25.70592	47.76	-20.53	31.38	-6.65	-3.52
pin_10	-80.76158	25.70591	47.76	-16.95	31.38	-8.27	-4.38
pin_11	-80.76159	25.70593	47.76	-16.10	31.38	-7.64	-4.05
pin_12	-80.76160	25.70595	47.76	-16.13	31.38	-6.18	-3.27
pin_13	-80.76164	25.70593	47.76	-14.44	31.38	-10.63	-5.63
pin_14	-80.76162	25.70592	47.76	-14.44	31.38	-7.64	-4.05
pin_15	-80.76162	25.70589	47.76	-14.47	31.38	-8.58	-4.54
pin_16	-80.76197	25.71793	47.78	-13.56	31.40	-11.89	-6.30
pin_17	-80.76200	25.71795	47.78	-12.84	31.40	-14.75	-7.81
pin_18	-80.76204	25.71798	47.78	-13.60	31.40	-12.19	-6.45
pin_19	-80.76203	25.71798	47.78	-12.63	31.40	-12.98	-6.87
pin_20	-80.76203	25.71792	47.78	-10.42	31.40	-12.55	-6.64
pin_21	-80.76201	25.71789	47.78	-12.06	31.40	-9.51	-5.04
pin_22	-80.76204	25.71788	47.78	-9.09	31.40	-5.29	-2.80
pin_23	-80.76210	25.71791	47.78	-9.86	31.40	-4.79	-2.54

The incident angle of May 7, 2013 backscatter was normalized (Table 4) using the cosine law, based on Lambert's law for optics, applying the change detection techniques and a linear algorithm was developed plotting the

differences in moisture content ($\text{cm}^3\text{cm}^{-3}$) versus the differences in normalized backscatter (dB).

The algorithm was then used to obtain the modeled moisture content and to compare it with the observation values obtained in situ concurrent with the satellite recorded images.

4.4 Laboratory experiments

4.4.1 Introduction

The main purpose of the laboratory experiments is to obtain the pair values, water content (Θ) and matric potential (ψ_m or h), also called soil water content. In order to obtain the soil water content, several experiments need to be performed, such as bulk density, specific gravity, tension plates, pressure chamber, and saturated hydraulic conductivity for each of the three different soil layers (5, 10, and 20 cm height).

Measurements of volumetric water content from surface samples, and biomass vegetation, were estimated for radar algorithms development.

4.4.2 Soil

Two types of soil occur in the Everglades: marl and peat. Marl is product of Periphyton, product of short-hydroperiods, and is the main soil near the edges of the southern Everglades, where the bedrock lies close to the surface. Marsh peat is a product of long-hydroperiods and usually occurs in areas where the bedrock lays deeper (Lodge, 2005).

Two types of peat occur in Everglades marshes: Everglades peat and Loxahatchee peat. Everglades peat is composed of the remains of sawgrass and often called sawgrass peat. It is brown to black color due to its charcoaled matter from frequent fires.

Loxahatchee peat occurs in deeper marsh areas as the SRS. It is lighter colored (fire is rare in sloughs) and contains the remains of slough vegetation, specially the roots, rhizomes, leaves and seeds of waterlilies. When the peat soil becomes too finely divided (often due to animal activity from earthworms to alligators), the soil is commonly called muck (Lodge, 2005).

Wetland soil in the SRS is characterized as mucky peat in texture and black color as a result of slow decomposition of vegetation. However, the soil in our AOI has a sandy (98%) texture without organic content. Three different horizons (0-5, 5-15, and 15-25 cm depth) were identified in situ.

4.4.2.1 Vertical discretization

The finite element grid is constructed by dividing the soil profile into linear elements with sizes defined by the z-coordinates of the nodes that form the element corners (Figure 24).

The common rule is that the finer the finite element sizes, the more precise the results will be. On the other hand, the number of calculations increases, as additional equations must be solved for every further finite element. The size of the finite elements can be gradually increased with depth to reflect the much slower changes in pressure heads at greater depths (Šimůnek, 2013).

Figure 24 Soil vertical discretization

The pressure head (water content) front for the soil (sandy) profile is very sharp and the entire front is only about 5 cm thick. Therefore, in order to describe this front using a numerical model, we need several nodes at the front, implying that our spatial discretization must be of the order of 1 cm or less. We decided to use 4 compartments from the surface of 0.5 cm each, and 23 compartments of 1 cm; making a total vertical discretization of 27 nodes.

The maximum ponding layer thickness (cm) determines which water layer can be present on top of the soil surface before runoff starts. It is recommended to use < 1 cm (SWAP Manual) for the compartment thickness near the soil surface for correct simulation of infiltration and evaporation fluxes. Deeper in the

soil profile, where the soil water flow is less dynamic, the compartment thickness may increase.

The maximum depth is governed by the maximum water table depth occurring at the beginning of the data collection. The maximum depth of the higher finite element is 25 cm.

4.4.2.2 Hydraulic parameters

The WRC obtained in the laboratory was used to estimate the soil hydraulic parameters. The WRC equation that “best fits” the curve expressed by van Genuchten function (1980a) is:

$$\theta(h) = \frac{\theta_s - \theta_r}{[1 + (-\alpha h)^n]^m} + \theta_r \quad (23)$$

where:

θ_s = saturation water contact [$\text{cm}^3\text{cm}^{-3}$]

θ_r = residual water contact [$\text{cm}^3\text{cm}^{-3}$]

n and m = fitting parameters (steeper of the curve) [-]

α = air entry potential [cm^{-1}]

h = pressure head [cm]

For the air entry and capillary region, “undisturbed” soil samples were used to maintain intact the soil pore-size distribution which determines the retention curve in these sections. Undisturbed core samples were stored at 35°F with the purpose of better preserving their structure; however, some of the samples were stored for up to three months before processing, suffering some structural alterations.

Specific gravity was performed in accordance with the American Society for Testing and Materials (ASTM) D854-06 specific gravity procedures. Bulk density was calculated in the pressure chamber after drying of the sample, weighed and divided by the volume of the plastic cylinder that contained the specimen. Calculated bulk density for each sample, together with its specific density, were used to obtain the porosity using the following formula:

$$Porosity = 1 - \frac{Bulk\ density}{Specific\ weight} \quad (24)$$

The porosity was used to estimate the initial degree of saturation of each sample.

Figure 25 Pressure plate extractor

Soilmoisture 15 Bar Pressure Plate Extractor (**Error! Reference source not found.**) was used for suction pressures between 50 to 1500 kPa with sieved

(<2 mm) samples (Tables A42 to A60). The experiment was repeated three times for each sampled location in order to have statistical value.

Fredlund Soil-Water Characteristic Curve (SWCC) Device (Figure 26) was used with undisturbed (core) soil samples for suction pressures between zero and 5 kilo-Pascal (Tables A35 to A41). The wetting process performed during the specimen preparation did not result in an initial degree of saturation of 100%. The soil water characteristic curve has an initial degree of saturation of 100%. Hence we corrected the pair values, θ and ψ , obtained from the laboratory experiment, to reflect the effective saturation following Fredlund Xing procedures (Perez-Garcia et al., 2006) in correcting for a specimen not starting at 100% saturation (Tables A61 to A79).

Figure 26 Oedometer (Fredlund pressure chamber)

Three field core samples from the AOI were extracted with acrylic test cylinders of 2.5 inches diameter and air-sealed. Before the experiment, each

sample was saturated in the laboratory from the bottom up with water, and installed in equipment (Figure 27) developed in the laboratory to measure the vertical hydraulic conductivity (K_s) in saturated soil.

Figure 27 Apparatus used for measuring hydraulic conductivity of saturated soil

Each test runs for a minimum of 20 minutes and up to 1 hour, to allow the test conditions to stabilize. The hydraulic conductivity at the end of each test is reported as the hydraulic conductivity for that test.

4.4.3 Volumetric water content procedures

A bulk density core sampler (Figure 28) was used to collect soil samples, and twenty-three soil moisture measurements were taken in locations 1 and 2 (Table 1 and Table 2). The samples were bagged immediately to minimize moisture loss and taken to the lab for analysis. Proper labeling of the zip lock bags as well as soil containers used in the lab is essential.

Figure 28 Aluminum sampling rings used to obtain surface samples

4.4.4 Biomass and canopy water content

Wet weights of the plant wet samples were taken as soon as possible after collection as plant matter can degrade quickly. To slow this process, samples were kept wrapped in paper and inside a plastic bag during its transport to the laboratory.

After the wet weight was determined, the plastic bag was removed and the plant sample and paper bag placed into the drying tray. The plant sample was dried for 72 hours at laboratory conditions; and the plant water content was calculated based on the weight difference.

4.4.5 Parameter estimations

4.4.5.1 Specific gravity

Specific gravity was done following ASTM D854-06 specific gravity procedure. Table 5 contains the results of the samples from the three (3) locations (X1, X2, and X3), and for each layer (A, B and C), obtained in laboratory (Tables A82 to A90).

Table 5 Summary of specific gravity obtained in laboratory

Code	Sample#1	Sample#2	Sample#3	Average
X1-A	2.56	2.64	2.58	2.60
X1-B	2.65	2.67	2.62	2.65
X1-C	2.65	2.57	2.58	2.60
X2-A	2.50	2.59	2.56	2.55
X2-B	2.51	2.57	2.46	2.51
X2-C	3.21	2.23	2.40	2.61
X3-A	2.66	2.53	2.64	2.61
X3-B	2.64	2.65	2.61	2.63
X3-C	2.59	2.70	2.61	2.63

4.4.5.2 Saturated hydraulic conductivity

Hydraulic conductivity, K , is the property of the soil that describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation.

Saturated hydraulic conductivity was conducted in the laboratory (Tables A91 to A97) following the ASTM D 4511-00 for essentially saturated peat using an apparatus manufactured in the laboratory (Figure 27).

Table 6 Hydraulic conductivity results

Point	Soil Layer	k (cm/s)	Average k (cm/s)
X1	A	0.0270	0.02700
	B	0.0600	0.06000
	C	0.0083	0.00830
X2	A	0.0226	0.02760
		0.0318	
		0.0284	
	B	0.0782	0.06562
		0.0614	
		0.0572	
	C	0.0415	0.04414
		0.0364	
		0.0546	
X3	A	0.0542	0.06979
		0.0681	
		0.0871	
	B	0.0512	0.05130
		0.0439	
		0.0588	
	C	0.0075	0.03909
		0.0370	
		0.0728	

Table 6 contains the results of the hydraulic conductivity testing. Each test was run for a minimum of 40 minutes to allow the test conditions to stabilize. The hydraulic conductivity at the end of each test is reported as the hydraulic conductivity for that test.

4.4.5.3 Water retention curves (WRC)

The soil water retention curve, $\theta(h)$, contains five potentially unknown parameters: θ_r , θ_s , α , n , and m . The RETC code is used to fit all of these

parameters simultaneously to observed data. RETC uses a nonlinear least-squares optimization approach to estimate the unknown model parameters from observed retention and conductivity data.

Van Genuchten is used for type of retention curve model, where the parameter is $m = 1 - 1/n$. RETC sand flow parameter estimates θ_r , θ_s , α , and n are used as initial parameters to be fitted by RETC. Saturated hydraulic conductivity, K_s , together with the retention curve data (pair of data pressure - θ) obtained in the laboratory was input into RETC.

The WRC was estimated for each layer of locations X1, X2, and X3. Three samples (A, B and C) were processed for each layer for statistical purposes; however, not all samples produced acceptable results and those were rejected. Acceptable results were defined as samples that during the application of pressure in the pressure plates maintain a constant pressure during the experiment and were not affected due to equipment pressure leaks or laboratory building maintenance. WRC graphics are shown in appendices (Figure A87 to Figure A105). Table A98 shows a summary of the soil parameters obtained from their WRC.

HIDRUS was used to represent the WRC of each sample location (X1, X2, and X3) (Figure 29 to Figure 31). Each sample location graphic contains the WRC of its three layers, layer A (0-5 cm), layer B (5-15 cm), and layer C (15-25 cm).

Figure 29 WRC for each layer of location X1

Figure 30 WRC for each layer of location X2

Figure 31 WRC for each layer of location X3

4.4.5.4 Spatial averaging of hydraulic parameters

The spatial averaging of hydraulic parameters has been estimated following the guidelines suggested by van Genutchten using arithmetic mean to average K and n in all layers, geometric mean to average α in layers A and B, and Harmonic mean to average α in layer C (Table).

4.4.5.4 Volumetric water content

Surface core samples at 2.5 cm depth were taken at each of the twenty-three flagged locations in our research area, simultaneously with the satellite passing and recording the images on May 4 and May 7, 2013, at 6 am. Table 1 and Table 2 are showing the sample weights (wet and dry) obtained in the laboratory, and the calculated VWC. This data is used for the conversion and verification of the soil surface moisture needed as boundary condition for SWAP.

4.4.5.5 Biomass water content

Following are the estimations of the vegetation biomass in the AOI:

Table 7 Biomass water content

Biomass	Feb 1 st	Feb 8 th	
Area	0.33	0.33	m ²
Bag container	30.00	30.00	g
Total weight	167.7	145.3	g
Mass weight	137.7	115.3	g
Biomass	417.27	349.39	g/m ²

Due to the low above-ground biomass content, less than 0.5 Kg m⁻², the effect of the vegetation in the radar backscatter was ignored (Ulaby et al., 1996).

4.4.5.6 Soil texture

Composition of sand, silt and clay for each layer of the soil profile was obtained in the laboratory following the mechanical analysis; a laboratory procedure was used to identify soil separates (Table 8). Sand is the soil textural classification using the soil textural triangle.

Table 8 Soil texture of each layer of the soil profile

		Weight (g)	Percentage
Layer A	Sand	2016.1	96.86%
	Silt	55.44	2.66%
	Clay	10	0.48%
Layer B	Sand	1739.9	96.06%
	Silt	50.22	2.77%
	Clay	21.2	1.17%
Layer C	Sand	1563.4	95.93%
	Silt	47.736	2.93%
	Clay	18.564	1.14%

4.4.5.7 Organic content

Organic content of the soil profile was obtained by weight difference before and after burning a sample at 500°C during 2 hours (Table 9).

Table 9 Profile organic content

Zone	Organic content
A	22%
B	2%
C	2%

4.5 Modeling of Root Soil Moisture

4.5.1 Introduction

SWAP was used to model the root soil moisture from June 3 to June 7, 2013. SWAP data input consisted of two types of files, main input file (*.swp) and meteorological input file (*.yyy); the extension of the main file is fixed, and the meteorological file has an extension equal to the last 3 digits of the year (e.g. 2013 gives .013). SWAP uses the TTUTIL library (Kraalingen & Rappoldt, 2000) for reading input files. Output from SWAP is stored in general ASCII files.

4.5.2 Geographic Information System

A Geographic Information System (GIS) is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information (Folger, 2010). ArcGIS was used to organize SWAP modeling at each cell of the 117-cell grid in the AOI and to produce the graphical output representing the spatial temporal behavior of the moisture content at different depths.

Each cell was assigned different initial conditions based on their measured surface moisture content, as well as a different bottom boundary condition based on their different measured surface elevations. Meteorological data was the same for all cells.

4.5.3 Computer Script

In order to model each cell of the AAOI, a script (Script 2, Page 298), written in python for batch processing of the SWAP model, was developed to run SWAP in each of the 117-grid cells, and to retrieve their results.

The script runs in a loop creating a folder for each of the swap cells. Three changes for every cell are made to the file before writing it in the folders: the pressure and head values, the ground water levels by date and time, and the soil hydraulic parameters (θ_s , θ_r , α , m and K_s). The SWAP model is then executed using the "cellName.swp python (Script 3, Page 303) and "swap.exe" files for each cell in the folders. Lastly, the SWAP results (result.vap) from every cell are copied and appended to a new text file.

With each cell result, a geodatabase and a point feature class is created. Next, it creates a field in the attribute table of the feature class to which name of SWAP cells are attached. In the next step, the program imports the accumulated SWAP model results for all cells as a geodatabase table. Then, new fields are created in the table with appropriate storage types and the fields are calculated using original fields. It then creates a time series table layer and is saved in the geodatabase. Finally, it creates a relationship class between the point feature class and results table by cell names.

An ArcGIS toolbox was created to facilitate temporal visualization of SWAP results by depth.

4.5.4 Data

4.5.4.1 Main input file

Main input file SWAP.swp, is a generic representation of each one of the 117-grid modeled cells.

The main input file contains the following sections:

- General section
 - Soil water section
 - Bottom boundary section
 - Heat flow section
- Meteorology section

where the general and meteorology sections remain the same for each grid cell, the initial surface pressure head and bottom boundary condition change for each grid cell (Table A99).

The initial surface pressure head was estimated using the measured surface soil moisture of June 3, 2013 at noon.

4.5.4.1.1 General section

Following are the common data entry sections into the general section of the main input file:

General section:

- Part 2: Simulation period
 - Start = 03-jun-2013
 - End = 07-jun-2013

- Part 3: Number of output times during a day
 - Print/day = 24
 - Out/date = 03-jun-2013 through 07-jun-2013
- Part 4: Output files
 - SWVAP = output profiles of moisture and temperature
 - Number of nodes = 26
 - Thickness of compartments (cm) = 0.5 0.5 0.5 0.5 1.0 1.0 1.0 1.0
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
1.0

Meteorology section:

- File name of meteorological data without extension .YYY = ENP detail

Soil water section:

- Part 1: Initial soil moisture condition
 - Type of initial soil moisture condition = pressure head as function of depth is input
- Part 2: Ponding, runoff
 - In case of ponding, minimum thickness for runoff = 0.2 cm
 - Drainage resistance for surface runoff = 0.5 cm
- Part 3: Soil evaporation
 - Coefficient to derive E_{pot} from E_{Tref} = 1.0
 - Method for reduction of potential soil evaporation reduction to maximum = Darcy flux and to maximum Black (1969)
 - Soil evaporation coefficient of Black = 0.35
- Part 4: Vertical discretization of soil profile

- LAY = number of soil layer, start with 1 at soil surface, [1..MAHO, I]
- SUBLAY = number of sub layer, start with 1 at soil surface, [1..MACP, I]
- HSUBLAY = height of sub layer, [0.0..1000.0 cm, R]
- HCOMP = height of compartments in this layer, [0.0..1000.0 cm, R]
- NCOMP = number of compartments in this layer (= HSUBLAY/HCOMP), [1..MACP, I]

LAY	SUBLAY	HSUBLAY	HCOMP	NCOMP
1	1	2.0	0.5	4
1	2	3.0	1.0	3
2	3	10.0	1.0	10
3	4	10.0	1.0	10

- Part 5: Soil hydraulic functions

- LAY = number of soil layer, as defined in part 4 [1..MAHO, I]
- RES = Residual water content, [0..0.4 cm³/cm³, R]
- SAT = Saturated water content, [0..0.95 cm³/cm³, R]
- ALFA = Shape parameter alpha of main drying curve, [0.0001..1 /cm, R]
- NPAR = Shape parameter n, [1..4 -, R]
- KSAT = Saturated vertical hydraulic conductivity, [1.d-5..1000 cm/d, R]
- EXP = Exponent in hydraulic conductivity function, [-25..25 -, R]
- Mualem - van Genuchten parameters:

LAY	RES	SAT	ALFA	NPAR	KSAT	EXP
1	0.066	0.58	1.5682	1.908	0.0462	0.999
2	0.009	0.46	0.5626	1.476	0.0597	0.999
3	0.000	0.47	0.3030	1.488	0.0289	0.999

- Part 9: Preferential flow due to macropores

- No macropore flow

- Part 11 Numerical solution of Richards' equation

- Minimum timestep = 1.0d-6
- Maximum timestep = 1.7d-4

- Maximum dif. groundwater level between iterations = 100
- Maximum relative difference in pressure heads per compartment = $1.0d-2$
- Maximum difference in pressure heads per compartment = $1.0d-1$
- Maximum water balance error of ponding layer = $1.0d-4$
- Maximum number of iteration cycles = 30
- Maximum number of back track cycles within an iteration cycle = 3

Bottom boundary section”

- Bottom boundary condition
 - Prescribe groundwater level (cm):

DATE1	GWLEVEL
03-jun-2013_01:00:00.00	-8.3
04-jun-2013_12:00:00.00	-7.99
05-jun-2013_13:00:00.00	-8.3
06-jun-2013_04:00:00.00	-7.08
06-jun-2013_05:00:00.00	-4.03
06-jun-2013_06:00:00.00	-0.98
06-jun-2013_17:00:00.00	-2.51
07-jun-2013_03:00:00.00	-2.51
07-jun-2013_07:00:00.00	-3.73
07-jun-2013_24:00:00.00	-4.03

Heat flow section”

- Part 4: Numerical method
 - for each soil type the soil texture (g/g mineral parts)
 - and the organic matter content (g/g dry soil)

	SOILLAY	PSAND	PSILT	PCLAY	ORGMAT
1		0.96	0.03	0.01	0.220
2		0.96	0.03	0.01	0.020
3		0.96	0.03	0.01	0.020

4.5.4.1.2 Meteorological input file

The meteorological input file consists of data obtained from a rain gauge installed within the 117-cell grid area, continuously measuring rainfall for a 5-day period (Table A20), and data from South Florida Water Management District (SFWMD) station L31NS that continuously measures 1-hr interval solar radiation, air temperature, relative humidity, and groundwater level (Table A20 and Table A20).

4.5.4.2 Observations

Volumetric moisture content was taken using a POGO portable soil moisture probe (Figure 17) at noon during four consecutive days at each of the 117 grid-cells. The time used to collect these soil moisture measurements did not exceed 1.5 hours (a time window when we believe the moisture process in the field is relatively stable). In addition, four profile hydra probes were installed across the AAOI (Figure 18) and volumetric moisture measurements were recorded during five consecutive days at noon (June 2-6, 2013).

4.5.5 Error estimation

To evaluate the performance of the proposed remote sensing and SWAP modeling with respect to the point measurements of surface and profile, we used coefficient of determination (R^2), covariance (σ^2), and root mean square error (RMSE). The statistics of R^2 and RMSE are defined as

$$R^2 = \frac{\sum(P - O)^2}{n} \quad (25)$$

$$\sigma^2 = \sum (P - O)^2$$

$$RMSE = \sqrt{\frac{\sum (P - O)^2}{n}}$$
(27)

where P and O are predicted and observed soil moisture and n is the number of observations.

4.6 Overview of Research Approach

Following is a flow chart summarizing the overview of the research approach (Figure 32).

4.6.1 Field work

The field data was classified into three different types (Figure 33), to connect RADARSAT-2 images with a surface area (3m-grid), to estimate the soil surface moisture of the AAOI (1m-grid) for modeling and representation purposes, and for surface and profile soil sampling (point base) (Figure 33).

Figure 32 Research approach flow chart

Figure 33 Field work flow chart

4.6.2 Remote sensing to predict surface soil moisture

Two consecutive radar images, of 3-m resolution, were processed and geo-referenced and its pixel values (dB) differences compared with the difference of the 23 surface soil moisture obtained concurrently with the satellite recorded the images. A linear algorithm was obtained using 8 pixel values and applied to remaining 15 pixel values in order to validate or reject the algorithm. The RMSE was used as a measurement of approximation (Figure 34).

Figure 34 Radar observation to surface soil moisture flow chart

Additional field measurements to characterize the biomass and soil surface roughness index were performed in case only one radar image was available, and it was necessary to account their effect on the estimation of soil moisture from single backscatter.

4.6.3 Laboratory and meteorological data

The laboratory work consisted in measuring the hydraulic parameters of each soil sample taken in the field at each layer of the soil profile. The point-base soil parameters obtained in the laboratory were spatial-averaged and assigned to each 1-m grid of the AAOI following van Genuchten guidelines (Figure 35).

Figure 35 - Laboratory and meteorological data flow chart

4.6.4 SWAP initial state and computer script

The initial state of the surface moisture content taken at the same time as the radar image was recorded, the groundwater levels and meteorological information obtained from the USGS, and the hydraulic parameters for each cell (117) of the AAOI, were input in separated excel files.

A computer script, written in python computer language (Script 2, Page 298), executes the SWAP model, containing the model parameters, interacting with the excel files that contain the variable data for each of the 117 cells of the AAOI. The modeling results are kept in a data base (Figure 36).

Figure 36 SWAP initial state and computer script flow chart

4.6.5 GIS toolbox

A second computer script was written in python (Script 3, Page 303) to interact the results in the data base with GIS, by creating a GIS toolbox that allows the conversion of the results data base into a vector file readable by GIS, and to manage the data into a spatial temporal graphic (Figure 37).

Figure 37 GIS toolbox flowchart

4.6.6 Error estimation

To measure the error of the predicted results, an excel file was created where the predicted results and field observations are compared and its error measured using RMSE (Figure 38).

Figure 38 Prediction versus observation flow chart

4.6.7 Model applications

Three additional applications were performed:

1. A comparative analysis between the three soils characterized in the AAOI (X1, X2, and X3) with the purpose of comparing the profile temporal moisture content and its average using van Genuchten procedures.

For this purpose only one cell of the AAOI was used (Figure 39).

Figure 39 Sensitivity analysis between X1, X2 and X3 soil flow chart

2. A daily comparative analysis between mineral soil and organic soil using meteorological data and water table levels of the driest period of the past 10 years in the ENP (Figure 40).
3. An hourly comparative analysis of modeling an organic soil using regular flow versus modeling the same soil using preferential flow (Figure 40).

Figure 40 Model applications flow chart

5. RESULTS AND DISCUSSION

5.1 Remote sensing to predict surface soil moisture

During speckle filtering, 3 x 3 pixels were averaged to eliminate the noise affecting the backscatter value of location adjacent to areas with different characteristics. “The most likely reason for poor results at high spatial resolution is the insensitivity of the radar to changes in soil moisture, effects of residual speckle, and the natural variability of surface characteristics that interact to affect the backscatter that confound relationship”(Thoma, 2006). The radar backscatter values from location 2 (Figure 14) were rejected for the estimation of the algorithm due to the close proximity to the road and flooded areas, resulting in unreliable backscatter values. The same criterion was employed during the algorithm optimization eliminating the backscatter reading of location 1 point 3 (Figure 22), due to its close proximity to the road (i.e., an outlier).

5.1.1 Change detection algorithm

An unsupervised change detection algorithm was calculated in Excel using five 3-m radar backscatter difference between May 4 and May 7 acquisitions (Table A27), to estimate five 3-m soil moisture difference values obtained at the same time as the radar acquisitions in location 1. The algorithm assumes that soil moisture and the radar backscatter observations are linearly related in the five 3-m values, as follows:

$$\theta(a, t) = -0.0379[\sigma^o(a, t)] - 0.4856 \quad (28)$$

where a represents the five 3-m scale, $\sigma^o(a,t)$ is the radar backscatter difference to 3-m at time t , and $\theta(a,t)$ is the soil moisture at 3-m at time t . The difference in the radar backscatter is measured in decibels and the soil moisture in $\text{cm}^3 \text{cm}^{-3}$. The algorithm does not contemplate the effect of vegetation or surface roughness.

Figure 41 Unsupervised linear regression using change detection approach

The coefficient of determination (R^2) obtained for the unsupervised linear algorithm (Figure 41) is 0.90 using C-band, hh polarizations, 3-m resolution, and 5 pixels (Table A27), which compares with the $R^2=0.67$ (Piles et al., 2009) that was obtained using L-band radar, hh polarization, 400-m resolution, and 843 pixels during the NASA 2002 SMAP campaign.

The unsupervised algorithm was applied to the remaining 10 3-m location points, using the radar backscatter values (dB), to estimate their soil moisture with a root-mean square error of 18.8% (Table A29) when compared to the surface moisture measured in situ (Figure A80). The measured points on Figure 42 represent the surface soil moisture content at the location points on the AOI. Red dots represent the soil moisture measured in situ during May 4th, and the blue dots represent the modeled surface moisture obtained using the change detection algorithms with the radar backscatter value (decibels) of May 4th.

Figure 42 Surface moisture versus modeled using an unsupervised algorithm

The unsupervised algorithm was site-calibrated to soil moisture by adding its RMSE to the modeled values (Table A29) as recommended by Thoma (Thoma et al., 2006), improving the RMSE to 8.4% (Figure A82); the site-

calibrated algorithm was optimized by eliminating the third location point (Table A30), due to its proximity to the road, obtaining an optimized RMSE of 3.6% (Figure 43); an error difference superior to the 6.1% error obtained by Piles, and 44% obtained by Hu (Hu et al., 2001).

Figure 43 Volumetric Soil Moisture Content Measured versus Modeled

5.1.2 Single radar observation algorithm

Due to the particular field condition of the AAOI, where the surface roughness index is uniform ($Z_s = 1.31 \times 10^{-2}$) and the vegetation biomass ($< 0.5 \text{ Kg/m}^2$) can be ignored (Ulaby, Dubois and van Zyl 1996), it is assumed that the radar backscatter value is correlated to the surface soil moisture. We have

developed algorithms using single radar backscatter values (dB) together with measured soil moisture taken at the same time for days May 4 and May 7.

The selected algorithm, that returns the highest square of the product moment correlation coefficient through the given data points ($R^2 = 0.58$), has been optimized eliminating one measured point out of range (outlier), obtaining a supervised algorithm with $R^2 = 0.90$ (Figure 44).

Figure 44 Supervised linear regression using radar backscatter of May 4, 2013

The optimized algorithm has been applied to all location points, with the exception of point location 3 (outlier), to obtain the estimated moisture content and to compare it with the in-situ measured moisture content. An RMSE of 2.3% was obtained using radar backscatter values of May 4, 2013 (Figure 45).

Figure 45 Soil moisture measured versus modeled using radar backscatter of May 4, 2013

5.2 Vadose zone modeling

The soil of the vadose zone in the AAOI is of a sandy (98%) texture without organic content. Three different horizons (0-5, 5-15, and 15-25 cm depth) were identified in situ. The maximum water table depth occurred at the beginning of the data collection producing a maximum vadose depth of 25 cm. For SWAP modeling purposes, we used 4 compartments from the surface of 0.5 cm each, and 23 compartments of 1 cm; making a total vertical discretization of 27 nodes (Figure 24).

5.2.1 Soil hydraulic parameters

The soil hydraulic parameters needed to model the soil moisture in the vadose zone using SWAP model were obtained in the laboratory. The WRC, that is the physical lab representation of tension and estimated unsaturated hydraulic

conductivity as function of soil moisture, was used to estimate the soil hydraulic parameters at each one of its three horizons, using undisturbed samples for the air entry and capillary region of the curve. Forty-three successful laboratory experiments were performed, during a period of 200 days (Table A35 to Table A60, and Table A82 to Table A98), to obtain triple soil hydraulic parameters for each layer of the three site locations. For modeling purposes, a spatial average of the three locations was used, and its estimation was obtained by using arithmetic mean to average K_s and n in all layers, geometric mean to average α in layers A and B, and Harmonic mean to average α in layer C (Table 10).

Table 10 Spatial averaging of hydraulic parameters

Layer	θ_s	θ_r	α	n	K_s
A	0.57783	0.0662	1.45748	1.908112	0.0462
B	0.46276	0.0092	0.08467	1.476505	0.0597
C	0.46866	0.0000	0.10679	1.488429	0.0289

5.2.1.1 Unsaturated hydraulic conductivity

The hydraulic conductivity is much less under unsaturated than saturated conditions because of water moving first through larger pores that drain more readily, and later through small pores or as films along the walls of larger pores. Values of K can vary by orders of magnitude based on water content.

The spatial variability of the soil hydraulic parameters in the field, in both depth and 2D, are determined by the unsaturated flow that exhibits a large degree of spatial heterogeneity represented by its nonlinearity of the unsaturated

flow equation by van Genuchten's model for the soil WRC, and it is combined in SWAP model with Mualem hydraulic conductivity (Mualem 1976) as a function of the relative saturation (Equation 17).

In order to measure the unsaturated K , RETC software, a program designed to fit a number of different analytical functions to soil water retention data, was used to represent K as a function of water content; and the soil parameters used for modeling correspond to the soil sample X3A-2, soil that has a porosity of 47%. The curve representing the unsaturated hydraulic conductivity as a function of water content (Figure 46) shows a significant decrease of the value of K_θ as soon as the soil moves from saturated to unsaturated state (less than 47% of water content), and the changes in K_θ values observed in the graphic can only be appreciated by representing them at logarithm scale. Changes per negative unit at logarithm scale represents decreasing values of one order of magnitude. It is observed that the curve at very low water content (<4%) continuous fluid paths may not exist and water may move in the vapor phase.

Figure 46 Hydraulic conductivity curve as function of water content, X3A-2

5.2.2 GIS model visualization

The developed ArcGIS python script (Script 1 and Script 2) was successfully used to generate a geo-database and to import SWAP model results for model output visualization.

Script 1 purpose:

1. Python script runs in a loop and creates a folder for each of the swap cells
2. SWAP.exe and SWAP.swp files (containing individual details of each cell) are copied from SWAPhome folder to each of the folders by cell name; however, three changes are made to the file before it is written in the folders for every cell:
 - a. The pressure (ZI) and head (H) values are changed
 - b. Soil parameters are changed
 - c. Ground water levels by date and time are changed
3. SWAP model is executed for each cell in the folders
4. SWAP results from every cell are copied and appended into a new text file.

Script 2 purpose:

1. A point feature class for all SWAP cells was created.
2. The accumulated swap results table (a text file to which all the SWAP results were appended) was imported as geo-database table.

3. A time series query table combining all-time series records for each swap cell was generated.
4. A relationship class between point feature class and the geo-database results table was created.

A GIS toolbox was created to visualize, at any one of the 27 node bottom depths, the temporal soil moisture content of each swap cell. Following is a graphic sequence process for visualization (Figures 47– 50).

Figure 47 A point feature class for all SWAP cells in GIS screen

Figure 48 Enabling time to the layer and setting the time interval

Figure 49 Query builder to select depth to visualize data

Figure 50 GIS time slider tools used to visualize time intervals

5.2.3 Modeling and confirmation of moisture distribution patterns

The SWAP model was run hourly for the period of June 3-7, 2013, and resulted in soil moisture estimation up to a profile depth of 0.25 m in all 117 pixels of the AAOI. Figure 51 illustrates the evolution, every 6 hours, of average (from pixel ensemble) soil moisture fields at 0.8 cm depth. A hyetograph (mm)

and the water table level (cm as NAVD88) graphics are included to better represent the soil moisture temporal changes.

Figure 51 Model-predicted soil moisture grid at 0.8 cm depth between June 3 and 7, 2013. Hyetograph and water table level (blue) graphic included

The decrease in moisture during the periods with no rain can be appreciated in the modeling of soil moisture graphics (Figure 51); however, during the period between the night of June 5 and the morning of June 6 (6 am), a small increase in moisture is noted in some cells despite the fact that there was no rain recorded in the AOI. This moisture increase can be attributed to the increase of the capillarity fringe (a zone where water is under tension, but is very

near saturation) as a result of the increase of the water table level during such period; the effect is more notorious at the 2.5 cm depth modeling (Figure 52).

Figure 52 Model-predicted soil moisture grid at 2.5 cm depth between June 3 and 7, 2013. Hyetograph and water table level (blue) graphic included

The sharp differences between pixels (Figure 52) represent the variation in moisture content between the pixels due to pixel differences on the initial moisture content taken in situ (between 30% to fully saturated at 55%) ,soil properties, and their elevation.

The first grid of Figure 52 (June 3rd at 12pm) represents the initial values of each pixel (117) measured in situ at 2.5 cm depth. All other pixel values were

predicted by the SWAP model using one average soil property for all pixels, and different surface elevations for each pixel.

The increases in pixel differences apparent during modeling from June 3rd to June 7th are due to the effect of the difference in the initial moisture content of each pixel that affect its hydraulic conductivity, and the effect of the capillary rise due to their different closeness to the water table.

As shown in the soil moisture modeling graphic at 6.5 cm depth (Figure 53), there is almost no moisture variation due to saturation of the majority of the AOI cells due to the close proximity to the water table (depth between 10 to 30 cm), a depth where the capillary dominates this region as it is quantified in its WRC (capillary region, that is presented and discussed in section 5.3.1).

