FAO GLOBAL SOIL PARTNERSHIP

Draft Plan of Action for Pillar Four of the Global Soil Partnership

Building an enduring and authoritative global system to monitor and forecast the condition of the Earth's soil resources

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1. Introduction

The Global Soil Partnership (GSP) was formally endorsed by the FAO Council in December 2012. It has five pillars of action:

1. Promote sustainable management of soil resources for soil protection, conservation and sustainable productivity
2. Encourage investment, technical cooperation, policy, education awareness and extension in soil
3. Promote targeted soil research and development focusing on identified gaps and priorities and synergies with related productive, environmental and social development actions
4. Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines
5. Harmonization of methods, measurements and indicators for the sustainable management and protection of soil resources

This report presents a draft plan of action for Pillar Four. It provides design options and pathways for building the global soil information system.

The report is the primary outcome of a workshop convened by FAO in Rome during March 2012. The workshop considered the status of current methods for soil survey and monitoring, existing soil information systems, and future directions for Pillar Four (FAO 2012). The meeting commissioned this report and asked for the following topics to be addressed in relation to the establishment of Pillar Four:

- Governance and structural organization
- The links between global soil information and end-users
- Primary soil data and spatial data products including accuracy issues.
- Reporting on global soil health: soil capacity and functions.
- Technical monitoring
- Global monitoring network
- Archives, references and standards

A representative group of experts was asked to prepare the report. The members were:

- Africa: Martin Yemefack
- Asia: Ganlin Zhang
- Europe: Rainer Baritz
- Latin America: Aracely Castro
- Middle East and North Africa: Rachid Moussadek
- North America: Jon Hempel
- Oceania: Neil McKenzie
- Secretary: Ronald Vargas

The committee has prepared the report with careful attention being given to the mandate of the GSP which is to improve governance of the limited soil resources of the planet in order to guarantee healthy and productive soils for a food secure world, climate change mitigation as well as support other essential ecosystem services, in accordance with the sovereign right of each State over its natural resources. The issue of sovereignty extends to data and information insofar that the global soil information system has to support the integrity of national information systems but at the same time produce a harmonized global view.

The report begins with a summary of the primary reasons for having a global soil information system. This is followed by a set of design issues and key decisions that need to be made. In some cases, the preferred outcome is clear so the committee has simply provided a recommendation. In other cases, the decision is more complex and several options have been presented. Some of these options relate to priorities but others have significant implications for existing institutions involved in gathering and supplying soil information.

In May 2013, a draft of this report was sent out for review to GSP partners of soil information institutions globally, and to the participants of the GSP Soil Information workshop (Rome, March 2012). In total, 260 comments, 45 text proposals and various editorials were received. Comments addressing similar issues were condensed, so that at the end 134 comments were processed. A protocol lists the changes done, and the responses of the writing team to each comment; those comments considered to be out of scope for this report were summarized in a short note to FAO.

By necessity, this report presents preliminary design options and pathways for building the global soil information system. The potential investment necessary to build each component of the system is yet to be specified. Likewise, priorities and a detailed roadmap for implementation have not been proposed. These next steps depend on which recommendations proposed by this report are accepted by the ITPS.

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2. Why do we need a global system for observing and forecasting soil condition?

There is a growing awareness that soil resources are finite and require careful management to ensure food security and maintain essential ecosystem services. A prerequisite for sustainable management is reliable information on soil resources and in particular, on how different soils respond to various forms of land use and management.

Around the world, millions of people profitably use existing soil information to either produce more food or protect environmental assets or both. People currently gain access to soil information through a variety of channels and many countries now have district or national soil information systems, many of which are online. Each of these systems is tailored to meet the needs of users working across a restricted range of soils and land management systems. They employ a wide range of technical standards and often target specific scales. This raises the question: why do we need a global system for observing and forecasting soil condition if these systems are being developed for specific purposes? There are three compelling reasons or applications for such a system.

Application 1: Answer critical questions at the global scale

A global system for observing and forecasting soil condition is needed because there are critical questions that have to be answered at the global scale. There is a qualitative appreciation of the pressures on global soil resources but limited consistent evidence on their condition and trajectories of change. In short, the world's soils need to support at least a 70% increase in food production by 2050 but there are fundamental uncertainties:

- Is there enough arable land with suitable soils to feed the world?
- Are soil constraints partly responsible for the often large gaps between actual and potential crop yields?
- Can changes to soil management have a significant impact on the seemingly unsustainable global demand for nutrients?
- To what extent and cost can changes to soil management contribute to climate change adaptation, particularly at smallholder agriculture scale?
- Can changes to soil management have a significant impact on atmospheric concentrations of greenhouse gases without jeopardizing other functions such as food and fiber production?
- How will the extent and rate of soil degradation threaten food security and the provision of ecosystem services in coming decades?
- Can water-use efficiency be improved through better soil management in key regions facing water scarcity?
- How will climate change interact with the distribution of soils to produce new patterns of land use?

Application 2: Provide the global context for more local decisions

A comprehensive global view is also needed to deal with the transnational aspects of food security and degradation of natural resources. Because of trade, most urbanized people are protected from local resource depletion. The area of land and water used to support a global citizen is scattered all over the planet. As a consequence, soil degradation and loss of productivity are not just local or national issues – they are genuinely international.

A global context provides international organizations, governments and other stakeholders with an understanding of how land use decisions in one district, country or region have consequences elsewhere. Examples of policies that need this type of context include those relating to bio-fuels, carbon farming, urban expansion and any form of intervention that affects land use and relevant ecosystem services across large areas. In these issues, most local responses require global context.

Application 3: Supply fundamental data sets for understanding Earth-system processes

In terrestrial systems, soils play a central role in determining the stores, flows and transformations of energy, water, carbon, nutrients, solutes, contaminants and genetic material. An ability to estimate the functional properties of soils in time and space is therefore crucial to our scientific understanding of Earth-system processes. This process-understanding has scientific value in its own right. It also provides the essential foundation for managing the major natural resource issues facing the world (e.g. climate change, food security, biodiversity loss). At present, the scientific quality of global data sets on soils compares poorly with other fundamental data sets such as those for weather, climate, net primary productivity, biodiversity, land cover and geology.

3. Decisions on system design

The three primary reasons for having a global soil information system are compelling. However, the design of the required system is far from straightforward. At least six broad issues need to be discussed and resolved.

Issue 1: Degree of integration between global, national and other systems

Soil data and information can be used for many purposes from local through to national and global scales. For efficiency, the systems of measurement and analysis need to be integrated across this hierarchy of scales so that data collected at lower levels feed through to analyses at the higher levels. The alternative of having a separate data gathering program for the global system is not desirable because it would be expensive and inefficient, but may result necessary if sufficient harmonization of methods and data across countries is lacking.

The dramatic advances in web-based technology make the integration of local, national and global systems possible (see also Appendix 3). However, data and information have to be collected and managed according to consistent standards to enable integrated analysis. A central task for the GSP is to develop, manage and facilitate the use of these standards so that data can be shared at low cost – most of this activity will be coordinated together with Pillar Five.

The ability to incorporate local-scale information into the global system (and *vice versa*) is important but it does not mean that the global system should contain all the information held by these subsidiary systems. This would make the global system unmanageable. Furthermore, most soil-related questions are strongly conditioned by local factors (e.g. particular types of soils and soil forming factors, systems of land use, availability of inputs) and many locally specific variables are recorded. Necessary requirements for documentation, harmonization, quality control and representativity might be the main factor that only a subset of this data eventually feeds into a global system (see Issue 3 below) but it is essential to have well-designed systems for aggregating between scales.

It is important to differentiate the purpose of the global soil information system and the related within-country systems. A general operating principle is that a query requiring soil information should be handled by the smallest, lowest, or least centralized authority capable of addressing that matter effectively. Otherwise, unrealistic expectations will be placed on the global system and it will become unmanageably complex. The primary purpose of the global system is to address the three applications outlined in Section 2.

