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Update of the 1:5 million Soil and Terrain Database for Latin America and the Caribbean (SOTERLAC)

(Version 2.0)

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SUMMARY

The Soil and Terrain database for Latin America and the Caribbean (SOTERLAC), version 2.0, at scale 1:5 million, replaces version 1.02. The update includes changes in the GIS file and in the attributes database.

The topographic base of the SOTERLAC map was adapted to a version congruent to the Digital Chart of the World.

The SOTERLAC attribute database has changed in respect to the number of pedon attributes that can be stored. Contrary to the preceding, compact version, version 2.0 can accommodate all pedon attributes considered in a 1:1 million scale SOTER database.

Keywords: SOTER database, SOTERLAC version 2.0, Latin America, Caribbean.

1 INTRODUCTION

The Soil and Terrain database for Latin America and the Caribbean (SOTERLAC), version 1.02 at scale 1:5 M, was released in 1998 (FAO *et al.* 1998). It was the result of a joint effort of the United Nations Environmental Programme (UNEP), the Food and Agriculture Organisation of the United Nations (FAO), ISRIC - World Soil Information, and the International Potato Centre (CIP) over the years 1993 –1997. It was the first release of a soil and terrain database linked to GIS using the SOTER[1] methodology (van Engelen and Wen 1995; van Engelen and Peters 1995) at continental scale. SOTERLAC consists of a geometric database using a geographic information system (GIS) linked to a relational database management system (RDBMS) for the attribute data files. A viewer programme was developed for consulting thematic maps and the SOTER database, version 1.02.

The topographic base map of SOTERLAC version 1.02 was similar to the Latin American sheet of the Soil Map of the World (FAO-Unesco 1974-1981). This base map, however, is not fully compatible with maps of other continents. In version 2.0 the topographic base of SOTERLAC was changed to the Digital Chart of the World (DCW) at scale 1:1 M (DMA 1993; ESRI 1992), the SOTER default. The layers give information on the topology, location and extent of country boundaries, coastlines, rivers, drainage systems and lakes.

Since the release of SOTERLAC version 1.02, comments have been received and a number of errors and inconsistencies were detected in the database. Comments focussed on SOTER units not correctly representing the landform or soils in a particular region, and incorrect or incomplete soil compositions. These inconsistencies have been corrected in the present SOTERLAC database. Moreover, new SOTER units were defined, while new profiles and additional information for Brazil and Puerto Rico have been included.

The data files of SOTERLAC (version 1.02) could accommodate only a limited number of attributes for the representative profiles (van Engelen and Peters 1995). This limited the possible uses of the database, especially, when specific soil information is requested,

[1] SOTER stands for SOil and TERrain database

for example, about exchangeable cations. Therefore, the update of the SOTERLAC database started in 2004 by adding additional representative profile data, using the common structure of the 1:1M SOTER database (van Engelen and Wen 1995). It is ISRIC's intention to update the profile information on a country by country basis. In the present version, the profile information for Brazil, Peru and Puerto Rico, which makes out roughly one third of the profiles in the database, has been updated.

2 MATERIALS AND METHODS

2.1 Source of data

The compilation of the 1:5 M SOTER database for Latin America and the Caribbean (SOTERLAC) started in 1993 and was completed in 1998 (FAO *et al.* 1998). The compilation was done in phases, the first phase included 6 countries (van Engelen and Peters 1995). Data for the remaining countries were compiled later. Most Latin American countries participated in the compilation of a national SOTER database

The present update of SOTERLAC consists of correcting of erroneous data, replacing of a number of synthetic profiles with real ones, and for two countries the expansion of representative profile data. New representative profile information was compiled from published reports and the web (EMBRAPA 2005) .

