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WETLAND SOILS OF THE WORLD, THEIR CHARACTERIZATION AND DISTRIBUTION IN THE FAO-UNESCO APPROACH

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WETLAND SOILS OF THE WORLD, THEIR CHARACTERIZATION AND DISTRIBUTION IN THE FAO-UNESCO APPROACH [1]

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Two concepts of wetlands are distinguished, a genetic concept such as is used in the FAO-Unesco Legend (6) for the definition of hydromorphic properties, and a utilitarian concept that would be more suitable for use in land evaluation. The place of hydromorphic soils in the FAO-Unesco Legend is discussed, and possible amendments to the Legend are mentioned. Suggestions are made for the characterization by means of a hydrograph of soil wetness regimes for land evaluation purposes. Possibilities to inventory hydromorphic soils on the basis of the FAO-Unesco Soil Map of the World (5), with and without application of map unit composition rules, are evaluated. There is a need for elaborating the Legend and updating the Soil Map of the World in such a way that it can be used as a data base for the computer-assisted appraisal of land resources.

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The meaning of the American English word wetlands given in Webster's New Collegiate Dictionary is "land or areas as tidal flats or swamps containing much soil moisture." This description clearly refers to permanently wet, flat landscapes. But in pedology it is probably more meaningful to define wetlands in terms of moisture regime only. This means that wetland soils are not by definition confined to low-lying landforms such as floodplains, deltas, and depressions, but may also occur on higher parts of the landscape like river terraces, footslopes, and even the tops of hills.

In a general way, a distinction can be made between two possible definitions of wetlands: one related to use and use possibilities of the land, which may be called a utilitarian definition, and one related to soil genesis (soil formation) which may be called a genetic definition.

These concepts can be described as follows:

- Wetland soil, utilitarian concept: a soil subject to periods of excessive wetness to the extent that it influences greatly the soil's use possibilities;
- Wetland soil, genetic concept: a soil that bears marks of its formation under wet, reducing conditions, notably grey colors and mottling.

In practice, there is considerable overlap between the two definitions, but they are not identical. The utilitarian definition excludes hydromorphic soils that are not subject to prolonged water saturation such as artificially drained floodplains in use for growing upland crops. The genetic definition excludes soils subject to waterlogging but without showing morphologic evidence thereof such as young alluvial soils and upland soils recently brought under use for wet rice growing.

The utilitarian concept is probably the most meaningful for land use planning purposes. However, there exist no soil wetness classification system or world soil wetness inventory, so that systematic information on soil wetness cannot be readily obtained.

The choice of a wetland definition depends also on the scope of the study in which it is used, and on the source of information on which it is based. For the occasion of the Polders of the World congress ISRIC made recently a study on the distribution and agricultural potential of the world's wetland soils (18). This study focussed on the soils of those flat wetlands where the improvement of internal drainage would lead or had already lead to an increase of agricultural productivity. The quickest and cheapest way to complete this utilitarian type of inventory was by interpreting the **FAO-Unesco Soil Map of the World** at scale 1:5 million (5, 6), in spite of the genetic nature of the definitions of its soil units.

WETLAND SOILS IN THE FAO-UNESCO LEGEND

Like most soil classification systems, the FAO-Unesco Legend (6) is genetic in approach. As a consequence no distinction is made between present soil wetness regimes and relict features of past wetness regimes. Also, features of wetness are not viewed in isolation but in conjunction with other soil properties whereby the relative importance of a given wetness regime is weighted differently for different soil units. This means that the wetness regime alone cannot be used as an entry for singling out wetland soils from the soil map legend and that one has to resort to deductions in cases where the wetness regime is not specified.

For practical reasons, the best choice as counterparts of wetland soils in the **FAO-Unesco Legend** is probably: "soils showing hydromorphic properties within 50 cm of the surface," which means showing morphological evidence of waterlogging and reduced conditions within 50 cm. This corresponds with the definitions of aquic suborders of **Soil Taxonomy** (17). However, it is a common misinterpretation, that the Legend places all soils with hydromorphic properties in one group. The **Legend** does make a hierarchical distinction between **weakly developed** soils which are **strongly** influenced by groundwater, the Gleysols, and the soils which show **strong** groundwater influence in combination with **strong** profile development, the "gleyic" groups.