Recommendation 1: The design and operation of the global soil information system will use data primarily from national and within-country systems and will focus on delivering products and information services for regional and global purposes. Agreements about harmonization requirements to achieving comparability of measurements and observations as well as systems for aggregating data and information between scales are therefore essential.

Issue 2: Distributed versus centralized design

The Group on Earth Observations (GEO) provides the forum and mechanisms for building global environmental information systems.[1] This includes achieving international consensus on system architecture, developing standards, and promoting the best practices for gathering, analyzing and supplying information on earth systems (e.g. oceans, atmosphere, land cover, forests and biodiversity). The soil community has been slow to engage fully with this major international effort while lacking global-scale projects and incentives for data holders. However, the development of Pillars Four and Five within the GSP now provides a natural mechanism for engagement.

A clear consensus that has emerged through the work of GEO and related international initiatives was on the design and implementation of environmental information systems. The emphasis is on the interoperable systems and web-based delivery of information services. Interoperability here does not only refer to within-domain data sets (e.g. the match between soil mapping data along borders), but explicitly includes the possibility that data from different domains (soil, climate, land use) can be easily processed and queried together. The global soil information system can advance quickly by participating in the Global Earth Observing System of Systems (GEOSS) and learning from closely related initiatives on Global Land Cover, Global Geology Data (OneGeology) and Global Forest Observation. The activities in these initiatives (including global soil data) were recently combined into Task IN-02-C2 'Development of Regional/Global Information and Cross-cutting Datasets'.[2] A recent key achievement, which also supports this task, is the development of ISO 28258 on the exchange of digital soil-related data.

> **Recommendation 2**: That the global soil information system and its associated Community of Practice formally joins and actively supports the much larger effort to build and maintain the Global Earth Observing System of Systems overseen by the Group on Earth Observations.

The considerations of previous sections further specify the options for the design of the global soil information system. An independent global database without direct links to national or regional databases is not practical because countries are the main providers of data. At the other extreme, a federated international system with more than 190 nation states providing component data services without coordination is also unlikely to be successful. The main problem being that many countries still do not have the technical capacity and infrastructure for providing updated soil information and reliable web-services into the global system.

A middle course is therefore necessary. It requires a federated system with a mix of arrangements for delivering data sets and web-services tailored to match the capabilities of data holders (e.g. research bodies, national facilities). In some parts of the world, good collaborative arrangements may allow a leading country or institution to provide the soil information system and services on behalf of several other countries. Such arrangements are to some extend already operational in Europe and are being developed for nations in the Pacific region with good prospects for similar arrangements in other parts of the world (e.g. Middle East, West Africa, Latin America). Brokering these arrangements is best done through the regional soil partnerships that are being developed through the GSP. There may still be the need for some global information services to be provided by a single agency (e.g. supply of a consolidated global data set such as the Harmonized World Soil Database). The OneGeology project provides a good model with several agencies taking responsibility for managing the world portal for geology data.

[1] www.earthobservations.org
[2] http://www.earthobservations.org/ts.php?id=136

> **Recommendation 3**: The global soil information system will be comprised of consistent spatial data sets and services provided by a mix of institutions with soil information facilities in place (research, industry, land owners). However, national soil agencies will play a predominant role as facilitators for the collection, management, quality assurance and provision of the diverse data collections and storage systems; in some cases, also organizations are important which act on behalf of other countries through mutual agreement.

Issue 3: Comprehensive versus harmonized minimum data sets

Soil is a complex material and hundreds of different soil properties can be measured according to an even larger number of measurement methods. This complexity has the potential to stall the global effort on improving access to harmonized soil information. On the other hand, there is huge missed potential if specifications for a global effort are too restrictive.

There have been many proposals for standard data sets to be collected in soil and land resource surveys. Agreement on the ideal or optimum data set is rare, even for districts with a limited range of land uses. However, it is fairly straightforward to reach consensus on a minimum data set (Nix 1984). A major effort is required to define the minimum data sets for the global soil information system. This has already been done for some products (e.g. GlobalSoilMap). Even though these specifications were designed by a restricted group of main data providers world-wide, it does consider the current knowledge about the data requirements of methods for hazard assessments and soil biophysical modeling.

The second issue relates to the multiplicity of measurement methods even for standard soil properties (e.g. approximately 20 methods are used to measure pH). Data products delivered by the global soil information system require an agreed measurement and correlation standard. The latter specifies how to translate data obtained using different methods onto a common basis provided sufficient documentation. This does not stop countries from using measurement methods that are locally appropriate. It simply requires the ability to translate results into a harmonized system. It does, however, require a worldwide reference database to support the harmonization process.

> **Recommendation 4:** The global soil information system intends to include a maximum amount of digital soil information, however, it must facilitate that information can be harmonized thus becoming comparable globally. Data from contributing organizations need to conform to mutually agreed standards set out according to an agreed measurement method, or can be transformed using a global reference system.

This recommendation has far-reaching consequences. Some may interpret it as creating a barrier to information sharing, particularly with the increasing popularity of crowd-sourcing soil information and the rapid increase in methods for proximal sensing of soil properties. However, it is based on the experience of managing large national soil databases over long periods of time. Databases that do not have procedures for recording and translating between measurement methods quickly become unmanageable or only a small proportion of the data holdings can be used with confidence. Synergies with Pillar Five are expected, particularly in the development of models for data translation. A key requirement is the provision of robust and effective metadata to all users and stakeholders.

Issue 4: Balancing the effort between mapping and monitoring

The global soil information system has to address questions with a geographic and temporal dimension. Detecting and forecasting soil change through time is technically more demanding than mapping (Section 7), but is of crucial importance for applications related to the major global multilateral environmental agreements like UNFCCC, CBD and UNCCD.

Developing a comprehensive and operational monitoring capability within the global soil information system is still at an early stage of development. A balance has to be struck between the more operational aspects of delivering spatial information versus the development and design tasks needed before monitoring systems can be implemented based on current and available funding. Because different indicators and parameters have different change rates, and because of different responses to management and climate change, different requirements to measurement and sampling follow, which affects the design of a the monitoring systems (e.g. different levels of sampling intensity and different return intervals are needed).

> **Recommendation 5:** A stepwise approach is suggested for Pillar Four: First complete a reliable baseline for selected soil properties, and then build on it an operational global soil monitoring capability.

Issue 5: Roles, responsibilities, and incentives for data providers

The global soil information system is unlikely to be successful if national soil-information agencies are treated simply as data suppliers, and if potential other local data providers (industry, research, farmers) are excluded. Certainly, national systems are an important mediator for providing digital soil information according to agreed international specifications. Additional costs are certainly associated with the assessment of new data sets, data transformations, digitization, re-sampling, interlaboratory ring tests, quality checks and data delivery of such data from local (most likely national) systems into the global system. Costs are also involved with developing and improving new (global) data products. However, if managed well, the global program positively feeds back to participating institutions since more and more soil-related policies have transboundary dimensions (e.g. effects of land degradation on food supply, water management, climate change), and this provides the essential incentive for their engagement. Some of the primary benefits of being a partner to the global soil information system should include the following.

- Adoption of standards for system design and web-based delivery will save costs and avoid duplication for each country
- Adoption of data formats supported by the global soil information system will provide access to a range of third party tools such as farming systems models, hydrologic models and other apps for mobile devices
- Training and capability development delivered via Pillar Four (and Pillar Two) will directly strengthen national and local soil information delivery
- Participation in the broader international technical and scientific community involved in Pillar Four will also generate within-country benefits (e.g. more efficient adoption of best practices for all aspects of digital soil mapping)
- Countries will be able to ensure that the international assessments of soil health for their jurisdiction are based on the best available data rather than outdated or incomplete data sets (as is often the case now)
- Better decision making based on the knowledge of current and forecast soil conditions.