2.2 Methodology

The SOTER methodology was initially developed as a land resources information system for scales of 1:1 million (van Engelen and Wen 1995). SOTER combines a geometric database with an attribute database, storing the SOTER units' location, extent and topology, and the units' soil and terrain characteristics. The concept is based on the relation between the physiography (landform), parent materials and soils within a certain area. It identifies areas of land with a distinctive and often repetitive, pattern of landform, lithology, surface form, slope, parent material and soils. The methodology uses a stepwise approach identifying major landforms or terrain units at its highest level of distinction, followed by subdividing the terrain units on basis of differences in parent material and soils. The so-created units are called SOTER units (Figure 1), which represent unique combinations of terrain and soil characteristics (van Engelen and Wen 1995); (Dijkshoorn 2002).

Each SOTER unit has a unique identifier, the SOTER unit-ID (SUID), which forms the link between the geometric and the attribute database. The attribute database consists of different tables that are linked through primary keys.

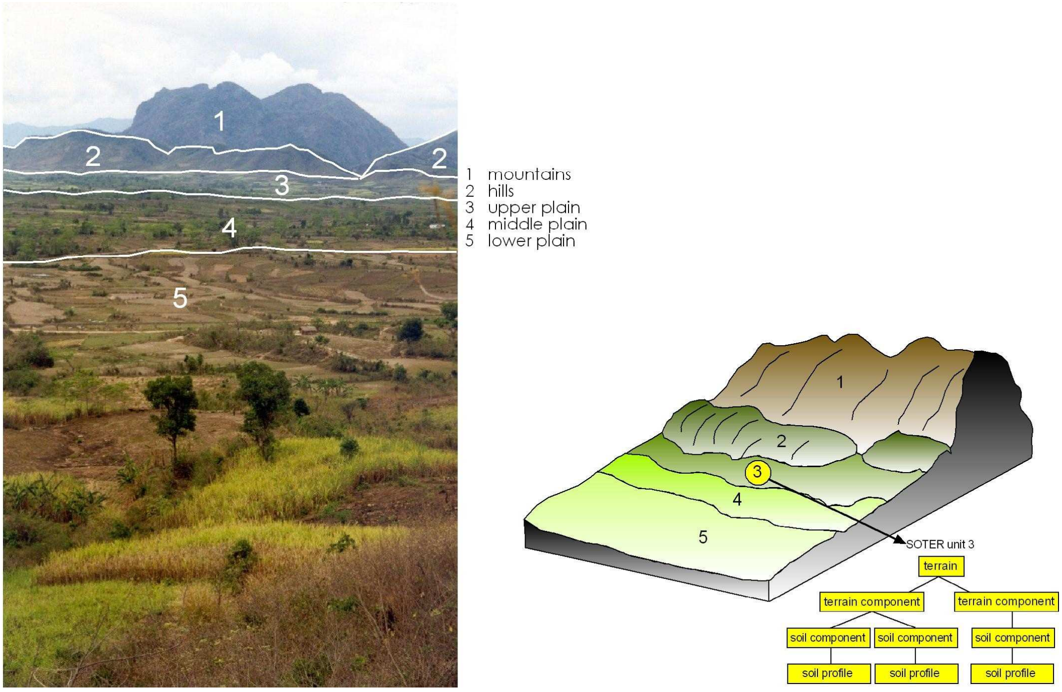

Figure 1. Representation of SOTER units and the structure of a SOTER unit

The SOTER methodology has been applied at a range of scales, ranging from 1:5 million to 1:200,000, using a standard database structure. However, for SOTERLAC version 1.02, a more compact database structure was made, so that only a limited number of soil and terrain characteristics could be recorded. The present study uses the full SOTER composition for the representative profiles (Table 1).

Although the attribute information of the original dataset is adequate for some interpretations, e.g. Carbon stocks of Amazon soils (Batjes and Dijkshoorn 1999), it is insufficient for other assessments. For example, essential information on the composition of the exchange complex and physical soil information was lacking. In some cases this information has not been analysed, estimates have been made by using taxo-transfer rules and is available in a harmonized database (Batjes 2005).