In addition, four profile hydraprobes were installed measuring percentage of moisture at different depths during five consecutive days; however, due to the presence of bedrock, the hydra probes reached different depths obtaining limited or no readings for depths less than 10 cm, and fully saturated readings for depths higher than 10 cm. False readings were produced because possible lack of contact between the installed hydra probe and the rock, and limited readings were the result of the lack of uniformity in depths of probe installation that did not allow enough readings at each depth to allow a minimum level of statistical analysis.

Figure 53 Model-predicted soil moisture grid at 6.5 cm depth between June 3 and 7, 2013. Hyetograph and water table level (blue) graphic included

To evaluate the model performance, model outputs were compared with soil moisture observations from measurements taken with a POGO probe at 2.5 cm depth during four consecutive days, obtaining an error approximation of 4.0% and a positive covariance of 9.14×10^{-4} (Figure 54); this approximation confirms that modeling of the soil moisture trend that uses the soil hydraulic properties estimated in the laboratory in agreement with atmospheric changes, like precipitation and surface temperature, is possible.

Figure 54 Moisture content measured versus modeled, node 54 at 2.5 cm depth

5.2.4 Modeling applications

Three modeling simulations were performed. One was made to compare the moisture saturation between three soil samples that were retrieved from the AAOI and its average used to understand their differences; the second one to confirm the adaptability of pythom script to different time scale and changes of soil properties; and the third one to incorporate the macropore flow concept in the modeling of preferential flow at the field scale with the purpose of evaluating the effect of preferential flow on the water flow of peat soil for further studies in the ENP ecosystem.

5.2.4.1 Comparative analysis between soils X1, X2, and X3

A sensitivity analysis of the percentage of moisture saturation has been made for the three soils characterized in the laboratory (X1, X2, and X3) and the

Spatial Averaging (AVG) has been obtained using van Genuchten guidelines, for the purpose of evaluating the spatial average and understanding their differences. Following are comparative analyses, modeling node 56 of the AAOI, for a period of five days (120 hours), for top layer A (from 0 to 5 cm depth) at 0.2, 0.8 and 2.5 cm depths (Figure 55, 56 and Figure 57), and layer B (from 5 to 15 cm depth) at 6.5 cm depth (Figure 60).

Figure 55 Comparative moisture saturation analysis of top layer (0.2 cm depth) of 3 soils sampled at different locations within the AAOI

RMSE was used to measure the difference in moisture saturation between two soils. The moisture saturation in layer A at 0.2 cm depth (Figure 55) behaves similarly for the 3 types of soils showing errors of 5.7%, 12.2%, and 17.1%.

Figure 56 Comparative moisture saturation analysis of top layer (2.5 cm depth) of 3 soils sampled at different locations within the AAOI

Figure 57 Comparative moisture saturation analysis of top layer (2.5 cm depth) of 3 soils sampled at different locations within the AAOI

Šimůnek defines the capillarity region in the middle range of h , “as matric potential becomes less negative , a succession of larger pores fill as capillarity

pulls water into these pores” Šimůnek (2008). The shape parameter that defines this region of the curve and reflects the pore-size distribution is α . In the present study, $30\% < S < 80\%$ has been selected as corresponding to the limit between capillary and non-capillary zone.

Analyzing the comparative moisture saturation at 0.8 cm and 2.5 cm depths (Figure 56 and Figure 57) between time 0 to 80 hours, moisture saturation that belongs to the capillary zone in the WRC, the effect of the precipitation is still noticed at 0.8 cm depth; however, at 2.5 cm depth the precipitation is unnoticed and the moisture saturation remains constant reflecting only the effect of the capillary rise.

Figure 58 Temporal pressure head at 2.5 cm depth during SWAP modeling

To understand the differences in moisture saturation between soils X1, X2, and X3 at 2.5 cm depth the pressure head is analyzed at 2.5 cm depth during the first 80 hours of modeling (Figure 58) as well as the moisture saturation at the

same depth (Figure 57). The constant degree of saturation for each soil type remains between 40 to 75%, range that corresponds to the capillary zone of the WRC (Šimůnek J. 2008).

Figure 59 WRC for soils X1, X2, and X3, top layer A, showing their capillary region and the position of the pressure head position on the curve indicating their water content (θ) in the Y-axis

Figure 59 shows the WRC of top layer A for soils X1, X2, and X3, with the capillary zone represented by a blue square, and the pressure head represented by a black arrow. The black arrow position value ($X = 0$) represents the logarithm value of the constant temporal pressure head of 1 cm ($\log_{10}(1) = 0$) shown in the Figure 58. Following the arrowhead in the WRC, its value in the horizontal direction is the soil moisture content obtained in the laboratory for the top layer (A) for soils X1, X2, and X3 (see WRC θ values in Table 11).

Comparing the saturation values (S) of the three soils at 2.5 cm depth obtained from the WRC with the SWAP simulation saturation values (see SWAP

modeling in Table 11), a close approximation found for the three soils (10%, 1%, and 4%), validates the use of the Mualen-van Genuchten function (Van Genutchen, 1980), where α , n , and m are empirical shape factors used by SWAP modeling to determine the moisture content (Equation 9).

Table 11 Comparative moisture saturation values obtained from SWAP modeling and from WRC for soils X1, X2, and X3 at 2.5 cm depth

Soil	Porosity	SWAP modeling		WRC		Error
		θ	S	θ	S	
X1	0.47	0.36	76%	0.32	68%	10%
X2	0.60	0.45	76%	0.45	75%	1%
X3	0.55	0.23	42%	0.22	40%	4%

The same procedure is followed to analyze the second layer B, at 6.5 cm depth (Figure 60), where the degree of saturation of the three soils (X1, X2, and X3) remains constant, unaffected by the precipitation, and above 50% of saturation.

Figure 60 Comparative moisture saturation analysis of the second layer (6.5 cm depth) of 3 soils sampled at different locations within the AAOI, including hydrograph (mm)

Figure 61 Temporal pressure head at 6.5 cm depth during SWAP modeling

The pressure head range 0-80 hour period, simulated by SWAP, averages 0.70 cm of pressure head (Figure 61). Figure 62 shows the WRC of second layer B for soils X1, X2, and X3, the capillary zone represented by a blue square, and the pressure head represented by a black arrow. The black arrow position value ($X = -0.2$) represents the logarithm value of the constant temporal pressure head of 0.7 cm ($\log_{10}(0.7) = -0.20$) shown in the Figure 62. Following the arrowhead in the WRC, its value in the horizontal direction is the soil moisture content obtained in the laboratory for top layer B for soils X1, X2, and X3 (see WRC θ values in Table 12).

Comparing the saturation values (S) of the three soils at 6.5 cm depth obtained from the WRC with the SWAP simulation saturation values (see SWAP modeling in Table 12), a close approximation found for the three soils (4%, 18%,

and 0%), validate the use of Mualen-van Genuchten function (Van Genuchten, 1980 used by SWAP modeling to determine the moisture content (Equation 9).

Figure 62 WRC for soils X1, X2, and X3, second layer B, showing their capillary region and the position of the average pressure head position on the WRC that indicates their water content (θ) in the Y-axis

Table 12 Comparative moisture saturation values obtained from SWAP modeling and from WRC for soils X1, X2, and X3 at 6.5 cm depth

Soil	Porosity	SWAP modeling		WRC		Error
		θ	S	θ	S	
X1	0.42	0.34	80%	0.35	83%	-4%
X2	0.82	0.66	80%	0.54	66%	18%
X3	0.32	0.32	100%	0.32	100%	0%

The analysis clearly shows that the behavior of unsaturated soil is not only controlled by the WRC of the soil, but also by the groundwater level in the soil. A decrease in pressure corresponds to a decrease of the water level; consequently, the variations in pressure in the vadose zone are directly related to the thickness of the capillary zone.

The bottom layer (15 – 25 cm) was not analyzed because it was fully saturated having the water table above the bottom layer.

5.2.4.1.1 Capillary rise from soil texture tables

Capillary flow depends on soil type, soil moisture evapotranspiration, water table depth, and recharge. Evapotranspiration depletes the soil moisture content in the vadose zone. If no recharge through rainfall takes place, a difference in potential induces capillary rise from the groundwater. In the unsaturated zone, the pressure head is negative. At the water table the pressure head is zero. The water moves from locations with a higher potential to locations with lower potentials. Capillary rise from the groundwater to the unsaturated soil takes place under the influence of this head difference.

The capillary rise is estimated, using the table for particle-size analysis developed by Terzaghi (Terzaghi and Peck 1948) (Table 13), for comparison with the estimated capillary rise obtained during the comparative modeling of soils X1, X2, and X3 at different depths.

Table 13 Capillary rise range (H_c) for sand soils estimated by Terzaghi (Terzaghi and Peck 1948) based on soil particle-size analysis

	H_c (cm)	Particles (mm)	D_{10} Sieve #
Coarse sand	1.5 - 5.0	2.0 - 0.6	4 - 10
Medium sand	5 - 15	0.6 - 0.2	10 - 40
Fine sand	15 - 50	0.2 - 0.06	40 - 200

The depth of the water table in Node 56 at the analyzed surface depths (0.8, 2.5, and 6.5 cm) were estimated (Table 14).

Table 14 Estimated depth of the water table in the node 56 at 0.8, 2.5, and 6.5 cm surface depths

Node 56	cm
Surface elevation	213.15
Water table	201.02
Vadose depth:	12.13
- at 0.8 cm depth	11.33
- at 2.5 cm depth	9.63
- at 6.5 cm depth	5.63

Soils X1, X2, and X3 correspond to a medium sand type with an effective grain diameter (D_{10}) of 0.40 mm. According to the Terzaghi table, its capillary rise is estimated between 5 and 15 cm high. Compared with the vadose modeled depths, ranging from 11.33 to 5.63 cm, it validates that the modeled vadose depths, of 0.8, 2.5, and 6.5 cm, lie in the capillary zone.

5.2.4.2 Comparative analysis between mineral and organic soils

To test the python script adaptability to changes in time scale and soil properties, to record SWAP spatial-temporal results, and to transform and create a readable GIS database, a comparative water content of the AAOI at different depths has been modeled between the current mineral soil and an ENP peat soil from January 9 to June 1, 2002 (Figure 63 and Figure 64); time period that corresponds to the driest period registered during the past 10 years in the ENP.

Daily weather conditions were obtained from the USDA, and initial modeling conditions were assumed; these were used during modeling of moisture content. Soil profile was also kept the same, but the soil parameters vary depending on the current mineral soil or the assumed organic soil.

Figure 63 Comparative daily moisture content simulation between mineral soil and organic soil in the AAOI at 4.5 cm depth

Figure 64 Comparative daily moisture content simulation between mineral soil and organic soil in the AAOI at 10.5 cm depth

Figure 63 and Figure 64 shows a comparative spatial-temporal analysis of water content at 4.5 and 10.5 cm depths between the current mineral soil and the assumed organic soil. The results show greater water retention of the organic soil compared to the mineral soil at both depths

5.2.4.3 Comparative analysis between preferential and uniform flow

SWAP Macropore capabilities have been used to model the water content of the AAOI at different depths and its results compared, using the same physical and meteorological conditions, with the results obtained modeling uniform flow. The purpose was to evaluate the effect of preferential flow on the water flow of peat soils for further studies in the ENP ecosystem.

The soil input parameters required for SWAP Macropore flow, macropore geometry and soil shrinkage characteristics, have been assumed using the parameters provided in the SWAP manual for a Netherlands peat soil. The input parameters of the macropore geometry (Script 4, Page 310) were adjusted to fit with the AAOI soil profile dimensions (Figure A110).

Temporal meteorological data used for SWAP simulation modeling were the same data as the ones used for modeling the moisture content in the AAOI from June 3 to June 7, 2013. For the purpose of modeling a deeper vadose zone, the modeling water table level was decreased by 20 cm; however, the initial water table level used for SWAP to estimate the initial pressure head of each profile compartment in hydrostatic equilibrium with the groundwater level, has not been changed.

Comparative moisture saturation and hydraulic conductivity analysis were performed to 0.5 and 17.5 cm depth during the first 90 hours (Figure 65 and Figure 68), and Figure 66 and Figure 69 magnification and better visualization, during short hour ranges.

Figure 65 Soil moisture saturation at 0.5 cm depth by modeling same soil, with and without preferential flow, including hyetograph

After the initial precipitation starting at hour 5, the Soil Moisture Saturation (SSS) at 0.5 cm depth, due to preferential flow, remains below the SSS estimated with uniform flow; but, an hour later, it propagates quicker than the uniform flow until the next precipitation that occurs at hour 26, when the SSS reached 92% modeled with uniform flow versus 50% SSS when modeled with preferential flow (Figure 66).

The important characteristic of the preferential flow is that “during wetting, part of the moisture front propagate quickly” (Šimůnek, Jarvis, et al. 2002), increasing the average semi-saturated hydraulic conductivity (K_{θ}) of the matrix pore as observed in the Figure 67, after the precipitation at hour 5, when comparing K_{θ} of uniform flow and preferential flow. This rapid flow through macropores after a precipitation shows that water and solutes can move almost

immediately to deeper layers or the groundwater, bypassing the soil capacity for storage, absorption and transformation of pollutants.

Figure 66 Soil moisture saturation at 0.5 cm depth comparison between uniform and preferential flow during the first 30 hours of modeling

Figure 67 Unsaturated hydraulic conductivity at 0.5 cm depth comparison between uniform and preferential flow during the first 30 hours of modeling

The comparative analysis of SSS at 17.5 cm depth (Figure 68) shows that the SSS remains constant at 27% due to preferential flow, but the estimated SSS

with uniform flow reflects the precipitation that occurs in the soil surface showing changes of SSS between 14% and 92%. During periods of no watering activities, when the SSS reaches storage capacity and remains constant, an increase in water storage with preferential flow is used, as observed in Figure 69 between hours 44 to 47; this increase in water storage is based on the description of macropore geometry proposed by Hendrix et al. (2010) is discussed in Chapter 2.2.8., and shown in Table A101 and Table A102. Soil shrinkage characteristics reported by SWAP preferential flow modeling are presented in Table A103.

Figure 68 Soil moisture saturation at 17.5 cm depth comparison between uniform and preferential flow, including hyetograph

The increase in porosity produced by the macropore geometry (Figure 70) is the sum of the two classes, the Main Bypass (MB) domain that represents the

main system of continuous structural and shrinkage cracks, and the Internal Catchment (IC) domain representing discontinuous non-interconnected macropores ending at different depths. The details of the geometry parameters are shown in Table A101 and Table A102.

Figure 69 Soil moisture saturation at 17.5 cm depth by modeling same soil with and without preferential flow between hours 40-50

The effect on the soil water content, due to the increase in water storage in the macropores up to 15 cm depth, extends deeper in the soil matrix, as demonstrated in the previous comparative analysis of SSS at 17.5 cm depth.

At the present time it is not possible to model with preferential flow in the ENP because of the lack of required soil parameters; only modeling with

standard flow can be tested by installing hydro-probes to monitor the water content at different depths and to compare it with the model predictions. If, after calibration of the model and following rain events, the model predictions show higher increase of moisture content compared with that measured in situ, we can assume that preferential flow is the factor and it should be further investigated.

Figure 70 Total soil porosity increase per depth as the sum of the two classes, the Main Bypass (MB) domain and the Internal Catchment (IC) domain

6. ASSUMPTIONS AND LIMITATIONS

Due to the unusual intensity of the rainy season that flooded our AOI, the study area was moved from a natural area containing organic soil (peat), to the only nearby elevated area, which contained sand soil, within the area of research approved under the ENP permit; however, due to the water table elevation, the modeling of moisture content in the vadose zone was limited to no more than 10 cm depth.

To convert satellite radar observation into moisture content, surface moisture was measured at twenty three georeferenced locations, intending to use 10 measurements to develop an algorithm and 13 to validate it. Each measurement was representing the average moisture content of one radar footprint (3m x 3m), introducing a significant error assuming a nine square meters average with only one measurement.

The short period of dry season did not allow the use of two consecutive radar images of the AAOI with same incident angle, which are generated every of 28 days, to apply the change detection approach to estimate the soil surface moisture. Lambert's cosine law for optics was applied to normalize the radar signal to one angle relative to the incident angle of the first image, introducing an additional element of error.

A GPS with a low resolution global position was used to obtain the geographic coordinates of the radar image locations, introducing a scaling error. Recent studies using GPS multipath to measure position and surface moisture

fluctuations have been successful to monitor surface soil moisture (Larson, et al., 2010).

Elevation and initial boundary conditions, used for SWAP modeling of moisture distribution, were measured at the center of each grid-cell and it was assumed to be the same for the entire grid-cell.

We used boring methods of sampling introducing errors in determining the soil properties. Once a sample is taken at a particular point, the soil in that point is disturbed, its properties are changed, and another location in the close vicinity is chosen for the next sample. This procedure allows another variable, the heterogeneity of the soil to be introduced into the moisture density measurements. Furthermore, due to inherent spatial and temporal variability of the hydraulic properties in the field, large numbers of samples are generally required to properly characterize the spatial distribution of the hydraulic properties.

Field filled methodology was not used to obtain soil hydraulic conductivity (K) because it would require a new (or modified) ENP permit with additional requests and justification, which may be difficult to get approved or processed in the timeframe of the research funding. Saturated hydraulic conductivity was obtained at the laboratory using soil core samples taken in the field at three different depths (0-5, 7-12, and 15 cm depth) representing the soil layers.

Due to the soil characteristics of the AAOI, only four profile hydroprombes were installed in the AAOI with the purpose of obtaining observations and measuring the errors with modeling predictions.

Macroporosity was not applied to the AAOI because of its sandy soil type. AAOI soil did not contain significant cracks produced by plant roots, worms, or soil shrinkage produced by change in moisture, making the application of preferential flow during modeling not relevant; however, a simulation in the AAOI, replacing the mineral soil for organic soil properties, was performed to observe the changes in moisture content when applying the effect of preferential flow in the modeling process.

ENP Soil Macroporosity input parameters were not available and they were taken from SWAP manual and adapted to the AAOI soil profile. Running SWAP model was not possible due to error on SWAP script to read a variable input data into Darcy's formula. The error was reported to SWAP principals and after verification of our input data, a revised SWAP file eliminating the script error was provided; it was successfully used for modeling preferential flow.

7. CONCLUSIONS

Radar images, using the change detection approach, can be used to detect surface moisture retrieval for natural environments, as long as, the surface has the same soil characteristics and biomass $<0.5 \text{ Kg/m}^2$.

An analysis of soil moisture retrievals and measurements collected in situ shows the retrievals are in agreement with the measurements. Spite of the close approximation of the prediction with the observations (RMSE = 4.0%), the reduce amount of field observation does not allow the validation of the model; however, the trend of the spatial-temporal moisture in the unsaturated zone, between the model prediction and the atmospheric changes, has been validated.

Point base modeling of soil moisture in the vadose zone has been achieved developing field and laboratory procedures to characterize the soil profile of the vadose zone, and to capture the required field data needed to run the ecohydrological SWAP model.

The computer script, which interacts between SWAP and GIS, has proven to produce graphics representing the spatial-temporal changes of moisture content in the vadose zone, and it is prepared to manage changes of soil types, initial boundary conditions (top and bottom), surface elevation, and spatial-temporal dimensions, for each grid-cell.

Soil moisture at depths deeper than 6.5 cm are influenced by capillary rise and its hydraulic conductivity is no longer estimated by SWAP model. The

capillary region of wetlands has a major effect in the moisture content in the vadose zone.

Macroporosity host preferential soil water flow and rapid transport of solutes, increasing the hydraulic conductivity of soil, allowing water to infiltrate and drain quickly. This accelerated movement of surface is critical to organic soils like the ENP, and has great significance when applied to nutrients and pollutants.

8. RECOMMENDATIONS

During our research to identify the study area, we encountered wetland areas containing a mixture of spatial soil patterns. In order to use radar observations in the study area to measure moisture content, spatial patterns of soil types within the landscape must be identified and independent radar observation algorithms developed for each pattern.

Before any decision is made on the satellite approach to be used for natural bare or sparsely vegetated soil environments of similar soil characteristics, the measurement of the vegetation biomass and surface roughness index (Z_s) must be obtained. If the biomass value is $<0.5 \text{ Kg/m}^2$, and the surface roughness is of specular reflection and uniform, a single radar image must be used, avoiding the additional expenses and errors produced with more complicated approaches like the change detection approach.

High precision GPS must be used to georeference each location where soil samples are retrieved for moisture content and used for the developing of radar observation algorithms. Careful registration of the radar image and georeference of field work areas are necessary for meaningful results. Further studies made into the ENP must contemplate the use of at least three (3) GCPs to be able to accurately apply 2D correction.

Because satellite remote sensing is used to develop soil moisture retrieval algorithms at the satellite scale, it is critical to obtain accurate measurements of the mean soil moisture within the satellite footprint. The physical measured

moisture refers to a point-base located inside the pixel but not representing the pixel moisture density, generating a source of error. To reduce the error, it is recommended that a strategy based on the satellite footprint size be developed to better represent the pixel footprint moisture.

Recent studies using GPS multipath to measure spatial-temporal near-surface soil moisture have shown good agreement ($R^2 = 0.9$ to 0.76) with in-situ measurements for unsaturated soils, presenting a more affordable and versatile approach than radar satellites (Larson, et al., 2010). It is recommended that the use of GPS multipath in future studies be evaluated.

Due to inherent spatial and temporal variability of the hydraulic properties in the field, large numbers of samples are generally required to properly characterize the spatial distribution of the hydraulic properties. A planned strategy must be developed to maximize the number of location samples accounting for the laboratory time required to process each bore sample.

Temporal modeling can be improved by taking moisture content readings from the moment the soil surface in the AOI starts drying, until its surface becomes flooded again. During our current study, we had a late start due to the unexpected change of our original location; we were only able to obtain five days of readings before the surface became flooded.

To better capture meteorological data, a rain station that records minute and hourly rain, and meteorological information, should be installed in the AOI, rather than depending on the USGS station located 3+ km from the AOI.

The quantity of field observation measurements per station was not enough to properly compare them with the model results and to obtain error difference measurements during the modeling time. An average of one hundred observations per station, made for a one week hourly modeling, is recommended.

Readings of VWC in the field before sunrise can be used for comparison with the estimated VWC obtained with a calibrated model with the purpose of learning whether there is an increase of expected moisture content due to hydraulic lift.

Because of the great impact of macropore on water and solute transport through the vadose zone, the use of Macroporosity is recommended for modeling the semi saturated soil zone of the ENP.

In order to use the Macroporosity concept, it is necessary to know the shrinkage properties of the peat. It is recommended that procedures be developed for measuring the ENP peat shrinkage characteristics due to change in moisture content. Patricia Garnier (Garnier, et al., 1998) used the dual-energy synchrotron X-ray to measure, for the first time, the water content and bulk density changes during the fast initial phase of the swelling process. Garnier (Garnier, et al., 1997) proposed an evaporation experiment to determine simultaneously the WRC, K and shrinkage characteristic.

SWAP 3.2 was chosen to simulate the transport of water at field scale in the vadose zone by their unique capabilities to model preferential flow and

linkage to other models. Because SWAP 3.2 was primary designed to simulate processes during crop growing seasons, where the vadose depth is larger than the depths observed in wetlands, a critical zone of the wetland soils, as the capillary region, is not properly analyzed. It is recommended for further ENP studies, to integrate into SWAP a model that estimates the rate of the capillary rise in the vadose zone.

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APPENDICES

Figure A71 Alternative area of interest (AAOI) showing 117-cells, soil core samples, and profile hydra probes locations

CELL #	Elevation NGVD 1929	
	ft	cm
1	7.06	-215.19
2	6.87	-209.40
3	6.63	-202.08
4	6.69	-203.91
5	6.67	-203.30
6	6.61	-201.47
7	6.67	-203.30
8	6.65	-202.69
9	6.57	-200.25
10	6.57	-200.25
11	6.63	-202.08
12	6.59	-200.86
13	6.63	-202.08
14	6.56	-199.95
15	6.53	-199.03
16	6.51	-198.42
17	7.03	-214.27
18	6.95	-211.84
19	6.84	-208.48
20	6.85	-208.79
21	6.89	-210.01
22	6.86	-209.09
23	6.86	-209.09
24	6.83	-208.18
25	6.85	-208.79
26	6.79	-206.96
27	6.85	-208.79
28	6.77	-206.35
29	6.73	-205.13
30	6.75	-205.74
31	6.68	-203.61
32	6.62	-201.78
33	7.22	-220.07
34	7.02	-213.97
35	6.89	-210.01
36	6.86	-209.09
37	6.93	-211.23
38	7.12	-217.02
39	7.03	-214.27
40	6.99	-213.06
41	6.99	-213.06
42	6.95	-211.84
43	6.92	-210.92
44	6.87	-209.40
45	6.86	-209.09
46	6.86	-209.09
47	6.85	-208.79
48	6.76	-206.04
49	7.29	-222.20
50	7.03	-214.27
51	6.91	-210.62
52	6.87	-209.40
53	6.92	-210.92
54	6.99	-213.06
55	7.03	-214.27
56	7.03	-214.27
57	7.02	-213.97
58	6.99	-213.06
59	6.92	-210.92
60	6.89	-210.01
61	6.87	-209.40
62	6.88	-209.70
63	6.83	-208.18
64	6.67	-203.30
65	7.32	-223.11
66	7.05	-214.88
67	6.92	-210.92
68	6.87	-209.40
69	6.89	-210.01
70	6.91	-210.62

Table A15 Surface elevation

CELL #	Elevation NGVD 1929	
	ft	cm
71	6.95	-211.84
72	6.97	-212.45
73	6.97	-212.45
74	6.90	-210.31
75	6.87	-209.40
76	6.79	-206.96
77	6.77	-206.35
78	6.81	-207.57
79	6.79	-206.96
80	6.65	-202.69
81	7.33	-223.42
82	6.99	-213.06
83	6.87	-209.40
84	6.85	-208.79
85	6.79	-206.96
86	6.83	-208.18
87	6.77	-206.35
88	6.81	-207.57
89	6.75	-205.74
90	6.66	-203.00
91	6.63	-202.08
92	6.65	-202.69
93	6.63	-202.08
94	6.63	-202.08
95	6.59	-200.86
96	6.56	-199.95
97	7.33	-223.42
98	6.97	-212.45
99	6.85	-208.79
100	6.77	-206.35
101	6.74	-205.44
102	6.63	-202.08
103	6.57	-200.25
104	6.47	-197.21
105	6.57	-200.25

CELL #	Elevation NGVD 1929	
	ft	cm
106	6.52	-198.73
107	6.52	-198.73
108	6.37	-194.16
109	6.37	-194.16
110	6.37	-194.16
111	6.37	-194.16
112	6.55	-199.64
113	7.17	-218.54
114	7.02	-213.97
115	6.67	-203.30
116	6.59	-200.86
117	6.61	-201.47

Table A15 Surface elevation (Cont.)

	2013/06/02	2013/06/03	2013/06/04	2013/06/05	2013/06/06
TEMP (°C):	32.8	30.8	31.8	31.0	31.4
RAIN (cm):	0.00	0.61	0.71	0.00	8.00
WATER TABLE (ft):	6.61	6.63	6.63	6.56	6.79
CELL #	%	%	%	%	%
1	27.6	20.9	27.0	24.5	32.6
2	22.1	29.4	29.1	23.9	36.3
3	33.8	34.9	47.7	37.1	U
4	29.7	31.4	45.5	37.3	U
5	31.0	30.3	40.3	32.5	U
6	31.6	40.2	52.7	40.8	U
7	n/a	38.8	41.2	40.9	U
8	n/a	38.4	46.0	42.7	U
9	n/a	38.8	45.4	40.9	U
10	n/a	50.4	58.7	37.0	U
11	n/a	41.2	36.6	37.4	U
12	n/a	39.0	46.9	38.2	U
13	n/a	39.3	56.5	38.6	U
14	n/a	U	58.8	40.6	U
15	n/a	U	U	U	U
16	n/a	U	U	U	U
17	22.8	17.4	34.2	29.0	33.4
18	29.1	34.0	40.0	26.7	39.0
19	30.2	32.4	39.1	32.8	38.2
20	29.2	31.9	38.6	25.0	45.2
21	28.5	31.7	36.9	31.4	40.1
22	33.3	30.8	38.5	35.6	35.5
23	n/a	34.6	38.5	40.3	39.7
24	n/a	32.5	45.2	44.0	44.8
25	n/a	34.3	36.5	35.1	43.0
26	n/a	35.7	41.6	31.1	U
27	n/a	26.3	37.2	26.1	40.3
28	n/a	36.1	42.9	34.7	U
29	n/a	37.3	43.4	38.0	U
30	n/a	37.6	49.2	34.4	U

WT : water table **n/a** : not available **U** : underwater

Table A16 Measured surface soil moisture June 2-6, 2013

	2013/06/02	2013/06/03	2013/06/04	2013/06/05	2013/06/06
TEMP (°C):	32.8	30.8	31.8	31.0	31.4
RAIN (cm):	0.00	0.61	0.71	0.00	8.00
WATER TABLE (ft):	6.61	6.63	6.63	6.56	6.79
CELL #	%	%	%	%	%
31	n/a	37.4	51.1	35.8	U
32	n/a	46.8	47.8	40.4	U
33	22.5	14.4	36.2	21.6	31.1
34	28.6	33.0	37.6	26.2	38.3
35	30.3	32.1	38.8	30.5	40.2
36	30.9	26.5	36.3	31.1	40.1
37	28.2	27.2	33.1	26.3	37.6
38	25.4	27.1	34.7	33.1	36.8
39	n/a	19.5	28.3	30.8	33.6
40	n/a	26.3	35.5	28.2	37.9
41	n/a	24.9	33.9	31.2	38.9
42	n/a	29.9	36.8	25.6	36.8
43	n/a	27.6	33.7	25.8	40.5
44	n/a	27.0	43.3	27.8	40.0
45	n/a	31.0	41.0	27.5	39.0
46	n/a	31.0	40.9	29.7	38.4
47	n/a	27.8	42.4	34.9	U
48	n/a	36.8	54.4	43.3	U
49	13.7	20.2	30.0	17.6	34.0
50	26.3	25.5	31.7	32.7	36.5
51	30.4	30.5	37.8	31.2	34.9
52	30.1	28.5	38.4	32.5	41.2
53	30.5	29.4	35.2	30.0	40.9
54	24.4	26.7	33.6	30.2	33.9
55	n/a	28.0	31.3	26.4	35.3
56	n/a	25.5	31.2	30.2	32.3
57	n/a	25.8	30.4	31.7	35.2
58	n/a	30.6	37.1	30.6	36.9
59	n/a	34.8	34.9	31.0	39.7
60	n/a	28.6	37.3	30.5	39.5
61	n/a	31.8	37.6	30.2	36.6
62	n/a	32.8	39.5	25.9	42.3
63	n/a	30.4	39.3	32.2	U
64	n/a	34.5	46.1	38.0	U

WT : water table n/a : not available U : underwater

Table A16 Measured surface soil moisture June 2-6, 2013 (Cont.)

	2013/06/02	2013/06/03	2013/06/04	2013/06/05	2013/06/06
TEMP (°C):	32.8	30.8	31.8	31.0	31.4
RAIN (cm):	0.00	0.61	0.71	0.00	8.00
WATER TABLE (ft):	6.61	6.63	6.63	6.56	6.79
CELL #	%	%	%	%	%
65	22.9	15.3	27.4	18.7	31.5
66	28.2	30.2	30.5	35.9	38.7
67	30.9	32.1	35.6	32.2	37.8
68	27.1	28.3	37.9	26.0	40.2
69	29.5	27.7	31.5	29.0	40.0
70	22.5	29.3	34.3	28.0	35.4
71	n/a	27.4	31.0	22.3	33.7
72	n/a	28.9	34.1	31.5	31.7
73	n/a	23.1	28.8	25.3	35.3
74	n/a	25.0	35.4	31.2	36.7
75	n/a	28.5	35.6	24.3	38.6
76	n/a	32.5	36.5	27.7	U
77	n/a	42.6	26.9	37.5	U
78	n/a	42.5	43.8	33.7	U
79	n/a	33.1	34.5	26.8	U
80	n/a	39.6	49.8	49.6	U
81	16.2	27.7	34.5	28.4	33.4
82	25.7	30.6	32.8	28.0	37.9
83	26.1	31.2	38.2	26.9	46.4
84	31.3	28.0	37.8	34.8	44.2
85	28.0	27.4	36.9	30.5	46.2
86	29.5	35.1	36.3	35.5	U
87	n/a	33.0	39.2	26.7	U
88	n/a	30.1	30.4	31.5	U
89	n/a	23.6	35.5	29.4	U
90	n/a	31.5	42.0	39.5	U
91	n/a	37.0	52.1	40.5	U
92	n/a	33.8	39.1	37.4	U
93	n/a	34.1	46.7	40.3	U
94	n/a	48.2	48.5	44.6	U
95	n/a	U	56.5	41.6	U
96	n/a	U	U	U	U
97	23.9	17.1	28.0	23.8	33.7

WT : water table n/a : not available U : underwater

Table A16 Measured surface soil moisture June 2-6, 2013 (Cont.)

	2013/06/02	2013/06/03	2013/06/04	2013/06/05	2013/06/06
TEMP (°C):	32.8	30.8	31.8	31.0	31.4
RAIN (cm):	0.00	0.61	0.71	0.00	8.00
WATER TABLE (ft):	6.61	6.63	6.63	6.56	6.79
CELL #	%	%	%	%	%
98	30.5	31.4	40.8	28.8	39.9
99	27.6	29.0	36.8	31.2	WT
100	27.6	29.0	31.5	26.5	U
101	23.4	29.9	41.0	34.3	U
102	35.6	38.2	45.4	39.0	U
103	n/a	U	U	U	U
104	n/a	U	U	U	U
105	n/a	U	U	U	U
106	n/a	U	U	U	U
107	n/a	U	U	U	U
108	n/a	U	U	U	U
109	n/a	U	U	U	U
110	n/a	U	U	U	U
111	n/a	U	U	U	U
112	n/a	U	U	U	U
113	27.7	23.8	35.5	28.1	36.1
114	22.9	23.7	33.0	28.4	28.0
115	28.5	33.3	45.8	29.1	U
116	36.0	39.1	48.1	WL	U
117	36.0	U	U	U	U

WT : water table n/a : not available U : underwater

Table A16 Measured surface soil moisture June 2-6, 2013 (cont.)