Recommendation 6: Aim to achieve net benefit for all partners involved in the global soil information system and monitor this through regular engagement and review.

This report does not consider the investment and funding model for Pillar Four. However, it has been assumed that it will be similar to successful models used for related global systems (e.g. weather, climate, land cover, agricultural statistics). The initial investment would most likely come from a leading group of countries with the longer term funding being determined by the ability of countries to contribute.

Issue 6: Opportunities created by technical advances

There is a tremendous amount of soil information collected world-wide. At the same time, new technologies appear (e.g. remote sensing, on the spot soil conditions analysis, crowd sourcing), substantial progress in national soil information system development is observed, and specifications for soil data exchange have been developed (e.g. ISO). Despite these developments, harmonized data collections and repeated soil sampling (monitoring) is still missing at the global level; existing data sets are still far from meeting user requirements in terms of density and representation, quality and harmonization. There is no progress towards establishing a global soil observing system although there is continuous field work all around the world, and guiding reference material exists as well (standards for soil analysis, world reference system for soil classification, international field guide for soil profile description). Current local soil information is still poorly described and quality controlled, which prevents its use for improving global soil information.

In the future, available soil data will likely depend less on governmental institutions; the spectrum of data providers will be more heterogeneous as the platforms and efforts for the exchange of digital data sets will be more easily accessible, the training of land owners will improve etc. More soil data from research and other disciplines such as spatial planning will be available. When looking at GEOSS and developments such as in precision agriculture, it also becomes clear that new analytical technologies, remote sensing and GIS will alter the quality and quantity of data sets about soils, and the tools for processing this information. These developments need to be considered in a growing global soil information system.

Recommendation 7: Follow up developments in research and create a mechanism for incorporating new technical developments for further improving of the Global Soil Information System.

4. People and systems

Context

The global soil information system requires a full-time leadership and coordination team, resourcing for technical and scientific activities, and mechanisms for supporting the operational system. It will not evolve quickly enough through voluntary processes and in-kind support from various national institutions. Existing operational facilities at national, regional and global levels could play a predominant role for delivering the necessary coordination and supporting activities to a global system.

Leadership and technical support teams

At a minimum, the following teams are needed to develop and run the global soil information system.

- Executive leadership group responsible for strategy and governance and overall management (see Section 7) and with clear lines of accountability to the ITPS and other Pillars of the GSP.
- Communication and liaison team responsible for relationships with all participating organizations and clients
- Training and capability development team (see below)
- Small operational team running the facilities and providing technical services including those relating to information and computing technology, soil laboratories (e.g. advice on quality assurance and accreditation), and pedology.
- A broad support network of technical and scientific specialists based in contributing organizations.

> **Recommendation 8:** Immediately establish full-time leadership and technical support teams on the basis of the existing facilities of GSP members with sufficient resources to build the global soil information system by 2018.

Training and capability development

The technical capability for soil data acquisition and information delivery has to be rebuilt in most parts of the world. This involves education and training, provision of physical infrastructure (e.g. laboratories and computing systems), development of standards and establishing professional networks. The primary task is to establish technical teams with sufficient critical mass. Experience in successful programs around the world indicates the team requires skills in:

- Field survey and monitoring
- Laboratory measurement (including spectral analysis)
- Digital soil mapping and web-based services
- Land evaluation (especially in relation to agronomy and forestry)
- Communication and extension.

The number of such teams per country depends on its size and complexity. In some regions, several small nations may be serviced by a single team if a suitable agreement can be reached (e.g. Pacific nations). Large countries may have five, ten or even more such teams. Experience has also shown that it is more effective to have a smaller number of permanent teams rather than a major project-based effort with a large number of teams. This is especially critical to the success of monitoring programs. The regional teams need to be coordinated and financed by national and international scientific and technical agencies.

The proposed education and training activities will produce a new generation of specialists inmapping, monitoring and forecasting of soil condition. As a consequence, partners of the global soil information system will have access to improved information on the distribution and trends in soil resources for their regions as well as global context to assist them achieve more sustainable systems of land use.

> **Recommendation 9**: Train a new generation of specialists in mapping, monitoring and forecasting of soil condition with an emphasis on countries where improved soil knowledge is essential for food security and restoration and maintenance of ecosystem services.

Spatial data infrastructure

Web-based delivery of soil information requires a significant investment into the expertise and facilities for analysing and managing large and complex information resources. Fortunately, the global soil information system can take advantage of the principles and practices developed by the Global Earth Observing System of Systems, but also other existing spatial data infrastructure while using OGC- and ISO-standards (e.g. INSPIRE in Europe). More specifically, the following elements need to be developed.

- **Exchange Schema (SoilML)**: Build on the new ISO 28258 for the exchange of digital soil-related data. This will allow owners of soil data to publish via the Web. This new standard still requires tests by a broader community of soil data holders in order to gain acceptance and to become routinely applied. This task is now also part of the work programme of the Working Group Soil Information Standards (WG SIS) of the International Union of Soil Sciences (IUSS).
- **Web Services**: Establish web services for digital soil data and provide easy access to the standard data products specified below.
- **Develop a dynamic web portal for global soil information**: Such a portal provides best practice knowledge, metadata, links to data products etc. world-wide, and also hosts a world soil viewer. It provides information to the user in a seamless fashion that is customized to suit their needs. It includes not only global products, but acts as a hub for national, regional and other user-specific soil information.
- **Build catalogs**: These provide summaries of the availability of data at various sources and they are needed to ensure the web-based services are delivered efficiently.

See also Appendix 3 for further technical requirements and specifications of a global soil data infrastructure. The general aim for building a global soil data infrastructure is to ensure that soil data and information are freely available on the web and in a format that can be readily used for a wide range of purposes. This availability will stimulate the use of soil information and result in many new applications. The web-based architecture will also create the opportunity for new sources of soil data to be efficiently shared (e.g. from new sensors such as infrared spectroscopy and *in situ* monitoring systems).

> **Recommendation 10**: Develop the spatial data infrastructure and information systems necessary for delivering consistent and reliable soil information products as web services.

5. Data products

It is essential to have orderly specifications and delivery of global soil data products. This is especially important for users working on issues such as climate change, land use, farming systems and other topics where simulation modeling is used as the primary form of analysis (especially in the absence of soil observing and monitoring systems). There is also a vast variety of mostly local interpretative approaches including best management practices, building mostly on expert knowledge. The latter is very difficult to collect and synthesize for global purposes.

Simulation modeling is essential for analyzing many of the complex issues relating to food security, ecosystem function and climate change. The data model for the soil component in most simulation studies (e.g. grid size, number of soil layers, soil variables) cannot be changed easily thus modelers need to have a clear understanding of the current and future data products so they can engineer their models accordingly.

Three primary data sets form the core of the global soil information system and they describe soil grids, polygons and profiles. The following sections describe recommendations and tiers for developing these data sets.

Other forms of soil knowledge are also important but they tend to have a more local or regional focus. The need to build a global system is less urgent for these forms of soil knowledge and in some cases, difficult to justify even though they may relate in various ways to the three applications outlined in Section 2. Examples include the following.

- Information on pedogenesis and landscape evolution provides essential context for natural resource management but the qualitative models, detailed process understanding and chronologies of landscape development often have a local or district focus. Documentation via scientific journal papers and technical bulletins is an effective mode of communication.
- Information on interactions between different forms of soil management and soil health is important for sustainable land management. Again the information is strongly dependent on local context and a range of economic, cultural and social factors. Publications on best-management practices provide one means of information delivery. Preparation of a global knowledge base, while conceivable, is not the highest priority for Pillar Four.
- Traditional knowledge relating to the soil and land has great significance in regions where there is long cultural association with the land. Again, existing modes of investigation and information sharing are effective.