The above definition of wetland soils applies directly to Gleysols (Aquents, Aquepts), Histosols and the gleyic groups of other units, because they all have by definition hydromorphic properties within 50 cm of the surface. An exception forms the Gleyic Cambisol unit (aquic subgroup of Ochrepts) in which hydromorphic properties appear below 50 cm but within 100 cm of the surface.

There are some other soil units that may or may not have hydromorphic properties within 50 cm so that they cannot be subdivided in a part wetland soils and a part non-wetlands. In ISRIC's inventory (18), they have been placed in the wetland category. They include the following:

Fluvisols (Fluvents) do not necessarily have hydromorphic properties, but most of them are regularly flooded under natural conditions. Hydromorphic Fluvisols differ from Gleysols by having fine stratification and/or irregular decrease of organic matter with depth. In fact, both soil units are often confounded, and even the **Soil Map of the World** project has failed to separate them systematically during the mapping of the floodplains and deltas of the larger rivers.

Planosols are wetland soils in the genetic sense (stagnogley soils). They correspond partly with Albaqualfs and Albaquults, partly with the pale-great groups of Alfisols or of Argialbolls. The 50 cm depth limit does not apply, because the **Legend** stipulates that Planosols have hydromorphic properties at least in a part of the E horizon, while the E horizon may extend down to 125 cm from the surface. The same applies to the plinthic groups of Ferralsols (Oxisols), Acrisols (Ultisols), and Luvisols (Alfisols), which are defined on the basis of having plinthite within 125 cm of the surface, while in the key to the soil units the plinthic groups take precedence over the gleyic groups. The same situation applies to the Placic Podzols in relation to the Gleyic Podzols. Like the Planosols, the plinthic groups and Placic Podzols are genetically wetland soils, and many of them do show their hydromorphic properties within 50 cm depth.

Also, the position of the Pellic Vertisols in relation to the wetland soils cannot be judged from their definition, because hydromorphic properties are not a requirement. In reality many Pellic Vertisols are close to meeting the diagnostic soil color criterion for hydromorphic properties and could therefore be considered as wetland soils.

POSSIBLE AMENDMENTS TO THE FAO-UNESCO LEGEND

The **FAO-Unesco Legend** counts 106 soil units, which, have been clustered into 26 major groupings. There are two categorial levels: major soil units (comparable to orders) and soil units or groups (comparable to great groups). The **Legend** has been specifically made for a 1:5 000 000 soil map. If it has to serve as a basis for an internationally accepted soil classification and nomenclature, like for instance the International Reference Base for soil classification (IRB), the **Legend** has to be elaborated on to some extent. In relation to the classification of hydromorphic soils, the following points need attention.

The number of gleyic groups could be increased, to make the **Legend** more systematic. From the 26 major soil units 9 have a gleyic group. The absence of gleyic groups in the other major units is due to various reasons, of which we mention a few:

- The limited geographic importance at the global scale, or scattered distribution of a missing gleyic group, would not justify its representation on the map as a separate unit. Or there was insufficient knowledge of its distribution at the global scale so that it could not be separated systematically.

A soil that actually belongs to a conceivable but not defined soil unit now, according to the **Legend** either is placed in another unit or can simply not be properly classified. As examples:

- a Gleyic Regosol and a Gleyic Arenosol meet the definition of a Gleysol;
- a Gleyic Nitosol and a Gleyic Andosol are not foreseen;

- a Gleyic Chernozem without an argillic horizon meets the definition of a Mollic Gleysol, while a Gleyic Chernozem with an argillic horizon is not foreseen.

- If hydromorphic properties are already implied in the definition, as is the case of Histosols, Gleysols, and Planosols, a distinction of gleyic groups would in fact not add much information on the kind of soil.
- For some soil groupings, the hydromorphic properties, if present, are considered of lesser importance than other soil properties. This is the case with Vertisols, Fluvisols and Ferralsols. Perhaps intergrade groups can be introduced such as Gleyo-Dystric Fluvisol and Gleyo-Pellic Vertisol.