STATION # 1	ABOVE SURFACE (cm)	0°			120°			240°			AVERAGE		
		0 (cm)	6.2 (cm)	16.2 (cm)	0 (cm)	6.2 (cm)	16.2 (cm)	0 (cm)	6.2 (cm)	16.2 (cm)	0 (cm)	6.2 (cm)	16.2 (cm)
02-Jun	23.8		38.5	35.4		39.5	36.1		40.1	36.1		39.4	35.9
03-Jun	23.8		40.1	36.7		42.0	35.6		40.3	35.6		40.8	36.0
04-Jun	23.8		45.0	36.7		43.2	35.6		45.0	35.6		25.0	36.7
05-Jun	23.8		39.6	36.7		43.0	35.6		47.0	35.6		43.2	36.0
06-Jun	23.8		44.5	36.7		44.5	35.6		44.5	35.6		44.5	36.0

STATION # 2	ABOVE SURFACE (cm)	0°			120°			240°			AVERAGE		
		3.8 (cm)	13.8 (cm)	23.8 (cm)	3.8 (cm)	13.8 (cm)	23.8 (cm)	3.8 (cm)	13.8 (cm)	23.8 (cm)	3.8 (cm)	13.8 (cm)	23.8 (cm)
02-Jun	16.2	52.6	59.7	63.8	55	60.7	62.7	53.9	56	55.8	53.8	58.8	60.8
03-Jun	16.2	52.6	59.7	63.8	55	60.7	62.7	53.9	56	55.8	53.8	58.8	60.8
04-Jun	16.2		14.5	36.3		11.4	37.3		18.7	36.2		14.9	36.6
05-Jun	16.2		7.4	36.9		15.9	36		13.7	35.8		12.3	36.2
06-Jun	16.2		58.8	36.8		48.2	35.6		54.9	35.6		54.0	36.0

STATION # 3	ABOVE SURFACE (cm)	0°			120°			240°			AVERAGE		
		9.1 (cm)	19.1 (cm)	29.1 (cm)	9.1 (cm)	19.1 (cm)	29.1 (cm)	9.1 (cm)	19.1 (cm)	29.1 (cm)	9.1 (cm)	19.1 (cm)	29.1 (cm)
02-Jun	10.9	58.3	32.4	43.6	49	31.3	41.8	56.1	32.8	43.9	54.5	32.2	43.1
03-Jun	10.9	53.3	32.2	43.6	59.4	32.5	43.9	51.5	31.4	41.9	54.7	32.0	43.1
04-Jun	10.9	53.7	32.4	46.5	55	31.7	42.6	58.1	33.7	44.4	55.6	32.6	44.5
05-Jun	10.9	56	31.1	42.1	58.3	33.6	43.8	51.1	32	42.5	55.1	32.2	42.8
06-Jun	10.9												

STATION # 4	ABOVE SURFACE (cm)	0°			120°			240°			AVERAGE		
		0 (cm)	1.3 (cm)	11.3 (cm)	0 (cm)	1.3 (cm)	11.3 (cm)	0 (cm)	1.3 (cm)	11.3 (cm)	0 (cm)	1.3 (cm)	11.3 (cm)
02-Jun	28.7		65.9	36.1		65.9	36.1		65.9	36.1		65.9	36.1
03-Jun	28.7		65.9	36.1		58.9	35.9		56.1	35.7		60.3	35.9
04-Jun	28.7		69.7	37.4		60.7	37		63.1	36.1		64.5	36.8
05-Jun	28.7		74.6	35.7		59.5	35.5		75.3	35.6		69.8	35.6
06-Jun	28.7												

Table A17 Profile hydra probe data June 2-6, 2013

Date: Feb 08, 2013

Biomass

Area	0.33 m ²
Bag container	30.00 g
Total weight	145.3 g
Mass weight	115.3 g
Biomass	349.39 g/m ²

Organic Content

Total wet	95.03 g
Container	12.33 g
Net wet	82.70 g
Total dry weight	39.95 g
Water content	42.75 g
Mass dry weight	27.62 g

dried @ 105°F
for 48 hrs

Container 1C	24.13 g
Dry mass + container	38.32 g
net dry mass	14.19 g

burned @ 505°F for 4 hours

Dry mass + container	35.5 g
Dash weight	11.37 g
Mass Content	80.13 %

Organic Content	19.87 %
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Container 2C	25.22 g
Dry mass + container	36.36 g
net dry mass	11.14 g

burned @ 505°F for 4 hours

Dry mass + container	34.00 g
Dash weight	8.78 g
Mass Content	78.82 %

Organic Content	21.18 %
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Average Organic %	20.53 %
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Table A18 Vegetation biomass February 8, 2013

Source: Oregon RGR-202 rain gage station in situ

Figure A72 Rain gage station

FIELD TIME: 11:45 TO 12:30

	2013/06/02	2013/06/03	2013/06/04	2013/06/05	2013/06/06	
TEMP:	32.8	30.8	31.8	31.0	31.4	°C
RAIN:	0.00	0.24	0.28	0.00	3.15	INCHES
RAIN:	0.00	0.61	0.71	0.00	8.00	cm
Water-table:	6.61	6.63	6.63	6.56	6.79	NGVD 1929
		<u>0.24"</u>	<u>0.28"</u>		<u>3.15"</u>	
		9:00 AM	4:00 PM		8:00 PM	
		11:00 AM	6:00 PM		6:30 AM	

Rain distribution based on USGS station (USGS 254000080460001 G – 620)

Date	h	Rain (cm)
3-Jun-2013	9	0.30
3-Jun-2013	11	0.31
4-Jun-2013	16-18	0.71
5-Jun-2013	22	1.00
5-Jun-2013	24	2.00
6-Jun-2013	2	1.00
6-Jun-2013	4	2.00
6-Jun-2013	6	2.00

Table A19 Rain distribution based on USGS hourly rain distribution

Date	Record nr	Rad kJ/m2	Temp C	Hum kPa	Wind m/s	Rain mm
1-Jun-2013	1	-111.6	24.337	0.605	1.945	0.00
1-Jun-2013	2	-172.8	24.068	0.589	2.259	0.00
1-Jun-2013	3	-140.4	23.813	0.565	2.305	0.00
1-Jun-2013	4	-165.6	23.633	0.563	1.352	0.00
1-Jun-2013	5	-176.4	23.512	0.555	1.435	0.00
1-Jun-2013	6	-165.6	23.385	0.544	1.706	0.00
1-Jun-2013	7	-72.0	23.507	0.546	2.292	0.00
1-Jun-2013	8	205.2	24.061	0.579	1.711	0.00
1-Jun-2013	9	932.4	24.880	0.665	1.499	0.00
1-Jun-2013	10	1742.4	25.712	0.736	2.528	0.00
1-Jun-2013	11	1404.0	25.700	0.819	2.423	0.00
1-Jun-2013	12	2509.2	27.219	1.004	2.957	0.00
1-Jun-2013	13	2764.8	27.094	0.994	2.253	0.00
1-Jun-2013	14	536.4	27.654	1.015	3.005	0.00
1-Jun-2013	15	25.2	25.336	0.647	3.025	0.00
1-Jun-2013	16	2246.4	26.800	0.786	2.368	0.00
1-Jun-2013	17	108.0	26.773	0.784	5.722	0.00
1-Jun-2013	18	-129.6	24.422	0.619	4.792	0.00
1-Jun-2013	19	-162.0	22.030	0.518	1.724	0.00
1-Jun-2013	20	-126.0	23.382	0.544	2.086	0.00
1-Jun-2013	21	-140.4	23.361	0.544	1.524	0.00
1-Jun-2013	22	-158.4	22.957	0.538	2.786	0.00
1-Jun-2013	23	-129.6	23.322	0.548	0.752	0.00
1-Jun-2013	24	-176.4	23.674	0.562	1.670	0.00
2-Jun-2013	1	-144.0	23.720	0.558	1.909	0.00
2-Jun-2013	2	-147.6	23.725	0.556	1.910	0.00
2-Jun-2013	3	-176.4	23.283	0.542	1.840	0.00
2-Jun-2013	4	-180.0	23.124	0.540	1.794	0.00
2-Jun-2013	5	-151.2	23.301	0.543	1.430	0.00
2-Jun-2013	6	-86.4	23.613	0.549	1.402	0.00
2-Jun-2013	7	-82.8	23.599	0.550	0.426	0.00
2-Jun-2013	8	90.0	24.078	0.576	0.283	0.00
2-Jun-2013	9	1080.0	25.621	0.734	0.447	0.00
2-Jun-2013	10	1828.8	25.519	0.811	0.902	0.00
2-Jun-2013	11	2206.8	26.286	0.867	2.050	0.00
2-Jun-2013	12	2304.0	27.140	0.993	2.380	0.00
2-Jun-2013	13	2520.0	27.439	0.972	4.162	0.00

Table A20 SFWM: hourly meteorology data, June 1-7, 2013

Date	Record nr	Rad kJ/m2	Temp C	Hum kPa	Wind m/s	Rain mm
2-Jun-2013	14	1616.4	27.407	0.981	5.212	0.00
2-Jun-2013	15	1990.8	28.303	1.088	5.271	0.00
2-Jun-2013	16	684.0	28.561	1.125	5.458	0.00
2-Jun-2013	17	158.4	27.444	0.917	7.582	0.00
2-Jun-2013	18	270.0	26.171	0.835	4.511	0.00
2-Jun-2013	19	39.6	26.722	0.801	2.244	0.00
2-Jun-2013	20	-111.6	26.403	0.769	2.967	0.00
2-Jun-2013	21	-162.0	26.088	0.746	3.450	0.00
2-Jun-2013	22	-187.2	25.577	0.738	2.055	0.00
2-Jun-2013	23	-190.8	25.005	0.690	2.134	0.00
2-Jun-2013	24	-198.0	24.951	0.680	1.050	0.00
3-Jun-2013	1	-176.4	25.216	0.676	2.071	0.00
3-Jun-2013	2	-194.4	24.588	0.614	1.422	0.00
3-Jun-2013	3	-180.0	24.490	0.598	1.770	0.00
3-Jun-2013	4	-180.0	24.363	0.595	2.161	0.00
3-Jun-2013	5	-154.8	24.510	0.619	2.162	0.00
3-Jun-2013	6	-147.6	24.506	0.610	2.160	0.00
3-Jun-2013	7	-79.2	23.004	0.579	4.882	1.50
3-Jun-2013	8	97.2	23.068	0.582	3.827	1.50
3-Jun-2013	9	237.6	24.009	0.627	2.771	1.60
3-Jun-2013	10	561.6	24.415	0.660	3.035	1.50
3-Jun-2013	11	712.8	24.839	0.716	4.229	0.00
3-Jun-2013	12	1033.2	25.975	0.798	3.529	0.00
3-Jun-2013	13	939.6	26.397	0.870	2.969	0.00
3-Jun-2013	14	694.8	27.327	0.957	3.091	0.00
3-Jun-2013	15	684.0	27.094	0.929	2.972	0.00
3-Jun-2013	16	511.2	26.902	0.916	2.658	0.00
3-Jun-2013	17	493.2	27.018	0.945	2.596	0.00
3-Jun-2013	18	324.0	27.285	0.983	2.153	0.00
3-Jun-2013	19	100.8	27.490	0.955	2.790	0.00
3-Jun-2013	20	-140.4	23.435	0.569	0.789	0.00
3-Jun-2013	21	-230.4	23.923	0.608	1.429	0.00
3-Jun-2013	22	-198.0	24.414	0.609	1.672	0.00
3-Jun-2013	23	-133.2	24.205	0.591	1.026	0.00
3-Jun-2013	24	-169.2	23.994	0.593	1.558	0.00
4-Jun-2013	1	-144.0	24.333	0.597	1.448	0.00
4-Jun-2013	2	-133.2	22.645	0.533	1.856	0.00

Table A20 SFWM: hourly meteorology data, June 1-7, 2013 (Cont.)

Date	Record nr	Rad kJ/m2	Temp C	Hum kPa	Wind m/s	Rain mm
4-Jun-2013	3	-183.6	22.690	0.546	2.524	0.00
4-Jun-2013	4	-140.4	22.859	0.542	1.794	0.00
4-Jun-2013	5	-147.6	23.373	0.557	2.316	0.00
4-Jun-2013	6	-115.2	23.549	0.555	1.217	0.00
4-Jun-2013	7	-93.6	23.620	0.561	0.682	0.00
4-Jun-2013	8	-46.8	23.908	0.564	1.049	0.00
4-Jun-2013	9	21.6	24.076	0.574	1.671	0.00
4-Jun-2013	10	154.8	24.711	0.601	1.599	0.00
4-Jun-2013	11	277.2	25.078	0.617	2.137	0.00
4-Jun-2013	12	594.0	25.455	0.650	2.598	0.00
4-Jun-2013	13	61.2	22.850	0.568	4.225	0.00
4-Jun-2013	14	486.0	25.218	0.672	4.256	0.00
4-Jun-2013	15	-50.4	25.113	0.677	2.220	0.00
4-Jun-2013	16	82.8	25.564	0.709	3.375	0.00
4-Jun-2013	17	25.2	25.795	0.706	2.614	3.50
4-Jun-2013	18	-39.6	26.163	0.719	3.509	3.60
4-Jun-2013	19	-25.2	26.071	0.722	2.549	0.00
4-Jun-2013	20	-133.2	25.662	0.670	2.115	0.00
4-Jun-2013	21	-93.6	25.433	0.686	3.190	0.00
4-Jun-2013	22	-172.8	25.101	0.636	3.195	0.00
4-Jun-2013	23	-162.0	25.075	0.632	3.048	0.00
4-Jun-2013	24	-115.2	25.131	0.637	2.832	0.00
5-Jun-2013	1	-129.6	24.867	0.610	1.900	0.00
5-Jun-2013	2	-122.4	24.706	0.598	2.155	0.00
5-Jun-2013	3	-133.2	24.750	0.604	1.802	0.00
5-Jun-2013	4	-136.8	24.743	0.606	1.780	0.00
5-Jun-2013	5	-122.4	24.614	0.596	1.921	0.00
5-Jun-2013	6	-176.4	24.751	0.609	2.838	0.00
5-Jun-2013	7	-129.6	24.561	0.592	2.450	0.00
5-Jun-2013	8	-75.6	24.826	0.604	2.072	0.00
5-Jun-2013	9	-32.4	25.083	0.615	2.605	0.00
5-Jun-2013	10	3.6	24.983	0.606	2.007	0.00
5-Jun-2013	11	104.4	25.241	0.613	2.440	0.00
5-Jun-2013	12	104.4	25.808	0.643	2.412	0.00
5-Jun-2013	13	698.4	29.760	1.007	3.929	0.00
5-Jun-2013	14	777.6	30.032	1.027	4.667	0.00
5-Jun-2013	15	543.6	29.872	0.963	4.426	0.00

Table A20 SFWM: hourly meteorology data, June 1-7, 2013 (Cont.)

Date	Record nr	Rad kJ/m2	Temp C	Hum kPa	Wind m/s	Rain mm
5-Jun-2013	16	255.6	29.472	0.893	4.014	0.00
5-Jun-2013	17	36.0	28.992	0.856	4.059	0.00
5-Jun-2013	18	133.2	28.460	0.819	4.354	0.00
5-Jun-2013	19	46.8	28.078	0.785	4.064	0.00
5-Jun-2013	20	-57.6	27.840	0.732	3.279	0.00
5-Jun-2013	21	-216.0	27.660	0.756	3.876	0.00
5-Jun-2013	22	-230.4	27.476	0.746	3.339	0.00
5-Jun-2013	23	-97.2	26.046	0.663	2.724	0.00
5-Jun-2013	24	-72.0	24.128	0.609	4.193	0.00
6-Jun-2013	1	-68.4	24.552	0.605	5.378	0.00
6-Jun-2013	2	-154.8	24.858	0.601	4.171	0.00
6-Jun-2013	3	-100.8	25.072	0.599	2.674	0.00
6-Jun-2013	4	-111.6	25.604	0.615	6.433	0.00
6-Jun-2013	5	-75.6	25.794	0.634	6.549	0.00
6-Jun-2013	6	-133.2	26.150	0.628	6.920	0.00
6-Jun-2013	7	-39.6	26.528	0.643	2.600	0.00
6-Jun-2013	8	39.6	26.872	0.699	4.274	0.00
6-Jun-2013	9	460.8	28.194	0.860	5.525	0.00
6-Jun-2013	10	756.0	29.010	0.930	7.756	0.00
6-Jun-2013	11	1335.6	29.772	0.995	9.111	0.00
6-Jun-2013	12	1533.6	29.856	1.017	10.635	0.00
6-Jun-2013	13	1918.8	30.318	1.081	11.332	0.00
6-Jun-2013	14	2682.0	30.170	1.076	10.505	0.00
6-Jun-2013	15	1249.2	30.226	1.040	10.537	0.00
6-Jun-2013	16	1605.6	30.072	0.869	11.024	0.00
6-Jun-2013	17	147.6	29.584	0.963	5.941	0.00
6-Jun-2013	18	406.8	28.982	0.908	6.312	0.00
6-Jun-2013	19	79.2	28.218	0.824	4.332	0.00
6-Jun-2013	20	-79.2	27.462	0.769	6.571	0.00
6-Jun-2013	21	-93.6	25.766	0.669	6.974	0.00
6-Jun-2013	22	-194.4	24.962	0.623	4.189	5.00
6-Jun-2013	23	-183.6	24.924	0.622	3.441	5.00
6-Jun-2013	24	-208.8	24.832	0.628	2.362	10.00
7-Jun-2013	1	-230.4	24.782	0.627	3.634	10.00
7-Jun-2013	2	-180.0	24.810	0.618	3.617	5.00
7-Jun-2013	3	-133.2	25.150	0.636	2.913	5.00
7-Jun-2013	4	-158.4	24.948	0.629	3.585	10.00

Table A20 SFWM: hourly meteorology data, June 1-7, 2013 (Cont.)

Date	Record nr	Rad kJ/m2	Temp C	Hum kPa	Wind m/s	Rain mm
7-Jun-2013	5	-162.0	24.876	0.619	3.818	10.00
7-Jun-2013	6	-108.0	25.684	0.646	3.974	10.00
7-Jun-2013	7	-43.2	27.178	0.732	4.631	10.00
7-Jun-2013	8	291.6	27.966	0.842	6.156	0.00
7-Jun-2013	9	943.2	28.766	0.908	6.585	0.00
7-Jun-2013	10	1512.0	29.356	0.976	6.160	0.00
7-Jun-2013	11	1735.2	29.878	1.019	4.613	0.00
7-Jun-2013	12	936.0	30.174	0.877	5.847	0.00
7-Jun-2013	13	943.2	30.320	1.082	4.788	0.00
7-Jun-2013	14	1569.6	30.162	1.024	7.148	0.00
7-Jun-2013	15	784.8	29.892	1.095	6.518	0.00
7-Jun-2013	16	1850.4	29.672	1.042	7.863	0.00
7-Jun-2013	17	1249.2	29.236	0.911	8.266	0.00
7-Jun-2013	18	201.6	28.776	0.943	5.673	0.00
7-Jun-2013	19	108.0	28.072	0.789	4.050	0.00
7-Jun-2013	20	-93.6	27.548	0.724	4.032	0.00
7-Jun-2013	21	-172.8	27.302	0.699	3.992	0.00
7-Jun-2013	22	-154.8	27.090	0.691	2.127	0.00
7-Jun-2013	23	-129.6	26.730	0.699	3.710	0.00
7-Jun-2013	24	-136.8	26.332	0.674	3.342	0.00

Table A20 SFWM: hourly meteorology data, June 1-7, 2013 (Cont.)

LOCATION.--Lat 25°39'22.0", long 80°45'59.2" referenced to North American Datum of 1983, in NW ¼ NE ¼ sec.30, T.55 S., R.36 E., Miami-Dade County, FL, Hydrologic Unit 03090202, at look-out tower in Everglades National Park, 6.5 mi south of U.S. Highway 41, and 18.9 mi southwest of the intersection of U.S. Highway 41 and State Road 997.

DATUM.--Land-surface datum is 6.8 ft. above National Geodetic Vertical Datum of 1929. Measuring point: Top of shelf, 9.85 ft. above National Geodetic Vertical Datum of 1929, Sep. 7, 2005, to present.

Elevation above NGVD 1929, feet								
TIME	01-Jun	02-Jun	03-Jun	04-Jun	05-Jun	06-Jun	07-Jun	08-Jun
00:00 EDT	6.56 ^P	6.69 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.70 ^P	6.86 ^P	6.81 ^P
01:00 EDT	6.56 ^P	6.69 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.70 ^P	6.86 ^P	6.81 ^P
02:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.68 ^P	6.69 ^P	6.86 ^P	6.81 ^P
03:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.68 ^P	6.69 ^P	6.86 ^P	6.81 ^P
04:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.71 ^P	6.85 ^P	6.81 ^P
05:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.81 ^P	6.85 ^P	6.81 ^P
06:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.91 ^P	6.85 ^P	6.81 ^P
07:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.90 ^P	6.82 ^P	6.81 ^P
08:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.90 ^P	6.82 ^P	6.81 ^P
09:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.89 ^P	6.82 ^P	6.81 ^P
10:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.89 ^P	6.82 ^P	6.81 ^P
11:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.87 ^P	6.82 ^P	6.81 ^P
12:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.68 ^P	6.87 ^P	6.82 ^P	6.81 ^P
13:00 EDT	6.56 ^P	6.69 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.87 ^P	6.82 ^P	6.81 ^P
14:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.87 ^P	6.82 ^P	6.81 ^P
15:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.87 ^P	6.82 ^P	6.81 ^P
16:00 EDT	6.56 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.87 ^P	6.82 ^P	6.81 ^P
17:00 EDT	6.56 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.86 ^P	6.82 ^P	6.81 ^P
18:00 EDT	6.62 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.86 ^P	6.82 ^P	6.81 ^P
19:00 EDT	6.72 ^P	6.68 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.86 ^P	6.82 ^P	6.81 ^P
20:00 EDT	6.72 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.67 ^P	6.86 ^P	6.81 ^P	6.81 ^P
21:00 EDT	6.71 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.70 ^P	6.86 ^P	6.81 ^P	6.81 ^P
22:00 EDT	6.70 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.70 ^P	6.86 ^P	6.81 ^P	6.81 ^P
23:00 EDT	6.69 ^P	6.67 ^P	6.67 ^P	6.68 ^P	6.70 ^P	6.86 ^P	6.81 ^P	6.81 ^P
COUNT	24	24	24	24	24	24	24	24
MAX	6.72	6.69	6.67	6.68	6.7	6.91	6.86	6.81
MIN	6.56	6.67	6.67	6.67	6.67	6.69	6.81	6.81

Table A21 USGS G-620 Station: water table elevation

Figure A73 Measuring soil roughness with pin profilometer

Figure A74 QuiP graphic output of surface roughness index (RMS height and correlation length)

Label	Lon	Lat	Incident_angle	Sigma0_HH_dB
pin_1	-80.76151	25.70601	47.76294	-14.76841
pin_2	-80.76150	25.70598	47.76294	-17.62364
pin_3	-80.76148	25.70594	47.76278	-22.56848
pin_4	-80.76151	25.70593	47.76294	-22.56848
pin_5	-80.76154	25.70594	47.76294	-19.00768
pin_6	-80.76154	25.70598	47.76309	-19.00768
pin_7	-80.76157	25.70597	47.76309	-19.00768
pin_8	-80.76155	25.70594	47.76294	-22.56848
pin_9	-80.76154	25.70592	47.76294	-20.52703
pin_10	-80.76158	25.70591	47.76309	-16.94943
pin_11	-80.76159	25.70593	47.76325	-16.10109
pin_12	-80.76160	25.70595	47.76325	-16.12893
pin_13	-80.76164	25.70593	47.76341	-14.43577
pin_14	-80.76162	25.70592	47.76341	-14.43577
pin_15	-80.76162	25.70589	47.76341	-14.47138

Table A22 RADARSAT-2 observation values, 04-May 2013: Location 1

Figure A75 RADARSAT-2 image, 04-May 2013: Location 1

Label	Lon	Lat	Incident_angle	Sigma0_H_H_dB
1	-80.76151	25.70601	31.377827	-12.606165
2	-80.76150	25.70598	31.377827	-9.803432
3	-80.76148	25.70594	31.377510	-8.871643
4	-80.76151	25.70593	31.377827	-8.984770
5	-80.76154	25.70596	31.377827	-6.967456
6	-80.76154	25.70598	31.378143	-8.431979
7	-80.76157	25.70597	31.378143	-6.756290
8	-80.76155	25.70594	31.377827	-6.967456
9	-80.76154	25.70592	31.377827	-6.645712
10	-80.76158	25.70591	31.378143	-8.273992
11	-80.76159	25.70593	31.378143	-7.638556
12	-80.76160	25.70595	31.378460	-6.175649
13	-80.76164	25.70593	31.378460	-10.627179
14	-80.76162	25.70592	31.378460	-7.638556
15	-80.76162	25.70589	31.378460	-8.575707

Table A23 RADARSAT-2 observation values, 07-May 2013: Location 1

Figure A76 RADARSAT-2 image, 07-May 2013: Location 1

Label	Lon	Lat	Incident_angle	Sigma0_HH_dB
pin_16	-80.76197	25.71793	47.775105	-13.5587620
pin_17	-80.76200	25.71795	47.775260	-12.8406330
pin_18	-80.76204	25.71798	47.775417	-13.5956490
pin_19	-80.76203	25.71798	47.775417	-12.6266190
pin_20	-80.76203	25.71792	47.775260	-10.4217320
pin_21	-80.76201	25.71789	47.775105	-12.0594450
pin_22	-80.76204	25.71788	47.775260	-9.0934790
pin_23	-80.76210	25.71791	47.775578	-9.8615660

Table A24 RADARSAT-2 observation values, 04-May 2013: Location 2

Figure A77 RADARSAT-2 image, 04-May 2013: Location 2

Label	Lon	Lat	Incident_angle	Sigma0_H_H_dB
16	-80.76197	25.7179	31.396852	-11.894392
17	-80.76200	25.718	31.396852	-14.745893
18	-80.76204	25.718	31.397170	-12.186021
19	-80.76203	25.718	31.397170	-12.979976
20	-80.76203	25.7179	31.397170	-12.549136
21	-80.76201	25.7179	31.396852	-9.514535
22	-80.76204	25.7179	31.397170	-5.285974
23	-80.76210	25.7179	31.397486	-4.792986

Table A25 RADARSAT-2 observation values, 07-May 2013: Location 2

Figure A78 RADARSAT-2 image, 07-May 2013: Location 2

Flag	Lon	Lat	04-May			07-May					$\sigma^{01} - \sigma_{ref}^{02}$ dB	θ_{May-4} cm ³ cm ⁻³	θ_{May-7} cm ³ cm ⁻³	$\Delta_{(May4-May7)}$ cm ³ cm ⁻³
			$\theta_{reference}$ incident _angle	σ^{01} Sigma0_ HH_dB	θ_{02} incident _angle	σ^{02} Sigma0_ HH_dB	$\cos_{ref}$	$\cos_{ref}^2$	$\cos_{02}$	σ_{ref}^{02} Normalized dB				
pin_1	-80.76151	25.70601	47.76	-14.77	31.38	-12.61	0.67	0.45	0.85	-6.68	-8.09	0.31	0.35	-0.04
pin_2	-80.76150	25.70598	47.76	-17.62	31.38	-9.80	0.67	0.45	0.85	-5.19	-12.43	0.36	0.40	-0.04
pin_3	-80.76148	25.70594	47.76	-22.57	31.38	-8.87	0.67	0.45	0.85	-4.70	-17.87	0.31	0.50	-0.18
pin_4	-80.76151	25.70593	47.76	-22.57	31.38	-8.98	0.67	0.45	0.85	-4.76	-17.81	0.47	0.59	-0.11
pin_5	-80.76154	25.70596	47.76	-19.01	31.38	-6.97	0.67	0.45	0.85	-3.69	-15.32	0.47	0.55	-0.08
pin_6	-80.76154	25.70598	47.76	-19.01	31.38	-8.43	0.67	0.45	0.85	-4.47	-14.54	0.39	0.28	0.11
pin_7	-80.76157	25.70597	47.76	-19.01	31.38	-6.76	0.67	0.45	0.85	-3.58	-15.43	0.39	0.25	0.14
pin_8	-80.76155	25.70594	47.76	-22.57	31.38	-6.97	0.67	0.45	0.85	-3.69	-18.88	0.47	0.29	0.18
pin_9	-80.76154	25.70592	47.76	-20.53	31.38	-6.65	0.67	0.45	0.85	-3.52	-17.01	0.47	0.64	-0.16
pin_10	-80.76158	25.70591	47.76	-16.95	31.38	-8.27	0.67	0.45	0.85	-4.38	-12.57	0.34	0.37	-0.03
pin_11	-80.76159	25.70593	47.76	-16.10	31.38	-7.64	0.67	0.45	0.85	-4.05	-12.06	0.32	0.39	-0.06
pin_12	-80.76160	25.70595	47.76	-16.13	31.38	-6.18	0.67	0.45	0.85	-3.27	-12.86	0.32	0.51	-0.18
pin_13	-80.76164	25.70593	47.76	-14.44	31.38	-10.63	0.67	0.45	0.85	-5.63	-8.81	0.28	0.41	-0.13
pin_14	-80.76162	25.70592	47.76	-14.44	31.38	-7.64	0.67	0.45	0.85	-4.05	-10.39	0.28	0.38	-0.10
pin_15	-80.76162	25.70589	47.76	-14.47	31.38	-8.58	0.67	0.45	0.85	-4.54	-9.93	0.28	0.46	-0.18
pin_16	-80.76197	25.71793	47.78	-13.56	31.40	-11.89	0.67	0.45	0.85	-6.30	-7.26	0.58	0.64	-0.06
pin_17	-80.76200	25.71795	47.78	-12.84	31.40	-14.75	0.67	0.45	0.85	-7.81	-5.03	0.63	0.59	0.04
pin_18	-80.76204	25.71798	47.78	-13.60	31.40	-12.19	0.67	0.45	0.85	-6.45	-7.14	0.78	0.63	0.15
pin_19	-80.76203	25.71798	47.78	-12.63	31.40	-12.98	0.67	0.45	0.85	-6.87	-5.75	0.75	0.57	0.18
pin_20	-80.76203	25.71792	47.78	-10.42	31.40	-12.55	0.67	0.45	0.85	-6.64	-3.78	0.52	0.41	0.11
pin_21	-80.76201	25.71789	47.78	-12.06	31.40	-9.51	0.67	0.45	0.85	-5.04	-7.02	0.9	0.82	0.08
pin_22	-80.76204	25.71788	47.78	-9.09	31.40	-5.29	0.67	0.45	0.85	-2.80	-6.29	0.54	0.46	0.08
pin_23	-80.76210	25.71791	47.78	-9.86	31.40	-4.79	0.67	0.45	0.85	-2.54	-7.32	0.59	0.57	0.02

Table A26 Difference of backscatter and surface moisture between May 4 and May 7, 2013

Location Points	Backscatter difference (dB)	Moisture difference (cm ³ cm ⁻³)
8	-18.8781167	0.18286718
7	-15.4291693	0.14037894
6	-14.5416301	0.11037894
15	-9.9292460	-0.17751241
13	-8.8070722	-0.12614644

Table A27 Data used to develop linear algorithm

Figure A79 Unsupervised linear algorithm estimation using Table A27 data

Figure A80 Surface moisture versus modeled using an unsupervised algorithm

Location Points	Modeled ($\text{cm}^3\text{cm}^{-3}$)	Measured ($\text{cm}^3\text{cm}^{-3}$)	(Difference) ² ($\text{cm}^3\text{cm}^{-3}$) ²
1	0.07412269	0.31462586	0.0578418
2	0.18233596	0.35813081	0.0309038
3	0.36974552	0.31359850	0.0031525
4	0.36974552	0.47334565	0.0107330
5	0.23479111	0.47334565	0.0569083
9	0.29237426	0.47334565	0.0327506
10	0.15678334	0.34242170	0.0344616
11	0.12463144	0.32265547	0.0392135
12	0.12568641	0.32330407	0.0390527
14	0.06151587	0.28385356	0.0494340
Σ :			0.3544519
σ^2 :			3.54E-02
RMSE :			18.8%

Table A28 RMSE and covariance (σ^2) calculation using an unsupervised algorithm

Figure A81 Surface moisture versus modeled using a supervised algorithm

Location Points	Modeled ($\text{cm}^3\text{cm}^{-3}$)	Measured ($\text{cm}^3\text{cm}^{-3}$)	(Difference) ² ($\text{cm}^3\text{cm}^{-3}$) ²
1	0.25312269	0.31462586	0.0037826
2	0.36133596	0.35813081	0.0000103
3	0.54874552	0.31359850	0.0552941
4	0.54874552	0.47334565	0.0056851
5	0.41379111	0.47334565	0.0035467
9	0.47137426	0.47334565	0.0000039
10	0.33578334	0.34242170	0.0000441
11	0.30363144	0.32265547	0.0003619
12	0.30468641	0.32330407	0.0003466
14	0.24051587	0.28385356	0.0018782
Σ :			0.0709536
σ^2 :			7.10E-03
RMSE :			8.4%

Table A29 RMSE and covariance (σ^2) calculation using a supervised algorithm

Figure A82 Optimized surface moisture versus modeled using a supervised algorithm

Location Points	Modeled ($\text{cm}^3 \text{cm}^{-3}$)	Measured ($\text{cm}^3 \text{cm}^{-3}$)	(Difference) ² ($\text{cm}^3 \text{cm}^{-3}$) ²
1	0.36133596	0.31462586	0.0021818
2	0.54874552	0.35813081	0.0363340
4	0.54874552	0.47334565	0.0056851
5	0.41379111	0.47334565	0.0035467
9	0.47137426	0.47334565	0.0000039
10	0.33578334	0.34242170	0.0000441
11	0.30363144	0.32265547	0.0003619
12	0.30468641	0.32330407	0.0003466
14	0.24051587	0.28385356	0.0018782
Σ :			0.0118665
σ^2 :			1.32E-03
RMSE :			3.6%

Table A30 Optimized RMSE and covariance (σ^2) calculation using a supervised algorithm

Location Points	04-May	
	Sigma0_ HH_dB	cm ³ cm ⁻³
1	-14.7684088	0.3146259
2	-17.6236401	0.3581308
3	-22.5684834	0.3135985
4	-22.5684834	0.4733457
5	-19.0076809	0.4733457
6	-19.0076809	0.3903789
7	-19.0076809	0.3903789
8	-22.5684834	0.4733457
9	-20.5270252	0.4733457
10	-16.9494286	0.3424217
11	-16.1010933	0.3226555
12	-16.1289291	0.3233041
13	-14.4357748	0.2838536
14	-14.4357748	0.2838536
15	-14.4713831	0.2846832

Table A31 Single radar observation data and measured soil moisture, May 4, 2013

Figure A83 Unsupervised linear regression estimation using single radar observation, May 4, 2013

Location Points	07-May	
	Sigma0_ HH_dB	cm ³ cm ⁻³
1	-12.6061650	0.3549211
2	-9.8034320	0.4028150
3	-8.8716430	0.4984081
4	-8.9847700	0.5866030
5	-6.9674560	0.5500000
6	-8.4319790	0.2800000
7	-6.7562900	0.2500000
8	-6.9674560	0.2904785
9	-6.6457120	0.6360544
10	-8.2739920	0.3714698
11	-7.6385560	0.3864610
12	-6.1756490	0.5050276
13	-10.6271790	0.4100000
14	-7.6385560	0.3804256
15	-8.5757070	0.4621956

Table A32 Single radar observation data and measured soil moisture, May 7, 2013

Figure A84 Unsupervised linear regression estimation using single radar observation, May 7, 2013

Location Points	04-May	
	Sigma0_HH_dB	cm ³ cm ⁻³
1	-14.7684088	0.314625856
2	-17.6236401	0.358130812
4	-22.5684834	0.473345654
5	-19.0076809	0.473345654
6	-19.0076809	0.390378944
7	-19.0076809	0.390378944
8	-22.5684834	0.473345654
9	-20.5270252	0.473345654
10	-16.9494286	0.34242170
11	-16.1010933	0.322655467
12	-16.1289291	0.323304069
13	-14.4357748	0.283853558
14	-14.4357748	0.283853558
15	-14.4713831	0.284683224

Table A33 Supervised single radar observation data and measured soil moisture, May 4, 2013

Figure A85 Supervised linear regression estimation using single radar observation, May 4, 2013

Algorithm: $y = -0.025x - 0.071$

Location Points	Modeled ($\text{cm}^3 \text{cm}^{-3}$)	Measured ($\text{cm}^3 \text{cm}^{-3}$)	(Difference) ² ($\text{cm}^3 \text{cm}^{-3}$) ²
1	0.29821022	0.31462586	0.0002695
2	0.36959100	0.35813081	0.0001313
4	0.49321208	0.47334565	0.0003947
5	0.40419202	0.47334565	0.0047822
6	0.40419202	0.39037894	0.0001908
7	0.40419202	0.39037894	0.0001908
8	0.49321208	0.47334565	0.0003947
9	0.44217563	0.47334565	0.0009716
10	0.35273571	0.34242170	0.0001064
11	0.33152733	0.32265547	0.0000787
12	0.33222323	0.32330407	0.0000796
13	0.28989437	0.28385356	0.0000365
14	0.28989437	0.28385356	0.0000365
15	0.29078458	0.28468322	0.0000372
Σ :			0.0077004
σ^2 :			5.50E-04
RMSE :			2.3%

Table A34 Evaluation of algorithm using single radar observation versus measured soil moisture, May 4, 2013

Figure A86 Soil moisture measured versus modeled using single radar backscatter observation on May 4, 2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)