Recommendation 11: That Pillar Four supports the ongoing development and maintenance of three primary data sets central to the global soil information system (global soil grids, polygons and profiles) to be defined according to specifications responding to end user needs.

The Global Soil Grid

Soil data in a grid format are important because they are compatible with other forms of biophysical data (e.g. land-cover, vegetation, terrain, remote sensing). There are several options, starting from the improvement of existing global data products towards high-resolution global soil property mapping using digital soil mapping. These options and the need for specific global data products are the results of the following processes:

- User experiences about the FAO world soil map and the Harmonized World Soil Database (HWSD)
- Stakeholder questionnaire about data needs (basis for the FAO 2012 report on soil information needs)
- Experience from the discussions about the GEO task Global Soil Data.
- Experience gained through the development of the GlobalSoilMap initiative and pilot studies.

Option 1: Updated Harmonized World Soil Database (HWSD)

> **Recommendation 12 – Option 1**: Update the current Harmonized World Soil Database and use it as the de facto standard soil grid for the world until better products are released (see Options 2–4 below).

A collaboration led by the FAO produced the HWSD several years ago at a resolution of approximately 1km[3]. It is now widely used by the climate-change and other modeling communities. FAO will be updating the product within 12 to 15 months with the support of interested GSP Partners. The HWSD represents the soil with two layers down to a depth of 1m. The product provides a comprehensive set of soil attributes. The original HWSD did not incorporate data from several large countries and instead relied on interpretations of the FAO Soil Map of the World together with data provided by the European Commission, IIASA, ISRIC and the Chinese Academy of Sciences. The update needs to include data from the countries that did not contribute so far. While the HWSD has been an invaluable first step in providing gridded data globally, it is constrained by the following:

- The two-layer soil model (topsoil, subsoil) is inadequate for many studies that involve simulation of the water balance, plant growth, greenhouse gases, susceptibility to mass movement, etc.
- Restricting soil data to 1 m is problematic, especially for hydrological and ecological studies where the dynamics of water, carbon, nutrients and solutes need to be considered to a much greater depth especially in more strongly weathered landscapes and when perennial vegetation is involved. Other applications need to know the depth of the soil (e.g. landslide prediction, landscape hydrology).
- The grid resolution of 1 km is useful for synoptic studies and sufficient for global-level presentations. However, the representativity of soil profiles and soil polygons, which form the HWSD data base, is still fairly insufficient and prevent reliable spatially-explicit conclusions and statistics. Uncertainties are unknown. Many applications now require soil data at resolutions that match digital elevation models and remotely sensed imagery (typically 100m or finer).

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[3] www.fao.org/nr/land/soils/harmonized-world-soil-database/en/

Option 2: *GlobalSoilMap* 100m grid

> **Recommendation 12 – Option 2**: The global soil grid is produced according to the *GlobalSoilMap* specifications via web-services provided by national soil agencies or organizations acting on behalf of one or more countries through mutual agreement.

In 2008, work began on the design and planning for a soil grid of the world at fine resolution (100 m) and this became known as *GlobalSoilMap*. Its purpose is to integrate the best available data from local and national sources and deliver the information online as part of the Global Earth Observing System of Systems. Soil information is to be available in a format and resolution compatible with other fundamental data sets on terrestrial systems (i.e. vegetation, land cover, terrain, remote sensing).

GlobalSoilMap was catalyzed through an initial investment from the Bill and Melinda Gates Foundation. Their focus was Africa but they also established an international consortium with responsibility for the global effort. The technical and logistical complexity of the project is substantial but great strides have been made during the initial research phase of the project.[4] Achievements to date include:

- preparation of comprehensive and scientifically innovative technical specifications
- completion of proof-of-concept studies (USA, Nigeria, South Korea, Denmark, Australia)
- strong international collaboration and enthusiasm to produce the operational system.

The product has a flexible method for estimating and extracting soil data for any depth or depth-integral. A variety of digital soil mapping methods is used to provide estimates of soil properties and these depend on local data availability. Estimates of uncertainty are also provided.

The resolution of 100 m was selected because it matched the resolution of another key global data set – the SRTM digital elevation model. It is also at the coarsest resolution for resolving hill slopes in many landscapes – the scale at which a large amount of soil variation occurs. This resolution provides better support at local scales where most decisions are made. It should be noted that some countries are working at finer resolutions (e.g. 50m) and then supplying grid estimates at the 100 m resolution in accordance with the Technical Specifications.

GlobalSoilMap is in its initial phase of product delivery. The *GlobalSoilMap* products can be aggregated and delivered in a wide range of formats and it forms the logical basis for the future delivery of gridded soil data. Once coverage is completed for a region, products at coarser resolution (e.g. 1 km, 10 km) can be produced (e.g. format of the HWSD) with ease but the opposite is not true.

Key issues:

- Specifications for GlobalSoilMap need to be endorsed by GSP Partners and need to be critically scrutinized against actual user needs and an independent cost-benefit analysis.
- *GlobalSoilMap* is now at the point where the resourcing outlined in Section 4 is needed to scale-up the project and deliver on the original vision: otherwise coverage is unlikely to exceed 50% by 2018

[4] See www.soils.org/files/publications/csa-news/creating-a-global-digital-soil-map.pdf, and Arrouays et al. (2013). *GlobalSoilMap*: towards a fine-resolution global soil map. Advances in Agronomy [in prep].

- Pillar Four provides a logical institutional home for *GlobalSoilMap* but this requires support through the current planning process for Pillar Four and endorsement by the Intergovernmental Technical Panel on Soils
- Some countries do not have institutions or the capacity to provide inputs to *GlobalSoilMap* so an alternative process is needed for producing the grid across these areas.
- If the GSM work is not accompanied by improving a world soil profiles data base (either centralized, or via web feature services) with original analytical data, then the input data used for GSM will not be available as input to other communities (to fulfill possible future information needs).

Option 3: ISRIC 1km grid

> **Recommendation 12 – Option 3**: ISRIC produces a 1km global grid within 12 months using its own data holdings with a view to developing the Global Soil Information Facility in the longer term including updates to this grid.

In response to the urgent need by global soil data users for an updated global soil grid, ISRIC has proposed that it generates a 1km grid (SoilGrids1km) with the first version being delivered by the end of 2013. The proposal is outlined in Appendix 1. It closely mirrors the *GlobalSoilMap* product except for its mode of production and resolution.

Unlike *GlobalSoilMap*, SoilGrids1km is produced centrally using environmental covariates (mostly at 1km resolution) and soil profile data held by ISRIC. For additional information, see Appendix 2.

Key issues:

- Quick delivery of the needed soil data and information at global scale in a format suitable for most current applications.
- The soil profile data held by ISRIC is still substantially less than that held by soil information institutions around the world. Transfer of the latter (or parts of it according to agreed specifications and harmonization requirements) to ISRIC would require a clear commitment of the GSP community to build its system on ISRIC tools. Currently, there is no other set of global data management tools and global soil portal functionalities. There might be the issue that institutional hurdles due to IPR issues restrict the transfer of national data into the ISRIC system. That might change if this is continued under the GSP Pillar 4 umbrella.
- The grid product is produced centrally rather than as a compilation of national grids. There is a chance for inconsistencies between the global grid and national products following the same specifications, especially for countries that produce their own grids using data that are not available to ISRIC. Mechanisms for overcoming this issue are being considered but the details would require agreements with the relevant countries.
- There is a perceived inconsistency between this centralized approach and the GSP's emphasis on the sovereign rights of countries and its desire to build technical capability in member nations. On the other hand, the feasibility of fully decentralized systems for timely producing global products is also questionable. It appears that the development of the WISE data base at ISRIC (and the experiences going along with it, e.g. plausibility testing) represents a key component of any future global soil information system.
- Some national institutions are concerned that rapid production of the 1km grid will diminish the momentum for *GlobalSoilMap 100m*.
- While this product maybe suitable for modelling and describing regional trends, it is too coarse to resolve average-sized farms, especially in developing countries.