There are also arguments for making the system internally more consistent by assigning the term "gleyic" the same meaning and by using it at the same categorical level throughout the Legend, and by using it also if hydromorphic properties are only implied. The uniform meaning of "gleyic" would become: having hydromorphic properties within 50 cm of the surface. It would, however, break up the present system. In particular, the Gleysol unit would fall apart. Other definitions of the present **Legend** that would need to be changed are as follows:

- Gleyic groups are not distinguished in Planosols and Fluvisols.
- Gleyic groups of Greyzems and Phaeozems indicate hydromorphic properties within 50 cm in the presence of an argillic horizon.
- Gleyic in relation with Cambisols means hydromorphic properties appearing between 50 and 100 cm depth.

Such uniformity may seem superfluous to many soil correlators, but it would certainly be helpful in communicating with non soil people.

Other aspects of hydromorphic properties requiring systematization include various forms of pseudogley (or surface gley) and groundwater gley, alone or in combinations.

Pseudogley is the kind of hydromorphism related to periodic saturation and reduction in the upper part of the profile, while the lower part remains aerated. Stagnogley is an extreme form of pseudogley formed under permanently wet conditions (15). Morphologically related with pseudogley are the surface gley phenomena in paddy fields (see below).

Gley as used in contrast to pseudogley refers to groundwater gley phenomena. The type of gley depends on the depth and fluctuation of the water table:

- Anmoor gley or humic gley if the groundwater is permanently near the surface;
- Gley or mineral gley if the groundwater fluctuates at shallow depth.

Many intermediate types may be distinguished like semi gley and pseudogley over gley or amphigley (2).

Differences in character between groundwater gley soils and pseudogley soils require a different position in soil systematics (15), but in the **FAO-Unesco Legend** and in the **US Soil Taxonomy** such a distinction has still to be worked out.

Like in **Soil Taxonomy**, no special provisions are made in the **Legend** for the classification of naturally freely draining soils which have a gleyed surface horizon as a result of long lasting wet rice cultivation. It is probably desirable to separate these paddy soils from their well drained counterparts, for which the terms "anthraquic" (3) or "aquorizemic" (10) seem appropriate.

The classification of two pairs of soil profiles from Japan, which form part of ISRIC's soil monolith collection (12), may serve as an example. The four soils all have a deep groundwater table and high permeability. One pair of soils was formed in alluvial material and one pair in volcanic ash. Each pair comprises a paddy soil and an adjacent non-paddy soil. The Fluvisol paddy has been in use for the production of rice for 55 years, the Andosol paddy for about 200 years. Their (tentative) classifications are indicated in Table 1.

Table 1. The classification of ISRIC soil monoliths from Japan [a)]

	SOILS ON ALLUVIAL MATERIAL	SOILS ON VOLCANIC MATERIAL
	Non-paddy soil (monolith J4)	Non-paddy soil (monolith J2)
FAO-Unesco:	Dystric Fluvisol	Humic Andosol
USDA:	Typic Udifluvent, fine, mixed, non-acid, mesic	Typic Dystrandept, coarse loamy, mixed, mesic
Japan:	Brown Lowland Soil	Ando Soil
	Paddy-soil (monolith J3)	Paddy-soil (monolith J1)
FAO-Unesco:	(Antraquo*)-Dystric Fluvisol	(Ando)-Dystric Gleysol or (Anthraquo*-Ochric Andosol)
USDA:	(Anthr)aquic Udifluvent, fine, mixed, non-acid, mesic	Typic Haplaquent, coarse loamy, mixed, non-acid, mesic
Japan:	Brown Lowland Paddy Soil	Gleyed Andosol

* or "aquorizemo".

a) Source: Okazaki (12)

CHARACTERIZATION OF SOIL WETNESS FOR LAND EVALUATION PURPOSES

For land evaluation purposes, knowledge of the present and possibly future soil wetness or soil moisture regimes is necessary. The notion of hydromorphic properties within 50 cm depth is too vague for any quantitative assessment, because it gives no information on the duration, depth, and fluctuations of the groundwater table. It has been found many times already that mottling could not be related to the length of the periods of water saturation (19).

This situation calls for an autonomous characterization of the soil wetness regime, completely apart from the classification of the soil proper. The design of classes of wetness regimes should be left to the national or regional organizations in the first instance, but preferably on the basis of some standardized concepts. To be meaningful for land evaluation, separate criteria for class subdivisions should be developed for such different kinds of land use as wetland rice and dryland crops.