Start Date 2013/07/24

End Date 2013/07/29

Pressure 0.5 kPa

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X1A1	12	6.50	33.70	30.70	20.68	1.48	2.60	0.15
X1A2	14	6.60	34.10	31.30	19.63	1.59		0.14
X1A3	15	6.40	34.20	31.30	19.70	1.59		0.15
X1B1	16	6.40	33.90	31.10	19.70	1.58	2.65	0.14
X1B2	17	6.50	33.80	31.20	19.78	1.58		0.13
X1B3	18	6.50	34.20	31.10	19.70	1.58		0.16
X1C1	19	6.40	33.40	31.10	19.70	1.58	2.60	0.12
X1C2	20	6.50	34.40	31.20	19.70	1.58		0.16
X1C3	21	6.60	34.40	31.30	19.70	1.59		0.16

Table A35 Drying pressure plate 0.5 bar, 07/29/2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)

Start Date 2013/07/16

End Date 2013/07/19

Pressure 1 BAR

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X1A1	16	6.40	32.40	31.20	19.31	1.62	2.60	0.06
X1A2	17	6.50	31.50	30.30	19.47	1.56		0.06
X1A3	18	6.50	31.40	30.20	19.31	1.56		0.06
X1B1	19	6.50	31.70	31.00	19.55	1.59	2.65	0.04
X1B2	20	6.50	30.20	29.50	19.47	1.52		0.04
X1B3	21	6.70	31.60	31.00	19.47	1.59		0.03
X1C1	22	6.60	33.20	32.60	19.63	1.66	2.60	0.03
X1C2	23	6.70	32.00	31.40	19.55	1.61		0.03
X1C3	24	6.60	31.70	31.10	19.39	1.60		0.03

Table A36 Drying pressure plate 1 bar, 07/19/2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)Start Date 2013/07/10End Date 2013/07/18Pressure 5 BAR

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X1A1	16	6.50	32.40	31.20	19.63	1.59	2.60	0.06
X1A2	17	6.60	32.50	31.40	19.63	0.63		0.06
X1A3	18	6.50	32.50	31.40	19.63	1.60		0.06
X1B1	19	6.50	31.90	31.10	19.63	1.58	2.65	0.04
X1B2	20	6.50	31.80	31.20	19.63	1.59		0.03
X1B3	21	6.60	32.10	31.50	19.63	1.61		0.03
X1C1	22	6.60	32.10	31.60	19.63	1.61	2.60	0.03
X1C2	23	6.70	32.20	31.60	19.63	1.61		0.03
X1C3	24	6.70	32.10	31.60	19.63	1.61		0.03

Table A37 Drying pressure plate 5 bars, 07/18/2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)Start Date 2013/07/09End Date 2013/07/15Pressure 15 BAR

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X1A1	16	6.50	32.10	31.90	19.63	1.63	2.60	0.01
X1A2	17	6.60	32.30	31.30	19.63	1.59		0.05
X1A3	18	6.50	32.30	31.10	19.63	1.58		0.06
X1B1	19	6.50	31.70	31.20	19.63	1.59	2.65	0.03
X1B2	20	6.50	31.70	31.30	19.63	1.59		0.02
X1B3	21	6.60	31.90	31.40	19.63	1.60		0.03
X1C1	22	6.60	31.80	31.50	19.63	1.61	2.60	0.02
X1C2	23	6.70	31.80	31.50	19.63	1.61		0.02
X1C3	24	6.70	31.60	31.30	19.63	1.59		0.02

Table A38 Drying pressure plate 15 bars, 07/15/2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)

Start Date 2013/11/20

End Date 2013/11/22

Pressure 0.5 BAR

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X2A1	1	6.612	35.618	31.420	19.63	1.60	2.5880	0.21
X2A2	2	6.646	34.798	31.456	19.63	1.60		0.17
X2A3	3	6.625	34.461	31.465	19.63	1.60		0.15
X2B1	4	6.659	34.013	31.546	16.35	1.93	2.5926	0.15
X2B2	5	6.684	33.874	31.571	16.35	1.93		0.14
X2B3	6	6.510	33.419	31.314	16.35	1.91		0.13
X2C1	7	6.497	33.776	31.198	16.22	1.92	2.6345	0.16
X2C2	8	6.466	33.889	31.185	16.22	1.92		0.17
X2C3	9	6.545	33.877	31.279	16.22	1.93		0.16
X3A1	10	6.433	35.862	31.243	19.63	1.59	2.6278	0.24
X3A2	11	6.457	34.550	31.269	19.63	1.59		0.17
X3A3	12	6.389	34.574	31.208	19.63	1.59		0.17
X3B1	13	6.393	35.674	31.209	16.35	1.91	2.5782	0.27
X3B2	14	6.532	35.319	31.321	16.35	1.92		0.24
X3B3	15	6.429	34.689	31.284	16.35	1.91		0.21
X3C1	16	6.405	35.157	31.276	16.35	1.91	2.6837	0.24
X3C2	17	6.522	34.852	31.373	16.35	1.92		0.21
X3C3	18	6.493	34.521	31.309	16.35	1.91		0.20

Table A39 Drying pressure plate 0.5 bar, 11/22/2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)Start Date 2013/11/14End Date 2013/11/15Pressure 1 BAR

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X2A1	1	6.607	33.759	31.287	19.63	1.59	2.5880	0.13
X2A2	2	6.651	33.896	31.352	19.63	1.60		0.13
X2A3	3	6.627	33.414	31.380	19.63	1.60		0.10
X2B1	4	6.659	32.967	31.463	16.35	1.92	2.5926	0.09
X2B2	5	6.685	33.000	31.530	16.35	1.93		0.09
X2B3	6	6.521	32.901	31.300	16.35	1.91		0.10
X2C1	7	6.497	33.010	31.307	16.22	1.93	2.6345	0.10
X2C2	8	6.466	33.182	31.363	16.22	1.93		0.11
X2C3	9	6.548	33.354	31.423	16.22	1.94		0.12
X3A1	10	6.433	34.202	31.292	19.63	1.59	2.6278	0.15
X3A2	11	6.481	34.056	31.280	19.63	1.59		0.14
X3A3	12	6.391	34.035	31.122	19.63	1.59		0.15
X3B1	13	6.402	33.929	31.255	16.35	1.91	2.5782	0.16
X3B2	14	6.550	33.955	31.357	16.35	1.92		0.16
X3B3	15	6.429	33.596	31.307	16.35	1.91		0.14
X3C1	16	6.404	33.820	31.314	16.35	1.91	2.6837	0.15
X3C2	17	6.521	33.712	31.202	16.35	1.91		0.15
X3C3	18	6.492	33.756	31.417	16.35	1.92		0.14

Table A400 Drying pressure plate 1 bar, 11/15/2013

LABORATORY: DRYING PRESSURE PLATE (50 - 1500 kPa)

Start Date 2013/11/16

End Date 2013/11/19

Pressure 15 BAR

Code	Sample #	Container Weight (g)	Wet Weight (g)	Dry Weight (g)	Volume (cm ³)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Moisture Content
X2A1	1	6.611	33.528	31.465	19.63	1.60	2.5880	0.11
X2A2	2	6.651	33.100	31.612	19.63	1.61		0.08
X2A3	3	6.627	33.275	31.606	19.63	1.61		0.09
X2B1	4	6.661	32.300	31.591	19.63	1.61	2.5926	0.04
X2B2	5	6.681	32.473	31.637	19.63	1.61		0.04
X2B3	6	6.512	32.159	31.450	19.63	1.60		0.04
X2C1	7	6.498	31.616	31.285	19.49	1.60	2.6345	0.02
X2C2	8	6.466	31.555	31.259	19.57	1.60		0.02
X2C3	9	6.546	31.693	31.395	19.56	1.60		0.02
X3A1	10	6.435	33.078	31.317	19.63	1.60	2.6278	0.09
X3A2	11	6.462	32.971	31.356	19.63	1.60		0.08
X3A3	12	6.392	32.720	31.309	19.63	1.60		0.07
X3B1	13	6.395	31.765	31.311	19.63	1.60	2.5782	0.02
X3B2	14	6.533	31.892	31.449	19.63	1.60		0.02
X3B3	15	6.429	31.778	31.378	19.63	1.60		0.02
X3C1	16	6.404	31.740	31.345	19.63	1.60	2.6837	0.02
X3C2	17	6.521	31.784	31.482	19.63	1.60		0.02
X3C3	18	6.497	31.791	31.452	19.63	1.60		0.02

Table A41 Drying pressure plate 15 bars, 11/19/2013

Date: 2013/05/13
Wetting dates: 2013/05/13
Document #: X1A2
Sample code: X1A2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175
Metal ring+plastic (g): 346
Metal ring+plastic+sample+ceramic (g): 582
Saturated weight (g)*: 61

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/05/23	2:00PM	50	50	0.00	-3.75
2013/05/24	11:15AM	69	69	0.55	-3.2
2013/05/28	10:30AM	82	82	0.75	-3
2013/05/29	10:00AM	96	96	1.00	-2.75
2013/05/31	3:00PM	104	104	2.50	-1.25

End of test:

Wet sample + container (g)	70.92
Dry sample + container (g)	62.6
Container (g)	0
Wet sample (g) ^ψ :	70.92
Dry sample weight (g)	62.6
Water content (g)	8.32

Water balance analysis:

Saturated weight (g)*:	61
Wet sample (g) ^ψ :	70.92
Water loss (g):	-9.92
Reading water loss (g):	9.2
Approximation (g):	-19.12

Table A42 Drying Fredlund device, sample X1A2

Date: 2013/05/23
Wetting dates: 2013/05/23
Document #: X1A3
Sample code: X1A3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.05
Metal ring+plastic (g): 346.8
Metal ring+plastic+sample+ceramic (g): 598.3
Saturated weight (g)*: 76.45

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/06/04	15:45	22	22	0.00	-3.65
2013/06/05	15:45	53	53	0.50	-3.15
2013/06/07	10:00	80	80	0.75	-2.9
2013/06/10	9:00	89	89	1.00	-2.65
2013/06/12	10:00	91	91	2.50	-1.15

End of test:

Wet sample + container (g)	146.12
Dry sample + container (g)	138.31
Container (g)	83.65
Wet sample (g) ^ψ :	62.47
Dry sample weight (g)	54.66
Water content (g)	7.81

Water balance analysis:

Saturated weight (g)*:	76.45
Wet sample (g) ^ψ :	62.47
Water loss (g):	13.98
Reading water loss (g):	13.4
Approximation (g):	0.58

Table A43 Drying Fredlund device, sample X1A3

Date: 2013/06/04
Wetting dates: 2013/06/04
Document #: X1B1
Sample code: X1B1
Initials: A.J.

Soil volume (cm³): 38.44
Ceramic weight (g): 186.05
Metal ring+plastic (g): 275.0
Metal ring+plastic+sample+ceramic (g): 538.5
Saturated weight (g)*: 77.45

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/06/12	10:30	80	80	0.00	-3.7
2013/06/13	10:30	103	103	0.50	-3.2
2013/06/14	9:15	124	124	0.75	-2.95
2013/06/17	10:00	127	127	1.00	-2.7
2013/06/18	-	131	131	2.50	-1.2

End of test:

Wet sample + container (g)	134.03
Dry sample + container (g)	127.72
Container (g)	69.05
Wet sample (g) ^ψ :	64.98
Dry sample weight (g)	58.67
Water content (g)	6.31

Water balance analysis:

Saturated weight (g)*:	77.45
Wet sample (g) ^ψ :	64.98
Water loss (g):	12.47
Reading water loss (g):	9.4
Approximation (g):	3.07

Table A44 Drying Fredlund device, sample X1B1

Date: 2013/06/19
Wetting dates: 2013/06/19
Document #: X1B2
Sample code: X1B2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.05
Metal ring+plastic (g): 346.8
Metal ring+plastic+sample+ceramic (g): 609.3
Saturated weight (g)*: 87.45

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/06/21	10:00	97	97	0.00	-3.75
2013/06/23	11:00	99	99	0.55	-3.2
2013/06/27	9:50	110	110	0.75	-3
2013/06/28	11:20	113	113	1.00	-2.75
2013/07/01	11:20	120	120	2.50	-1.25

End of test:

Wet sample + container (g)	159.25
Dry sample + container (g)	146.3
Container (g)	83.7
Wet sample (g) ^ψ :	75.55
Dry sample weight (g)	62.6
Water content (g)	12.95

Water balance analysis:

Saturated weight (g)*:	87.45
Wet sample (g) ^ψ :	75.55
Water loss (g):	11.9
Reading water loss (g):	4.6
Approximation (g):	7.3

Table A45 Drying Fredlund device, sample X1B2

Date: 2013/06/27
Wetting dates: 2013/06/27
Document #: X1B3
Sample code: X1B3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g):
Metal ring+plastic (g): 527.1
Metal ring+plastic+sample+ceramic (g): 618
Saturated weight (g)*: 90.9

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/07/02	12:40	101	101	0.00	-3.8
2013/07/08	12:00	106	106	0.55	-3.25
2013/07/09	10:50	145	145	1.00	-2.8
2013/07/10	10:25	151	151	2.50	-1.3
2013/07/11	12:00	147	147	5.00	1.2

End of test:

Wet sample + container (g)	159.9
Dry sample + container (g)	156
Container (g)	83.17
Wet sample (g) ^ψ :	76.73
Dry sample weight (g)	72.83
Water content (g)	3.9

Water balance analysis:

Saturated weight (g)*:	90.9
Wet sample (g) ^ψ :	76.73
Water loss (g):	14.17
Reading water loss (g):	10
Approximation (g):	4.17

Table A46 Drying Fredlund device, sample X1B3

Date: 2013/07/11
Wetting dates: 2013/07/11
Document #: X1C2
Sample code: X1C2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.5
Metal ring+plastic (g): 351.8
Metal ring+plastic+sample+ceramic (g): 615.5
Saturated weight (g)*: 88.2

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/07/15	15:03	101	101	0.00	-3.75
2013/07/16	11:00	162	162	1.00	-2.75
2013/07/17	11:40	172	172	2.00	-1.75
2013/07/17	-	172	172	2.50	-1.25

End of test:

Wet sample + container (g)	159.8
Dry sample + container (g)	155.9
Container (g)	83.7
Wet sample (g) ^ψ :	76.1
Dry sample weight (g)	72.2
Water content (g)	3.9

Water balance analysis:

Saturated weight (g)*:	88.2
Wet sample (g) ^ψ :	76.1
Water loss (g):	12.1
Reading water loss (g):	14.2
Approximation (g):	-2.1

Table A47 Drying Fredlund device, sample X1C2

Date: 2013/07/15
Wetting dates: 2013/07/15
Document #: X1C3
Sample code: X1C3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 186.1
Metal ring+plastic (g): 347.1
Metal ring+plastic+sample+ceramic (g): 616.8
Saturated weight (g)*: 83.6

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/07/17	14:55	130	130	0.00	-3.7
2013/07/18	11:40	192	192	1.00	-2.7
2013/07/19	10:50	202	202	2.00	-1.7
2013/07/19	14:35	202	202	3.00	-0.7

End of test:

Wet sample + container (g)	154.6
Dry sample + container (g)	150.8
Container (g)	83.6
Wet sample (g) ^ψ :	71
Dry sample weight (g)	67.2
Water content (g)	3.8

Water balance analysis:

Saturated weight (g)*:	83.6
Wet sample (g) ^ψ :	71
Water loss (g):	12.6
Reading water loss (g):	14.4
Approximation (g):	-1.8

Table A48 Drying Fredlund device, sample X1C3

Date: 2013/10/10
Wetting dates: 2013/10/09
Document #: X2A2
Sample code: X2A2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.9
Metal ring+plastic (g): 350.6
Metal ring+plastic+sample+ceramic (g): 598.9
Saturated weight (g)*: 72.4

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/10/10	1:20PM	139	139	0.00	-0.25
2013/10/11	12:30PM	160	160	0.50	0.25
2013/10/13	4:10PM	168	168	1.00	0.75
2013/10/14	9:30AM	180	180	1.50	1.25

End of test:

Wet sample + container (g)	132.6
Dry sample + container (g)	116.1
Container (g)	69.8
Wet sample (g) ^ψ :	62.8
Dry sample weight (g)	46.3
Water content (g)	16.5

Water balance analysis:

Saturated weight (g)*:	72.4
Wet sample (g) ^ψ :	62.8
Water loss (g):	9.6
Reading water loss (g):	8.2
Approximation (g):	1.4

Table A49 Drying Fredlund device, sample X2A2

Date: 2013/10/15
Wetting dates: 2013/10/14
Document #: X2A3
Sample code: X2A3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 186.2
Metal ring+plastic (g): 346.5
Metal ring+plastic+sample+ceramic (g): 604.8
Saturated weight (g)*: 72.1

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/10/15	1:30PM	96	96	0.00	-0.25
2013/10/16	1:35PM	119	119	0.50	0.25
2013/10/17	2:30PM	125	125	0.75	0.50
2013/10/18	2:00PM	134	134	1.00	0.75

End of test:

Wet sample + container (g)	139.9
Dry sample + container (g)	121.5
Container (g)	74.8
Wet sample (g) ^ψ :	65.1
Dry sample weight (g)	46.7
Water content (g)	18.4

Water balance analysis:

Saturated weight (g)*:	72.1
Wet sample (g) ^ψ :	65.1
Water loss (g):	7
Reading water loss (g):	7.6
Approximation (g):	-0.6

Table A50 Drying Fredlund device, sample X2A3

Date: 2013/10/24
Wetting dates: 2013/10/17
Document #: X2B2
Sample code: X2B2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 176
Metal ring+plastic (g): 351.1
Metal ring+plastic+sample+ceramic (g): 613
Saturated weight (g)*: 85.9

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/10/27	3:00PM	90	90	0.00	-0.25
2013/10/28	10:00AM	107	107	0.50	0.25
2013/10/29	9:30AM	111	111	0.75	0.50
2013/10/30	10:45AM	139	139	1.15	0.90
2013/11/01	10:48AM	140	140	2.00	1.75

End of test:

Wet sample + container (g)	149.4
Dry sample + container (g)	140.4
Container (g)	74.8
Wet sample (g) ^ψ :	74.6
Dry sample weight (g)	65.6
Water content (g)	9

Water balance analysis:

Saturated weight (g)*:	85.9
Wet sample (g) ^ψ :	74.6
Water loss (g):	11.3
Reading water loss (g):	10
Approximation (g):	1.3

Table A51 Drying Fredlund device, sample X2B2

Date: 2013/11/01
Wetting dates: 2013/10/26
Document #: X2B3
Sample code: X2B3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 186.6
Metal ring+plastic (g): 346.5
Metal ring+plastic+sample+ceramic (g): 607.3
Saturated weight (g)*: 74.2

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/11/01	3:00PM	91	91	0.00	-0.25
2013/11/02	10:00AM	100	100	0.50	0.25
2013/11/03	9:30AM	113	113	0.75	0.50
2013/11/04	10:45AM	140	140	1.00	0.75
2013/11/05	10:48AM	152	152	2.00	1.75
2013/11/06	10:30AM	160	160	3.00	2.75
2013/11/07	1:10PM	165	165	5.00	4.75

End of test:

Wet sample + container (g)	132.3
Dry sample + container (g)	126.9
Container (g)	74.8
Wet sample (g) ^ψ :	57.5
Dry sample weight (g)	52.1
Water content (g)	5.4

Water balance analysis:

Saturated weight (g)*:	74.2
Wet sample (g) ^ψ :	57.5
Water loss (g):	16.7
Reading water loss (g):	14.8
Approximation (g):	1.9

Table A52 Drying Fredlund device, sample X2B3

Date: 2013/11/03
Wetting dates: 2013/11/03
Document #: X2C2
Sample code: X2C2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.5
Metal ring+plastic (g): 351.8
Metal ring+plastic+sample+ceramic (g): 600.8
Saturated weight (g)*: 73.5

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/11/07	2:45PM	80	80	0.00	-0.35
2013/11/09	10:00AM	52	52	0.50	0.15
2013/11/10	2:50PM	123	123	1.00	0.65
2013/11/12	9:30AM	139	139	2.00	1.65
2013/11/13	12:00PM	146	146	4.00	3.65

End of test:

Wet sample + container (g)	128.7
Dry sample + container (g)	124.5
Container (g)	69.8
Wet sample (g) ^ψ :	58.9
Dry sample weight (g)	54.7
Water content (g)	4.2

Water balance analysis:

Saturated weight (g)*:	73.5
Wet sample (g) ^ψ :	58.9
Water loss (g):	14.6
Reading water loss (g):	13.2
Approximation (g):	1.4

Table A53 Drying Fredlund device, sample X2C2

Date: 2013/11/03
Wetting dates: 2013/11/03
Document #: X2C3
Sample code: X2C3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 186.1
Metal ring+plastic (g): 346.1
Metal ring+plastic+sample+ceramic (g): 623.2
Saturated weight (g)*: 91

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/11/13	1:30PM	80	80	0.00	-0.35
2013/11/14	1:30PM	78	78	0.50	0.15
2013/11/15	9:30PM	118	118	1.00	0.65
2013/11/16	5:15PM	130	130	2.00	1.65
2013/11/18	10:50AM	124	124	4.00	3.65
2013/11/20	10:15AM	110	110	5.00	4.65

End of test:

Wet sample + container (g)	174.3
Dry sample + container (g)	169.3
Container (g)	92.6
Wet sample (g) ^ψ :	81.7
Dry sample weight (g)	76.7
Water content (g)	5

Water balance analysis:

Saturated weight (g)*:	91
Wet sample (g) ^ψ :	81.7
Water loss (g):	9.3
Reading water loss (g):	8.8
Approximation (g):	0.5

Table A54 Drying Fredlund device, sample X2C3

Date: 2013/11/13
Wetting dates: 2013/11/07
Document #: X3A1
Sample code: X3A1
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.2
Metal ring+plastic (g): 351.8
Metal ring+plastic+sample+ceramic (g): 597.2
Saturated weight (g)*: 70.2

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/09/10	2:40PM	137	137	0.00	0.05
2013/09/11	11:20AM	193	193	0.50	0.55
2013/09/12	1:00PM	202	202	0.75	0.80
2013/09/13	12:10PM	207	207	1.00	1.05

End of test:

Wet sample + container (g)	147.2
Dry sample + container (g)	136.3
Container (g)	92.6
Wet sample (g) ^ψ :	54.6
Dry sample weight (g)	43.7
Water content (g)	10.9

Water balance analysis:

Saturated weight (g)*:	70.2
Wet sample (g) ^ψ :	54.6
Water loss (g):	15.6
Reading water loss (g):	14
Approximation (g):	1.6

Table A55 Drying Fredlund device, sample X3A1

Date: 2013/09/02
Wetting dates: 2013/09/02
Document #: X3A2
Sample code: X3A2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 185.8
Metal ring+plastic (g): 344.6
Metal ring+plastic+sample+ceramic (g): 608.1
Saturated weight (g)*: 77.7

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/09/04	2:56PM	84	84	0.00	-3.75
2013/09/05	1:30PM	103	103	0.50	-3.25
2013/09/06	12:00PM	130	130	0.75	-3.00
2013/09/07	2:00PM	149	149	1.00	-2.75
2013/09/09	10:00PM	151	151	2.50	-1.25

End of test:

Wet sample + container (g)	156
Dry sample + container (g)	143.5
Container (g)	92.6
Wet sample (g) ^ψ :	63.4
Dry sample weight (g)	50.9
Water content (g)	12.5

Water balance analysis:

Saturated weight (g)*:	77.7
Wet sample (g) ^ψ :	63.4
Water loss (g):	14.3
Reading water loss (g):	13.4
Approximation (g):	0.9

Table A56 Drying Fredlund device, sample X3A2

Date: 2013/09/13
Wetting dates: 2013/09/13
Document #: X3A3
Sample code: X3A3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 186.5
Metal ring+plastic (g): 346.4
Metal ring+plastic+sample+ceramic (g): 606.3
Saturated weight (g)*: 73.4

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/09/14	6:50PM	82	82	0.00	0.30
2013/09/16	9:20AM	150	150	0.50	0.80
0/17/13	2:25PM	160	160	0.75	1.05
2013/09/19	3:20PM	150	150	1.00	1.30

End of test:

Wet sample + container (g)	151.5
Dry sample + container (g)	135
Container (g)	92.6
Wet sample (g) ^ψ :	58.9
Dry sample weight (g)	42.4
Water content (g)	16.5

Water balance analysis:

Saturated weight (g)*:	73.4
Wet sample (g) ^ψ :	58.9
Water loss (g):	14.5
Reading water loss (g):	13.6
Approximation (g):	0.9

Table A57 Drying Fredlund device, sample X3A3

Date: 2013/09/25
Wetting dates: 2013/09/25
Document #: X3B2
Sample code: X3B2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.6
Metal ring+plastic (g): 351
Metal ring+plastic+sample+ceramic (g): 613.1
Saturated weight (g)*: 86.5

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/09/20	3:00PM	133	133	0.00	0.15
2013/09/22	2:40PM	176	176	0.50	0.65
2013/09/23	10:15AM	201	201	0.75	0.90
2013/09/24	1:25PM	213	213	1.00	1.15

End of test:

Wet sample + container (g)	162
Dry sample + container (g)	155.4
Container (g)	92.6
Wet sample (g) ^ψ :	69.4
Dry sample weight (g)	62.8
Water content (g)	6.6

Water balance analysis:

Saturated weight (g)*:	86.5
Wet sample (g) ^ψ :	69.4
Water loss (g):	17.1
Reading water loss (g):	16
Approximation (g):	1.1

Table A58 Drying Fredlund device, sample X3B2

Date: 2013/09/18
Wetting dates: 2013/09/18
Document #: X3B3
Sample code: X3B3
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 186.2
Metal ring+plastic (g): 347.2
Metal ring+plastic+sample+ceramic (g): 622.3
Saturated weight (g)*: 88.9

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/09/25	2:50PM	102	102	0.00	-0.30
2013/09/26	3:50PM	122	122	0.50	0.20
2013/09/27	12:15PM	148	148	0.75	0.45
2013/09/28	12:30PM	159	159	1.00	0.70
2013/10/02	3:40PM	159	159	2.00	1.70

End of test:

Wet sample + container (g)	148.9
Dry sample + container (g)	141.6
Container (g)	69.9
Wet sample (g) ^ψ :	79
Dry sample weight (g)	71.7
Water content (g)	7.3

Water balance analysis:

Saturated weight (g)*:	88.9
Wet sample (g) ^ψ :	79
Water loss (g):	9.9
Reading water loss (g):	11.4
Approximation (g):	-1.5

Table A59 Drying Fredlund device, sample X3B3

Date: 2013/10/02
Wetting dates: 2013/10/01
Document #: X3C2
Sample code: X3C2
Initials: A.J.

Soil volume (cm³): 45.22
Ceramic weight (g): 175.5
Metal ring+plastic (g): 352.1
Metal ring+plastic+sample+ceramic (g): 617.5
Saturated weight (g)*: 89.9

Date	Time	Volume (0.1 cm ³)		Pressure (kPa)	
		Left	Right	Total	Column
2013/10/02	4:05PM	103	103	0.00	0.20
2013/10/03	4:30PM	154	154	0.55	0.75
2013/10/04	3:30PM	161	161	0.75	0.95

End of test:

Wet sample + container (g)	153.6
Dry sample + container (g)	148.1
Container (g)	74.8
Wet sample (g) ^ψ :	78.8
Dry sample weight (g)	73.3
Water content (g)	5.5

Water balance analysis:

Saturated weight (g)*:	89.9
Wet sample (g) ^ψ :	78.8
Water loss (g):	11.1
Reading water loss (g):	11.6
Approximation (g):	-0.5

Table A60 Drying Fredlund device, sample X3C2

PROCEDURE TO ADJUST FREDLUND DEVICE AT 100% SATURATION

Adjustment drying curve for initial saturation less than 100% take from (Perez-Garcia, et al., 2006)

Fit an initial value for zero pressure equal to the soil porosity. Assuming the initial pressure value is 0.5 kPa.

From this point, pick off $(S)_{0.5}$ as the degree of saturation at a matric suction value of 0.5 kPa.

Let $(S)_{05}$ represent the “observed” degree of saturation for the first SWCC data points.

Compute $\Delta S_a = 100 - S_{0.5}$

Compute $\Delta S_{0.5} = \Delta S_a \times (S_{0.5}/100)$

Compute $(S_{0.5})_{ADJ} = S_{0.5} + \Delta S_{0.5}$

Compute $R_1 = (S_{0.5})_{ADJ} \div S_{0.5}$

For subsequent data, starting with the first observed $S = (S_n)_{OBS}$ where $n = 1$ is the first as measured data point and n increases to correspond to additional measured points.

$(S_n)' = (S_n)_{OBS} \times R_1$

Compute $\Delta(S_n)' = (S_n)' - (S_n)_{OBS}$

Compute $(\Delta(S_n)')_{ADJ} = (\Delta(S_n)' \times (S_n)_{OBS}) / 100$

Compute $(S_n)_{COR} = (S_n)_{OBS} + (\Delta(S_n)')_{ADJ}$

For the corrected SWCC, plot $(S_n)_{COR}$ versus matric suction. The first data point will be $(S_{0.5})_{ADJ}$. Volumetric water content plots should also be adjusted to reflect these newly computed/corrected degree of saturation points.

Adjustment to 100% saturation

Document #: X1A2

Pressure		reading mm	Δ reading	reading		θ g	w loss inverted $\Delta\theta$ g	Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa			$\Delta\theta$ g	θ g			θ g	θ %	
0	0.00	50	0	0.000	18.41	0.00	0.00	18.41	40.71%	0.47
5.5	0.55	69	19	3.269	15.14	0.59	0.59	15.73	34.79%	0.43
7.5	0.75	82	32	5.505	12.90	1.67	1.67	14.58	32.24%	0.35
10	1.00	96	46	7.914	10.50	2.82	2.82	13.32	29.45%	0.29
25	2.50	104	54	9.290	9.12	3.31	3.31	12.43	27.50%	0.29

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:
7.913978 cm³

volume = 45.22 cm³

dry mass = 62.6 g

dry dens = 2.5952 g/cm³

dry mass = 24.12 cm³

water = 21.10 cm³

θ_{end} = 9.1 g

Porosity = 0.4666 cm³cm⁻³

Saturated beginning = 13.72 cm³

Saturated end = 9.12 cm³

loss water during = 4.60 cm³

loss water reading = 7.91 cm³

water loss = 3.31 cm³

100% saturation

Table A61 Adjustment at 100% saturation (0 – 5 kPa) X1A2

Adjustment to 100% saturation

Document #: X1A3

Pressure		reading mm	Δ reading	reading		θ g	w loss inverted		Total		saturation adjusted $\text{cm}^3 \text{cm}^{-3}$
cm	kPa			$\Delta\theta$ g	θ g		$\Delta\theta$ g	θ %			
0	0.00	22	0	0.000	19.88	19.88	0.00	43.96%	19.88	43.96%	0.53
5	0.50	53	31	5.333	14.55	14.55	1.77	36.09%	16.32	36.09%	0.47
7.5	0.75	80	58	9.978	9.90	9.90	3.94	30.61%	13.84	30.61%	0.38
10	1.00	89	67	11.527	8.35	8.35	4.69	28.84%	13.04	28.84%	0.29
25	2.50	91	69	11.871	8.01	8.01	4.83	28.39%	12.84	28.39%	0.29

factor: 93 mm = 8 cm^3 = 8 g H_2O

1 mm = 0.086022 cm^3

total water from reading mm:

11.52688 cm^3

volume = 45.22 cm^3
 dry mass = 54.66 g
 dry dens = 2.5952 g/cm^3
 dry mass = 21.06 cm^3
 water = 24.16 cm^3
 θ_{end} = 8.0 g
 Porosity = 0.5342 $\text{cm}^3 \text{cm}^{-3}$

Saturated beginning = 14.71 cm^3
 Saturated end = 8.01 cm^3
 loss water during = 6.70 cm^3
 loss water reading = 11.53 cm^3
 water loss = 4.83 cm^3

100% saturation

Table A62 Adjustment at 100% saturation (0 – 5 kPa) X1A3

Adjustment to 100% saturation

Document #: X1B1

Pressure		reading	Δ	reading		w loss		Total		saturation
cm	kPa	mm	reading	$\Delta\theta$	θ	$\Delta\theta$	θ	θ	θ	adjusted
0	0.00	80	0	0.000	15.48	0.00	15.48	g	40.28%	$\text{cm}^3\text{cm}^{-3}$
5	0.50	103	23	3.957	11.53	1.21	12.74	g	33.15%	0.42
7.5	0.75	124	44	7.570	7.91	2.69	10.61	g	27.59%	0.39
10	1.00	127	47	8.086	7.40	3.12	10.52	g	27.36%	0.34
25	2.50	131	51	8.774	6.71	3.39	10.10	g	26.26%	0.29

factor: 93 mm = 8 cm^3 = 8 g H_2O

1 mm = 0.086022 cm^3

total water from reading mm:

8.086022 cm^3

volume = 38.44 cm^3
 dry mass = 58.67 g
 dry dens = 2.6463 g/cm^3
 dry mass = 22.17 cm^3
 water = 16.27 cm^3
 θ_{end} = 6.7 g
 Porosity = 0.4232 $\text{cm}^3\text{cm}^{-3}$

Saturated beginning = 11.41 cm^3
 Saturated end = 6.71 cm^3
 loss water during = 4.70 cm^3
 loss water reading = 8.09 cm^3
 water loss = 3.39 cm^3

100% saturation

Table A63 Adjustment at 100% saturation (0 – 5 kPa) X1B1

Adjustment to 100% saturation

Document #: X1B2

cm	Pressure		reading mm	Δ reading	reading		θ g	w loss inverted $\Delta\theta$ g	Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
	kPa				$\Delta\theta$ g				θ g	θ %	
0	0.00		97	0	0.000		17.61	0.00	17.61	38.94%	0.48
5.5	0.55		99	2	0.344		17.26	0.04	17.30	38.26%	0.44
7.5	0.75		110	13	2.237		15.37	0.45	15.82	34.99%	0.39
10	1.00		113	16	2.753		14.85	0.80	15.66	34.62%	0.33
25	2.50		120	23	3.957		13.65	1.15	14.80	32.73%	0.33

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

2.752688 cm³

volume =	45.22 cm ³	Saturated beginning =	15.25 cm ³
dry mass =	62.6 g	Saturated end =	13.65 cm ³
dry dens =	2.6463 g/cm ³	loss water during =	1.60 cm ³
dry mass =	23.66 cm ³	loss water reading =	2.75 cm ³
water =	21.56 cm ³	water loss =	1.15 cm ³
θ_{end} =	13.7 g		
Porosity =	0.4769 cm ³ cm ⁻³		

Table A64 Adjustment at 100% saturation (0 – 5 kPa) X1B2

Adjustment to 100% saturation

Document #: X1B3

cm	Pressure		reading mm	Δ reading	reading		θ g	w loss inverted $\Delta\theta$ g	Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
	kPa				$\Delta\theta$ g				θ g	θ %	
0	0.00		101	0	0.000		11.41	0.00	11.41	25.24%	0.39
5.5	0.55		106	5	0.860		10.55	0.41	10.96	24.24%	0.36
10	1.00		145	44	7.570		3.84	3.75	7.59	16.78%	0.28
25	2.50		151	50	8.602		2.81	3.92	6.73	14.88%	0.21
50	5.00		147	46	7.914		3.50	3.60	7.10	15.71%	0.21

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

8.602151 cm³

volume =	45.22 cm ³	Saturated beginning =	8.5 cm ³
dry mass =	72.83 g	Saturated end =	3.5 cm ³
dry dens =	2.6463 g/cm ³	loss water during =	5.00 cm ³
dry mass =	27.52 cm ³	loss water reading =	8.60 cm ³
water =	17.70 cm ³	water loss =	3.60 cm ³
θ_{end} =	3.5 g		
Porosity =	0.3914 cm ³ cm ⁻³		
	100% saturation		

Table A65 Adjustment at 100% saturation (0 – 5 kPa) X1B3

Adjustment to 100% saturation

Document #: X1C2

Pressure		reading mm	Δ reading	reading $\Delta\theta$ g		θ g	w loss inverted $\Delta\theta$ g	Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa							θ g	θ %	
0	0.00	101	0	0.000	16.12	0.00	0.00	16.12	35.64%	0.39
10	1.00	162	61	10.495	5.62	4.39	4.39	10.02	22.15%	0.35
20	2.00	172	71	12.215	3.90	5.12	5.12	9.02	19.94%	0.23
25	2.50	172	71	12.215	3.90	5.12	5.12	9.02	19.94%	0.23