- It must also be tested by direct comparison in test cases, what the reliability and the benefits of this option are for users, compared to a revision of the HWSD (Option 1).
- It was also raised during the initial review of this Pillar 4 concept that options are needed to obtain quick results if new data is supplied by countries. This argument supports options 3 and 4. It seems that various countries will require and wish to use tools such as ISRIC's GSIF to produce 1 km, or even 100 m coverage, depending on the data available.

Option 4: Hybrid

> **Recommendation 12 – Option 4**: The global soil grid is produced using a hybrid approach involving SoilGrids1km and *GlobalSoilMap* under the direction and governance of the GSP and Intergovernmental Technical Panel on Soils. The first data release would be on World Soils Day in December 2014.

With this option, SoilGrids1km would provide the default grid data wherever nationally produced grids were not available. The launch date for the initial product would be World Soils Day in December 2014. The extra time is needed to establish the governance structure necessary to deal with the national and institutional matters that will need to be resolved prior to any data release.

Key issues:

- The hybrid approach may still be perceived as being a centralized approach with the same issues outlined as for SoilGrids1km
- The hybrid approach may not allay the concerns of national institutions over the potential loss of support for the higher resolution product
- ISRIC and the *GlobalSoilMap* Consortium would have to relinquish a degree of independence by coming under the governance structure for Pillar 4.
- GSP needs to keep the momentum for developing 100 m coverage, a resolution requested by many stakeholders.
- Advantage to use ISRIC tools is the existing experience for global data handling. ISRIC pursues a multi-participant, collaborative approach even if evaluations/modeling and development of web services for data products is implemented centrally.

Global Soil Polygons and Supporting Classification

There is reasonable agreement on the design of hierarchical polygon systems at the national and global level. Some would argue that polygon-based are outdated and need to be replaced by grid-based systems. However, polygons and grids are complementary and both are needed for the following reasons.

- Many soil surveys were conducted at times with sufficient personnel and funding. Upon available documentation, this information is valuable because the same intensity of field work will not find support anymore.
- Traditional soil surveys provide landscape boundaries according to scale-dependent rules for soil formation and soil association building. Information about the spatial distribution of soils and its properties based on data bases which store sets of typical soil profiles allows for a global spatially explicit view on the resource soil (allowing 2.5-D evaluations).
- Many decisions on land use and management require the delineation of areas with sharp boundaries either for legal or practical reasons
- Soils are natural bodies of material and in some landscapes they are best delineated using polygons because this accurately depicts physical reality (e.g. distinct sedimentary bodies such as alluvial terraces)
- There is educational value in being able to identify landscape units with distinctive patterns that reflect landscape evolution and pedogenesis
- Stratification of landscapes into zones with a similar evolutionary history is also valuable for digital soil mapping because the relationships between environmental covariates and soil properties are often conditional on this history – the polygons can be used as a nominal environmental covariate.
- A global soil polygon map is needed and can be easily applied because of its simple 2-dimensional format. Based on the experience with the coarse 1.5 Mio global soil map of FAO, a very broad community of stakeholders including other GSP pillars is in demand of a revised and improved global soil map (see also FAO 2012[5]).

> **Recommendation 13**: Replace the FAO/UNESCO Soil Map of the World by completing the SOTER coverage for the world by incorporating the missing coverage from North America, Oceania and Europe using revised technical specifications.

Many countries have national soil information systems based on conventional methods of soil survey and land evaluation. These systems typically have a hierarchy of soil and land mapping units with descriptions of soil properties and soil classes. Many have interpretations of land suitability derived using some variant of the FAO Guidelines for Land Evaluation (FAO 1976).

The *de facto* global standard for soil polygons is provided by SOTER (notionally at a cartographic scale of 1:1 500 000). The coverage provided by SOTER-compliant databases is incomplete. While the urgency for completing the SOTER coverage is not as immediate as for the gridded soil data, there are good reasons for completing the global coverage. The key tasks are as follows.

- Prepare specifications for an electronic SOTER (eSOTER) product based on those for SOTER with particular emphasis on specifying the taxonomic requirements (e.g. consider addition of the proposed Universal Soil Classification) and terrain characterization (where digital elevation models can now be used).

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[5] FAO (2012). State of the Art Report on Global and Regional Soil Information: Where are we? Where do we go? Global Soil Partnership Technical Report. FAO, Rome, 2012.

- Progressively deliver eSOTER data via a web services and ensure compatibility with SoilML
- Negotiate a timeline for completion with the key parties.

The consistent polygon coverage would replace the FAO/UNESCO Soil Map of the World.

Key issues:

- The completion of SOTER may draw resources away from the effort to produce the global soil grid. However, it is likely that different groups of partners become involved.
- Most applications for polygon data are at the national or sub-national level. Therefore, SOTER requires very clear specifications and coordination.
- Based on rates of progress to date, it may be difficult to achieve the momentum necessary to complete the product. It is therefore important that a strong global incentive is produced by GSP.
- Completion of the polygon coverage does not appear to be the top priority for any international agency or consortium. An incentive for global action is urgently required.

Soil profile and point data

There are strong reasons for developing a global data base of soil profiles, because it contains comprehensive and representative soil profile and analytical data. The widespread use of the WISE[6] database has demonstrated the value of such a system.

However, maintaining and updating large soil profile databases is expensive, particularly when the data come from multiple sources (e.g. employing a variety of laboratory methods and sampling strategies, plausibility checks, quality assurance, maintenance).

Soil profile data represent precisely georeferenced point soil data. The issue of rights management (IPR) becomes very sensitive if such data is collected on private land (for IPR, see also Appendix 3). Precisely georeferenced point soil data collected on private land are infringing in some countries national legislation on privacy if delivered to public services without prior consent of the land owner. Therefore, IPR issues need to be clearly solved before such data are built into a global soil information system.

The further development of a world soil profile data base likely has two Tiers. While an open archive for all kinds of field-based data collections as a first Tier would enable and preserve a maximum amount of available data sets, open for all kinds of consecutive uses. Stronger requirements towards harmonization, quality assurance and representativity are the conditions for building a higher Tier data set. There are many use cases in which a Tier 2 data set is needed because it is too difficult for users to judge the representativity and validity of information contained in a huge global data base. In both Tiers, soil information agencies would be encouraged to provide data as a freely available web services. Provision as a web services (based on an agree specification for data exchange, such as SoilML) would allow the compilation of a single database for particular studies if required. A global soil profile archive could serve as a soil profile reference and conversion library, with analyses available for all samples by multiple methods. This is needed to quality assure global projects and studies, and also to further develop and improve global data products and statistics about soils as a resource.

[6] Batjes, N.H. (2008). ISRIC-WISE harmonized global soil profile dataset (version 3.1). Report 2008/02, ISRIC –World Soil Information, Wageningen.

Tier 1: Comprehensive soil profile and analytical database

> **Recommendation 14 – Tier 1**: Compile a large soil profile and analytical database for the world without the stringent requirement for a minimum data set (apart from geo-referencing and metadata) or representativeness.

Such a database represents a continuously growing archive of soil profile descriptions and analysis world-wide. Nomenclatures and analytical methods do not need to be harmonized as long as each data set is accompanied by sufficient meta information so that quality checks and some coarse level of harmonization can be achieved. Data are physically provided either by using a global data collection tool (such as ISRIC'S soilprofiles.org, which extends the former WISE data base, see Appendix 2) or by setting up web feature services following agreed specifications for digital data exchange.

This Tier is about the compilation of a larger soil profile database for the world without the stringent requirement for a minimum data set (apart from geo-referencing). This data set could be used, for example, to help produce the SoilGrids1km product. The number of soil profiles in this database is likely to exceed 100 000 and could be much greater than 10^7 if soil testing data (e.g. from commercial soil testing companies) are included.