Table 1. Non-spatial attributes of a SOTER unit and their occurrence in percentage in the SOTERLAC database (version 2.0)

TERRAIN	% filled
1 ISO country code	100
2 SOTER unit-ID	100
3 year of data collection	95
4 map-ID	60
5 slope gradient	100
6 relief intensity	95
7 major landform	100
8 regional slope	100
9 hypsometry	100
10 general lithology	100

TERRAIN COMPONENT	%
11 ISO country code	100
12 SOTER unit-ID	100
13 terrain component number	100
14 proportion of SOTER unit	100
15 length of slope	84
16 local surface form	70

SOIL COMPONENT	%
17 ISO country code	100
18 SOTER unit-ID	100
19 terrain component number	100
20 soil component number	100
21 proportion of SOTER unit	100
22 profile-ID	88
23 position in terrain component	88
24 surface rockiness	83
25 surface stoniness	83
26 rootable depth	87

PROFILE	%
27 profile-ID	100
28 profile database ID	62
29 latitude	82
30 longitude	82
31 elevation	76
32 sampling date	68
33 lab ID	81
34 drainage	100
35 infiltration rate	-
36 surface organic matter	-
37 classification WRB	-
38 WRB classification specifier	-
39 classification FAO'88	100
40 classification version	100
41 phase (FAO)	19
42 national classification	50
43 Soil Taxonomy	50

HORIZON	%
44 profile-ID	100
45 horizon number	100
46 diagnostic horizon	65
47 diagnostic property	38
48 horizon designation	97
49 lower depth	100
50 distinctness of transition	24
51 moist colour	94
52 dry colour	-
53 grade of structure	22
54 size of structure	22
55 type of structure	92
56 abundance of coarse fragments	87
57 size of coarse fragments	-
58 very coarse sand	10
59 coarse sand	32
60 medium sand	10
61 fine sand	32
62 very fine sand	10
63 total sand	91
64 silt	91
65 clay	91
66 particle size class	91
67 bulk density	36
68 moisture content at various tensions	-
69 hydraulic conductivity	-
70 infiltration rate	-
71 pH H_2O	92
72 pH KCl	33
73 electrical conductivity	-
74 soluble Na^+	-
75 soluble Ca^{2+}	-
76 soluble Mg^{2+}	-
77 soluble K^+	-
78 soluble Cl^-	-
79 soluble SO_4^{2-}	-
80 soluble HCO_3^-	-
81 soluble CO_3^{2-}	-
82 exchangeable Ca^{2+}	33
83 exchangeable Mg^{2+}	33
84 exchangeable Na^+	34
85 exchangeable K^+	34
86 exchangeable $Al3^+$	32
87 exchangeable acidity	33
88 CEC soil	90
89 total carbonate equivalent	-
90 gypsum	-
91 total organic carbon	89
92 total nitrogen	73
93 P_2O_5	25
94 phosphate retention	-
95 Fe dithionite	-
96 Al dithionite	-
97 Fe pyrophosphate	-
98 Al pyrophosphate	-
99 clay mineralogy	-

Moreover, it is the intention to ‘reclassify’ the representative profiles according to WRB standard (ISSS *et al.* 1998). This is not possible with the limited number of profile characteristics held in version 1.02. Even with the updated profile information, it is still difficult to reclassify all profiles conform WRB. In addition, the question arises if reclassification would not also require redefining the soil boundaries (Jenet 2004).

Brazil was selected as the first country for the update of SOTERLAC, with the intention to reclassify the representative profiles according to WRB. The representative profiles for Puerto Rico were also updated. In version 2.0 of the SOTERLAC database, WRB classification is only given for updated profiles.

No changes were made in the number of attributes stored in the terrain, terrain component and soil component data tables. The information terrain, terrain component and soil component in version 2.0 is similar to that in version 1.02, except for some corrections in the terrain table. Table 1 gives all non spatial attributes, including the percentages of occurrence of each attribute in SOTERLAC, version 2.0.