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

12.21505 cm³

volume = 45.22 cm³

dry mass = 72.2 g

dry dens = 2.6 g/cm³

dry mass = 27.77 cm³

water = 17.45 cm³

θ_{end} = 3.9 g

Porosity = 0.3859 cm³cm⁻³

100% saturation

Saturated beginning =

Saturated end =

loss water during =

loss water reading =

water loss =

11 cm³

3.9 cm³

7.10 cm³

12.22 cm³

5.12 cm³

Table A66 Adjustment at 100% saturation (0 – 5 kPa) X1C2

Adjustment to 100% saturation

Document #: X1C3

Pressure		reading	Δ	reading		w loss		Total		saturation
cm	kPa	mm	reading	$\Delta\theta$	θ	$\Delta\theta$	θ	θ	θ	adjusted
0	0.00	130	0	0.000	16.19	0.00	16.19	g	%	$\text{cm}^3\text{cm}^{-3}$
10	1.00	192	62	10.667	5.52	4.47	9.99	g	%	
20	2.00	202	72	12.387	3.80	5.19	8.99	g	%	
30	3.00	202	72	12.387	3.80	5.19	8.99	g	%	

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

12.3871 cm³

volume =	45.22 cm ³	Saturated beginning =	11 cm ³
dry mass =	67.2 g	Saturated end =	3.8 cm ³
dry dens =	2.6 g/cm ³	loss water during =	7.20 cm ³
dry mass =	25.85 cm ³	loss water reading =	12.39 cm ³
water =	19.37 cm ³	water loss =	5.19 cm ³
θ_{end} =	3.8 g		
Porosity =	0.4284 cm ³ cm ⁻³		

Table A67 Adjustment at 100% saturation (0 – 5 kPa) X1C3

Adjustment to 100% saturation

Document #: X2A2

Pressure		reading mm	Δ reading	reading		θ g	w loss inverted		Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa			$\Delta\theta$ g	θ g		$\Delta\theta$ g	θ %			
0	0.00	139	0	0.000	23.55	0.00	0.00	23.55	52.09%		0.60
5	0.50	160	21	3.613	19.94	1.07	1.07	21.01	46.46%		0.54
10	1.00	168	29	4.989	18.56	2.09	2.09	20.65	45.67%		0.47
15	1.50	180	41	7.054	16.50	2.95	2.95	16.50	36.49%		0.41

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

7.053763 cm³

volume =	45.22 cm ³	Saturated beginning =	20.6 cm ³
dry mass =	46.3 g	Saturated end =	16.5 cm ³
dry dens =	2.588 g/cm ³	loss water during =	4.10 cm ³
dry mass =	17.89 cm ³	loss water reading =	7.05 cm ³
water =	27.33 cm ³	water loss =	2.95 cm ³
θ_{end} =	16.5 g		
Porosity =	0.6044 cm ³ cm ⁻³		
		100% saturation	

Table A68 Adjustment at 100% saturation (0 – 5 kPa) X2A2

Adjustment to 100% saturation

Document #: X2A3

Pressure		reading mm	Δ reading	reading $\Delta\theta$ g		θ g	w loss inverted $\Delta\theta$ g	Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa							θ g	θ %	
0	0.00	96	0	0.000	24.94	0.00	0.00	24.94	55.15%	0.60
5	0.50	119	23	3.957	20.98	1.26	1.26	22.25	49.19%	0.55
7.5	0.75	125	29	4.989	19.95	2.09	2.09	22.04	48.73%	0.49
10	1.00	134	38	6.538	18.40	2.74	2.74	18.40	40.69%	0.45

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

6.537634 cm³

volume =	45.22 cm ³	Saturated beginning =	22.2 cm ³
dry mass =	46.7 g	Saturated end =	18.4 cm ³
dry dens =	2.588 g/cm ³	loss water during =	3.80 cm ³
dry mass =	18.04 cm ³	loss water reading =	6.54 cm ³
water =	27.18 cm ³	water loss =	2.74 cm ³
θ_{end} =	18.4 g		
Porosity =	0.6010 cm ³ cm ⁻³		
		100% saturation	

Table A69 Adjustment at 100% saturation (0 – 5 kPa) X2A3

Adjustment to 100% saturation

Document #: X2B2

Pressure		reading	Δ	reading		w loss		Total		saturation
cm	kPa	mm	reading	$\Delta\theta$	θ	$\Delta\theta$	θ	θ	θ	adjusted
0	0.00	90	0	0.000	17.60	0.00	17.60	g	%	$\text{cm}^3\text{cm}^{-3}$
5	0.50	107	17	2.925	14.68	0.49	15.17			
7.5	0.75	111	21	3.613	13.99	1.45	15.44			
11.5	1.15	139	49	8.430	9.17	3.46	12.63			
20	2.00	140	50	8.602	9.00	3.53	12.53			

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

8.430108 cm³

volume =	45.22 cm ³	Saturated beginning =	13.9 cm ³
dry mass =	65.6 g	Saturated end =	9 cm ³
dry dens =	2.588 g/cm ³	loss water during =	4.90 cm ³
dry mass =	25.35 cm ³	loss water reading =	8.43 cm ³
water =	19.87 cm ³	water loss =	3.53 cm ³
θ_{end} =	9.0 g		
Porosity =	0.4395 cm ³ cm ⁻³		

Table A70 Adjustment at 100% saturation (0 – 5 kPa) X2B2

Adjustment to 100% saturation

Document #: X2B3

Pressure		reading mm	Δ reading	reading $\Delta\theta$ g		θ g	w loss inverted $\Delta\theta$ g		Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa								θ g	θ %	
0	0.00	91	0	0.000	18.13	0.00	0.00	18.13	48%		0.83
5	0.50	100	9	1.548	16.58	0.10	0.10	16.68	45%		0.66
7.5	0.75	113	22	3.785	14.35	0.81	0.81	15.15	40%		0.46
10	1.00	140	49	8.430	9.70	2.71	2.71	12.41	33%		0.31
20	2.00	152	61	10.495	7.64	4.10	4.10	11.73	31%		0.31
30	3.00	160	69	11.871	6.26	4.97	4.97	11.23	30%		0.30
50	5.00	165	74	12.731	5.40	5.33	5.33	10.73	29%		0.29

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:
12.73118 cm³

volume = 45.22 cm³

dry mass = 20.096 g

dry dens = 2.5926 g/cm³

dry mass = 7.75 cm³

water = 37.47 cm³ 100% saturation

θ_{end} = 5.400 g

Porosity = 0.8286 cm³cm⁻³

Saturated beginning = 12.80 cm³

Saturated end = 5.40 cm³

loss water during = 7.40 cm³

loss water reading = 12.73 cm³

water loss = 5.33 cm³

Table A71 Adjustment at 100% saturation (0 – 5 kPa) X2B3

Adjustment to 100% saturation

Document #: X2C2

cm	Pressure		reading mm	Δ reading	reading $\Delta\theta$ g		θ g	w loss inverted $\Delta\theta$ g		Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
	kPa									θ g	θ %	
0	0.00		80	0	0.000		16.25	0.00		16.25	35.95%	0.54
5	0.50		52	-28	-4.817		21.07	-1.05		20.02	44.28%	0.50
10	1.00		123	43	7.398		8.86	2.48		11.33	25.06%	0.47
20	2.00		139	59	10.151		6.10	3.80		9.90	21.90%	0.44
40	4.00		146	66	11.355		4.90	4.25		9.15	20.24%	0.44

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

10.15054 cm³

volume =	45.22 cm ³	Saturated beginning =	10.8 cm ³
dry mass =	54.7 g	Saturated end =	4.9 cm ³
dry dens =	2.6345 g/cm ³	loss water during =	5.90 cm ³
dry mass =	20.76 cm ³	loss water reading =	10.15 cm ³
water =	24.46 cm ³	water loss =	4.25 cm ³
θ_{end} =	4.9 g		
Porosity =	0.5408 cm ³ cm ⁻³		
	100% saturation		

Table A72 Adjustment at 100% saturation (0 – 5 kPa) X2C2

Adjustment to 100% saturation

Document #: X2C3

Pressure		reading mm	Δ reading	reading		θ g	w loss inverted		Total		saturation adjusted $\text{cm}^3 \text{cm}^{-3}$
cm	kPa			$\Delta\theta$ g	$\Delta\theta$ g		$\Delta\theta$ g	θ %	θ g	θ %	
0	0.00	80	0	0.000	10.56	10.56	0.00	31%	10.56	31%	0.76
5	0.50	78	-2	-0.344	10.91	10.91	-0.53	30%	10.38	30%	0.62
10	1.00	118	38	6.538	4.02	4.02	7.93	35%	11.95	35%	0.62
20	2.00	130	50	8.602	1.96	1.96	6.26	24%	8.22	24%	0.62
40	4.00	124	44	7.570	2.99	2.99	3.76	20%	6.75	20%	0.62
50	5.00	110	30	5.161	5.40	5.40	2.56	23%	7.96	23%	0.47

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

5.16129 cm³

volume = 45.22 cm³

dry mass = 29.114 g

dry dens = 2.6345 g/cm³

dry mass = 11.05 cm³

water = 34.17 cm³ 100% saturation

θ_{end} = 5.400 g

Porosity = 0.7556 cm³cm⁻³

Saturated beginning = 8.00 cm³

Saturated end = 5.40 cm³

loss water during = 2.60 cm³

loss water reading = 5.16 cm³

water loss = 2.56 cm³

Table A73 Adjustment at 100% saturation (0 – 5 kPa) X2C3

Adjustment to 100% saturation

Document #: X3A1

Pressure			reading mm	Δ reading	reading		w loss inverted		Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa	$\Delta\theta$ g			θ g	θ g	θ %				
0	0.00	96	0	0.000	17.44	0.00	0.00	17.44	38.56%	0.63	
5	0.50	119	23	3.957	13.48	0.21	0.21	13.69	30.28%	0.53	
7.5	0.75	125	29	4.989	12.45	0.35	0.35	12.80	28.31%	0.32	
10	1.00	134	38	6.538	10.90	0.46	0.46	10.90	24.10%	0.24	
factor: 93 mm = 8 cm ³ = 8 g H ₂ O											0.33
total water from reading mm:											0.10 0.497766
6.537634 cm ³											0.33 0.21 0.423837
											1.758342 0.000608 0.18
											0.000441

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

volume = 45.22 cm³

dry mass = 43.7 g

dry dens = 2.6278 g/cm³

dry mass = 16.63 cm³

water = 28.59 cm³

θ_{end} = 10.9 g

Porosity = 0.6322 cm³cm⁻³

100% saturation

Saturated beginning = 17.9 cm³

Saturated end = 10.9 cm³

loss water during = 7.00 cm³

loss water reading = 6.54 cm³

water loss = 0.46 cm³

Table A74 Adjustment at 100% saturation (0 – 5 kPa) X3A1

Adjustment to 100% saturation

Document #: X3A2

Pressure		reading mm	Δ reading	reading		θ g	w loss inverted		Total		saturation adjusted $\text{cm}^3\text{cm}^{-3}$
cm	kPa			$\Delta\theta$ g	θ g		$\Delta\theta$ g	θ %			
0	0.00	84	0	0.000	24.23	0.00	0.00	53.58%	24.23	53.58%	0.57
5	0.50	103	19	3.269	20.96	0.88	0.88	48.30%	21.84	48.30%	0.53
7.5	0.75	130	46	7.914	16.31	3.12	3.12	42.97%	19.43	42.97%	0.49
10	1.00	149	65	11.183	13.04	4.54	4.54	38.89%	17.59	38.89%	0.45
25	2.50	151	67	11.527	12.70	4.68	4.68	38.44%	17.38	38.44%	0.45

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

11.1828 cm³

volume =	45.22 cm ³	Saturated beginning =	19.2 cm ³
dry mass =	50.9 g	Saturated end =	12.7 cm ³
dry dens =	2.6278 g/cm ³	loss water during =	6.50 cm ³
dry mass =	19.37 cm ³	loss water reading =	11.18 cm ³
water =	25.85 cm ³	water loss =	4.68 cm ³
θ_{end} =	12.7 g		
Porosity =	0.5717 cm ³ cm ⁻³		
	100% saturation		

Table A75 Adjustment at 100% saturation (0 – 5 kPa) X3A2

Adjustment to 100% saturation

Document #: X3A3

Pressure		reading mm	Δ reading	reading		θ g	w loss inverted		Total		saturation adjusted $\text{cm}^3 \text{cm}^{-3}$
cm	kPa			$\Delta\theta$ g	θ g		$\Delta\theta$ g	θ %			
0	0.00	96	0	0.000	23.04	0.00	0.00	23.04	50.95%		0.64
5	0.50	119	23	3.957	19.08	-0.12	-0.12	18.96	41.93%		0.55
7.5	0.75	125	29	4.989	18.05	-0.20	-0.20	17.85	39.47%		0.43
10	1.00	134	38	6.538	16.50	-0.26	-0.26	16.50	36.49%		0.31

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

6.537634 cm³

volume =	45.22 cm ³	Saturated beginning =	23.3 cm ³
dry mass =	42.4 g	Saturated end =	16.5 cm ³
dry dens =	2.6278 g/cm ³	loss water during =	6.80 cm ³
dry mass =	16.14 cm ³	loss water reading =	6.54 cm ³
water =	29.08 cm ³	water loss =	-0.26 cm ³
θ_{end} =	16.5 g		
Porosity =	0.6432 cm ³ cm ⁻³		

100% saturation

Table A76 Adjustment at 100% saturation (0 – 5 kPa) X3A3

Adjustment to 100% saturation

Document #: X3B2

Pressure		reading	Δ	reading		w loss		saturation	
cm	kPa	mm	reading	$\Delta\theta$	θ	inverted	Total	θ	adjusted
0	0.00	96	0	0.000	13.14	$\Delta\theta$	θ	g	$\text{cm}^3 \text{cm}^{-3}$
5	0.50	119	23	3.957	9.18	g	%		
7.5	0.75	125	29	4.989	8.15				
10	1.00	134	38	6.538	6.60				

factor: 93 mm = 8 cm³ = 8 g H₂O
1 mm = 0.086022 cm³

total water from reading mm:
6.537634 cm³

volume = 45.22 cm³
dry mass = 62.8 g
dry dens = 2.5782 g/cm³
dry mass = 24.36 cm³
water = 20.86 cm³
 θ_{end} = 6.6 g
Porosity = 0.4613 cm³cm⁻³

100% saturation

Saturated beginning = 14.6 cm³
Saturated end = 6.6 cm³
loss water during = 8.00 cm³
loss water reading = 6.54 cm³
water loss = -1.46 cm³

Table A77 Adjustment at 100% saturation (0 – 5 kPa) X3B2

Document #: X3B3

factor: $93 \text{ mm} = 8 \text{ cm}^3 = 8 \text{ g H}_2\text{O}$

$$1 \text{ mm} = 0.086022 \text{ cm}^3$$

9.806452 cm³

volume =	45.22 cm ³	Saturated beginning =	13 cm ³
dry mass =	71.7 g	Saturated end =	7.3 cm ³
dry dens =	2.5782 g/cm ³	loss water during =	5.70 cm ³
dry mass =	27.81 cm ³	loss water reading =	9.81 cm ³
water =	17.41 cm ³	water loss =	4.11 cm ³
		100% saturation	

$$\theta_{\text{end}} = 7.3 \text{ g}$$
$$\text{Porosity} = 0.3850 \text{ cm}^3 \text{ cm}^{-3}$$

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Adjustment to 100% saturation

Document #: X3C2

Pressure		reading mm	Δ reading	reading $\Delta\theta$ g		θ g	w loss inverted $\Delta\theta$ g	Total		saturation adjusted $\text{cm}^3 \text{cm}^{-3}$
cm	kPa							θ g	θ %	
0	0.00	103	0	0.000		15.48	0.00	15.48	34.23%	0.40
5.5	0.55	154	51	8.774		6.70	1.16	7.87	17.40%	0.36
7.5	0.75	161	58	9.978		5.50	1.32	6.82	15.09%	0.20

factor: 93 mm = 8 cm³ = 8 g H₂O

1 mm = 0.086022 cm³

total water from reading mm:

9.978495 cm³

volume =	45.22 cm ³	Saturated beginning =	11.3 cm ³
dry mass =	73.3 g	Saturated end =	0 cm ³
dry dens =	2.6837 g/cm ³	loss water during =	11.30 cm ³
dry mass =	27.31 cm ³	loss water reading =	9.98 cm ³
water =	17.91 cm ³	water loss =	1.32 cm ³
θ_{end} =	5.5 g		
Porosity =	0.3960 cm ³ cm ⁻³		
	100% saturation		

Table A79 Adjustment at 100% saturation (0 – 5 kPa) X3C2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.4700	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0270	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.47	1
2	0.55	0.43	1
3	0.75	0.35	1
4	1	0.29	1
5	2.5	0.29	1
6	50	0.14	1
7	100	0.06	1
8	500	0.06	1
9	1500	0.05	1

RSquared for regression of observed vs fitted values = 0.953

Nonlinear least-squares analysis: final results 95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.47132
Alpha (cm ⁻¹)	1.68899
n	1.40200

Figure A87 Water retention curve and soil parameters, X1A-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.5300	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0270	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.53	1
2	0.50	0.47	1
3	0.75	0.38	1
4	1	0.29	1
5	2.50	0.29	1
6	50	0.15	1
7	100	0.06	1
8	500	0.06	1
9	1500	0.06	1

RSquared for regression of observed vs fitted values = 0.962

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.53688
Alpha (cm ⁻¹)	3.53817
n	1.29454

Figure A88 Water retention curve and soil parameters, X1A-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.4200	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0600	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.42	1
2	0.5	0.39	1
3	0.75	0.34	1
4	1	0.29	1
5	2.5	0.29	1
6	50	0.15	1
7	100	0.04	1
8	500	0.04	1
9	1500	0.03	1

RSquared for regression of observed vs fitted values = 0.970

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.41918
Alpha (cm ⁻¹)	1.46396
n	1.33013

Figure A89 Water retention curve and soil parameters, X1B-1

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.4800	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0600	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.48	1
2	0.55	0.44	1
3	0.75	0.39	1
4	1	0.33	1
5	2.5	0.33	1
6	50	0.13	1
7	100	0.04	1
8	500	0.03	1
9	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.977

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.47580
Alpha (cm ⁻¹)	1.23021
n	1.38152

Figure A90 Water retention curve and soil parameters, X1B-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.3600	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0656	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.39	1
2	0.55	0.36	1
3	1	0.28	1
4	2.5	0.21	1
5	5	0.21	1
7	50	0.03	1
8	100	0.03	1
9	1500	0.03	1

RSquared for regression of observed vs fitted values = 0.981

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.00191
ThetaS (cm ³ /cm ³)	0.39365
Alpha (cm ⁻¹)	1.35350
n	1.41200

Figure A91 Water retention curve and soil parameters, X1B-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.3900	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0083	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.39	1
2	1	0.35	1
3	2	0.23	1
4	2.5	0.23	1
5	50	0.16	1
6	100	0.03	1
7	500	0.03	1
8	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.936

Nonlinear least-squares analysis: final results 95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.39618
Alpha (cm ⁻¹)	1.39334
n	1.34671

Figure A92 Water retention curve and soil parameters, X1C-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.4300	1
3	Alpha (cm ⁻¹)	0.3600	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0083	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.43	1
2	1	0.38	1
3	2	0.24	1
4	3	0.24	1
5	50	0.16	1
6	100	0.03	1
7	500	0.03	1
8	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.944

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.43661
Alpha (cm ⁻¹)	1.40864
n	1.36591

Figure A93 Water retention curve and soil parameters, X1C-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.6000	1
3	Alpha (cm ⁻¹)	0.0360	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0318	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.60	1
2	0.5	0.54	1
3	1	0.47	1
4	1.5	0.41	1
5	50	0.17	1
6	100	0.13	1
7	1500	0.08	1

RSquared for regression of observed vs fitted values = 0.998

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.05457
ThetaS (cm ³ /cm ³)	0.60444
Alpha (cm ⁻¹)	1.56005
n	1.38138

Figure A94 Water retention curve and soil parameters, X2A-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.6000	1
3	Alpha (cm ⁻¹)	0.0360	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0284	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.60	1
2	0.5	0.55	1
3	0.75	0.49	1
4	1	0.45	1
5	50	0.15	1
6	100	0.10	1
7	1500	0.09	1

RSquared for regression of observed vs fitted values = 0.997

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.08239
ThetaS (cm ³ /cm ³)	0.60516
Alpha (cm ⁻¹)	1.28609
n	1.56392

Figure A95 Water retention curve and soil parameters, X2A-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.4400	1
3	Alpha (cm ⁻¹)	0.0360	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0782	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.44	1
2	0.5	0.40	1
3	0.75	0.33	1
4	1.15	0.28	1
5	2	0.28	1
6	50	0.14	1
7	100	0.09	1
8	1500	0.04	1

RSquared for regression of observed vs fitted values = 0.980

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.44532
Alpha (cm ⁻¹)	2.83108
n	1.26705

Figure A96 Water retention curve and soil parameters, X2B-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.8300	1
3	Alpha (cm ⁻¹)	0.0360	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0572	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.83	1
2	0.5	0.66	1
3	0.75	0.46	1
4	1	0.31	1
5	2	0.31	1
6	3	0.30	1
7	5	0.29	1
8	50	0.13	1
9	100	0.10	1
10	1500	0.04	1

RSquared for regression of observed vs fitted values = 0.943

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.06248
ThetaS (cm ³ /cm ³)	0.83890
Alpha (cm ⁻¹)	3.89937
n	1.51593

Figure A97 Water retention curve and soil parameters, X2B-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.5400	1
3	Alpha (cm ⁻¹)	0.0360	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0364	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.54	1
2	0.5	0.50	1
3	1	0.47	1
4	2	0.44	1
5	4	0.44	1
6	50	0.17	1
7	100	0.11	1
8	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.990

Nonlinear least-squares analysis: final results 95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.50820
Alpha (cm ⁻¹)	0.21737
n	1.47643

Figure A98 Water retention curve and soil parameters, X2C-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0780	1
2	ThetaS (cm ³ /cm ³)	0.7600	1
3	Alpha (cm ⁻¹)	0.0360	1
4	n	1.5600	1
5	m	0.3590	0
6	l	0.5000	0
7	Ks (cm/s)	0.0546	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.76	1
2	0.5	0.62	1
3	1	0.62	1
4	2	0.62	1
5	4	0.62	1
6	5	0.47	1
7	50	0.16	1
8	100	0.12	1
9	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.970

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.68217
Alpha (cm ⁻¹)	0.21674
n	1.58375

Figure A99 Water retention curve and soil parameters, X2C-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0650	1
2	ThetaS (cm ³ /cm ³)	0.6300	1
3	Alpha (cm ⁻¹)	0.0750	1
4	n	1.8900	1
5	m	0.4709	0
6	l	0.5000	0
7	Ks (cm/s)	0.0542	0

Observed data

Obsns. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.63	1
2	0.5	0.53	1
3	0.75	0.32	1
4	1	0.24	1
5	50	0.24	1
6	100	0.15	1
7	1500	0.15	1

RSquared for regression of observed vs fitted values = 0.974

Nonlinear least-squares analysis: final results 95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.18104
ThetaS (cm ³ /cm ³)	0.63112
Alpha (cm ⁻¹)	1.66112
n	5.14436

Figure A100 Water retention curve and soil parameters, X3A-1

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0650	1
2	ThetaS (cm ³ /cm ³)	0.5700	1
3	Alpha (cm ⁻¹)	0.0750	1
4	n	1.8900	1
5	m	0.4709	0
6	l	0.5000	0
7	Ks (cm/s)	0.0681	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.57	1
2	0.5	0.53	1
3	0.75	0.49	1
4	1	0.45	1
5	2.5	0.45	1
6	50	0.17	1
7	100	0.14	1
8	1500	0.08	1

RSquared for regression of observed vs fitted values = 0.987

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.01564
ThetaS (cm ³ /cm ³)	0.55758
Alpha (cm ⁻¹)	0.84028
n	1.31888

Figure A101 Water retention curve and soil parameters, X3A-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0650	1
2	ThetaS (cm ³ /cm ³)	0.6400	1
3	Alpha (cm ⁻¹)	0.0750	1
4	n	1.8900	1
5	m	0.4709	0
6	l	0.5000	0
7	Ks (cm/s)	0.0871	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ cm ⁻³)	Weighting coefficient
1	0	0.64	1
2	0.5	0.55	1
3	0.75	0.43	1
4	1	0.31	1
5	50	0.17	1
6	100	0.15	1
7	1500	0.07	1

RSquared for regression of observed vs fitted values = 0.980

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0.12976
ThetaS (cm ³ /cm ³)	0.63826
Alpha (cm ⁻¹)	1.39385
n	3.46229

Figure A102 Water retention curve and soil parameters, X3A-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0650	1
2	ThetaS (cm ³ /cm ³)	0.4600	1
3	Alpha (cm ⁻¹)	0.0750	1
4	n	1.8900	1
5	m	0.4709	0
6	l	0.5000	0
7	Ks (cm/s)	0.0439	0

Observed data

Obsns. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.46	1
2	0.5	0.41	1
3	0.75	0.23	1
4	1	0.21	1
5	50	0.24	1
6	100	0.16	1
7	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.641

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.32777
Alpha (cm ⁻¹)	0.02032
n	1.83675

Figure A103 Water retention curve and soil parameters, X3B-2

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0650	1
2	ThetaS (cm ³ /cm ³)	0.3900	1
3	Alpha (cm ⁻¹)	0.0750	1
4	n	1.8900	1
5	m	0.4709	0
6	l	0.5000	0
7	Ks (cm/s)	0.0588	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.39	1
2	0.5	0.37	1
3	0.75	0.33	1
4	1	0.30	1
5	2	0.30	1
6	50	0.21	1
7	100	0.14	1
8	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.941

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.33864
Alpha (cm ⁻¹)	0.03266
n	1.69578

Figure A104 Water retention curve and soil parameters, X3B-3

Initial values of the coefficients

No.	Name	Initial value	Index
1	ThetaR (cm ³ /cm ³)	0.0570	1
2	ThetaS (cm ³ /cm ³)	0.4000	1
3	Alpha (cm ⁻¹)	0.1240	1
4	n	2.2800	1
5	m	0.5614	0
6	l	0.5000	0
7	Ks (cm/s)	0.0370	0

Observed data

Obs. No.	Pressure head (kPa)	Water content (cm ³ /cm ³)	Weighting coefficient
1	0	0.40	1
2	0.55	0.36	1
3	0.75	0.20	1
4	50	0.21	1
5	100	0.15	1
6	1500	0.02	1

RSquared for regression of observed vs fitted values = 0.770

Nonlinear least-squares analysis: final results

95% Confidence limits

Variable	Value
ThetaR (cm ³ /cm ³)	0
ThetaS (cm ³ /cm ³)	0.32009
Alpha (cm ⁻¹)	0.02764
n	1.69842

Figure A105 Water retention curve and soil parameters, X3C-2

Sample	Layer	α	n
X1	A1	n/a	n/a
	A2	1.688899	1.402000
	A3	3.538170	1.294540
X2	A1	n/a	n/a
	A2	1.560050	1.381380
	A3	1.286090	1.563920
X3	A1	1.661120	5.143600
	A2	0.840280	1.318880
	A3	1.393850	3.462290
X1	B1	1.463960	1.330130
	B2	1.230210	1.361520
	B3	1.353500	1.412000
X2	B1	n/a	n/a
	B2	2.831080	1.267050
	B3	3.899370	1.515930
X3	B1	n/a	n/a
	B2	0.020320	1.836750
	B3	0.032660	1.695780
X1	C1	n/a	n/a
	C2	1.393340	1.346710
	C3	1.408640	1.365910
X2	C1	n/a	n/a
	C2	0.217370	1.476430
	C3	0.216740	1.583750
X3	C1	n/a	n/a
	C2	0.027640	1.698420
	C3	n/a	n/a

	arithmetic means	geometric means	harmonic means	arithmetic means	geometric means	harmonic means
Layer	α	α	α	n	n	n
A	1.70978	1.56821	1.45748	2.223801	1.908112	1.711267
B	1.54730	0.56268	0.08467	1.488451	1.476505	1.465192
C	0.65275	0.30304	0.10679	1.494244	1.488429	1.482726

Layer	n	n	n
A	2.22380	1.90811	1.71127
B	1.48845	1.47651	1.46519
C	1.49424	1.48843	1.48273

Table A80 Summary of soil hydraulic parameters α and n obtained on laboratory experiments and estimation of arithmetic, geometric and harmonic means

Date: Feb 01, 2013

Biomass

Area	0.33 m ²
Bag container	30.00 g
Total weight	167.7 g
Mass weight	137.7 g
Biomass	417.27 g/m ²

Organic Content

Total wet	81.93 g
Container	8.86 g
Net wet	73.07 g
Total dry weight	32.97 g
Water content	40.10 g
Mass dry weight	24.11 g

dried @ 105°F
for 48 hrs

	Container 1C	24.13 g
	Dry mass + container	36.00 g
	net dry mass	11.87 g
burned @ 505°F for 4 hours	Dry mass + container	33.18 g
	Dash weight	9.05 g
	Mass Content	76.24 %
	Organic Content	23.76 %

	Container 2C	25.22 g
	Dry mass + container	37.28 g
	net dry mass	12.06 g
burned @ 505°F for 4 hours	Dry mass + container	34.66 g
	Dash weight	9.44 g
	Mass Content	78.28 %
	Organic Content	21.72 %

Average Organic %	22.74 %
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Table A81 Vegetation biomass February 1, 2013

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	20.5	20.5	20.5
2	Weight of bottle(W_1) in g	37.6521	37.4538	37.4952
3	Weight of bottle + Dry Soil (W_2) in g	47.6632	47.5010	47.5480
4	Weight of bottle + Soil + Water (W_3) in g	93.5619	93.5838	93.6047
5	Weight of bottle + Water (W_4) in g	87.4552	87.3445	87.4438
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.5641	2.6385	2.5830
2	Average G (at 21°C)	2.595		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0111	10.0472	10.0528

Table A82 Specific weight location X1A

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	20.5	20.5	20.5
2	Weight of bottle(W_1) in g	37.7230	36.7306	41.0347
3	Weight of bottle + Dry Soil (W_2) in g	47.7560	46.7920	51.0884
4	Weight of bottle + Soil + Water (W_3) in g	93.7620	92.8787	97.1028
5	Weight of bottle + Water (W_4) in g	87.5183	86.5879	90.8823
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.6477	2.6684	2.6228
2	Average G (at 21°C)	2.646		
3	Correct G (at 27°C).			
	weight of soil (g)	10.033	10.0614	10.0537

Table A83 Specific weight location X1B

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	20.5	20.5	20.5
2	Weight of bottle(W_1) in g	36.8616	37.6810	37.6660
3	Weight of bottle + Dry Soil (W_2) in g	46.8830	47.6998	47.6727
4	Weight of bottle + Soil + Water (W_3) in g	92.9189	93.6145	93.6279
5	Weight of bottle + Water (W_4) in g	86.6722	87.4898	87.5005
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.6549	2.5728	2.5795
2	Average G (at 21°C)	2.602		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0214	10.0188	10.0067

Table A84 Specific weight location X1C

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	21	21	21
2	Weight of bottle(W_1) in g	37.6122	37.5484	40.9285
3	Weight of bottle + Dry Soil (W_2) in g	47.6660	47.5801	50.9641
4	Weight of bottle + Soil + Water (W_3) in	93.5655	93.5082	96.9541
5	Weight of bottle + Water (W_4) in g	87.5410	87.3504	90.8435
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.4952	2.5896	2.5568
2	Average G (at 21°C)	2.547		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0538	10.0317	10.0356

Table A85 Specific weight location X2A

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	21	21	21
2	Weight of bottle(W_1) in g	36.9042	36.8961	37.6174
3	Weight of bottle + Dry Soil (W_2) in g	46.9095	46.9315	47.6196
4	Weight of bottle + Soil + Water (W_3) in g	92.7532	92.9388	93.3903
5	Weight of bottle + Water (W_4) in g	86.7353	86.8030	87.4589
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.5092	2.5734	2.4571
2	Average G (at 21°C)	2.513		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0053	10.0354	10.0022

Table A86 Specific weight location X2B

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	22.5	22.5	22.5
2	Weight of bottle(W_1) in g	37.5907	36.8350	41.0583
3	Weight of bottle + Dry Soil (W_2) in g	47.6860	46.9231	51.1453
4	Weight of bottle + Soil + Water (W_3) in g	93.6299	92.9433	97.2344
5	Weight of bottle + Water (W_4) in g	86.6829	87.3781	91.3531
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	3.2066	2.2304	2.3984
2	Average G (at 21°C)	2.612		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0953	10.0881	10.087

Table A87 Specific weight location X2C

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	20.5	20.5	20.5
2	Weight of bottle(W_1) in g	36.8440	37.5271	37.6347
3	Weight of bottle + Dry Soil (W_2) in g	46.8559	47.5357	47.6616
4	Weight of bottle + Soil + Water (W_3) in g	92.8484	93.4148	93.7148
5	Weight of bottle + Water (W_4) in g	86.6014	87.3570	87.4847
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.6593	2.5333	2.6409
2	Average G (at 21°C)	2.611		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0119	10.0086	10.0269

Table A88 Specific weight location X3A

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	23	23	23
2	Weight of bottle(W_1) in g	36.7412	41.0120	37.6181
3	Weight of bottle + Dry Soil (W_2) in g	46.8408	51.0414	47.6946
4	Weight of bottle + Soil + Water (W_3) in g	92.8822	97.0464	93.6866
5	Weight of bottle + Water (W_4) in g	86.6138	90.8050	87.4675
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.6361	2.6477	2.6123
2	Average G (at 21°C)	2.632		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0996	10.0294	10.0765

Table A89 Specific weight location X3B

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	20.5	20.5	20.5
2	Weight of bottle(W_1) in g	36.7244	37.6149	41.0112
3	Weight of bottle + Dry Soil (W_2) in g	46.7507	47.6182	51.0307
4	Weight of bottle + Soil + Water (W_3) in g	92.7852	93.8362	97.1271
5	Weight of bottle + Water (W_4) in g	86.6283	87.5377	90.9480
CALCULATION				
1	Specific Gravity $G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.5912	2.7001	2.6090
2	Average G (at 21°C)	2.633		
3	Correct G (at 27°C).			
	weight of soil (g)	10.0996	10.0294	10.0765

Table A90 Specific weight location X3C

Sample	X1A/B/C				
Sample Height		2.5 cm			
Sample Diameter		4.8 cm	Sample Radius		2.4 cm
Sample Area		18.0864 cm ²			

Soil Layer	Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
A	12.5	50	104	0.5	102.39	0.488329	0.02700
	12.5	50	102	0.4			
	12.5	50	101	0.5			
B	12.5	50	45	1.1	46.08	1.085187	0.0600
	12.5	50	46	1.1			
	12.5	50	47	1.1			
C	12.5	50	335	0.1	333.00	0.15015	0.00830
	12.5	50	317	0.2			
	12.5	50	347	0.1			

Table A91 Saturated hydraulic conductivity location X1A, X1B, AND X1C

Sample	X2A				
Sample Height		2.5	cm		
Sample Diameter		4.8	cm	Sample Radius	2.4 cm
Sample Area		18.086	cm ²		

Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
12.5	50	122	0.4	122.33	0.408719	0.0226
12.5	50	124	0.4			
12.5	50	121	0.4			
16.5	50	81	0.6	87.00	0.574713	0.0318
16.5	50	90	0.6			
16.5	50	90	0.6			
14.5	50	95	0.5	97.33	0.513699	0.0284
14.5	50	100	0.5			
14.5	50	97	0.5			

Average K (cm/s)	0.027592
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Table A92 Saturated hydraulic conductivity location X2A