Tier 2: World reference soil profile dataset

> **Recommendation 14 – Tier 2**: Compile a database of soil profiles with comprehensive morphological, physical and chemical data that are globally representative of geographic regions, major soil types, or significant for other reasons. This dataset is very likely a subset of the Tier 1 soil profile collection. High requirements to data quality, parameters contained, harmonization, documentation and representation are applied.

This Tier 2 represents very specific requirements to the quality and documentation of soil profile data. Harmonized and quality-assured morphological, physical and chemical data need to be available which are globally representative of:

- geographic regions
- major soil types
- ecologically, agriculturally or scientifically significant soils

The precise criteria for selecting representative soils need to be defined along with the necessary technical specifications. Strong preference should be given to soil profiles with associated archived specimens to enable further measurement and analysis (e.g. to support the development of standard spectral libraries for proximal sensing). The number of soil profiles in this database is unlikely to exceed 20 000.

6. Monitoring and forecasting

As noted earlier, detecting and forecasting soil change with time is technically more demanding than mapping, but is of high relevance for monitoring and verification purposes in relation of a number of multilateral environmental agreements. Only a few countries have national monitoring systems with the capability to detect soil change with time (e.g. Japan, South Korea, France, Switzerland). The technical design and logistical considerations of these national systems are well known (e.g. McKenzie 2008). However, securing long-term institutional commitment is particularly difficult partly because the return on investment for existing systems is poorly documented.

In most parts of the world, scientists draw their evidence for inferences about soil change from a variety of sources including:

- long-term monitoring sites (from simple plots through to complex field experiments)
- simulation modeling
- proxies (e.g. monitoring changes in land management rather than soil variables directly, or comparing paired-sites where space is substituted for time)
- narratives (e.g. historical accounts of soil condition).

For countries lacking soil monitoring, it seems efficient to resample existing representative and well-described and analysed soil profiles (e.g. as developed under Recommendation 14, Tier 2).

> **Recommendation 15**: Encourage all GSP member countries to implement national monitoring systems with the capacity to detect soil change with time.

Before committing to a global system for monitoring and forecasting soil condition, a better understanding is required of the return on investment from these various sources of evidence. An initial task is to undertake a feasibility study to identify the most worthwhile components. Some aspects that need to be considered include the following.

- Determine whether expansion of the existing FAO statistical systems is feasible and worthwhile (i.e. FAO Stat and Aquastat). Variables to be assessed for an augmented system should include the drivers of soil change: for example; land management practices, agricultural inputs (e.g. fertilizer, lime, energy costs, tillage), loss of high-quality agricultural land.
- Investigate opportunities for coordinating and harmonizing existing soil monitoring programs (e.g. the Long Term Ecological Research network, the national systems mentioned earlier, and the emerging soil carbon monitoring systems) through the adoption of common measurement protocols; investigate options to extend them by using new data sources such as remote sensing.
- Evaluate the merit of preparing guidelines for the design and maintenance of local, national and international soil monitoring networks.
- Assess whether new monitoring networks are needed in high-priority regions where soil change is suspected to be occurring or likely to occur (e.g. hot spots such as permafrost regions, important food producing districts, landscapes where agricultural intensification is occurring).

- Study available concepts about soil condition indicators (e.g. Huber et al. 2008[7])

Recommendation 16: Undertake a feasibility study to identify investment priorities and design options for establishing a global system for monitoring and forecasting soil condition.

[7] Huber et al. (2008). Environmental Assessment of Soil for Monitoring: Volume I Indicators & Criteria. EUR 23490 EN/1, Office for the Official Publications of the European Communities, Luxembourg, 339 pp.

7. Analysis and synthesis functions

Reports on global soil health every five years

Regular reporting on the status and trends in soil health at the global scale serves several functions. The reports will identify the rate and extent of soil-change and the likely consequences for society, including soil productivity and sustainability. The regular reporting will also bring an operational discipline to the management of soil information. Systems for collecting and analyzing data can be progressively improved and a body of knowledge will be developed over several cycles of reporting. Such systems can be based on scientific reviews and systematic information collection from GSP partners, for example, but must eventually be based upon an operational soil monitoring system if the reporting should be representative, comparable, and based on reliable knowledge. A global reporting mechanism would also contribute directly to other global assessment activities, most notably:

- Assessment of the Land Degradation Neutral World target agreed at the Rio+20 conference
- General reporting by the Intergovernmental Panel on Climate Change (IPCC) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)
- Regular assessments by the FAO such as updates to the State of Land and Water Resources.

The reporting process will have a level of scientific rigor equivalent to the reporting processes under the IPCC. The ITPS will have oversight of the process and ensure that the best available information has been used including soil monitoring. The primary outcomes would be that:

- decision makers have a clear understanding of soil status and trends and the impacts of past and future decisions on the soil and the systems dependent on its health
- regular attention on the state of the world's soils leads to more sustainable systems of land use.

> **Recommendation 17:** A five-yearly report on global soil health is produced and endorsed by the Intergovernmental Technical Panel on Soils on the basis of operational soil monitoring at global scale.

Data provided to global reporting mechanisms

Additional need for soil condition statistics derives from other existing global reporting mechanisms, for example, the United Nations Convention to Combat Desertification (UNCCD), FAO State of Land and Water Resources, IPCC and IPBES. Information about soils as a resource will become increasingly important in various political initiatives related to resource efficiency, integrated water management, and the Millennium Ecosystem Assessments.

> **Recommendation 18:** Pillar Four focuses on data and information delivery to existing global reporting mechanisms and reports on global soil health are not produced on a separate five-year cycle.

8. Governance

The design and management of the global soil information system requires a governance structure and associated management systems. Detailed specification is premature. However, the following features are needed to ensure the global soil information system is successful.

A decision-making governing body is essential, while the system (products, network) needs to be technically coordinated. The ITPS seems the ideal authoritative body overlooking Pillar Four, and it can perhaps be best viewed as being the Board of Directors for the global soil information system. A coordinator of the global soil information system will be appointed by the ITPS, and will regularly report to it. The ITPS will not be in a position to deal directly with many of the technical and management aspects of the global soil information system. Rather, it will set strategy and determine the policies relevant to all operations. The following committees are proposed with each having a formal reporting responsibility to the ITPS.

- **Global soil information system management committee:** responsible for operational aspects of the global soil information system including development and implementation of policies on intellectual property, quality assurance, infrastructure, and user engagement.
- **Sub-committee on capacity development and training**: responsible for the design and implementation of training programs, collaborative activities and communication
- **Sub-committee on research and development**: responsible for the development and testing of new methods for soil mapping, monitoring and assessment
- **Sub-committee for engagement with GEOSS**: responsible for integration of the global soil information system into GEOSS.

These committees would provide oversight and guidance to the project teams responsible for developing and maintaining the global soil information system (Section 4).

Other existing mechanisms with global dimension might be taken on board depending on ITPS decision. For example, the Working Group Soil Information Standards of the International Soil Science Society plays an important role in supporting specifications development for data exchange, capacity building, and extension of the community of data providers and services.

Recommendation 19: The coordinator of the global soil information system is responsible for all project teams and reports directly to the ITPS. Advisory committees may also provide advice to the coordinator of the Global Soil Information System, and they also report directly to the ITPS.

A charter of ethics needs to be developed for the global soil information system. This will serve as a common credo to guide all organizations and individuals involved with the global soil information system. This affirmation of values and principles will summarize the intent and responsibilities of all institutional matters relating to Pillar Four (e.g. legal, administrative, codes of conduct for individuals and organizations). The charter of ethics will need to specifically address intellectual property (e.g. relating to data) because of its importance to the success of the global soil information system.