3 MODIFICATIONS

3.1 Modifications in the GIS file

3.1.1 Conversion to DCW format

The topographic base of the former version of SOTERLAC (1.02) was congruous to the FAO-Unesco Soil Map of the World (FAO-Unesco 1974 - 1981). The topographic base of SOTERLAC (version 2.0) has been revised, using the Digital Chart of the World (DMA 1993; ESRI 1992). All outer boundaries of the countries in Latin America and the Caribbean are now congruent to the DCW map, the SOTER standard. This change has resulted in slight modifications in the delineation of the of SOTER units, especially along coastlines, and has shifted some country boundaries. Locations of water bodies and lakes were also corrected. Compared to the previous version of SOTERLAC, the location of most Caribbean islands has shifted somewhat West. In addition, many small islands along the south Chilean coast did appear on the map. By excluding polygons of less than 10 km^2, these small features were eliminated (Jenness 2005).

3.1.2 Additional polygons

New polygons and new SOTER units were added to the geometric database for Argentina, Colombia and Puerto Rico. Some of the added polygons were simply corrections, others improvements of the database. The most important changes are described below.

Argentina
In the Misiones area, in Northeastern Argentina, changes were made in the polygons along the borders with Brazil. An extra SOTER unit was created for the upstream parts of the rivers Paraná, Iguazú and Uruguay. The actual SOTER unit was divided in an upstream and downstream unit. SUID 33 was cut north of Posadas (Rio Paraná) to accommodate for the strongly sloping river valleys (slope>10%) upstream (SUID 108) and the flat plains of the river downstream (SUID 33).

Colombia-Brazil-Venezuela

Based on a study of the Colombian Amazon and Orinoco rivers (IGAC 1999), three additional SOTER units were defined. The new SOTER units (SUID 63-65) correlated better with the data obtained from the RADAMBRASIL reports (RADAMBRASIL 1976-1977). Some polygons of SOTER units on the Brazilian and the Venezuelan side were slightly modified to guarantee a continuing of the SOTER unit on both sides of the border.

Guyana's

French Guyana had incorrect ISO country-code that prevented the GIS file to link properly to the attribute database. This has been corrected.

Another improvement included the incorporation of the Brokopondo lake in Suriname as polygon into the GIS file, according to the DCW drainage file (DMA 1993). Water bodies and other non-soil components were re-coded in the present version, as described in Annex 1.

Puerto Rico

Based on comments concerning the SOTER map of Puerto Rico, the SOTER units were revised using the information from the USDA State Soil Geographic Database (STATSGO) of the Natural Resources Conservation Service (NRCS), Lincoln. The modifications included a generalization of the soil map of Puerto Rico, scale 1:250.000, and an improvement of the terrain units of the island. In so far as possible, the details of the soil composition have been incorporated into the attribute data files. Five new SOTER units have been delineated, including a unit to characterize the nearby islands of Puerto Rico (a.o. Vieques).

3.1.3 Non-soil components

Standard codes have been introduced for non-soil components such as water bodies, land ice and glaciers, and urban areas in the geometric (GIS) and attribute database files. The new codes start with an ISO country code followed by a 'non-soil' code (Annex 1). There are two levels of distinction. The first level is a coding in the GIS file where polygons are defined. The 'non-soil' polygons get a label, different from the SOTER unit_ID label. The second level is a coding for a 'non-soil' component in the soil component table; this is a non-mappable part of the SOTER unit, for which the proportion of the SOTER unit is known. A code is given for the 'non-soil' component different from the profile_ID. In the present GIS file of SOTERLAC, some 70 polygons were identified as non-soil components, most of them being small lakes.

3.2 Corrections in the attribute database

3.2.1 Data entry errors

Some minor data changes were made in the database. All SOTER data sets are subject to a standard check on consistency of data. A SOTER integrity check was run revealing a few obvious data entry errors, particularly in the soil profile and analytical data. These were corrected and no record change track was kept.