Sample	X2B				
Sample Height		2.5 cm			
Sample Diameter		4.8 cm	Sample Radius		2.4 cm
Sample Area		18.0864 cm ²			

Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
13.5	50	34	1.5	35.33	1.42	0.078241
13.5	50	36	1.4			
13.5	50	36	1.4			
11	50	44	1.1	45.00	1.11	0.061434
11	50	46	1.1			
11	50	45	1.1			
10	50	49	1.0	48.33	1.03	0.057197
10	50	48	1.0			
10	50	48	1.0			

Average K (cm/s)	0.065624
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Table A93 Saturated hydraulic conductivity location X2B

Sample	X2C		
Sample Height	2.5 cm		
Sample Diameter	4.8 cm	Sample Radius	2.4 cm
Sample Area	18.0864 cm ²		

Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
12.5	50	66	0.8	66.67	0.75	0.041468
12.5	50	65	0.8			
12.5	50	69	0.7			
11	50	78	0.6	76.00	0.66	0.036375
11	50	79	0.6			
11	50	71	0.7			
14	50	52	1.0	50.67	0.99	0.054563
14	50	50	1.0			
14	50	50	1.0			

Average K (cm/s)	0.044135
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Table A94 Saturated hydraulic conductivity location X2B

Sample	X3A		
Sample Height	2.5 cm		
Sample Diameter	4.8 cm	Sample Radius	2.4 cm
Sample Area	18.0864 cm ²		

Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
11.5	50	51	1.0	54.50	0.98	0.054206
11.5	50	60	0.8			
11.5	50	55	0.9			
11.5	50	52	1.0			
13	50	41	1.2	40.60	1.23	0.068091
13	50	42	1.2			
13	50	42	1.2			
13	50	47	1.1			
15	50	31	1.6	31.750	1.575	0.087071
15	50	30	1.7			
15	50	33	1.5			
15	50	33	1.5			

Average K (cm/s)	0.069789
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Table A95 Saturated hydraulic conductivity location X3A

Sample	X3B		
Sample Height	2.5 cm		
Sample Diameter	4.8 cm	Sample Radius	2.4 cm
Sample Area	18.0864 cm ²		

Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
14.5	50	54	0.9	54.67	0.93	0.051195
14.5	50	55	0.9			
14.5	50	55	0.9			
13	50	67	0.7	63.00	0.79	0.043881
13	50	62	0.8			
13	50	60	0.8			
16	50	48	1.0	47.00	1.06	0.058819
16	50	47	1.1			
16	50	46	1.1			

Average K (cm/s)	0.051298
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Table A96 Saturated hydraulic conductivity location X3B

Sample	X3C		
Sample Height	2.5 cm		
Sample Diameter	4.8 cm	Sample Radius	2.4 cm
Sample Area	18.0864 cm ²		

Height (cm)	Volume (cm ³)	Time (s)	Flowrate (cm ³ /s)	Average Time (s)	Flowrate (cm ³ /s)	K (cm/s)
10	50	368	0.1	369.50	0.14	0.007482
10	50	371	0.1			
10	50	295	0.2			
12.5	50	80	0.6	74.67	0.67	0.037025
12.5	50	74	0.7			
12.5	50	70	0.7			
15	50	41	1.2	38.00	1.32	0.07275
15	50	37	1.4			
15	50	36	1.4			

Average K (cm/s)	0.039086
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Table A97 Saturated hydraulic conductivity location X3C

LOCATION	LAYER	θ_s	θ_r	α	n	K_s
X1	A2	0.4713	0.0000	1.6890	1.4020	0.0270
X1	A3	0.5369	0.0000	3.5382	1.2945	0.0270
X1	B1	0.4192	0.0000	1.4640	1.3301	0.0600
X1	B2	0.4758	0.0000	1.3021	1.3815	0.0600
X1	B3	0.3937	0.0019	1.3535	1.4120	0.0600
X1	C2	0.39618	0.0000	1.3933	1.3467	0.0083
X1	C3	0.43661	0.0000	1.4086	1.3659	0.0083
X2	A2	0.6044	0.0546	1.5601	1.3814	0.0318
X2	A3	0.6052	0.0824	1.2861	1.5639	0.0284
X2	B2	0.4453	0.0000	2.8311	1.2671	0.0782
X2	B3	0.8389	0.0625	3.8994	1.5159	0.0572
X2	C2	0.5082	0.0000	0.2174	1.4764	0.0364
X2	C3	0.6822	0.0000	0.2167	1.5838	0.0546
X3	A1	0.6311	0.1810	1.6611	5.1444	0.0542
X3	A2	0.5576	0.0156	0.8403	1.3189	0.0681
X3	A3	0.6383	0.1298	1.3939	3.4623	0.0871
X3	B2	0.3278	0.0000	0.0203	1.8368	0.0439
X3	B3	0.3386	0.0000	0.0327	1.6958	0.0588
X3	C2	0.3201	0.0000	0.0276	1.6984	0.0370

Table A98 Soil layers hydraulic parameters from laboratory experiments

gridloc	ZI (cm)	h (kPa)
SR01	-20.79	-195
SR02	-25.67	-320
SR03	-25.67	-150
SR04	-25.36	-395
SR05	-24.45	-250
SR06	-22.32	-420
SR07	-16.52	-320
SR08	-17.44	-250
SR09	-11.65	-140
SR10	-14.09	-105
SR11	-16.22	-115
SR12	-16.52	-190
SR13	-17.13	-130
SR14	-15.31	-130
SR15	-14.70	-120
SR16	-16.22	-195
SR17	-5.55	-115
SR18	-11.04	-140
SR19	-11.65	-120
SR20	-13.17	-120
SR21	-12.87	-130
SR22	-12.26	-120
SR23	-10.73	-120
SR24	-4.33	-105
SR25	-6.16	-120
SR26	-11.04	-120
SR27	-11.34	-160
SR28	-11.65	-140
SR29	-11.65	-140
SR30	-11.04	-140
SR31	-8.61	-140
SR32	-3.11	-75
SR33	-3.72	0
SR34	-7.69	-130

gridloc	ZI (cm)	h (kPa)
SR35	-9.21	-150
SR36	-12.26	-150
SR37	-13.17	-140
SR38	-13.48	-150
SR39	-12.26	-120
SR40	-5.55	-130
SR41	-3.72	-75
SR42	-11.34	-130
SR43	-19.27	-150
SR44	-15.31	-150
SR45	-12.87	-140
SR46	-10.43	-100
SR47	-4.33	-80
SR48	-2.50	0
SR49	-8.60	-110
SR50	-14.09	-150
SR51	-16.52	-140
SR52	-16.52	-300
SR53	-11.34	-100
SR54	-5.55	-80
SR55	-4.94	-80
SR56	-10.43	-110
SR57	-15.31	-190
SR58	-16.52	-190
SR59	-14.70	-140
SR60	-9.82	-140
SR61	0.54	0
SR62	-2.50	0
SR63	-7.99	-195
SR64	-14.70	-195
SR65	-16.22	-195
SR66	-15.31	-195
SR67	-11.04	-100
SR68	-2.50	0

Table A99 SWAP: water table depth (cm) and surface pressure head (kPa)

gridloc	Zl (cm)	h (kPa)
SR69	-2.50	0
SR70	-9.21	-100
SR71	-14.09	-140
SR72	-15.31	-140
SR73	-12.56	-195
SR74	-5.25	-120
SR75	-0.98	0
SR76	-0.98	0
SR77	-4.33	0
SR78	-11.65	-140
SR79	-13.17	-100
SR80	-13.17	-150
SR81	-11.04	-190
SR82	-4.33	-75
SR83	-3.11	-75
SR84	-8.60	-90
SR85	-11.65	-150
SR86	-12.26	-140
SR87	-9.21	-120
SR88	-4.94	-110
SR89	3.59	0
SR90	3.59	0
SR91	-4.33	-105
SR92	-8.60	-75
SR93	-11.65	-120
SR94	-11.34	-120
SR95	-7.38	-80
SR96	-4.33	-75
SR97	-2.20	0
SR98	-7.99	-80
SR99	-11.34	-120
SR100	-11.95	-120
SR101	-9.82	-75
SR102	-4.33	-55

gridloc	Zl (cm)	h (kPa)
SR103	3.59	0.0
SR104	3.59	0.0
SR105	-3.11	0.0
SR106	-9.21	-110.0
SR107	-10.43	-130.0
SR108	-11.04	-140.0
SR109	-5.86	-80.0
SR110	-1.28	0.0
SR111	-0.67	0.0
SR112	-4.03	-55.0
SR113	-8.29	-90.0
SR114	-5.55	-100.0
SR115	-4.94	-75.0
SR116	-2.20	0.0
SR117	-1.89	0.0

Table A99 SWAP: water table depth (cm) and surface pressure head (kPa) (Cont.)

Figure A106 Modeling of soil moisture content at 0.2 cm depth between June 3 and 7, 2013

Figure A107 Modeling of soil moisture content at 0.8 cm depth between June 3 and 7, 2013

Figure A108 Modeling of soil moisture content at 2.5 cm depth between June 3 and 7, 2013

Figure A109 Modeling of soil moisture content at 6.5 cm depth between June 3 and 7, 2013

Cell-grid	SWAP - wcontent				POGO field measurements				(Difference) ²			
	03-Jun	04-Jun	05-Jun	06-Jun	03-Jun	04-Jun	05-Jun	06-Jun	03-Jun	04-Jun	05-Jun	06-Jun
1	0.35	0.35	0.34	0.34	0.21	0.27	0.25	0.33	0.019321	0.006084	0.009409	0.000256
2	0.35	0.35	0.35	0.35	0.29	0.29	0.24	0.36	0.002879	0.003249	0.011236	0.000324
3	0.35	0.35	0.34	0.34	0.35	0.48	0.37	0.34	0.000000	0.016641	0.000841	0.000000
4	0.35	0.35	0.35	0.35	0.31	0.46	0.37	0.35	0.001156	0.011449	0.000784	0.000000
5	0.35	0.35	0.34	0.34	0.30	0.40	0.33	0.34	0.002025	0.003025	0.000289	0.000000
6	0.35	0.35	0.35	0.35	0.40	0.53	0.41	0.35	0.002916	0.032041	0.003969	0.000000
7	0.35	0.35	0.35	0.35	0.39	0.41	0.41	0.35	0.001600	0.004096	0.003721	0.000000
8	0.17	0.17	0.35	0.35	0.38	0.46	0.43	0.35	0.047089	0.085264	0.006561	0.000000
9	0.17	0.17	0.35	0.35	0.39	0.45	0.41	0.35	0.048841	0.081225	0.003969	0.000000
10	0.17	0.17	0.35	0.38	0.50	0.59	0.37	0.38	0.112896	0.173889	0.000576	0.000000
11	0.17	0.17	0.35	0.35	0.41	0.37	0.37	0.35	0.059536	0.038809	0.000784	0.000000
12	0.17	0.17	0.35	0.35	0.39	0.47	0.38	0.35	0.049729	0.090601	0.001296	0.000000
13	0.17	0.17	0.35	0.35	0.39	0.57	0.39	0.35	0.050625	0.156816	0.001600	0.000000
14	0.17	0.17	0.35	0.35	0.17	0.59	0.41	0.35	0.000000	0.175561	0.003600	0.000000
15	0.17	0.17	0.35	0.32	0.17	0.17	0.35	0.32	0.000000	0.000001	0.000000	0.000000
16	0.17	0.17	0.35	0.35	0.17	0.17	0.35	0.35	0.000000	0.000001	0.000000	0.000000
17	0.22	0.22	0.22	0.22	0.17	0.34	0.29	0.33	0.002116	0.014884	0.004900	0.012996
18	0.35	0.35	0.34	0.34	0.34	0.40	0.27	0.39	0.000100	0.002704	0.005776	0.002209
19	0.35	0.35	0.35	0.35	0.32	0.39	0.33	0.38	0.000676	0.001849	0.000361	0.001225
20	0.35	0.35	0.34	0.40	0.32	0.39	0.25	0.45	0.000961	0.001444	0.007921	0.002704
21	0.35	0.35	0.34	0.42	0.32	0.37	0.31	0.40	0.001089	0.000441	0.000625	0.000529
22	0.35	0.35	0.34	0.34	0.31	0.39	0.36	0.36	0.001764	0.001369	0.000289	0.000225
23	0.35	0.35	0.34	0.34	0.35	0.39	0.40	0.40	0.000016	0.001369	0.003721	0.002809
24	0.10	0.10	0.10	0.10	0.33	0.45	0.44	0.45	0.052900	0.127449	0.119025	0.124609
25	0.22	0.47	0.47	0.47	0.34	0.37	0.35	0.43	0.016129	0.011025	0.013924	0.001600
26	0.17	0.17	0.34	0.34	0.36	0.42	0.31	0.34	0.035721	0.061009	0.000576	0.000000
27	0.17	0.17	0.35	0.47	0.26	0.37	0.26	0.40	0.009216	0.041209	0.007225	0.004489
28	0.17	0.17	0.35	0.35	0.36	0.43	0.35	0.35	0.037636	0.067600	0.000001	0.000000
29	0.17	0.17	0.35	0.35	0.37	0.43	0.38	0.35	0.042436	0.070225	0.001156	0.000000
30	0.17	0.17	0.34	0.34	0.38	0.49	0.34	0.34	0.043681	0.104329	0.000081	0.000000
31	0.17	0.17	0.34	0.47	0.37	0.51	0.36	0.47	0.042436	0.116964	0.000400	0.000000
32	0.10	0.10	0.10	0.10	0.47	0.48	0.40	0.10	0.132496	0.139876	0.090000	0.000000
33	0.54	0.54	0.54	0.54	0.14	0.36	0.22	0.31	0.156816	0.031684	0.104976	0.052441
34	0.36	0.36	0.35	0.47	0.33	0.38	0.26	0.38	0.000784	0.000225	0.008281	0.007569
35	0.35	0.35	0.34	0.41	0.32	0.39	0.31	0.40	0.000841	0.001600	0.001521	0.000121
36	0.35	0.35	0.34	0.34	0.27	0.36	0.31	0.40	0.007225	0.000225	0.000784	0.003721
37	0.35	0.35	0.34	0.40	0.27	0.33	0.26	0.38	0.006084	0.000289	0.005776	0.000576
38	0.35	0.35	0.34	0.38	0.27	0.35	0.33	0.37	0.006241	0.000001	0.000064	0.000100
39	0.35	0.35	0.34	0.34	0.20	0.28	0.31	0.34	0.024025	0.004225	0.000961	0.000016
40	0.09	0.09	0.09	0.09	0.26	0.36	0.28	0.38	0.028561	0.068121	0.035344	0.081225
41	0.10	0.10	0.10	0.10	0.25	0.34	0.31	0.39	0.022801	0.058081	0.045796	0.084681
42	0.17	0.17	0.35	0.35	0.30	0.37	0.26	0.37	0.017161	0.039601	0.008100	0.000441
43	0.17	0.17	0.35	0.35	0.28	0.34	0.26	0.41	0.011881	0.028224	0.007744	0.003481
44	0.17	0.17	0.35	0.35	0.27	0.43	0.28	0.40	0.010609	0.069696	0.004624	0.003025
45	0.17	0.17	0.35	0.47	0.31	0.41	0.28	0.39	0.020449	0.058081	0.005041	0.005625

Table A100 Prediction and measured soil moisture content evaluation

Cell-grid	SWAP - wcontent				POGO field measurements				(Difference) ²			
	03-Jun	04-Jun	05-Jun	06-Jun	03-Jun	04-Jun	05-Jun	06-Jun	03-Jun	04-Jun	05-Jun	06-Jun
46	0.17	0.17	0.35	0.35	0.31	0.41	0.30	0.38	0.020164	0.057121	0.002401	0.001369
47	0.10	0.10	0.10	0.10	0.28	0.42	0.35	0.10	0.033124	0.107584	0.064009	0.000000
48	0.47	0.47	0.47	0.47	0.37	0.54	0.43	0.47	0.010404	0.005476	0.001369	0.000000
49	0.35	0.35	0.33	0.44	0.20	0.30	0.18	0.34	0.021609	0.002304	0.024964	0.010609
50	0.35	0.35	0.34	0.36	0.26	0.32	0.33	0.37	0.009025	0.000961	0.000144	0.000049
51	0.35	0.35	0.34	0.34	0.31	0.38	0.31	0.35	0.002025	0.000900	0.000729	0.000100
52	0.35	0.35	0.35	0.35	0.29	0.38	0.33	0.41	0.003969	0.001296	0.000441	0.004356
53	0.35	0.35	0.35	0.35	0.29	0.35	0.30	0.41	0.003136	0.000016	0.002025	0.003844
54	0.23	0.23	0.23	0.23	0.27	0.34	0.30	0.34	0.001369	0.011236	0.005184	0.011881
55	0.23	0.23	0.23	0.23	0.28	0.31	0.26	0.35	0.002209	0.006400	0.000961	0.014400
56	0.17	0.17	0.35	0.35	0.26	0.31	0.30	0.32	0.007569	0.020164	0.001936	0.000576
57	0.17	0.17	0.35	0.35	0.26	0.30	0.32	0.35	0.008281	0.018496	0.000841	0.000036
58	0.17	0.17	0.35	0.35	0.31	0.37	0.31	0.37	0.019321	0.041209	0.001600	0.000529
59	0.17	0.17	0.35	0.32	0.35	0.35	0.31	0.40	0.032761	0.032400	0.001296	0.005476
60	0.17	0.17	0.35	0.35	0.29	0.37	0.31	0.40	0.013924	0.041616	0.001681	0.002401
61	0.47	0.47	0.47	0.47	0.32	0.38	0.30	0.37	0.023104	0.008836	0.028224	0.010816
62	0.47	0.47	0.47	0.47	0.33	0.40	0.26	0.42	0.020164	0.005625	0.044521	0.002209
63	0.17	0.17	0.34	0.47	0.30	0.39	0.32	0.47	0.018769	0.049729	0.000196	0.000000
64	0.17	0.17	0.35	0.32	0.35	0.46	0.38	0.32	0.031684	0.085849	0.001156	0.000000
65	0.35	0.35	0.34	0.34	0.15	0.27	0.19	0.32	0.038025	0.005476	0.023104	0.000576
66	0.35	0.35	0.34	0.34	0.30	0.31	0.36	0.39	0.002116	0.001849	0.000400	0.002704
67	0.35	0.35	0.34	0.34	0.32	0.36	0.32	0.38	0.000841	0.000064	0.000441	0.001225
68	0.54	0.54	0.54	0.54	0.28	0.38	0.26	0.40	0.066049	0.025921	0.078400	0.019044
69	0.54	0.54	0.54	0.54	0.28	0.32	0.29	0.40	0.069169	0.050625	0.062500	0.019600
70	0.35	0.35	0.34	0.41	0.29	0.34	0.28	0.35	0.003136	0.000025	0.004096	0.003481
71	0.35	0.35	0.34	0.36	0.27	0.31	0.22	0.34	0.005776	0.001444	0.013225	0.000441
72	0.08	0.08	0.22	0.23	0.29	0.34	0.32	0.32	0.044521	0.069169	0.008649	0.007921
73	0.07	0.07	0.19	0.61	0.23	0.29	0.25	0.35	0.026896	0.048841	0.003721	0.065536
74	0.11	0.11	0.11	0.11	0.25	0.35	0.31	0.37	0.020449	0.061009	0.042025	0.067600
75	0.61	0.61	0.61	0.61	0.29	0.36	0.24	0.39	0.105625	0.064516	0.134689	0.050176
76	0.61	0.61	0.61	0.61	0.33	0.37	0.28	0.61	0.081225	0.060025	0.110889	0.000000
77	0.61	0.61	0.61	0.61	0.43	0.27	0.38	0.61	0.033856	0.116281	0.055225	0.000000
78	0.08	0.08	0.23	0.23	0.43	0.44	0.34	0.23	0.119025	0.128164	0.012321	0.000000
79	0.10	0.10	0.27	0.30	0.33	0.35	0.27	0.30	0.055225	0.062001	0.000001	0.000000
80	0.08	0.08	0.22	0.27	0.40	0.50	0.50	0.27	0.102400	0.178084	0.077841	0.000000
81	0.35	0.35	0.34	0.34	0.28	0.35	0.28	0.33	0.005184	0.000009	0.003481	0.000081
82	0.24	0.24	0.24	0.24	0.31	0.33	0.28	0.38	0.004489	0.007921	0.001681	0.019600
83	0.26	0.26	0.26	0.26	0.31	0.38	0.27	0.46	0.002601	0.014641	0.000064	0.041209
84	0.35	0.34	0.33	0.44	0.28	0.38	0.35	0.44	0.004489	0.001521	0.000196	0.000001
85	0.35	0.35	0.35	0.35	0.27	0.37	0.31	0.46	0.005776	0.000441	0.001764	0.013225
86	0.35	0.35	0.34	0.34	0.35	0.36	0.36	0.34	0.000001	0.000225	0.000256	0.000000
87	0.35	0.35	0.34	0.41	0.33	0.39	0.27	0.41	0.000400	0.001936	0.005929	0.000000
88	0.12	0.12	0.12	0.12	0.30	0.30	0.32	0.12	0.033856	0.034969	0.039204	0.000000
89	0.61	0.61	0.61	0.61	0.24	0.36	0.29	0.61	0.139876	0.065025	0.099856	0.000000
90	0.61	0.61	0.61	0.61	0.32	0.42	0.40	0.61	0.087025	0.036100	0.046225	0.000000

Table A100 Prediction and measured soil moisture content evaluation (Cont.)

Cell-grid	SWAP - wcontent				POGO field measurements				(Difference) ²			
	03-Jun	04-Jun	05-Jun	06-Jun	03-Jun	04-Jun	05-Jun	06-Jun	03-Jun	04-Jun	05-Jun	06-Jun
91	0.13	0.13	0.13	0.13	0.37	0.52	0.41	0.13	0.057121	0.152100	0.075076	0.000000
92	0.12	0.12	0.33	0.33	0.34	0.39	0.37	0.33	0.047089	0.072900	0.002209	0.000000
93	0.09	0.09	0.24	0.25	0.34	0.47	0.40	0.25	0.064009	0.143641	0.025281	0.000000
94	0.09	0.09	0.25	0.25	0.48	0.49	0.45	0.25	0.155236	0.157609	0.040401	0.000000
95	0.12	0.12	0.32	0.33	0.33	0.57	0.42	0.33	0.043681	0.197136	0.009025	0.000000
96	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.000000	0.000000	0.000000	0.000000
97	0.54	0.54	0.54	0.54	0.17	0.28	0.24	0.34	0.136161	0.067600	0.091204	0.041209
98	0.35	0.35	0.45	0.46	0.31	0.41	0.29	0.40	0.001225	0.003136	0.026244	0.003600
99	0.35	0.35	0.35	0.35	0.29	0.37	0.31	0.35	0.003600	0.000400	0.001296	0.000009
100	0.35	0.35	0.35	0.35	0.29	0.32	0.27	0.35	0.003600	0.001089	0.006724	0.000000
101	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.000016	0.000016	0.000016	0.000000
102	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.000000	0.000000	0.000000	0.000000
103	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.000000	0.000000	0.000000	0.000000
104	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.000000	0.000000	0.000000	0.000000
105	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.000000	0.000000	0.000000	0.000000
106	0.10	0.10	0.26	0.27	0.27	0.27	0.27	0.27	0.029241	0.029241	0.000025	0.000000
107	0.09	0.09	0.24	0.24	0.24	0.24	0.24	0.24	0.025281	0.025281	0.000064	0.000000
108	0.08	0.08	0.23	0.23	0.23	0.23	0.23	0.23	0.022801	0.022801	0.000025	0.000000
109	0.41	0.41	0.41	0.61	0.61	0.61	0.61	0.61	0.042025	0.042025	0.042025	0.000000
110	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.000000	0.000000	0.000000	0.000000
111	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.000000	0.000000	0.000000	0.000000
112	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.000000	0.000000	0.000000	0.000000
113	0.35	0.35	0.34	0.52	0.24	0.36	0.28	0.36	0.011449	0.000100	0.003364	0.024025
114	0.22	0.22	0.22	0.22	0.24	0.33	0.28	0.28	0.000169	0.011236	0.003600	0.003136
115	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.000000	0.000000	0.000000	0.000000
116	0.54	0.54	0.54	0.54	0.39	0.48	0.54	0.54	0.022201	0.003481	0.000000	0.000000
117	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.000000	0.000000	0.000000	0.000000
									3.137011	4.465843	1.870068	0.850047
σ^2 :									2.68E-02	3.82E-02	1.60E-02	7.27E-03
RMSE:									0.164	0.195	0.126	0.085

Table A100 Prediction and measured soil moisture content evaluation (Cont.)

Figure A110 Soil profile used for preferential flow model simulation

GEOMETRY

Z_AH = -26.0
 Z_IC = -35.0
 Z_ST = -41.0
 VIMpStSs = 0.04
 PplcSs = 0.6
 NumSbDm = 4
 PowM = 0.8
 RZah = 0.0
 SPoint = 1.0
 SwPowM = 0

 DiPoMi = 10.0
 DiPoMa = 50.0
 ZDiPoMa = -180.0

					e_o	ϑ_a	ϑ_i	e_i	
ISOILLAY3	SWSoilShr	SwShrInp	ThetCrMF	GeomFa	ShrParA	ShrParB	ShrParC	ShrParD	ShrPrE
1	2	3	0.88	3.0	2.5	13.5	4.5	0.9	0.0
2	0	3	0.80	3.0	2	13.0	3.6	0.7	0.0
3	2	3	0.85	3.0	1.2	12.6	2.9	0.4	0.0

ZnCrAr = -5.0

WATER FLOW

ISOILLAY4	SwSorp	SorpFacF	SorpMax	SorpAlfa
1	1	0.33	0.0	0.0
2	1	0.33	0.0	0.0
3	1	0.50	0.0	0.0

ShapeFacMp = 1.0
 CritUndSatVol = 0.1

SwDrRap = 1
 RapDraResRef = 15.0
 RapDraReaExp = 1.0

NumLevRapDra = 1
 PNDMXMP = 0.0

Table A101 Macroporosity parameters used for modeling preferential flow

* Project: Observations
 * File content: Macropore geometry: Pp = proportion (-);
 * Vls = volume static macropores(cm3/cm2).
 * Bot.depth = bottom depth compartment (cm).
 * File name: .\MacroGeom.Csv
 * Model version: Swap 3.2.36
 * Generated at: 18-Apr-2014 14:51:23

Compartment	Bot.depth	PpDm01	PpDm02	PpDm03	PpDm04	PpDm05	VlsTot	VlsMB	VlsIC
1	1	0.4	0.15	0.15	0.15	0.15	0.04	0.016	0.024
2	2	0.4	0.15	0.15	0.15	0.15	0.04	0.016	0.024
3	3	0.4	0.15	0.15	0.15	0.15	0.04	0.016	0.024
4	4	0.4	0.15	0.15	0.15	0.15	0.04	0.016	0.024
5	5	0.4	0.15	0.15	0.15	0.15	0.04	0.016	0.024
6	6	0.4405	0.1652	0.1652	0.1652	0.0639	0.0363	0.016	0.0203
7	7	0.5183	0.1944	0.1944	0.0929	0	0.0309	0.016	0.0149
8	8	0.61	0.2287	0.1613	0	0	0.0262	0.016	0.0102
9	9	0.7283	0.2717	0	0	0	0.022	0.016	0.006
10	10	0.8915	0.1085	0	0	0	0.0179	0.016	0.0019
11	11	1	0	0	0	0	0.0144	0.0144	0
12	12	1	0	0	0	0	0.0112	0.0112	0
13	13	1	0	0	0	0	0.008	0.008	0
14	14	1	0	0	0	0	0.0048	0.0048	0
15	15	1	0	0	0	0	0.0016	0.0016	0
16	16	1	0	0	0	0	0	0	0
17	17	1	0	0	0	0	0	0	0
18	18	1	0	0	0	0	0	0	0
19	19	1	0	0	0	0	0	0	0
20	20	1	0	0	0	0	0	0	0
21	22	1	0	0	0	0	0	0	0
22	24	1	0	0	0	0	0	0	0
23	26	1	0	0	0	0	0	0	0
24	28	1	0	0	0	0	0	0	0
25	30	1	0	0	0	0	0	0	0
26	32	1	0	0	0	0	0	0	0
27	34	1	0	0	0	0	0	0	0
28	36	1	0	0	0	0	0	0	0
29	38	1	0	0	0	0	0	0	0
30	40	1	0	0	0	0	0	0	0
31	45	1	0	0	0	0	0	0	0
32	50	1	0	0	0	0	0	0	0
33	55	1	0	0	0	0	0	0	0
34	60	1	0	0	0	0	0	0	0
35	70	1	0	0	0	0	0	0	0
36	80	1	0	0	0	0	0	0	0
37	100	1	0	0	0	0	0	0	0
38	120	1	0	0	0	0	0	0	0
39	140	1	0	0	0	0	0	0	0
40	160	1	0	0	0	0	0	0	0
41	180	1	0	0	0	0	0	0	0

Table A102 Macropore geometry used to simulate modeling of soil moisture content using preferential flow

* Project: Observations
 * File content: soil shrinkage characteristics
 * File name: .\SoilShrinkChar.csv
 * Model version: Swap 3.2.36
 * Generated at: 21-Apr-2014 15:17:03

layer	Moist Ratio (-)	Void Ratio (-)
1	0	2.5
1	0.0138	2.4951
1	0.0276	2.4902
1	0.0414	2.4853
1	0.0552	2.4804
1	0.069	2.4754
1	0.0829	2.4705
1	0.0967	2.4656
1	0.1105	2.4607
1	0.1243	2.4558
1	0.1381	2.4509
1	0.1519	2.446
1	0.1657	2.4411
1	0.1795	2.4362
1	0.1933	2.4313
1	0.2071	2.4263
1	0.221	2.4214
1	0.2348	2.4165
1	0.2486	2.4116
1	0.2624	2.4067
1	0.2762	2.4018
1	0.29	2.3969
1	0.3038	2.392
1	0.3176	2.3871
1	0.3314	2.3822
1	0.3452	2.3772
1	0.359	2.3723
1	0.3729	2.3674
1	0.3867	2.3625
1	0.4005	2.3576
1	0.4143	2.3527
1	0.4281	2.3478
1	0.4419	2.3429
1	0.4557	2.338
1	0.4695	2.3331
1	0.4833	2.3281
1	0.4971	2.3232

layer	Moist Ratio (-)	Void Ratio (-)
1	0.511	2.3183
1	0.5248	2.3134
1	0.5386	2.3085
1	0.5524	2.3036
1	0.5662	2.2987
1	0.58	2.2938
1	0.5938	2.2889
1	0.6076	2.284
1	0.6214	2.279
1	0.6352	2.2741
1	0.649	2.2692
1	0.6629	2.2643
1	0.6767	2.2594
1	0.6905	2.2545
1	0.7043	2.2496
1	0.7181	2.2447
1	0.7319	2.2398
1	0.7457	2.2349
1	0.7595	2.2299
1	0.7733	2.225
1	0.7871	2.2201
1	0.801	2.2152
1	0.8148	2.2103
1	0.8286	2.2054
1	0.8424	2.2005
1	0.8562	2.1956
1	0.87	2.1907
1	0.8838	2.1858
1	0.8976	2.1808
1	0.9114	2.1759
1	0.9252	2.171
1	0.939	2.1661
1	0.9529	2.1612
1	0.9667	2.1563
1	0.9805	2.1514
1	0.9943	2.1465
1	1.0081	2.1416

Table A103 Soil shrinkage characteristics reported by SWAP preferential flow modeling

layer	Moist Ratio (-)	Void Ratio (-)
1	1.0219	2.1367
1	1.0357	2.1317
1	1.0495	2.1268
1	1.0633	2.1219
1	1.0771	2.117
1	1.091	2.1121
1	1.1048	2.1072
1	1.1186	2.1023
1	1.1324	2.0974
1	1.1462	2.0925
1	1.16	2.0876
1	1.1738	2.0826
1	1.1876	2.0777
1	1.2014	2.0728
1	1.2152	2.0679
1	1.229	2.063
1	1.2429	2.0581
1	1.2567	2.0532
1	1.2705	2.0483
1	1.2843	2.0434
1	1.2981	2.0385
1	1.3119	2.0335
1	1.3257	2.0286
1	1.3395	2.0237
1	1.3533	2.0188
1	1.3671	2.0139
1	1.381	2.009
2	0	2
2	0.0089	1.9967
2	0.0177	1.9935
2	0.0266	1.9902
2	0.0355	1.987
2	0.0443	1.9837
2	0.0532	1.9805
2	0.0621	1.9772
2	0.0709	1.974
2	0.0798	1.9707
2	0.0887	1.9675
2	0.0975	1.9642
2	0.1064	1.961
2	0.1153	1.9577
2	0.1242	1.9545
2	0.133	1.9512

layer	Moist Ratio (-)	Void Ratio (-)
2	0.1419	1.948
2	0.1508	1.9447
2	0.1596	1.9415
2	0.1685	1.9382
2	0.1774	1.935
2	0.1862	1.9317
2	0.1951	1.9285
2	0.204	1.9252
2	0.2128	1.922
2	0.2217	1.9187
2	0.2306	1.9155
2	0.2394	1.9122
2	0.2483	1.909
2	0.2572	1.9057
2	0.266	1.9025
2	0.2749	1.8992
2	0.2838	1.8959
2	0.2926	1.8927
2	0.3015	1.8894
2	0.3104	1.8862
2	0.3192	1.8829
2	0.3281	1.8797
2	0.337	1.8764
2	0.3458	1.8732
2	0.3547	1.8699
2	0.3636	1.8667
2	0.3725	1.8634
2	0.3813	1.8602
2	0.3902	1.8569
2	0.3991	1.8537
2	0.4079	1.8504
2	0.4168	1.8472
2	0.4257	1.8439
2	0.4345	1.8407
2	0.4434	1.8374
2	0.4523	1.8342
2	0.4611	1.8309
2	0.47	1.8277
2	0.4789	1.8244
2	0.4877	1.8212
2	0.4966	1.8179
2	0.5055	1.8147
2	0.5143	1.8114

Table A103 Soil shrinkage characteristics reported by SWAP preferential flow modeling (Cont.)

layer	Moist Ratio (-)	Void Ratio (-)
2	0.5232	1.8082
2	0.5321	1.8049
2	0.5409	1.8017
2	0.5498	1.7984
2	0.5587	1.7952
2	0.5675	1.7919
2	0.5764	1.7886
2	0.5853	1.7854
2	0.5942	1.7821
2	0.603	1.7789
2	0.6119	1.7756
2	0.6208	1.7724
2	0.6296	1.7691
2	0.6385	1.7659
2	0.6474	1.7626
2	0.6562	1.7594
2	0.6651	1.7561
2	0.674	1.7529
2	0.6828	1.7496
2	0.6917	1.7464
2	0.7006	1.7431
2	0.7094	1.7399
2	0.7183	1.7366
2	0.7272	1.7334
2	0.736	1.7301
2	0.7449	1.7269
2	0.7538	1.7236
2	0.7626	1.7204
2	0.7715	1.7171
2	0.7804	1.7139
2	0.7892	1.7106
2	0.7981	1.7074
2	0.807	1.7041
2	0.8158	1.7009
2	0.8247	1.6976
2	0.8336	1.6944
2	0.8425	1.6911
2	0.8513	1.6878
2	0.8602	1.6846
2	0.8691	1.6813
2	0.8779	1.6781
2	0.8868	1.6748
3	0	1.2

layer	Moist Ratio (-)	Void Ratio (-)
3	0.0085	1.1977
3	0.017	1.1953
3	0.0256	1.193
3	0.0341	1.1906
3	0.0426	1.1883
3	0.0511	1.1859
3	0.0596	1.1836
3	0.0681	1.1812
3	0.0767	1.1789
3	0.0852	1.1765
3	0.0937	1.1742
3	0.1022	1.1718
3	0.1107	1.1695
3	0.1193	1.1671
3	0.1278	1.1648
3	0.1363	1.1624
3	0.1448	1.1601
3	0.1533	1.1577
3	0.1619	1.1554
3	0.1704	1.153
3	0.1789	1.1507
3	0.1874	1.1483
3	0.1959	1.146
3	0.2044	1.1436
3	0.213	1.1413
3	0.2215	1.1389
3	0.23	1.1366
3	0.2385	1.1342
3	0.247	1.1319
3	0.2556	1.1295
3	0.2641	1.1272
3	0.2726	1.1248
3	0.2811	1.1225
3	0.2896	1.1201
3	0.2981	1.1178
3	0.3067	1.1154
3	0.3152	1.1131
3	0.3237	1.1107
3	0.3322	1.1084
3	0.3407	1.106
3	0.3493	1.1037
3	0.3578	1.1013
3	0.3663	1.099

Table A103 Soil shrinkage characteristics reported by SWAP preferential flow modeling (Cont.)

layer	Moist Ratio (-)	Void Ratio (-)
3	0.3748	1.0966
3	0.3833	1.0943
3	0.3919	1.0919
3	0.4004	1.0896
3	0.4089	1.0872
3	0.4174	1.0849
3	0.4259	1.0825
3	0.4344	1.0802
3	0.443	1.0778
3	0.4515	1.0755
3	0.46	1.0731
3	0.4685	1.0708
3	0.477	1.0684
3	0.4856	1.0661
3	0.4941	1.0637
3	0.5026	1.0614
3	0.5111	1.059
3	0.5196	1.0567
3	0.5281	1.0543
3	0.5367	1.052
3	0.5452	1.0496
3	0.5537	1.0473
3	0.5622	1.0449
3	0.5707	1.0426
3	0.5793	1.0402
3	0.5878	1.0379
3	0.5963	1.0355
3	0.6048	1.0332
3	0.6133	1.0308
3	0.6219	1.0285
3	0.6304	1.0261
3	0.6389	1.0238
3	0.6474	1.0214
3	0.6559	1.0191
3	0.6644	1.0167
3	0.673	1.0144
3	0.6815	1.012
3	0.69	1.0097
3	0.6985	1.0073
3	0.707	1.005
3	0.7156	1.0026
3	0.7241	1.0003
3	0.7326	0.9979

layer	Moist Ratio (-)	Void Ratio (-)
3	0.7411	0.9956
3	0.7496	0.9932
3	0.7581	0.9909
3	0.7667	0.9885
3	0.7752	0.9862
3	0.7837	0.9838
3	0.7922	0.9815
3	0.8007	0.9791
3	0.8093	0.9768
3	0.8178	0.9744
3	0.8263	0.9721
3	0.8348	0.9697
3	0.8433	0.9674
3	0.8519	0.965

Table A103 Soil shrinkage characteristics reported by SWAP preferential flow modeling (Cont.)