Recommendation 20: A charter of ethics is developed for the global soil information system including protection of privacy of individuals and intellectual property rights.

Appendix 1: Summary of recommendations

Recommendation 1: The design and operation of the global soil information system will use data primarily from national and within-country systems and will focus on delivering products and information services for regional and global purposes. Agreements about harmonization requirements to achieving comparability of measurements and observations as well as systems for aggregating data and information between scales are therefore essential.

Recommendation 2: That the global soil information system and its associated Community of Practice formally joins the much larger effort to build and maintain the Global Earth Observing System of Systems overseen by the Group on Earth Observations.

Recommendation 3: The global soil information system will be comprised of consistent spatial data sets and services provided by a mix of institutions with soil information facilities in place (research, industry, land owners). However, national soil agencies will play a predominant role as facilitators for the collection, management, quality assurance and provision of the diverse data collections and storage systems; in some cases, also organizations are important which act on behalf of other countries through mutual agreement.

Recommendation 4: The global soil information system intends to include a maximum amount of digital soil information, however, it must facilitate that information can be harmonized thus becoming comparable globally. Data from contributing organizations need to conform to mutually agreed standards set out according to an agreed measurement method, or can be transformed using a global reference system.

Recommendation 5: A stepwise approach is suggested for Pillar Four: First complete a reliable baseline for selected soil properties, then build on it an operational global soil monitoring capability.

Recommendation 6: Aim to achieve net benefit for all partners involved in the global soil information system and monitor this through regular engagement and review.

Recommendation 7: Follow up developments in research and create a mechanism for incorporating new technical developments for further improving of the Global Soil Information System.

Recommendation 8: Immediately establish full-time leadership and technical support teams on the basis of the existing facilities of GSP members with sufficient resources to build the global soil information system by 2018.

Recommendation 9: Train a new generation of specialists in mapping, monitoring and forecasting of soil condition with an emphasis on countries where improved soil knowledge is essential for food security and restoration and maintenance of ecosystem services.

Recommendation 10: Develop the spatial data infrastructure and information systems necessary for delivering consistent and reliable soil information products as web services.

Recommendation 11: That Pillar Four supports the ongoing development and maintenance of three primary data sets central to the global soil information system (global soil grids, polygons and profiles) to be defined according to specifications responding to end user needs.

Recommendation 12 – Option 1: Update the current Harmonized World Soil Database and use it as the de facto standard soil grid for the world until better products are released (see Options 2–4 below).

Recommendation 12 – Option 2: The global soil grid is produced according to the *GlobalSoilMap* specifications via web-services provided by national soil agencies or organizations acting on behalf of one or more countries through mutual agreement.

Recommendation 12 – Option 3: ISRIC produces a 1km global grid within 12 months using its own data holdings with a view to developing the Global Soil Information Facility in the longer term including updates to this grid.

Recommendation 12 – Option 4: The global soil grid is produced using a hybrid approach involving *GlobalSoilMap* and SoilGrids1km under the direction and governance of the GSP and Intergovernmental Technical Panel on Soils. The first data release would be on World Soils Day in December 2014.

Recommendation 13: Replace the FAO/UNESCO Soil Map of the World by completing the SOTER coverage for the world by incorporating the missing coverage from North America, Oceania and Europe using revised technical specifications.

Recommendation 14 – Tier 1: Compile a large soil profile and analytical database for the world without the stringent requirement for a minimum data set (apart from geo-referencing and metadata) or representativeness.

Recommendation 14 – Tier 2: Compile a database of soil profiles with comprehensive morphological, physical and chemical data that are globally representative of geographic regions, major soil types, or significant for other reasons. This dataset is very likely a subset of the Tier 1 soil profile collection. High requirements to data quality, parameters contained, harmonization, documentation and representation are applied.

Recommendation 15: Encourage all GSP member countries to implement national monitoring systems with the capacity to detect soil change with time.

Recommendation 16: Undertake a feasibility study to identify investment priorities and design options for establishing a global system for monitoring and forecasting soil condition.

Recommendation 17: A five-yearly report on global soil health is produced and endorsed by the Intergovernmental Technical Panel on Soils on the basis of operational soil monitoring at global scale.

Recommendation 18: Pillar Four will include data and information delivery to existing global reporting mechanisms and reports on global soil health are not produced on a separate five-year cycle.

Recommendation 19: The coordinator of the global soil information system is responsible for all project teams and reports directly to the ITPS. Advisory committees may also provide advice to the coordinator of the Global Soil Information System, and they also report directly to the ITPS.

Recommendation 20: A charter of ethics is developed for the global soil information system including protection of privacy of individuals and intellectual property rights.

Appendix 2: Proposed ISRIC 1-km grid[8]

Current world soil information is often unsuited for global simulation studies in such areas as food production, climate change, nature conservation and soil degradation analyses. In accordance with its mandate as ICSU world data centre for soil information, ISRIC has developed the Global Soil Information Facilities (GSIF), a collection of databases, tools and associated cyber infrastructure for automated soil mapping (Figure A1). GSIF has already demonstrated considerable potential to help produce improved global to regional soil information products. Recently, GSIF was used to produce 3D soil property maps for Africa at 1 km resolution for the AfSIS project, according to the GlobalSoilMap.net specifications. The methodology used to produce maps for Africa is generic and implementations are flexible which make it relatively easy to extend its application to the whole world.

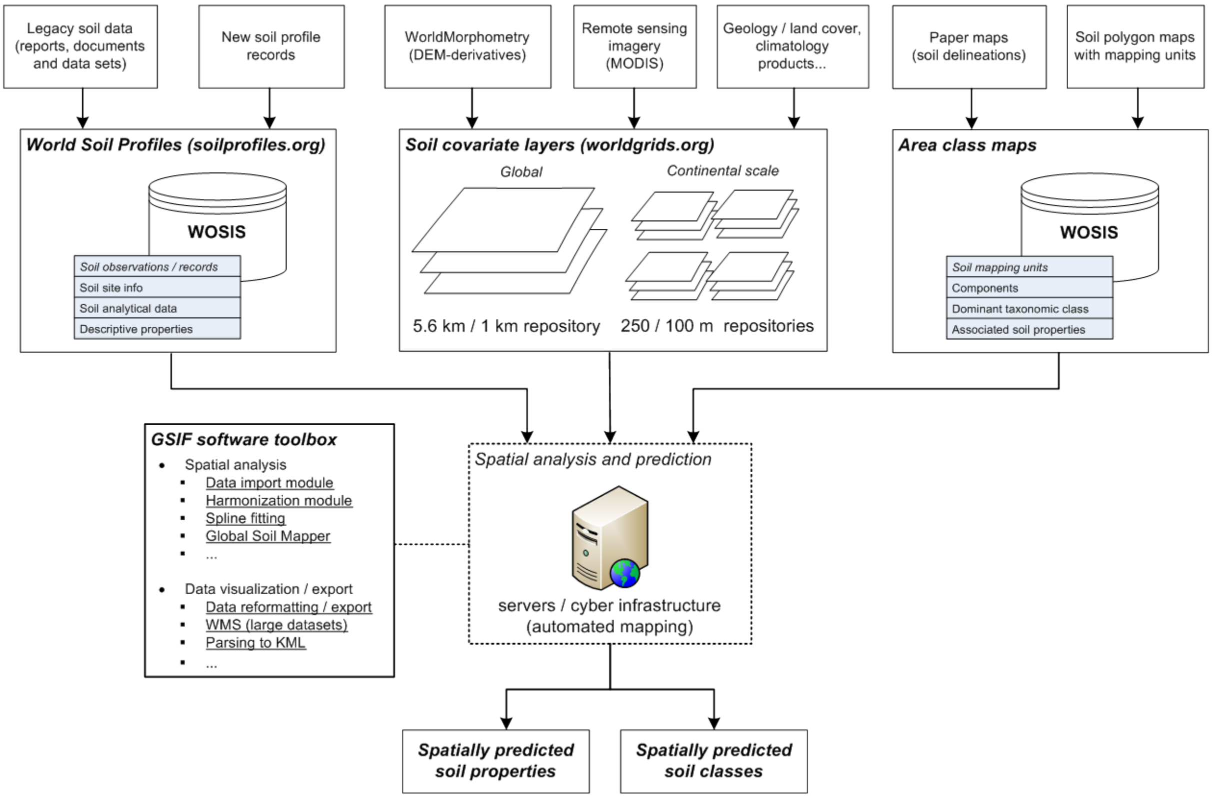

Figure A1. Schematic overview of the GSIF functionality.