The most important elements for the agricultural evaluation of soil wetness are the depth and fluctuations of the groundwater table and the duration of wet conditions in the rooting zone. Instead of a groundwater table one may also read "perched groundwater table" or "depth of flooding or ponding", whichever is applicable.

The wetness condition of a soil can be characterized at any moment by the depth of the water table. Here, wetness is used in the technical sense of the word. This technical concept is more operational than the genetic concepts of hydromorphic properties used in the FAO-Unesco Legend and of the definitions of aquic moisture regime and aquic suborders according to Soil Taxonomy. In this respect, it is not necessary that wetness results in reducing conditions, or that it lasts at least a few days, or that it is not a result of irrigation. Also, wetness in artificially drained soils is determined by the depth of the groundwater table, independent of past wetness regimes.

The soil wetness regime over a year or a season can be conveniently represented by a kind of hydrograph showing water level under or above the ground surface versus time. The hydrograph shows depth, duration, and nature of fluctuation of the groundwater and flooding regimes, including extreme values. The hydrograph could be used as an accessory characteristic of wetland soils and of other soils which are periodically partly or completely wet.

A "wetness regime classification" may bring some order to the thousands of possible different hydrographs. The distinction into types of wetness regime should be based on an understanding of their causes and their implications for the use of the land.

If only groundwater is concerned, a simple classification can be made on the basis of the average highest and lowest groundwater levels within a growing season, as is reported from Nigeria to characterize the wetness regime along a valley catena (19).

However, if flooding occurs more attention should probably be paid to the shape of the hydrograph: smoothness, peaks, gradients of falling and rising sections, duration. Also, the variations over the years, the occurrence of catastrophic events, and possibilities of manipulating the wetness regime by drainage, irrigation, and flood control measures have great influence on the land's use possibilities.

DISTRIBUTION OF WETLAND SOILS

The distribution of wetland soils, or rather of hydromorphic soils has two aspects: the geographic pattern of occurrence and the total area extents.

The pattern of occurrence of hydromorphic soils is closely related with physiography and climate. Naturally, they are found in places where the land's drainage capacity falls short of evacuating the water surplus over evaporation. The water surplus originates from rainfall, surface run off, and groundwater flow. In general, hydromorphic soils are most widespread in high rainfall areas and at the lower ends of toposequences. They are also very common in cold regions.

Considering individual soil units, Fluvisols and Gleysols occur in the floodplains and estuaries. In dry regions these soils have often turned into Solonchaks. In landforms situated somewhat above the present floodplain level like terraces and erosion surfaces, the soils have been exposed to soil forming processes for some period. If drainage is or has been impeded, gleyic groups are found. In subhumid climates they are often Gleyic Luvisols. Under warm climates with seasonally alternating wet and dry soil conditions, Planosols are also widespread, while under warm and humid conditions Gleyic Acrisols develop. Pellic Vertisols occur commonly in wide depressions in the tropics and subtropics with a marked dry season. Histosols are typical for swampy areas under any climatic regime, but are most widespread in cold climates.

It is with a certain reluctance that we give figures on area extents of wetland soils (Table 2). First of all, such figures are not accurate, because of the coarseness of the map (very small scale), and secondly, such figures are easily misinterpreted. But for comparison some totalized figures of ISRIC's wetland soil inventory (18) are given. At the time of the study area extents of individual soil units were not yet computerized, and the areas were measured on the map and totalized using a pocket calculator. The area extents were broken down by soil unit, by each of the 9 major regions (continents), by length of temperature determined growing season, and separated for aridic and non-aridic zone. Low potential wetland soils, which cannot be improved by better water management were excluded from the inventory, for example the coastal peat soils of Sumatra and Kalimantan, and the permafrost zone. On the other hand, saline soils and alluvial soils in deserts were included because here water is the limiting factor and not the soil, so that their development potential has to be interpreted from a water resource study.

THE SOIL MAP OF THE WORLD AS DATA BASE

A map unit of the **Soil Map of the World** represents a physiographic entity, or landscape, large enough for its delineation on the map, on which it is registered by the color and the symbol of its dominant soil unit, followed by a reference number. The composition of each map unit is described in terms of dominant soil, associated soils, and inclusions.