Script 1 - QuiP: Matlab script to estimate surface roughness index

```
function varargout = QuiP(varargin)
% QUIP M-file for QuiP.fig
%   QUIP, by itself, creates a new QUIP or raises the existing
%   singleton*.
%
%   H = QUIP returns the handle to a new QUIP or the handle to
%   the existing singleton*.
%
%   QUIP('CALLBACK',hObject,eventData,handles,...) calls the local
%   function named CALLBACK in QUIP.M with the given input arguments.
%
%   QUIP('Property','Value',...) creates a new QUIP or raises the
%   existing singleton*. Starting from the left, property value pairs are
%   applied to the GUI before profil_OpeningFunction gets called. An
%   unrecognized property name or invalid value makes property application
%   stop. All inputs are passed to QuiP_OpeningFcn via varargin.
%
%   *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
%   instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help QuiP

% Last Modified by GUIDE v2.5 04-Oct-2008 19:28:46

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',   gui_Singleton, ...
                  'gui_OpeningFcn', @QuiP_OpeningFcn, ...
                  'gui_OutputFcn',  @QuiP_OutputFcn, ...
                  'gui_LayoutFcn',  [], ...
                  'gui_Callback',    []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before QuiP is made visible.
function QuiP_OpeningFcn(hObject, eventdata, handles, varargin)
```

```

% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to QuiP (see VARARGIN)

% Choose default command line output for QuiP
handles.output = hObject;
set(handles.output,'Toolbar','figure'); %% Toolbar visible
set(handles.lens_corr,'String','-0.020')
set(handles.disty,'String','21.3')
set(handles.topred,'String','600')
set(handles.lowleft,'String','200')
set(handles.n_needles,'String','197')
set(handles.space,'String','0.5')
set(handles.upside_down,'value',1)
set(handles.len_slider,'value',str2num(get(handles.lens_corr,'string')))
set(handles.shadow_profil,'String','0.1')
set(handles.k,'String','30')

% Update handles structure
guidata(hObject, handles);
setappdata(handles.menu,'data',[])
% UIWAIT makes QuiP wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = QuiP_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

function instruction_Callback(hObject, eventdata, handles)
% hObject    handle to instruction (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of instruction as text
%        str2double(get(hObject,'String')) returns contents of instruction
%        as a double

% --- Executes during object creation, after setting all properties.
function instruction_CreateFcn(hObject, eventdata, handles)
% hObject    handle to instruction (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

```



```

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'))
    get(0,'defaultUicontrolBackgroundColor')
    set(hObject,'BackgroundColor','white');
end

function rms_Callback(hObject, eventdata, handles)
% hObject   handle to rms (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of rms as text
%   str2double(get(hObject,'String')) returns contents of rms as a double

% --- Executes during object creation, after setting all properties.
function rms_CreateFcn(hObject, eventdata, handles)
% hObject   handle to rms (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function L_Callback(hObject, eventdata, handles)
% hObject   handle to L (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of L as text
%   str2double(get(hObject,'String')) returns contents of L as a double

% --- Executes during object creation, after setting all properties.
function L_CreateFcn(hObject, eventdata, handles)
% hObject   handle to L (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in gaussian.

```

```

function gaussian_Callback(hObject, eventdata, handles)
% hObject    handle to gaussian (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

if get(hObject,'Value')
    axes(handles.axes1)
    hold on
    if get(findobj(gcf,'tag','menu'),'value')== 8
        pg = getappdata(handles.menu,'pg');
        x = getappdata(handles.menu,'x');

        plot(x,pg,'r')
    else
        Wg = getappdata(handles.menu,'Wg');
        f = getappdata(handles.menu,'f');
        NFFT = getappdata(handles.menu,'NFFT');

        plot(f,2*abs(Wg(1:NFFT/2)), 'r')
    end
    hold off
else
    the_curve = findobj(findobj(handles.axes1,'type','line'),'color','r');
    if ~isempty(the_curve)
        delete(the_curve);
    end
end

end

% --- Executes on button press in exponential.
function exponential_Callback(hObject, eventdata, handles)
% hObject    handle to exponential (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

if get(hObject,'Value')

    axes(handles.axes1)
    hold on
    if get(findobj(gcf,'tag','menu'),'value')== 8
        pe = getappdata(handles.menu,'pe');
        x = getappdata(handles.menu,'x');

        plot(x,pe,'g')
    else
        We = getappdata(handles.menu,'We');
        f = getappdata(handles.menu,'f');
        NFFT = getappdata(handles.menu,'NFFT');

```

```

        plot(f,2*abs(We(1:NFFT/2)), 'g')
    end
    hold off

else
    the_curve = findobj(findobj(handles.axes1, 'type', 'line'), 'color', 'g');
    if ~isempty(the_curve)
        delete(the_curve);
    end
end

% --- Executes on button press in power.
function power_Callback(hObject, eventdata, handles)
% hObject    handle to power (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

if get(hObject, 'Value')

    axes(handles.axes1)
    hold on
    if get(findobj(gcf, 'tag', 'menu'), 'value') == 8
        pp = getappdata(handles.menu, 'pp');
        x = getappdata(handles.menu, 'x');

        plot(x, pp, 'b')
    else
        Wp = getappdata(handles.menu, 'Wp');
        f = getappdata(handles.menu, 'f');
        NFFT = getappdata(handles.menu, 'NFFT');

        plot(f, 2*abs(Wp(1:NFFT/2)), 'b')
    end
    hold off

else
    the_curve = findobj(findobj(handles.axes1, 'type', 'line'), 'color', 'b');
    if ~isempty(the_curve)
        delete(the_curve);
    end
end

function shadow_profil_Callback(hObject, eventdata, handles)
% hObject    handle to shadow_profil (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject, 'String') returns contents of shadow_profil as text
%        str2double(get(hObject, 'String')) returns contents of shadow_profil as a double

```

```

hO = findobj(gcf,'tag','menu');
if get(hO,'value')==4
    menu_Callback(hO, eventdata, handles)
end

% --- Executes during object creation, after setting all properties.
function shadow_profil_CreateFcn(hObject, eventdata, handles)
% hObject    handle to shadow_profil (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function k_Callback(hObject, eventdata, handles)
% hObject    handle to k (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of k as text
%        str2double(get(hObject,'String')) returns contents of k as a double
[x,Y,L,FINV1,FINV2]=two_scale(handles);

% --- Executes during object creation, after setting all properties.
function k_CreateFcn(hObject, eventdata, handles)
% hObject    handle to k (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function rms_low_Callback(hObject, eventdata, handles)
% hObject    handle to rms_low (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of rms_low as text
%        str2double(get(hObject,'String')) returns contents of rms_low as a double

```

```

% --- Executes during object creation, after setting all properties.
function rms_low_CreateFcn(hObject, eventdata, handles)
% hObject    handle to rms_low (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function corr_low_Callback(hObject, eventdata, handles)
% hObject    handle to corr_low (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of corr_low as text
%        str2double(get(hObject,'String')) returns contents of corr_low as a double

```

```

% --- Executes during object creation, after setting all properties.
function corr_low_CreateFcn(hObject, eventdata, handles)
% hObject    handle to corr_low (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function rms_high_Callback(hObject, eventdata, handles)
% hObject    handle to rms_high (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of rms_high as text
%        str2double(get(hObject,'String')) returns contents of rms_high as a double

```

```

% --- Executes during object creation, after setting all properties.
function rms_high_CreateFcn(hObject, eventdata, handles)
% hObject    handle to rms_high (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB

```

```

% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function corr_high_Callback(hObject, eventdata, handles)
% hObject    handle to corr_high (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of corr_high as text
%    str2double(get(hObject,'String')) returns contents of corr_high as a double

% --- Executes during object creation, after setting all properties.
function corr_high_CreateFcn(hObject, eventdata, handles)
% hObject    handle to corr_high (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in menu.
function menu_Callback(hObject, eventdata, handles)
% hObject    handle to menu (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

val = get(hObject,'Value');
string_list = get(hObject,'String');
selected_string = string_list{val};
set(handles.gaussian,'visible','off')
set(handles.exponential,'visible','off')
set(handles.power,'visible','off')
set(handles.uipanel5,'visible','off');

switch selected_string
    case 'Choose action'

```

```

case 'Load image'
    set(handles.rms,'string','0');
    set(handles.L,'string','0');
    set(handles.rms_high,'string','0');
    set(handles.corr_high,'string','0');
    set(handles.rms_low,'string','0');
    set(handles.corr_low,'string','0');

    [filename, pathname] = uigetfile('*.jpg','Select image file');
    if isequal(filename,0) | isequal(pathname,0)
        return
    else
        fili = fullfile(pathname, filename);
    end
    cd(pathname);
    setappdata(handles.menu,'filename_input',filename);
    data = imread(fili);
    setappdata(handles.menu,'data',data);

    if get(handles.Lens_on,'value')
        hm = waitbar(0,{'Performing Lens Correction    ','Please Wait...'});
        axes(handles.axes1)
        handles.axes1 = newplot;

        LCORR(handles)
        close(hm)
    else
        setappdata(handles.menu,'data_lens',getappdata(handles.menu,'data'))
        axes(handles.axes1)
        handles.axes1 = newplot;

        imagesc(getappdata(handles.menu,'data'))
    end

case 'Select coordinates'
    data = getappdata(handles.menu,'data_lens');
    s = size(data);
    topred = str2double(get(handles.topred,'string'));
    lowleft = str2double(get(handles.lowleft,'string'));

    if get(handles.upside_down,'value')
        set(gca,'ylim',[lowleft-s(1)/12 lowleft+s(1)/12],'xlim',[1 s(2)/8])
        set(handles.instruction,'string','LOW - LEFT Red Corner ---- Click Right button');
        [tlc,tll,P] = impixel;

        set(gca,'ylim',[topred-s(1)/12 topred+s(1)/12],'xlim',[1 s(2)/8])
        set(handles.instruction,'string','HIGH - LEFT Red Corner ---- Click Right button');
        [blc,blt,P] = impixel;

```

```

set(gca,'ylim',[topred-s(1)/12 topred+s(1)/12],'xlim',[s(1) s(2)])
set(handles.instruction,'string','HIGH - RIGHT Red Corner ---- Click Right button');
[brc,brl,P] = impixel;

```

```

set(gca,'ylim',[lowleft topred],'xlim',[1 s(2)/8])
set(handles.instruction,'string','FIRST Profile Point center ---- Click Right button');
[Pti,Pll,P] = impixel;

```

```

set(gca,'ylim',[lowleft topred],'xlim',[s(2)-s(2)/8 s(2)])
set(handles.instruction,'string','LAST Profile Point center ---- Click Right button');
[Pf,Prl,P] = impixel;

```

```

setappdata(handles.menu,'tll',tll);
setappdata(handles.menu,'tlc',tlc);
setappdata(handles.menu,'bll',bll);
setappdata(handles.menu,'blc',blc);
setappdata(handles.menu,'brl',brl);
setappdata(handles.menu,'brc',brc);
setappdata(handles.menu,'Pti',Pti);
setappdata(handles.menu,'Pf',Pf);

```

else

```

set(gca,'ylim',[lowleft-s(1)/12 lowleft+s(1)/12],'xlim',[1 s(2)/8])
set(handles.instruction,'string','LOW - LEFT Red Corner ---- Click Right button');
[tlc,tll,P] = impixel;

```

```

set(gca,'ylim',[topred-s(1)/12 topred+s(1)/12],'xlim',[1 s(2)/8])
set(handles.instruction,'string','HIGH - LEFT Red Corner ---- Click Right button');
[blc,bll,P] = impixel;

```

```

set(gca,'ylim',[topred-s(1)/12 topred+s(1)/12],'xlim',[s(1) s(2)])
set(handles.instruction,'string','HIGH - RIGHT Red Corner ---- Click Right button');
[brc,brl,P] = impixel;

```

```

set(gca,'ylim',[topred lowleft],'xlim',[1 s(2)/8])
set(handles.instruction,'string','FIRST Profile Point center ---- Click Right button');
[Pti,Pll,P] = impixel;

```

```

set(gca,'ylim',[topred lowleft],'xlim',[s(2)-s(2)/8 s(2)])
set(handles.instruction,'string','LAST Profile Point center ---- Click Right button');
[Pf,Prl,P] = impixel;

```

```

setappdata(handles.menu,'tll',tll);
setappdata(handles.menu,'tlc',tlc);
setappdata(handles.menu,'bll',bll);
setappdata(handles.menu,'blc',blc);
setappdata(handles.menu,'brl',brl);

```



```

setappdata(handles.menu,'brc',brc);
setappdata(handles.menu,'Pti',Pti);
setappdata(handles.menu,'Pf',Pf);

end

axes(handles.axes1)

set(gca,'ylim',[1 s(1)],'xlim',[1 s(2)])

hO = findobj(gcf,'tag','menu');
set(hO,'value',4)
menu_Callback(hO, eventdata, handles)

case 'Extract profil'
    hm = waitbar(0,{ 'Extracting Profil'      'Please Wait...'});

    data = getappdata(handles.menu,'data_lens');
    s = size(data);
    bll = getappdata(handles.menu,'bll');
    tll = getappdata(handles.menu,'tll');
    tlc = getappdata(handles.menu,'tlc');
    brl = getappdata(handles.menu,'brl');
    blc = getappdata(handles.menu,'blc');
    brc = getappdata(handles.menu,'brc');
    topred = str2double(get(handles.topred,'string'));
    lowleft = str2double(get(handles.topred,'string'));
    esp = str2double(get(handles.space,'string'));
    n_needles = str2double(get(handles.n_needles,'string'));

    [CMY,K] = rgb2cmyk(data);

    shadow = str2double(get(handles.shadow_profil,'string'));
    factor = round(8*esp-3);
    sh = strel('rectangle',[1*factor,round(s(2)/320)*factor]);
    se = strel('rectangle',[round(s(1)/60),round(s(2)/320)]);

    tl = (imdilate((imdilate(imerode(CMY(:,2),se),se)>shadow),sh));

    xtige = zeros(1,s(2));

if get(handles.upside_down,'value')

for k = min(bll,brl)-10:-1:tll
    x = find(tl(k,1:s(2)));
    if ~isempty(x)
        xtige(x) = xtige(x)+(xtige(x)<1)*k;
    end
end

```

```

end

plow = find(xtige < tll);
xtige(plow) = tll + s(1)/8;

Pti = getappdata(handles.menu,'Pti');
Pf = getappdata(handles.menu,'Pf');

yrange_cm = str2double(get(handles.disty,'string'));
yrange = bll - tll;

aredsup = (bll-bll)/(brc-blc);
redsupC = aredsup.*[1:s(2)]+bll;

tt=(xtige-redsupC);
r = (Pf-Pti)/(n_needles-1);
tcm1 = tt(Pti:1:Pf)*yrange_cm/yrange;
pxtige = xtige(Pti:1:Pf);

xtcm(1) = Pti;
xxtcm(1)=1;
for xb = 1:n_needles-1;
    xtcn(xb+1) = Pti + r.*xb;
    xxtn(xb+1) = r.*xb;
end

for b = 1:n_needles;
    tcm(b) = interp1(1:1:length(tcm1),tcm1,xxtn(b),'nearest');
    ptn(b) = interp1(1:1:length(pxtige),pxtn,xxtn(b),'nearest');
end

else

for k = max(bll,bll)+10:1:tll
    x = find(tl(k,1:s(2)));
    if ~isempty(x)
        xtige(x) = xtige(x)+(xtige(x)<1)*k;
    end
end

plow = find(xtige > tll);
xtige(plow) = tll - s(1)/8;

Pti = getappdata(handles.menu,'Pti');
Pf = getappdata(handles.menu,'Pf');

yrange_cm = str2double(get(handles.disty,'string'));
yrange = bll - tll;

```

```

aredsup = (brl-bll)/(brc-blc);
redsupC = aredsup.*[1:s(2)]+bll;

tt =(xtige-redsupC);
r = (Pf-Pti)/(n_needles-1);
tcm1 = tt(Pti:1:Pf)*yrange_cm/yrange;
pxtige = xtige(Pti:1:Pf);

xtcm(1) = Pti;
xxtcm(1)=1;
for xb = 1:n_needles-1;
    xtcn(xb+1) = Pti + r.*xb;
    xxtcm(xb+1) = r.*xb;
end

for b = 1:n_needles;
    tcm(b) = interp1(1:1:length(tcm1),tcm1,xxtcm(b),'nearest');
    ptcn(b) = interp1(1:1:length(pxtige),pxtige,xxtcm(b),'nearest');
end

end

setappdata(handles.menu,'xtcm',xtcm);
setappdata(handles.menu,'tt',tt);
setappdata(handles.menu,'xtige',xtige);
setappdata(handles.menu,'ptcn',ptcn);
setappdata(handles.menu,'r',r);
setappdata(handles.menu,'Pti',Pti);
setappdata(handles.menu,'Pf',Pf);
setappdata(handles.menu,'redsupC',redsupC);
setappdata(handles.menu,'yrange_cm',yrange_cm);
setappdata(handles.menu,'yrange',yrange);
setappdata(handles.menu,'tcm',tcm);
esp = str2double(get(handles.space,'string'));

yp = (tcm-mean(tcm));

N = length(yp);
if get(handles.upside_down,'value')
yp(1:N)=yp(N:-1:1);
end
setappdata(handles.menu,'yp',yp);
s_rms = std(yp);
p2 = sum(yp.^2);

for j=1:N
    for i = 1:N+1-j
        p1(i) = yp(i).*yp(j+i-1);
    end
end

```

```

    end
    p3(j) = sum(p1)./p2;
end

p3f = find(p3 < 1/exp(1));
corrlength = p3f(1).*esp;

set(handles.rms,'string',sprintf("%.2f",s_rms));
set(handles.L,'string',corrlength);
[x,Y,L,FINV1,FINV2] = two_scale(handles);
axes(handles.axes1)
handles.axes1 = newplot;
imagesc(data)
hold on
plot([Pti:Pf], xtige(Pti:Pf), '-r', [1:s(2)], redsupC, '-b')
plot(xtcm, ptc, '-g')
hold off

set(handles.instruction,'string','Correct point if needed, then accept');
close(hm);

[p,filout,ext] = fileparts(getappdata(handles.menu,'filename_input'));

save(filout,'yp');

case 'Join profiles'
    number_profil_enter = {'Enter number of profil:', 'Direction (Left or Right)'};
    dlg_title = 'Join information';
    num_lines = 1;
    def = {'','Right'};
    answer = inputdlg(number_profil_enter,dlg_title,num_lines,def);
    number_profil = str2double(answer(1));
    TFR = strcmp(answer(2),'Right');
    TFL = strcmp(answer(2),'Left');
    n_needles = str2double(get(handles.n_needles,'string'));

    while TFR==0 && TFL==0
        number_profil_enter = {'Enter number of profil:', 'Direction (Left or Right)'};
        dlg_title = 'Error in Left / Right';
        num_lines = 1;
        def = {'','Right'};
        answer = inputdlg(number_profil_enter,dlg_title,num_lines,def);
        number_profil = str2double(answer(1));
        TFR = strcmp(answer(2),'Right');
        TFL = strcmp(answer(2),'Left');
    end
end

```

```

for n=1:number_profil
    sprofilnumber = strcat('Select profil number:',num2str(n));
    [filename, pathname] = uigetfile('*.mat',sprofilnumber);
    if isequal(filename,0) | isequal(pathname,0)
        return
    else
        fili = fullfile(pathname, filename);
    end
    load(fili,'yp');
    N=length(yp);

    if TFL==1
        B(number_profil-(n-1))={yp}; % Left
    end
    if TFR==1
        B(n)={yp}; % Right
    end
end

for k = 1:number_profil-1
    P1 =cell2mat(B(k));
    P2 =cell2mat(B(k+1));

    Plast = P1(n_needles);
    Pfirst = P2(1);

    diff = Plast-Pfirst;
    Pchange = P2 + diff;
    B(k+1) = {Pchange};
end

esp = str2double(get(handles.space,'string'));
PPJ = cell2mat(B);
N = length(PPJ);
x = [0:esp:(N.*esp)-esp];
g = polyfit(x,PPJ,1);
pente = polyval(g,x);

PJ = PPJ-pente;

Y = (PJ-mean(PJ));
s_rms = std(Y);
p2 = sum(Y.^2);

for j=1:N
    for i = 1:N+1-j
        p1(i) = Y(i).*Y(j+i-1);
    end
    p3(j) =sum(p1)./p2;
end

```

```

p3f = find(p3 < 1/exp(1));
corrlength = p3f(1).*esp;

set(handles.rms,'string',sprintf('%0.2f',s_rms));
set(handles.L,'string',corrlength);

setappdata(handles.menu,'yp',Y);

set(hObject, 'value',7)
menu_Callback(hObject, eventdata, handles)
two_scale(handles);

```

case 'Load profil'

```

[filename, pathname] = uigetfile('*.mat','Select mat file');
if isequal(filename,0) | isequal(pathname,0)
    return
else
    fili = fullfile(pathname, filename);
end
setappdata(handles.menu,'filename_input',filename);

load(fili,'yp');
setappdata(handles.menu,'yp',yp);
set(hObject, 'value',7)
menu_Callback(hObject, eventdata, handles)

```

case 'Plot profil'

```

set(handles.instruction,'string','Profil');
esp = str2double(get(handles.space,'string'));

Y= getappdata(handles.menu,'yp');
N = length(Y);
x = [0:esp:(N*esp)-esp];
axes(handles.axes1)
handles.axes1 = newplot;
plot(x,Y)
set(handles.axes1,'YLim',[-40 40])
set(get(handles.axes1,'XLabel'),'String','Distance (cm)')
set(get(handles.axes1,'YLabel'),'String','Profil (cm)')

s_rms = std(Y);
p2 = sum(Y.^2);

for j=1:N
    for i = 1:N+1-j

```

```

        p1(i) = Y(i).*Y(j+i-1);
    end
    p3(j) = sum(p1)./p2;
end

p3f = find(p3 < 1/exp(1));
corrlength = p3f(1).*esp;

set(handles.rms,'string',sprintf('%0.2f',s_rms));
set(handles.L,'string',corrlength);
two_scale(handles);

```

case 'Plot ACF'

```

set(handles.instruction,'string','Autocorrelation function');
setappdata(handles.menu,'graph','ACF');
Y= getappdata(handles.menu,'yp');
esp = str2double(get(handles.space,'string'));

set(handles.gaussian,'visible','on')
set(handles.exponential,'visible','on')
set(handles.power,'visible','on')

N = length(Y);
s_rms = std(Y);
p2 = sum(Y.^2);

for j=1:N
    for i = 1:N+1-j
        p1(i) = Y(i).*Y(j+i-1);
    end
    p3(j) = sum(p1)./p2;
end

p3f = find(p3 < 1/exp(1));
corrlength = p3f(1).*esp;
set(handles.rms,'string',sprintf('%0.2f',s_rms));
set(handles.L,'string',corrlength);

x = [0:esp:(N.*esp)-esp];

pg = exp(-(x.^2)./(corrlength.^2));
pe = exp(-x./corrlength);
pp = (1+(x.^2/corrlength.^2)).^(-1.5);
setappdata(handles.menu,'pg',pg);
setappdata(handles.menu,'pe',pe);
setappdata(handles.menu,'pp',pp);
setappdata(handles.menu,'x',x);

```

```

axes(handles.axes1)
handles.axes1 = newplot;
hold on
plot(x,p3,'k')
if get(handles.gaussian,'value')
    plot(x,pg,'r')
end
if get(handles.exponential,'value')
end
if get(handles.power,'value')
    plot(x,pp,'b')
end
hold off
set(get(handles.axes1,'XLabel'),'String','Distance (cm)')
set(get(handles.axes1,'YLabel'),'String','ACF')

```

case 'Plot Spectrum'

```

set(handles.instruction,'string','Spectrum of ACF');
setappdata(handles.menu,'graph','Spectrum');
Y= getappdata(handles.menu,'yp');
set(handles.gaussian,'visible','on')
set(handles.exponential,'visible','on')
set(handles.power,'visible','on')
esp = str2double(get(handles.space,'string'));

```

```

N = length(Y);
s_rms = std(Y);
p2 = sum(Y.^2);

```

```

for j=1:N
    for i = 1:N+1-j
        p1(i) = Y(i).*Y(j+i-1);
    end
    p3(j) =sum(p1)./p2;
end

```

```

p3f = find(p3 < 1/exp(1));
corrlength = p3f(1).*esp;
set(handles.rms,'string',sprintf('%0.2f',s_rms));
set(handles.L,'string',corrlength);

```

```

x = [0:esp:(N.*esp)-esp];

```

```

pg = exp(-(x.^2)./(corrlength.^2));
pe = exp(-x./corrlength);
pp = (1+(x.^2/corrlength.^2)).^(-1.5);

```

```

L=N;
T=esp/100;

```



```

Fs=1/T;
NFFT = 2^nextpow2(L);

W = fft(p3,NFFT)/L;
Wg = fft(pg,NFFT)/L;
We = fft(pe,NFFT)/L;
Wp = fft(pp,NFFT)/L;
f = Fs/2* linspace(0,1,NFFT/2)*2*pi; %Change freq for wavenumber

setappdata(handles.menu,'W',W);
setappdata(handles.menu,'Wg',Wg);
setappdata(handles.menu,'We',We);
setappdata(handles.menu,'Wp',Wp);
setappdata(handles.menu,'NFFT',NFFT);
setappdata(handles.menu,'f',f);

axes(handles.axes1)
handles.axes1 = newplot;
hold on
plot(f,2*abs(W(1:NFFT/2)), 'k')
if get(handles.gaussian,'value')
    plot(f,2*abs(Wg(1:NFFT/2)), 'r')
end
if get(handles.exponential,'value')
    plot(f,2*abs(We(1:NFFT/2)), 'g')
end
if get(handles.power,'value')
    plot(f,2*abs(Wp(1:NFFT/2)), 'b')
end
set(get(handles.axes1,'XLabel'),'String','Wave Number [rad/m] ')
set(handles.axes1,'xScale','log','yScale','log')
set(get(handles.axes1,'YLabel'),'String','Spectrum of ACF')
hold off

```

case 'Save profil'

```

yp= getappdata(handles.menu,'yp');

[filename, pathname] = uiputfile('*.mat','Save as');
if isequal(filename,0) | isequal(pathname,0)
    return
else
    filout = fullfile(pathname, filename);
end

save(filout,'yp');

```

case 'Save stats'

```

filename = getappdata(handles.menu,'filename_input');
[curdir,fpic,ext] =fileparts(filename);
curdir = pwd;
subdir =strfind(curdir,'\');
dirout = curdir(subdir(length(subdir))+1:length(curdir));

if length(getappdata(handles.menu,'yp')) > 222
    ff = inputdlg('Enter joint profil name');
    if isempty(ff{1})
        return
    else
        fpic = ff{1};
    end
end

fexist = exist([dirout '.txt']);
fod = fopen([dirout '.txt'],'a+');
if ~fexist
    fprintf(fod,'File\t RMS\t L\t K\t RMS_low\t L_low\t RMS_high\t L_high\n');
end
fprintf(fod,'%s \t%s \t%s \t%s \t%s \t%s \t%s \t%s \n',fpic,get(handles.rms,'string'),get(handles.L,'string'),...
    get(handles.k,'string'),get(handles.rms_low,'string'),...
    get(handles.corr_low,'string'),get(handles.rms_high,'string'),get(handles.corr_high,'string'));
fclose all;

case 'Two-scale'

    set(handles.instruction,'string','Two scale');

    [x,Y,L,FINV1,FINV2] =two_scale(handles);
    axes(handles.axes1)
    handles.axes1 = newplot;
    hold on
    plot(x,Y,'k')
    plot(x,real(FINV1(1:L)), 'r')
    plot(x,real(FINV2(1:L)), 'b')
    set(handles.axes1,'YLim',[-40 40])
    set(get(handles.axes1,'XLabel'),'String','Distance (cm)')
    set(get(handles.axes1,'YLabel'),'String','Profil (cm)')
    legend('Profil','Low Frequency','High Frequency')
    hold off

case 'Clear all'
    handles.axes1 = newplot;
    yp = [];
    xtcn = [];
    tt= [];
    xtige=[];

```

```

ptcm = [];
tcm = [];

setappdata(handles.menu,'xtcm',xtcm);
setappdata(handles.menu,'tt',tt);
setappdata(handles.menu,'xtige',xtige);
setappdata(handles.menu,'ptcm',ptcm);
setappdata(handles.menu,'tcm',tcm);
setappdata(handles.menu,'yp',yp);

set(handles.rms_high,'string','');
set(handles.corr_high,'string','');
set(handles.rms_low,'string','');
set(handles.corr_low,'string','');
set(handles.rms,'string','');
set(handles.L,'string','');

end

% --- Executes during object creation, after setting all properties.
function menu_CreateFcn(hObject, eventdata, handles)
% hObject    handle to menu (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function lens_corr_Callback(hObject, eventdata, handles)
% hObject    handle to lens_corr (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of lens_corr as text
%        str2double(get(hObject,'String')) returns contents of lens_corr as a double
if ~isempty(getappdata(handles.menu,'data'))
    hm = waitbar(0,{'Performing Lens Correction','Please Wait...'});
    LCORR(handles)
    close(hm)
end
set(handles.len_slider,'value',str2num(get(handles.lens_corr,'String')))

% --- Executes during object creation, after setting all properties.