A few other corrections were made, when records appeared incorrect, mainly due to improper copying from the original data source. It included also changes in the notation for missing values inherited from the dBase version of SOTERLAC 1.02. Some of these minor changes in SOTERLAC are listed in Annex 2.

3.2.2 Systematic corrections in the database

A systematic correction refers to the actual update of SOTERLAC and includes a.o to the substitution of synthetic soil profiles with measured profile data. Synthetic profiles in SOTERLAC do not have attribute data in the profile and horizon tables. They consist only of an ISO country code and a code for the soil mapping unit, usually the soil unit code according to the Revised Legend of the SMW (FAO-Unesco 1974).

Other improvements of the database include geo-referencing of selected representative profiles. The following changes were made:

Brazil
Brazil was the first country of the SOTERLAC database to be updated to a complete attribute dataset of the profiles, using the data structure of the 1:1 M SOTER. The Brazilian dataset in

SOTERLAC, version 2.0, now includes 583 profiles (Jenet 2004). All profiles are geo-referenced and have a drainage class. The dataset was updated using the Technical Bulletins of former surveys and, by access to web publications of the Brazilian soil database (EMBRAPA 2005). For about 15 profiles, no additional attribute data was found, as the data source was not accessible or unknown.

Puerto Rico

All available soil profile and horizon data are now included in SOTERLAC. The update and expansion of the SOTER units for Puerto Rico also resulted in an increase of the number of soil components. To replace synthetic profiles, 12 profiles were added. These profiles have been down-loaded from NRCS's Soil Characterization Database (Soil Survey Staff 2005). All geo-referenced positions of the given profiles for Puerto Rico were added.

Peru

The Peruvian dataset was improved by replacing over 20 synthetic profiles with measured profile data. At the same time, the dataset was extended with 10 new profiles. The profile data were obtained from INRENA reports (INRENA 1975-1990) and from the INRENA web page (INRENA 2005). The profile and horizon attribute data has been updated to the common structure of the 1:1M SOTER database.

Belize (Central America)

Profiles, from a land resources inventory of North Belize (King and Baillie 1992) were used to replace most of the Belize synthetic profiles present in version 1.02. The Belizean dataset was extended with 22 geo-referenced profiles. It adds also to the limited number of measured profiles of Central American countries, available in the SOTERLAC database.

4 RESULTS AND CONCLUSIONS

This study lead to a greatly revised Soil and Terrain database at 1:5 million scale for Latin America and the Caribbean (SOTERLAC version 2.0). It supersedes the older version 1.02 published by FAO (FAO *et al.* 1998).

The most important change included adaptation of the structure in the 1:1 million SOTER database for the profile and horizons tables, as described in Chapter 2 and 3, and summarized in Tables 2 and 3. Synthetic profiles were substituted with real ones. The update focussed on Brazil, Peru, Belize and Puerto Rico, hence a fairly large number of synthetic profiles that still remain in version 2.0 (table 2). These will be filled in future updates of SOTERLAC.
Moreover, the geographic base map was rectified to those of the Digital chart of the World (DMA 1993; ESRI 1992).

Table 2. Summary of the contents of SOTER units before and after the update

	Version 1.02 (old)	Version 2.0 (new)
SOTER units	1578	1585
Terrain components	2128	2140
Soil components	3780	3844
Profiles (total)	1832	1864
Profiles (synthetic)	245	200
Horizons	6617	7186

Some 70 profiles were added to the SOTERLAC database, partly replacing synthetic profiles: 22 profiles for Belize, 12 profiles for Puerto Rico and 30 profiles for Peru. Details per country are summarized in table 3, showing the number of SOTER units, terrain components, soil components and profiles.