The **Legend** stipulates that associated soils cover at least 20 % of the area and inclusions less than 20 %. This statement is not sufficiently specific for the purpose of calculating areas of individual soil units on the basis of the composition of the map units. Such a conversion of map units into soil units has been achieved by FAO's Agro-ecological Zones Project (7) by applying fixed "mapping unit composition rules" to the computerized list of map units.

It is noted that these rules (Table 3) were fixed only after the completion of the map. The rules imply that a dominant soil occupies between 24 and 100 % of the map unit's area, depending on the map unit's composition. Ratios of a dominant to a subdominant soil larger than 70/30 are not foreseen in the rules. Such high ratios are, however, not always negligible. This holds in particular for regions where agriculture is concentrated in relatively small portions of fertile land amidst large stretches of marginal land.

Table 3. Relative distribution of dominant soil, associated soil(s) and inclusion(s) expressed in percentage of the area of the mapping units[a)]

Dominant soil	Associated soil(s)		Inclusion(s)	
Percentage of area	Number of soil units	Percentage of area	Number of soil units	Percentage of area
100	0	0	0	0
70	1	30	0	0
60	1	30	1	10
60	2	20 + 20	0	0
50	2	20 + 20	1	10
30	3	20 + 20 + 20	1	10
50	1	30	2	10 + 10
40	1	30	3	10 + 10 + 10
50	1	30	4	5 + 5 + 5 + 5
40	2	20 + 20	2	10 + 10
30	2	20 + 20	3	10 + 10 + 10
30	3	20 + 20 + 20	2	5 + 5
25	3	20 + 20 + 20	3	5 + 5 + 5
24	3	20 + 20 + 20	4	4 + 4 + 4 + 4

a) Source: FAO (7).

To improve this situation a reassessment of the composition of mapping units would be needed, specifying the proportional occurrence of soil units in each map unit as it is, to replace the fixed composition rules. The collection of such additional data would require a huge effort, but the use of a computerized mapping unit file would permit storage and effective handling.

For the purpose of inventorying the hydromorphic soils of the world we may distinguish the hydromorphic map units from the freely draining map units.

The area extents of hydromorphic soils in Table 2 are obtained through measurements on the map of the predominantly hydromorphic map units. This procedure is prone to under- and overestimates, because it overlooks the intermingling of hydromorphic and freely draining soils. It appears that area extent figures of hydromorphic soils obtained through simple measurement on the map are much lower than those calculated with the mapping unit composition rules. For example, for the African continent a ratio of 1:1.7 was found. Africa's land surface represented by predominantly hydromorphic map units amounts to 7.2 % of its total land area, while the total extent of hydromorphic soils calculated on the basis of the map unit composition rules amounts to 12.1 %. These hydromorphic soils are distributed over the classification units as follows: Gleysols and Fluvisols together 66 %, Pellic Vertisols 16 %, Gleyic Luvisols 7 %, Planosols 4 %, Histosols 3 %, Gleyic Solonchaks 2 % and Gleyic Acrisols 1 %.

The scale of the **Soil Map of the World** is 1:5 million, which does not allow the separation of single areas smaller than 250 km^2 (2x5 mm on the map) or narrower than 5 km (1 mm on the map). This means that on the scale of a continent only the largest concentrations of hydromorphic soils appear on the map, where they occur in the bottoms of large basins and in the lowland areas at the edges of the continents.

In reality, however, hydromorphic soils do also occur as patches and strips in the map units with predominantly freely draining soils. Theoretically their extent could be calculated from the map unit composition rules for associated soils and inclusions, but in practice their occurrence has been overlooked in many cases.

This is largely due to the emphasis on mature zonal soils in the exploratory and reconnaissance type of soil maps on which the **Soil Map of the World** is based. On such maps azonal soils are shown only where they are dominant over large areas, and little attention is for instance given to valley bottom soils within upland regions. This may be justified on the basis of their lesser geographic extent, but if the economic and ecologic importance of hydromorphic soils is taken into account, they should at least receive as much attention as their more extensive freely draining counterparts.