```

```

function lens_corr_CreateFcn(hObject, eventdata, handles)
% hObject    handle to lens_corr (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in correction.
function correction_Callback(hObject, eventdata, handles)
% hObject    handle to correction (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
data = getappdata(handles.menu,'data_lens');
s = size(data);
Pti = getappdata(handles.menu,'Pti');
switch get(handles.uipanel5,'visible')
case 'off'
    msgbox(sprintf('1-Select "New" for correcting a point\n\n2-Right click to select new profil\n\n3-Use the slider to move profil\n\n4-Select "Done" when finish'),'For EACH Point')
    set(handles.uipanel5,'visible','on');
    set(handles.pts_slider,'value',round(Pti));
    pts_slider_Callback(hObject, eventdata, handles)
    return
case 'on'

CorrectionButton = 'OK';
switch CorrectionButton,
    case 'OK',
        [Xcorrectionpixel,Ycorrectionpixel,Pcorrection] = impixel;
    case 'Cancel',
        return
end

xtcm = getappdata(handles.menu,'xtcm');
tt= getappdata(handles.menu,'tt');
xtige = getappdata(handles.menu,'xtige');
r = getappdata(handles.menu,'r');
Pti = getappdata(handles.menu,'Pti');
Pf = getappdata(handles.menu,'Pf');
redsupC = getappdata(handles.menu,'redsupC');
yrange_cm = getappdata(handles.menu,'yrange_cm');
yrange = getappdata(handles.menu,'yrange');
esp = str2double(get(handles.space,'string'));
n_needles = str2double(get(handles.n_needles,'string'));

```

```

for g=1:5
    tt(Xcorrectionpixel-3+g)=(Ycorrectionpixel-redsupC(Xcorrectionpixel-3+g));
    xtige(Xcorrectionpixel-3+g)=(Ycorrectionpixel);
    tcm1 = tt(Pti:1:Pf)*yrange_cm/yrange;
    pxtige = xtige(Pti:1:Pf);
end

xtcm(1) = Pti;
xxtcm(1)=1;
for xb = 1:n_needles-1;
    xtcn(xb+1) = Pti + r.*xb;
    xxtcm(xb+1) = r.*xb;
end

for b = 1:n_needles;
    tcm(b) = interp1(1:1:length(tcm1),tcm1,xxtcm(b),'nearest');
    ptcn(b) = interp1(1:1:length(pxtige),pxtige,xxtcm(b),'nearest');
end

setappdata(handles.menu,'xtcn',xtcn);
setappdata(handles.menu,'tt',tt);
setappdata(handles.menu,'xtige',xtige);
setappdata(handles.menu,'ptcn',ptcn);
setappdata(handles.menu,'tcm',tcm);

yp = (tcm-mean(tcm));

N = length(yp);
yp(1:N)=yp(N:-1:1);
setappdata(handles.menu,'yp',yp);
s_rms = std(yp);
p2 = sum(yp.^2);

for j=1:N
    for i = 1:N+1-j
        p1(i) = yp(i).*yp(j+i-1);
    end
    p3(j) =sum(p1)./p2;
end

p3f = find(p3 < 1/exp(1));
corrlength = p3f(1).*esp;

set(handles.rms,'string',sprintf('%0.2f',s_rms));
set(handles.L,'string',corrlength);

two_scale(handles);

set((findobj(handles.axes1,'type','line','color','g')),'YData',ptcn)

```

```

[p,filout,ext]=fileparts(getappdata(handles.menu,'filename_input'));
save(filout,'yp');

end

% --- Executes on slider movement.
function len_slider_Callback(hObject, eventdata, handles)
% hObject    handle to len_slider (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'Value') returns position of slider
%         get(hObject,'Min') and get(hObject,'Max') to determine range of slider

set(handles.lens_corr,'String',num2str(get(handles.len_slider,'value')))
if ~isempty(getappdata(handles.menu,'data'))
    hm = waitbar(0,{'Performing Lens Correction    ':'Please Wait...'});
    LCORR(handles)
    close(hm)
end

% --- Executes during object creation, after setting all properties.
function len_slider_CreateFcn(hObject, eventdata, handles)
% hObject    handle to len_slider (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: slider controls usually have a light gray background.
if isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor',[.9 .9 .9]);
end

function LCORR(handles)
    data =getappdata(handles.menu,'data');
    data_lens = cf_lens(data,handles);
    set(handles.instruction,'string','Lens correction');
    setappdata(handles.menu,'data_lens',data_lens);

    if findobj(handles.axes1,'type','image')
        set(findobj(handles.axes1,'type','image'),'Cdata',data_lens)
    else
        imagesc(data_lens)
    end
    s = size(data);
    ss = [100:100:s(1)];
    set(handles.axes1,'YTick',ss)
    set(handles.axes1,'YGrid','on','XGrid','on')

```

```

set(handles.Lens_on,'value',1)

% --- Executes on button press in Lens_on.
function Lens_on_Callback(hObject, eventdata, handles)
% hObject    handle to Lens_on (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

if ~isempty(getappdata(handles.menu,'data'))
if get(handles.Lens_on,'value')
    hm = waitbar(0,{'Performing Lens Correction'    'Please Wait...'});
    LCORR(handles)
    close(hm)

else
    setappdata(handles.menu,'data_lens',getappdata(handles.menu,'data'))
    imagesc(getappdata(handles.menu,'data'))
end
end

function [x,Y,L,FINV1,FINV2] =two_scale(handles)

    Y= getappdata(handles.menu,'yp');
    esp = str2double(get(handles.space,'string'));
    N = length(Y);
    s_rms = std(Y);
    p2 = sum(Y.^2);

    for j=1:N
        for i = 1:N+1-j
            p1(i) = Y(i).*Y(j+i-1);
        end
        p3(j) =sum(p1)./p2;
    end

    p3f = find(p3 < 1/exp(1));
    corrlength = p3f(1).*esp;
    set(handles.rms,'string',sprintf('%0.2f',s_rms));
    set(handles.L,'string',corrlength);

    x = [0:esp:(N.*esp)-esp];

    L=N;
    T=esp/100;
    Fs=1/T;
    NFFT = 2^nextpow2(L);

    W = fft(Y,NFFT)/L;

```

```

f = Fs/2*linspace(0,1,NFFT/2)*2*pi; %Change freq for wavenumber
k_twoscale = str2double(get(handles.k,'string'));
kN = find(f>=k_twoscale);
NN=kN(1);

W1 = 0*W;
W2 = 0*W;
W1(1:NN) = W(1:NN);
W1(NFFT-NN:NFFT) = W(length(W)-NN:length(W));
W2(NN+1:NFFT-NN-1) = W(NN+1:NFFT-NN-1);
FINV = ifft(W,NFFT).*L;
FINV1 = ifft(W1,NFFT).*L;
FINV2 = ifft(W2,NFFT).*L;

RFINV = real(FINV);
RFINV1=real(FINV1);
RFINV2= real(FINV2);

s_rms_low = std(RFINV1);
p2 = sum(RFINV1.^2);

for j=1:N
    for i = 1:N+1-j
        p1(i) = RFINV1(i).*RFINV1(j+i-1);
    end
    p3(j) =sum(p1)./p2;
end

p3f = find(p3 < 1/exp(1));
corlength_low = p3f(1).*esp;
set(handles.rms_low,'string',sprintf('%.2f',s_rms_low));
set(handles.corr_low,'string',corlength_low);

s_rms_high = std(RFINV2);
p2 = sum(RFINV2.^2);

for j=1:N
    for i = 1:N+1-j
        p1(i) = RFINV2(i).*RFINV2(j+i-1);
    end
    p3(j) =sum(p1)./p2;
end

p3f = find(p3 < 1/exp(1));
corlength_high = p3f(1).*esp;
set(handles.rms_high,'string',sprintf('%.2f',s_rms_high));
set(handles.corr_high,'string',corlength_high);

```



```

if get(findobj(gcf,'tag','menu'),'value')==10
    axes(handles.axes1)

    plot(x,Y,'k',x,real(FINV1(1:L)), 'r',x,real(FINV2(1:L)), 'b')
    set(handles.axes1,'YLim',[-40 40])
    set(get(handles.axes1,'XLabel'),'String','Distance (cm)')
    set(get(handles.axes1,'YLabel'),'String','Profil (cm)')
    legend('Profil','Low Frequency','High Frequency')

end

% --- Executes on button press in batch_lens.
function batch_lens_Callback(hObject, eventdata, handles)
% hObject    handle to batch_lens (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

cf = get(handles.lens_corr,'string');

CF_OK = questdlg(sprintf('Correction Factor is\n\n    %s',cf),'CF','OK','Change','OK');
switch CF_OK
    case 'OK'
    case 'Change'
        return
end

button = questdlg('Want to process a full Folder or File(s)','Batch Lens
Correction','Folder','File(s)','Cancel','File(s)');

switch button
    case 'Folder'
        dir_batch = uigetdir;
        file_batch=dir('*.*jpg')
    case 'File(s)'
        [file_c, dir_batch] =uigetfile('*.*jpg','MultiSelect','on');
        if iscell(file_c)
            file_batch = cell2struct(file_c,'name',1);
        else
            file_batch(1).name = file_c;
        end
    case 'Cancel'
        return
end

cd(dir_batch);

hp = waitbar(0,'Processing Len Correction ... Please Wait') ;
for k =1:length(file_batch)

```

```

waitbar((k-1)/length(file_batch),hp,sprintf('Processing %s ... Please Wait',file_batch(k).name));
data = imread(file_batch(k).name);
data_lens = cf_lens(data,handles);
[p,f,ext] = fileparts(file_batch(k).name);
imwrite(data_lens,[f 'CF.jpg'],'jpg','Quality',90);

end
close(hp)
helpdlg('Corrected picture are rename *CF.jpg','New Files');

```

```

function data_lens = cf_lens(data,handles)

lens = str2double(get(handles.lens_corr,'string'));
r = @(x) sqrt(x(:,1).^2 + x(:,2).^2);
w = @(x) atan2(x(:,2), x(:,1));
f = @(x) [(r(x) + lens.*r(x).^3).*cos(w(x)),(r(x) + lens.*r(x).^3).*sin(w(x))];
q = @(x, unused) f(x);

tform = maketform('custom', 2, 2, [], q, []);
data_lens = imtransform(data, tform, 'UDData', [-1 1], 'VData', [-1 1], 'XData', [-1 1], 'YData', [-1
1]);

```

```

% --- Executes on slider movement.
function pts_slider_Callback(hObject, eventdata, handles)
% hObject    handle to pts_slider (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
data = getappdata(handles.menu,'data_lens');
s = size(data);
Pti = getappdata(handles.menu,'Pti');
set(handles.pts_slider,'Min',Pti);
set(handles.pts_slider,'Max',s(2)-s(2)/16);
xslider = get(hObject,'value');

if xslider == 1
    xslider = (s(1)/12+Pti);
    set(hObject,'value',xslider)
end
xrange = round([(xslider-s(2)/16) (xslider+s(2)/16)]);

xtige= getappdata(handles.menu,'xtige');
yslider = mean(xtige(xrange(1):xrange(2)));
yrange = round([(yslider-s(1)/12) (yslider+s(1)/12)]);
set(handles.axes1,'ylim',yrange,'xlim',xrange);

```

```

% --- Executes during object creation, after setting all properties.
function pts_slider_CreateFcn(hObject, eventdata, handles)
% hObject    handle to pts_slider (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

if isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor',[.9 .9 .9]);
end

% --- Executes on button press in pts_corr_done.
function pts_corr_done_Callback(hObject, eventdata, handles)
% hObject    handle to pts_corr_done (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
data = getappdata(handles.menu,'data_lens');
s = size(data);
set(handles.uipanel5,'visible','off');
set(handles.axes1,'ylim',[1 s(1)],'xlim',[1 s(2)])
set(handles.instruction,'string','');

% --- Executes on button press in pts_next.
function pts_next_Callback(hObject, eventdata, handles)
% hObject    handle to pts_next (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

correction_Callback(hObject, eventdata, handles)

function topred_Callback(hObject, eventdata, handles)
% hObject    handle to topred (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of topred as text
%        str2double(get(hObject,'String')) returns contents of topred as a double

% --- Executes during object creation, after setting all properties.
function topred_CreateFcn(hObject, eventdata, handles)
% hObject    handle to topred (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.

```

```
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function disty_Callback(hObject, eventdata, handles)
% hObject handle to disty (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of disty as text
% str2double(get(hObject,'String')) returns contents of disty as a double
```

```
% --- Executes during object creation, after setting all properties.
function disty_CreateFcn(hObject, eventdata, handles)
% hObject handle to disty (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function lowleft_Callback(hObject, eventdata, handles)
% hObject handle to lowleft (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of lowleft as text
% str2double(get(hObject,'String')) returns contents of lowleft as a double
```

```
% --- Executes during object creation, after setting all properties.
function lowleft_CreateFcn(hObject, eventdata, handles)
% hObject handle to lowleft (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function n_needles_Callback(hObject, eventdata, handles)
% hObject handle to n_needles (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
```

```

% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of n_needles as text
%        str2double(get(hObject,'String')) returns contents of n_needles as a double


% --- Executes during object creation, after setting all properties.
function n_needles_CreateFcn(hObject, eventdata, handles)
% hObject    handle to n_needles (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called


% Hint: edit controls usually have a white background on Windows.
%        See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in upside_down.
function upside_down_Callback(hObject, eventdata, handles)
% hObject    handle to upside_down (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% Hint: get(hObject,'Value') returns toggle state of upside_down


function space_Callback(hObject, eventdata, handles)
% hObject    handle to space (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% Hints: get(hObject,'String') returns contents of space as text
%        str2double(get(hObject,'String')) returns contents of space as a double


% --- Executes during object creation, after setting all properties.
function space_CreateFcn(hObject, eventdata, handles)
% hObject    handle to space (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called


% Hint: edit controls usually have a white background on Windows.
%        See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function [CMY,K] = rgb2cmyk(RGB)

simage = size(RGB);

```

```

RGB2D = reshape((1 - double(RGB)/255),simage(1)*simage(2),3);

K = min(RGB2D,[],2);
Km1 = 1-K;
x = find(Km1==0);
TF = isempty(x);
if TF==0
    Km1(x)=0.000000001;
end
CMY = reshape((RGB2D -[K K K])./[Km1 Km1 Km1],simage);
K = reshape(K, simage(1:2));

```

Script 2 - Python script runs in a loop and creates a folder for each swap cell

Source: GIS Department, Florida International University

Name: Daniel Gann & Himadri Biswas

Date: 2010/10/18

Purpose: This python script runs in a loop and creates a folder for each of the swap cells.

The swap.exe and swap.swp files are copied from the swapHome folder to each of the folders by cell name. However, the swap.swp file is modified before copying. Two changes are made to the file before writing it in the folders for every cell. Firstly, the pressure (ZI) and head (H) values are changed for every cell. Secondly, the ground water levels by date and time are changed for every cell. Then, the swap model is executed using the "cellName.swp" and "swap.exe" file for each cells in the folders. Lastly, the swap results (result.vap) from every cell are copied and appended into a new text file.

```
'''
#=====
#### Section 1
# import libraries

import os.path, csv, shutil, re
from itertools import islice
#import numpy as np
from numpy import genfromtxt

# =====
#### Section 2
## set user defined parameters

# define location of swap execution file (e.g. C:/swapHome/)
swapHome = "C:\swap\swapHome"

# provide the .csv file containing initial moisture values by cell. Make absolutely sure that the csv
file is in swapHome/Data folder
parF1File = "C:\swap\swapHome\Data\initialMoisture.csv"

# provide the .csv file containing soil hydraulic parameters. Make absolutely sure that the csv file
is in swapHome/Data folder folder
#parF2File = arcpy.GetParameter(2)

# provide the .csv file containing groundwater levels. Make absolutely sure that the csv file is in
swapHome/Data folder folder
parF3File = "C:\swap\swapHome\Data\gwlevel.csv"

# set the new ZI in kPa for every cell
ZI_00 = -0.5

# set the head (H) in cm for every cell
H_11 = 0.0
# =====
#### Section 3
```

```

## This section of the python script runs in a loop and creates folders for each of the processed
cells.
## The swap.exe and swap.swp files are copied from the swapHome folder to each of the cell
name folders.
## However, the swap.swp file is modified before copying. Two changes are made to the file
before writing it in the folders for every cell.
## Firstly, the pressure (ZI) and head (H) values are changed for every cell based on the initial
moisture look-up table content.
## Secondly, the ground water levels by date and time are changed for every cell based on the
ground water level look-up table.
## Finally, the swap model is executed using the "cellName.swp" and "swap.exe" file for each cell
in their respective folders.

# mdl represents the model execution file swap.exe located at swapHome
mdl = 'swap.exe'

# open and read .csv file (parF1File) with pressure (ZI) and head (H) values by cell names
parF1 = open(parF1File,'rb')
reader1 = csv.reader(parF1)

cellCount = 1

for par1line in islice(reader1, 1, None):
    # get the cell names (cellName) from first column of parF1File
    cellName = par1line[0]
    # get the pressure (ZI) in kPa values from second column of parF1File
    ZI = par1line[1]
    # get the head (H) values in cms from third column of parF1File
    H = par1line[2]

    # path to create new folders by swap cell number
    swapNewDir = os.path.join(swapHome, cellName)

    # create swap cell folders
    if not os.path.isdir(swapNewDir):
        os.makedirs (swapNewDir)
        print 'created', swapNewDir

    # copy the swap.exe file to each of the swap cell folders
    shutil.copy2((swapHome + "\\" + mdl), (swapNewDir + "\\" + mdl))

    origSwap = open(swapHome + "\\" + "swap.swp", "r")
    # create new empty file to write the new swap (newSwap) file for every cell
    newSwap = swapNewDir + '\\' + cellName + ".swp"

    ## open the new swap (newSwap) file to copy the contents of template swap file, new "ZI
    and H", and new "Groundwater levels" for every cell
    newSwapWrite = open(newSwap, 'w')
    for origSwapLine in origSwap:
        newSwapWrite.write(origSwapLine)

```



```

# write the new ZI and H values for every cell in a loop in the newSwap file
if "ZI H" in origSwapLine:
    # change next 2 lines
    ZI_H_1 = next(origSwap, "")
    #print ZI_H_1
    newLineNewSwap1 = str(ZI_00) + " " + H + "\n"
    newSwapWrite.write(newLineNewSwap1)
    print newLineNewSwap1
    ZI_H_2 = next(origSwap, "")
    #print ZI_H_2
    newLineNewSwap2 = ZI + " " + str(H_11) + '\n'
    print newLineNewSwap2
    newSwapWrite.write(newLineNewSwap2)

# write the new Date and Time and Groundwater levels for every cell in a loop in the
newSwap file
if "DATE1 GWLEVEL" in origSwapLine:
    # open csv containing Date and Time, and Ground water levels by cell name
    parF3 = open(parF3File)
    reader3 = genfromtxt(parF3, delimiter=',', dtype=None, names=True)
    for line in reader3:
        newSwapWrite.write(line["DATE1"] + " " + str(line[cellName]) + '\n')
    parF3.close()

cellCount += 1
line = 0
print cellCount

#close new swap file
newSwapWrite.close()

#close template swap file
origSwap.close()

#set model child directory
os.chdir(swapNewDir)

#execute swap model
os.system(swapNewDir + '\\' + mdl + " " + str(cellName) + ".swp")

#=====
### Section 4
## In this section all swap results from every cell (result.vap) are copied and appended to a new
text file

# create a new text file to append the swap result from every cell
swapResult = swapHome + "\\" + "swapResults.txt"
swapResults = open(swapResult, 'w')

#
def readline_number_x(f,x):

```

```

""" read specified line to get header only"""
for index,line in enumerate(iter(f)):
    if index+1 == x: return line
return None

def replace_words(text, word_dic):
    """
    take a text and replace words that match a key in a dictionary with
    the associated value, return the changed text
    """
    rc = re.compile('|'.join(map(re.escape, word_dic)))
    def translate(match):
        return word_dic[match.group(0)]
    return rc.sub(translate, text)

word_dic = {
    'date': 'date_',
    'time': 'time_'
}

# define swap home child directory
os.chdir(swapHome)

# create an empty folderNames list to append the name of all the cells
folderNames = []

# append the names of the folders that start with SR to folderNames list
for root, dirs, files in os.walk(swapHome):
    matching = [d for d in dirs if "SR" in d]
    if len(matching)>1:
        folderNames.append(matching)

print folderNames

# set file count to zero
fileCnt = 0

# write the swap results to the new text file
for e in folderNames[0]:
    #print e
    vapFile = swapHome + "\\" + e + "\\" + "result.vap"
    #print vapFile
    if fileCnt == 0:
        f = open(vapFile, 'rb')
        header = readline_number_x(f,12)
        newHeader = replace_words(header, word_dic)
        #print newHeader
        # write the header from the first file
        swapResults.write("cellName," + newHeader)
        swapResults.close()
        swapResults = open(swapResult, 'a')

```

```

with open(vapFile, 'rb') as f:
    for hLine in islice(f, 12, None):
        if ", " in hLine:
            print "line is dropped"
        else:
            # write the results excluding the header from next cell onwards
            swapResults.write(str(e) + ", " + hLine)
f.close()
fileCnt += 1

swapResults.close()

print "swapResults.txt successfully created"

#=====

```

Script 3 - Arc python script that generate a geo-database and import swap model results for model output visualization.

Source: GIS Department, Florida International University

```
"""
Name: Himadri Biswas & Daniel Gann
Version: 0.1
Date: 2010/10/18
Purpose: This purpose of this arc python script is to generate a geo-database and to import swap
model results for model output visualization.
For this purpose:
1. A point feature class for all swap cells is created.
2. The accumulated swap results table (text file to which all the result.vap were appended) is
imported as geo-database table.
3. A time series query table combining all time series records for each swap cell is generated.
4. A relationship class between point feature class and the geo-database results table is created.
"""

# =====
# import libraries
import arcpy, os
from numpy import genfromtxt

# =====
#### Section 1
## set user defined parameters

# set a name for geodatabase to be created. Do not put spaces between names e.g.
"swapProject". NOT "swap project". Remember it is NOT the path to the geodatabase.
Geodatabase name ONLY.
# format: string field
geoDBName = arcpy.GetParameter(0)

# set the .csv file containing initial moisture values by cell. Make sure it contains the names of the
cell in the first column
# this csv file is the same file that was used to run the other part of the script as parF1File
# format: text file
parF1File = arcpy.GetParameterAsText(1)

# provide a name for feature class to be created. Do not put spaces between names e.g.
swapCells. NOT swap Cells. Name only.
# format: string
#cellFCName = arcpy.GetParameter(2)

# set the workspace where geodatabase will be created and where the accumulated swap results
(text file) is located.
# format: workspace
swapHome = arcpy.GetParameter(2)
```

```

# set the number of rows and columns
# format = Long
numRow = arcpy.GetParameter(3)
numCol = arcpy.GetParameter(4)

# set the origin (Upper Left Corner) of the points by setting the Upper Left X and Upper Left Y
Coordinates
# format = Long
xUL = arcpy.GetParameter(5)
yUL = arcpy.GetParameter(6)

# set the horizontal resolution; spacing between the points for every cell in x and y direction
# format = Long
xRes = arcpy.GetParameter(7)
yRes = arcpy.GetParameter(8)

# set the file of the accumulated swap results (text file where all the result.vap were appended)
#format = text file
swapResults = arcpy.GetParameterAsText(9)

# set the name of swap results file with extension
swapResultsFile = os.path.basename(swapResults)

# set the name of results file without extension
swapResultsName = swapResultsFile.split(".")[0]

# set the time series output table query name
queryTableName = arcpy.GetParameterAsText(10)

# =====
### Section 2
## create geo-database and point feature class for swap cell

# set the path to where geo-database is created
geoDBPath = str(swapHome) + "\\ " + geoDBName + ".gdb"
arcpy.AddMessage("Geodatabase is set to" + " " + geoDBPath)

# if the geodatabase exists then display a message that says it exists else create the
geodatabase
if arcpy.Exists(geoDBPath):
    arcpy.AddMessage("Geodatabase already exists")
else:
    arcpy.CreateFileGDB_management(str(swapHome), geoDBName, "CURRENT")
    arcpy.AddMessage("Geodatabase" + " " + geoDBName + " " + "successfully created")

# set workspace to the newly created geodatabase
fcWorkspace = geoDBPath

# set environment variable for workspace
arcpy.env.workspace = fcWorkspace

```

```

# define swap cell feature class name
cellFCName = "swapCells"

# define swap cell feature class output path
cellFC = str(fcWorkspace) + "\\ " + cellFCName

# create point feature class for all cells
if arcpy.Exists(cellFC):
    arcpy.AddMessage("Swap cells feature class already exists")
else:
    arcpy.CreateFeatureclass_management(str(fcWorkspace), cellFCName, "POINT")
    arcpy.AddMessage("Feature class" + " " + cellFCName + " " + "created")

    # add a new column to the newly created feature class e.g. "cellName" to which cell names will
    be attached
    arcpy.AddField_management (cellFC, "cellName", "TEXT", "", "", "12")
    arcpy.AddMessage("Field cellName successfully created in the feature class attribute table")

# read the initialMoisture.csv file to get the name of swap cells
cellLoc = genfromtxt(parF1File, delimiter=',', dtype=None, names=True)

# create an empty list for cell names
cellName=[]

for line in cellLoc:
    cN = str(line['Loc'])

    # append the cell names in the list
    cellName.append(cN)

# create empty list for x coordinate
xArray = []
# create empty list for y coordinate
yArray = []

cnt = 1
for row in range(0,numRow):
    for col in range(0,numCol):
        y=yUL - yRes*row
        x=xUL + xRes*col
        if cnt <= len(cellName):
            # append x coordinate to xArray list
            xArray.append(x)
            # append y coordinate to yArray list
            yArray.append(y)
            cnt += 1

# combine c and y arrays into paired coordinates
cellArrayTemp = zip (xArray, yArray)

```

```

# combine paired coordinates with cell names
cellArray = zip(cellArrayTemp, cellName)

# create points in feature class
cursor = arcpy.da.InsertCursor(cellFC, ('SHAPE@XY', 'cellName'))
for row in cellArray:
    cursor.insertRow(row)

del cursor

# =====
### Section 3
## import the swap results (text file to which all the result.vap were appended) into the geo-
database as geo-database table

# path of the geodatabase table
resultsTablePath = str(fcWorkspace) + "\\ " + swapResultsName

# if the geodatabase table exists then display a message that says it exists else create the
geodatabase table
if arcpy.Exists(resultsTablePath):
    arcpy.AddMessage("Results table already exists")
else:
    arcpy.TableToGeodatabase_conversion((str(swapHome) + "\\ " + swapResultsFile),
str(fcWorkspace))
    arcpy.AddMessage("Geodatabase table" + " " + swapResults + " " + "successfully imported to
database" )

# create fields
arcpy.AddField_management (resultsTablePath, "dateTime", "TEXT", "", "", "50")
arcpy.AddMessage("dateTime field created")
arcpy.AddField_management (resultsTablePath, "wcontent_", "DOUBLE", 3)
arcpy.AddMessage("wcontent_ field created")
arcpy.AddField_management (resultsTablePath, "phead_", "DOUBLE", 2)
arcpy.AddMessage("phead_ field created")
arcpy.AddField_management (resultsTablePath, "hconduc_", "DOUBLE", 15)
arcpy.AddMessage("hconduc_ field created")
arcpy.AddField_management (resultsTablePath, "drainage_", "DOUBLE", 3)
arcpy.AddMessage("drainage_ field created")
arcpy.AddField_management (resultsTablePath, "rootext_", "DOUBLE", 3)
arcpy.AddMessage("rootext_ field created")
arcpy.AddField_management (resultsTablePath, "wflux_", "DOUBLE", 5)
arcpy.AddMessage("wflux_ field created")
arcpy.AddField_management (resultsTablePath, "temp_", "DOUBLE", 2)
arcpy.AddMessage("temp_ field created")
arcpy.AddField_management (resultsTablePath, "solute1_", "DOUBLE", 3)
arcpy.AddMessage("solute1_ field created")
arcpy.AddField_management (resultsTablePath, "solute2_", "DOUBLE", 3)
arcpy.AddMessage("solute2_ field created")
arcpy.AddField_management (resultsTablePath, "solflux_", "DOUBLE", 3)
arcpy.AddMessage("solflux_ field created")

```

```

arcpy.AddField_management (resultsTablePath, "top_", "DOUBLE", 3)
arcpy.AddMessage("top_ field created")
arcpy.AddField_management (resultsTablePath, "bottom_", "DOUBLE", 3)
arcpy.AddMessage("bottom_ field created")
arcpy.AddField_management (resultsTablePath, "day_", "LONG", 3)
arcpy.AddMessage("day_ field created")
arcpy.AddField_management (resultsTablePath, "dcum_", "LONG", 3)
arcpy.AddMessage("dcum_ field created")

# calculate fields
arcpy.CalculateField_management (resultsTablePath, "wcontent_", "!wcontent!",
"PYTHON_9.3")
arcpy.AddMessage("wcontent_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "phead_", "!phead!", "PYTHON_9.3")
arcpy.AddMessage("phead_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "hconduc_", "!hconduc!",
"PYTHON_9.3")
arcpy.AddMessage("hconduc_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "drainage_", "!drainage!",
"PYTHON_9.3")
arcpy.AddMessage("drainage_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "rootext_", "!rootext!", "PYTHON_9.3")
arcpy.AddMessage("rootext_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "wflux_", "!waterflux!", "PYTHON_9.3")
arcpy.AddMessage("wflux_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "temp_", "!temp!", "PYTHON_9.3")
arcpy.AddMessage("temp_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "solute1_", "!solute1!", "PYTHON_9.3")
arcpy.AddMessage("solute1_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "solute2_", "!solute2!", "PYTHON_9.3")
arcpy.AddMessage("solute2_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "solflux_", "!soluteflux!", "PYTHON_9.3")
arcpy.AddMessage("solflux_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "top_", "!top!", "PYTHON_9.3")
arcpy.AddMessage("top_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "bottom_", "!bottom!", "PYTHON_9.3")
arcpy.AddMessage("bottom_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "day_", "!day!", "PYTHON_9.3")
arcpy.AddMessage("day_ field calculated")
arcpy.CalculateField_management (resultsTablePath, "dcum_", "!dcum!", "PYTHON_9.3")
arcpy.AddMessage("dcum_ field calculated")

# delete unnecessary fields
arcpy.DeleteField_management(resultsTablePath, "wcontent")
arcpy.AddMessage("wcontent field deleted")
arcpy.DeleteField_management(resultsTablePath, "phead")
arcpy.AddMessage("phead field deleted")
arcpy.DeleteField_management(resultsTablePath, "hconduc")
arcpy.AddMessage("hconduc field deleted")
arcpy.DeleteField_management(resultsTablePath, "drainage")
arcpy.AddMessage("drainage field deleted")

```



```

arcpy.DeleteField_management(resultsTablePath, "rootext")
arcpy.AddMessage("rootext field deleted")
arcpy.DeleteField_management(resultsTablePath, "waterflux")
arcpy.AddMessage("waterflux field deleted")
arcpy.DeleteField_management(resultsTablePath, "temp")
arcpy.AddMessage("temp field deleted")
arcpy.DeleteField_management(resultsTablePath, "solute1")
arcpy.AddMessage("solute1 field deleted")
arcpy.DeleteField_management(resultsTablePath, "solute2")
arcpy.AddMessage("solute2 field deleted")
arcpy.DeleteField_management(resultsTablePath, "soluteflux")
arcpy.AddMessage("soluteflux field deleted")
arcpy.DeleteField_management(resultsTablePath, "top")
arcpy.AddMessage("top field deleted")
arcpy.DeleteField_management(resultsTablePath, "bottom")
arcpy.AddMessage("bottom field deleted")
arcpy.DeleteField_management(resultsTablePath, "day")
arcpy.AddMessage("day field deleted")
arcpy.DeleteField_management(resultsTablePath, "dcum")
arcpy.AddMessage("dcum field deleted")

# calculate date time field
expr = '!date_! + " " + !time_!'

arcpy.CalculateField_management (resultsTablePath, "dateTime", expr, "PYTHON_9.3")
arcpy.AddMessage("Date time field was calculated successfully")

# convert date time to time series field
#arcpy.ConvertTimeField_management (resultsTablePath, "dateTime", "YYYY-MM-DD
HH:mm:ss", "timeSeries", "DATE", "YYYYMMDDHHmmss")
#arcpy.AddMessage("Date time field was converted successfully to time series field")

# =====
### Section 4
## create time series query layer

# define query table output path
queryTablePath = str(fcWorkspace) + "\\ " + queryTableName

# make query layer
arcpy.MakeQueryTable_management([resultsTablePath, cellFC] , "queryTbl", "NO_KEY_FIELD",
"", [{"swapCells.Shape", 'Shape'}, {"swapCells.OBJECTID", 'OBJECTID'}, {"swapCells.cellName",
'cellName'}, {"swapResults.depth", 'depth'}, {"swapResults.wcontent_",
'wcontent'}, {"swapResults.phead_", 'phead'}, {"swapResults.hconduc_",
'hconduc'}, {"swapResults.temp_", 'temp'}, {"swapResults.dateTime", 'dateTime'}],
"swapCells.cellName = swapResults.cellName")

# save query layer to database
arcpy.CopyFeatures_management("queryTbl", queryTablePath)
#arcpy.CopyRows_management("queryTbl", queryTablePath)
arcpy.AddMessage("Time series query was successfully created")

```

```

# =====
### Section 5
## create relationship class between

# path of the relationship class
relationshipPath = str(fcWorkspace) + "\\ " + cellFCName + "Have" + swapResultsName

# if the relationship class exists then display a message that says it exist else create the
relationship class

if arcpy.Exists(relationshipPath):
    arcpy.AddMessage("Relationship class already exists")
else:
    # create relationship class between feature class and geo-database table
    arcpy.CreateRelationshipClass_management (cellFC, resultsTablePath, relationshipPath,
    "SIMPLE", "swapResults", "swapCell", "NONE", "ONE_TO_MANY", "NONE", "cellName",
    "cellName")
    arcpy.AddMessage("Relationship class successfully created")
# ===== end of file =====

```

Script 4 - Preferential flow input data due to macropores

Z_AH = -5.0 ! Depth bottom A-horizon [-1000..0 cm, R]
 Z_IC = -15.0 ! Depth bottom Internal Catchment (IC) domain [-1000..0 cm, R]
 Z_ST = -20.0 ! Depth bottom Static macropores [-1000..0 cm, R]
 VLMPSTSS = 0.04 ! Volume of Static Macropores at Soil Surface [0..0.5
 cm³/cm³, R]
 PPICSS = 0.6 ! Proportion of IC domain at Soil Surface [0..0.99 -, R]
 NUMSBDM = 4 ! Number of Subdomains in IC domain [0..MaDm-2 -, I]
 POWM = 0.8 ! Power M for frequency distribut. curve IC domain
 (OPTIONAL, default 1.0) [0..100 -, R]
 RZAH = 0.0 ! Fraction macropores ended at bottom A-horizon
 [OPTIONAL, default 0.0] [0..1 -, R]
 SPOINT = 1. ! Symmetry Point for freq. distr. curve [OPTIONAL, default
 1.0] [0..1 -, R]
 SWPOWM = 0 ! Switch for double convex/concave freq. distr. curve
 (OPTIONAL, Y=1, N=0; default: 0) [0..1 -, I]
 DIPOMI = 10.0 ! Minimal diameter soil polygons (shallow) [0.1..1000 cm, R]
 DIPOMA = 50.0 ! Maximal diameter soil polygons (deep) [0.1..1000 cm, R]

* Start of Table with shrinkage characteristics

* ISOILLAY3 = indicator (number) of soil layer, as defined in part 4 [1..MAHO, I]

* SWSoilShr = Switch for kind of soil for determining shrinkage curve: 0 = rigid
 soil, 1 = clay, 2 peat [0..2 -, I]

* SWSoilShr = Switch for determining shrinkage curve [1..2 -, I]: 1 = parameters
 for curve are given; 2 = typical points of curve are given

* GeomFac = Geometry factor (3 = isotropic shrinkage), [0..100, R]

* ShrParA to ShrParE = parameters for describing shrinkage curves,
 * depending on combination of SWSoilShr and SwShrInp
 [-1000..1000, R]:

* SWSoilShr = 0 : 0 variables required (all
 dummies: ThetCrMP to ShrParE)

* SWSoilShr = 1, SwShrInp 1 = : 3 variables required
 (ShrParA to ShrParC) (rest dummies)

* SWSoilShr = 1, SwShrInp 2 = : 2 variables required
 (ShrParA to ShrParB) (rest dummies)

* SWSoilShr = 2, SwShrInp 1 = : 5 variables required
 (ShrParA to ShrParE)

* SWSoilShr = 2, SwShrInp 2 = : 5 variables required
 (ShrParA to ShrParE)

ISOILLAY3 SwSoilShr SwShrInp ThetCrMP GeomFac ShrParA ShrParB ShrParC ShrParD
ShrParE

1	2	3	0.50	3.0	2.5	13.5	4.5	0.9	0.0
2	2	3	0.45	3.0	2.0	11.0	3.0	0.9	0.0
3	2	3	0.45	3.0	1.2	12.6	2.9	0.4	0.0

* End of Tabel with shrinkage characteristics

ZnCrAr = -5.0 ! Depth at which crack area of soil surface is calculated [-100..0
cm, R]

* Start of Table with sorptivity characteristics

* ISOILLAY4 = indicator (number) of soil layer, as defined in part 4 [1..MAHO, I]

* SWSorp = Switch for kind of sorptivity function [1..2 -, I]:

* 1 = calculated from hydraulic functions according to Parlange

* 2 = emperical function from measurements

* SorpFacParl = factor for modifying Parlange function (OPTIONAL, default 1.0)
[0..100 -, R]

* SorpMax = maximal sorptivity at theta residual [0..100 cm/d**0.5, R]

* SorpAlfa = fitting parameter for emperical sorptivity curve [-10..10 -, R]

ISOILLAY4 SwSorp SorpFacParl SorpMax SorpAlfa

1	1	0.33	0.0	0.0
2	1	0.33	0.0	0.0
3	1	0.50	0.0	0.0

* End of Tabel with sorptivity characteristics

* Shape factor Darcy exchange

SHAPEFACMP = 1.0

SwDrRap = 0 ! Switch for kind of drainage function TEMPORARY: TEST
option [1..2 -, I]:

RapDraResRef = 5.0 ! Reference rapid drainage resistance [0..1.E+10 /d, R]
! an array with a single element must be indicated using a
multiplier asterix

! (see TTUTIL-manual, par. 5.2 Defining arrays)

RapDraReaExp = 2.5 ! exponent for reaction rapid drainage to dynamic crack
width [0..100 -, R]

*Depth of drainlevel: only required when SwBotB = 3

ZDrLv = -85.0

*

* CRITICAL value for undersaturation volume

CritUndSatVol = 0.1 ! [0.0 .. 10.0 cm, R]

SwDarcy = 1

* vanaf swap32 (rev 16)

*Number of drainage system connected to rapid drainage

NumLevRapDra = 1 ! [1..NRLEVS, -, I]

* vanaf swap3.2.24

* Threshold value for ponding (cm) on soil surface before overland flow into macropores starts

PNDMXMP = 0.0 ! [0.0 .. 10.0, cm, R]

VITA

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1966 – 1975	B.A., Civil Engineering Universidad Nacional de Ingeniería, Lima, Perú
1978	Civil Engineer # 16509 Colegio de Ingenieros, Lima, Perú
1975 – 1977	M.B.A. Escuela Superior de Negocios, Lima, Perú
1999- 2005	C.E.O South African Royal Manufacturing Virginia, Republic of South Africa
2009 – 2011	Master Civil Engineer Florida International University, Miami, Florida
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PUBLICATIONS AND PRESENTATIONS

Perez, L. G. (1978). “*Water Pipe Design System for Huancasancos, Ayacucho, Peru*”. Presentation to Peruvian School of Civil Engineers to opt for CI (Colegio de Ingenieros) #16509.

Pérez, L. G., D. B. Jo Lau, and H.R. Fuentes (2011). “*Water Retention Characteristics of Unsaturated Peat Soils in the Shark River Slough Environs of the Everglades National Park (ENP): Experiments and Modeling Development to Support Environmental Restoration.*” Poster Presentation, 2011 Association of Environmental Engineering and Science Professors Education & Research Conference, Tampa, Florida, USA.

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