Missing key attributes in primary SOTER databases form often a drawback for direct use of the data in models and their application. A standardized procedure of taxo-transfer rules was developed to fill such gaps in the dataset (Batjes 2003). The taxo-transfer rules use soil parameter estimates computed for similar FAO soil units, depth intervals, soil textural classes, for 18 soil attributes. The scheme has been applied to SOTERLAC, version 2.0, creating a harmonized dataset for various environmental assessments (Batjes 2005).

Table 3. Details per country for SOTER units and their components

Country	area (1000 km²)	SOTER units	terrain components	soil components	profiles
Antilles*	8.2	9	12	23	18
Argentina	2788.8	105	120	290	218
Bahamas	12.9	2	2	4	0
Belize	22	14	18	36	22
Bolivia	1088.5	58	67	128	74
Brazil	8529.3	298	455	832	583
Chile	733.4	68	81	130	29
Colombia	1124.6	62	66	118	96
Costa Rica	51.7	48	55	72	16
Cuba	111.3	30	49	104	30
Dominican Rep. & Haiti	77.1	12	16	36	7
Ecuador	260.3	44	64	105	44
El Salvador	20.6	14	15	28	4
Falkland Islands	11	1	1	2	2
French Guyana	84	11	20	35	8
Guatemala	108.6	52	60	104	6
Guyana	216.1	20	35	58	40
Honduras	113.2	40	41	58	3
Jamaica	11.6	5	10	15	11
Mexico	1957.3	323	513	797	47
Nicaragua	120.5	48	50	66	12
Panama	74.4	32	37	56	10
Paraguay	396.2	27	40	89	44
Peru	1265.5	80	85	191	103
Puerto Rico	9.1	9	14	22	28
Surinam	146.4	17	25	46	16
Trinidad and Tobago	5.2	6	10	17	17
Uruguay	176.2	16	23	37	36
Venezuela	920	96	102	180	142

- Antilles include Antigua & Barbuda, Barbados, Dominica, Grenada, Guadeloupe, Martinique, Montserrat, Netherlands Antilles, St. Croix, St Kitts-Nevis, St. Lucia, St. Vincent, Turks & Caicos Islands and Virgin Islands.
- Area calculations based on Lambert Conformal Conic projection (central meridian 70 W, standard parallels 15ºN and 30ºS).

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APPENDICES

Appendix 1: Coding of miscellaneous polygons and non-soil components of a SOTER unit

In all SOTER databases polygons occur, which cannot be classified as landform or cover 'non-soil' areas. 'Non-landform' polygons include lakes, glaciers land ice and urban areas. The 'non-soil' areas are part of the landform, but do not have soil development for example rock outcrops, shifting sands and salt flats. These areas, however, can be recognized at SOTER unit level, covering a complete polygon or, be less dominant at soil component level, forming only a part of the polygon. They are categorized either under miscellaneous polygons or under miscellaneous soil components and coded in a similar way.

- *Miscellaneous polygons*

When the entire polygon represents (100%) water, glaciers, building or urban area, salt lake or flats, excavation or quarry, this

Table 4. Coding for miscellaneous non-soil components

SOTER code	FAO code[2]	Description	Former GIS code
ns1	WR	lakes, permanent inland water bodies	-9
ns2	GL	glacier, land ice, permanent snow fields	-7
ns3	ST	Salt plains, salt flats	
ns4	DS	dunes, (shifting) sands	
ns5	RK	rock outcrops, crumbly rock, rock debris, limestone rock land	
ns6	UR	urban , building areas	-8
ns7	QU	quarry, open air mining, (coal) and other excavations	-6
ns8	SW	perennial swamps, in-accessible marshes	
ns9	SL	salt lakes	
ns10	BL	badlands	
- -	- -		
ns99	ND	no data	

[2] FAO 1995. The Digital Soil Map of the World and derived soil properties, Notes, *Land and Water Digital Media Series 1*. FAO, Rome

is indicated in the GIS file, but no entry is made in the SOTER database (table 4).
These polygons are considered to be 'pure' SOTER units. In the GIS files, they are given a standard SOTER code (Table 4). The list can still be expanded in the future.
The label given to such polygons in the GIS file is:
ISO country code extended with the **SOTER code** from Table 4, for example, **ARns1** for lakes in Argentina.