So, mapping constraints together with a bias towards freely draining upland soils lead to an underestimation of the extent of hydromorphic soils. This results in a tendency such that, on different soil maps of a given region, the area of hydromorphic soil units increases with increasing map scale. Two examples, one from China, where the wetlands are exploited to the maximum, and one from Africa, where the wetlands are a relatively underdeveloped resource, may illustrate this tendency.

The uplands and plateaus of southcentral China, indicated as the red earth region on the **Soil Map of China** (13), appear on the **Soil Map of the World** as sloping Orthic Acrisols in association with Lithosols (Ao13-bc) or with both Lithosols and Chromic Luvisols (Ao18-bc). No mention is made of hydromorphic soils. Soil maps at a scale of 1:100 000 of 100 square mile sample blocks in this region (8) show dissected landscapes in which reducing, redoxing and oxidizing paddy soils together occupy some 20-40 % of the total area.

The example from Africa concerns the northwestern Ivory Coast, where the **Soil Map of the World** shows a map unit of Dystric Nitosols associated with Plinthic Acrisols and Litosols (Nd27) and a map unit of Ferric Acrisols associated with Orthic Acrisols and Dystric Nitosols (Af 5). No hydromorphic soils are indicated. Of the same area a series of maps exists at scales increasing from 1:2 million to 1:200 000, with maps of selected sample landscapes at 1:50 000 (1, 14, 4). The position of the hydromorphic soils on these maps of the area corresponding to both FAO map units is as follows:

- The 1:2 million map (1) gives a rough idea of soil regions and shows 3 % hydromorphic soils.
- The 1:500 000 map (14) used for the compilation of the FAO map, shows 9 % alluvial soils, roughly sketched on the map.
- The 1:200 000 map (4) shows about 11 % alluvia in a much finer pattern.
- The 1:50 000 maps (4) show the next order branches of the valley system and separate floodplain soils from lower slope soils. Together they occupy 17 % of the sample area in FAO's Nitosol unit and 29 % in the Acrisol unit.

The foregoing examples show the complete omission of hydromorphic soils from the map units, but other examples can be cited where they do occur, and where their calculated extent corresponds with information from more detailed soil maps. For instance, the 10 % cover of Eutric

Gleysols included in map unit Lf49 in Southwestern Nigeria is equal to the estimate of the land facet study at a scale of 1:125 000, in which use was also made of sample strips at a scale of 1:10 000 (11).

It will be clear that inventorying hydromorphic soils in areas where they are subdominant is a hazardous affair, whether it is done on the basis of the **Soil Map of the World** or of other general purpose soil surveys. The large margins used in wetland distribution studies become apparent in the results of the wetland inventory in the coastal countries of West Africa (9). The wetland area is estimated at somewhere between 12.6 and 28.5 % of the total area. The four types of wetlands and their estimated distribution as percentages of total area are:

- deltas, tidal swamps and large inland swamps 1.7- 3.5 %
- river floodplains (large floodplains) 2.5- 5.9 %
- overflow valleys (small floodplains) 3.6- 9.0 %
- streamflow valleys (small inland valleys) 4.7-10.0 %

This shows that the wetlands of the smallest size category represent the largest total extent. It means that a large part of the West African wetlands cannot be shown by normal cartographic means on an exploratory type of soil map even at a scale of 1:1 million, which is generally considered the maximum feasible for world maps (16).

A realistic appraisal of the world's wetland soils will require the updating of the **FAO-Unesco Soil Map of the World.** There are several lines of action that may be taken concurrently:

- increase of map scale from 1:5 million to 1:1 million, making the map surface 25 times larger. This would bring the smallest mappable area from 250 to 10 km^2. A larger number of floodplains could be put on the map, but many wet soils would still have to be included in other map units

- improvement in the cartographic delimitation of map units
- specific estimates of soil composition of individual map units
- elaboration of the **Legend**, e.g. through the approach of the International Reference Base for soil classification (IRB)
- computerization of the soil data base: mapping unit file, pedon data file, crossing of maps such as with overlays
- special attention for the definitions of wetness regimes, independently of soil units. The separate treatment of wetness and soils is to be preferred, because a combined subdivision can never completely represent satisfactorily the many differences in flooding-submergence-groundwater regimes. Separate treatment allows a greater flexibility for adaptation of both soils and wetness definitions, and is more suited for computer assisted data handling.

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