- *Miscellaneous soil components as part of a SOTER unit*

The same codes are maintained at soil component level in case a small lake, land ice, rock outcrops or shifting sand, is part of a SOTER unit and is not shown separately as polygon on the map. In this case, the non-soil component is described in the SOTER database at soil component level. The SOTER unit has a dominant landform, lithology and soil; the non-soil component is only a part of the unit and as such appears as a proportion of the SOTER unit in the soil component table. The coding for the non-soil components in the soil component table is according to Table 4. For example, **PRns5** stands for rock outcrop (and limestone rock land) in Puerto Rico.

Appendix 2: Minor changes in the database

- Horizons with no indicated lower depth

The lower depth for the last horizon in a profile has not been given for some profiles in SOTERLAC version 1.02. In particular, those soils with a lower horizon/layer marked with C or with R (hard bedrock underlying the soil). E.g., most Leptosols comprise only one or two horizons over bedrock; the lower depth boundary of the bedrock was usually indicated as –999.
For practical reasons these –999 have been substituted with estimated values, to allow model calculations. In version 2.0, the last measured lower depth (or upper depth of lowest horizon) was increased with + 10 cm. Only for these cases the last 10 cm substitutes the deeper than sign (>) in the profile description and the –999 in the database.

- Organic material layers (O and H horizons)

In the SOTERLAC database, all O horizons or layers of litter and other loose organic material on top of a mineral horizon were given a negative depth. As reference point of depth, zero (0) cm, the top of the upper mineral horizon has been taken; usually this is the top of the mineral Ah horizon. All O horizons (layers) above this point are given a negative depth value, all mineral horizons a positive depth value.

O horizons are seldom analysed, because they are often very thin, and changed easily by human influence. The negative depth value of O horizons is maintained in the present SOTERLAC version 2.0 for practical reasons. In assessments, the presence of the O horizon is often ignored and with a negative depth, they can easily be excluded from the calculation procedures.
In contrary to the O horizon, the H and AO horizons all have a positive depth in the database and are seen as a part of the profile, even when they appear with their upper boundary at the surface.

- Bulk density

Bulk density has been corrected when higher than 2.0 g cm^{-3}. No changes were made for very low bulk densities, such as occurring in volcanic soils.

In the database there are still a number of bulk densities larger than 1.8 g cm^{-3} e.g. profile CR028. However, these rather high values were kept. High bulk density is probably due to measurements on dry soil clods, while the standard practice a determination at approximately field capacity is.

Appendix 3: Technical information and details

- Availability

The updated 1:5M SOTERLAC database (version 2.0) can be downloaded from ISRIC's website: http://www.isric.org/ or http://www.worldsoils.org/ .
The SOTERLAC database, version 1.02, is still available on CD-ROM at FAO office, Rome; as 'Land and Water Digital Media Series N° 5': Soils and Terrain Digital Database for Latin America and the Caribbean (website: http://www.fao.org/ag/agl/lwdms.stm).

- Formats

The SOTERLAC database (version 1.02) was initially compiled using dBase IV® as relational database. At present, the updated SOTERLAC version 2.0 uses MS Access®.
The GIS files are available in ArcInfo export format (.E00 extension) and can be imported into ArcView, using Import71, or any other GIS.

- Projection

The 'projection' of the SOTERLAC map is geographic with coordinates using decimal degrees.

- Size of files

The size of the SOTERLAC files is approximately:

SOTERLAC GIS file:	5.93 Mb (zipped, 2.15 Mb)
SOTERLAC database:	8.63 Mb (zipped, 1.66 Mb)
SOTERLAC report	755 Kb unzipped