ISRIC proposes to produce a series of updatable soil property maps for the entire world at a grid resolution of 1 km (SoilGrids1km) using the GSIF framework, in a collaborative effort. ISRIC has made a formal offer to the GSP to produce these global soil information products, in cooperation with all other interested parties. The objective of the SoilGrids1km project is to produce and freely distribute 3D predictions and associated prediction accuracies of basic soil properties for the whole world (i.e., the Earth land surface excluding Antarctica) at 1 km resolution. It is foreseen that all maps will follow the specifications developed by the GlobalSoilMap.net project, except for adopting a grid resolution of 1 km instead of 100 m. Adopting the GlobalSoilMap.net specifications recognizes and

[8] This Appendix has been provided by Dr Prem Bindraban, Director of ISRIC World Soil Information, Wageningen.

acknowledges the important efforts of the GlobalSoilMap.net project in developing these new, *de facto*, global standards for digital mapping of soil property information. The properties to be mapped are organic carbon, pH, texture fractions, coarse fragments (> 2mm), bulk density and available water capacity for 6 depth intervals (i.e., 0-5, 5-15, 15-30, 30-60, 60-100 and 100-200 cm).

All maps will be produced using scripts that can be rerun at any time as new data become available. These scripts will be made public and maps will be updated at least annually, with proper version control including a suitable technical review process. Initial scripts will implement a 3D regression-kriging model applied to point soil profile data stored in the WorldSoilProfiles.org database and gridded covariate data stored in the WorldGrids.org database at ISRIC. All components of this automated mapping framework, including point profile data, covariates and prediction models are designed to permit and encourage regular update and improvement. The methodology will be published in the international, peer-reviewed scientific literature. From 2014 onwards, it is proposed that maps of soil types will also be produced and the initial set of soil properties will be extended to all major soil properties using pedotransfer functions.

The quality of the resulting maps strongly depends on the quality and quantity of the input data. All freely and publicly available national and regional soil profile data sets are expected to be acquired, in accord with the data providers, and used to produce an initial set of 1 km resolution maps. ISRIC is aware of over 70,000 profiles that are potentially freely available and is in the process of requesting necessary permissions from data providers to collate and use these publically available data sets. The project will seek collaboration with all interested international partners to improve and extend the central database (WOSIS) with additional national profile data. Collaboration with partners is crucial for acceptance and use of the intended products; potential partners will be invited to commit to the project and to provide additional data under conditions specified by the data provider and in accordance with the ISRIC Data Policy[9]. At present, ISRIC will enter any new soil profile data into the WOSIS database. In the near future, WorldSoilProfiles.org will be made available to all interested parties and will allow direct user entry of field records of soil properties; upon screening and harmonization, these data will be used to further improve the spatial predictions.

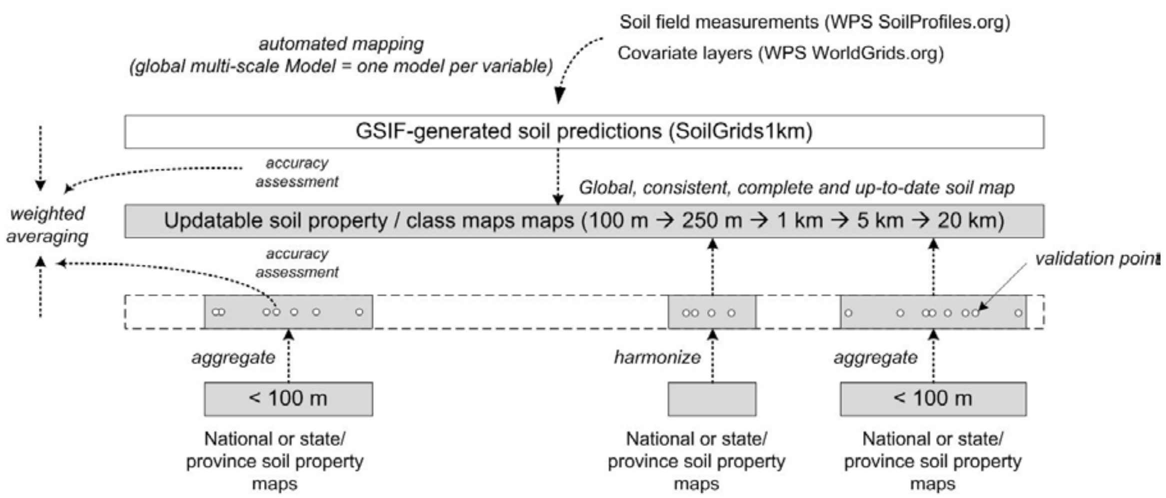

Figure A2. Proposed framework for merging the 1 km global product with national finer resolution products to improve map accuracy.

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[9] Data providers can currently opt for one of two options: (1) share and allow public access to all primary data via WorldSoilProfiles.org; (2) share data internally with ISRIC for production of the SoilGrids1km maps and allow public access to the final product, but not to the primary data. For details see the ISRIC Data Policy (http://www.isric.org/data/data-policy).

Data-rich nations that have fine resolution, high-quality national maps that are likely more accurate than the initial SoilGrids1km product will be encouraged to share and merge these detailed national maps with the SoilGrids1km initial maps using weighted averaging algorithms (Figure A2). It has been proposed that the weights be derived from the relative accuracies of the input maps. If national maps are significantly more accurate, then the merge will effectively lead to national maps 'overruling' the SoilGrids1km product.

It is proposed that the GSP review all 'final' products prior to public release and supply a review report identifying potential improvements. The SoilGrids1km products will be made freely available and registered under a Creative Commons license (CC-BY-NC 2.0). Partner nations/institutes will be encouraged to provide cyberspace in terms of mirror servers to support distributing the SoilGrids1km product most effectively. Contributions from all participating institutes will be fully acknowledged, duly reflecting the collaborative nature of the activities. If so desired, the initial 1 km maps can be branded and presented under the ISRIC, GSP and GlobalSoilMap banner. Increased participation of institutes from across the globe will be pursued, and training will be provided to encourage potential partners to get actively involved. It has been proposed that World Soil Day, December 5, 2013 be selected as the date on which the initial version of the global soil property maps (SoilGrids1km, version 1.0) be officially released and this achievement of the global soil science community celebrated.

Appendix 3: Structure and components of a Global Soil Information System[10]

1 Overview: concept of a distributed system for data exchange

Modern web technologies allow a very flexible exchange of digital, spatial data sets. This allows the continued responsibility and maintenance of data by its owner, while data sets which geographically match along borders and themes are provided with a minimum level of obstacles coming from communication, administration etc. This also includes the protection of intellectual property rights via tools for rights management and web security services. Figure 1 presents a schematic view of a network of data providers. An overarching data centre and network is necessary in order to facilitate that data specifications and harmonization requirements are considered, and that data providers receive support in building their local infrastructures. Guidance about the collection of data, to harmonization (e.g. terminology, methods – FAO/IUSS), or even technical implementation of data exchange standards (ISO 28258 on soils, OGC – IUSS WG SIS) is needed to fulfill the overall goal , making data available to end users (e.g. modelers and politicians).

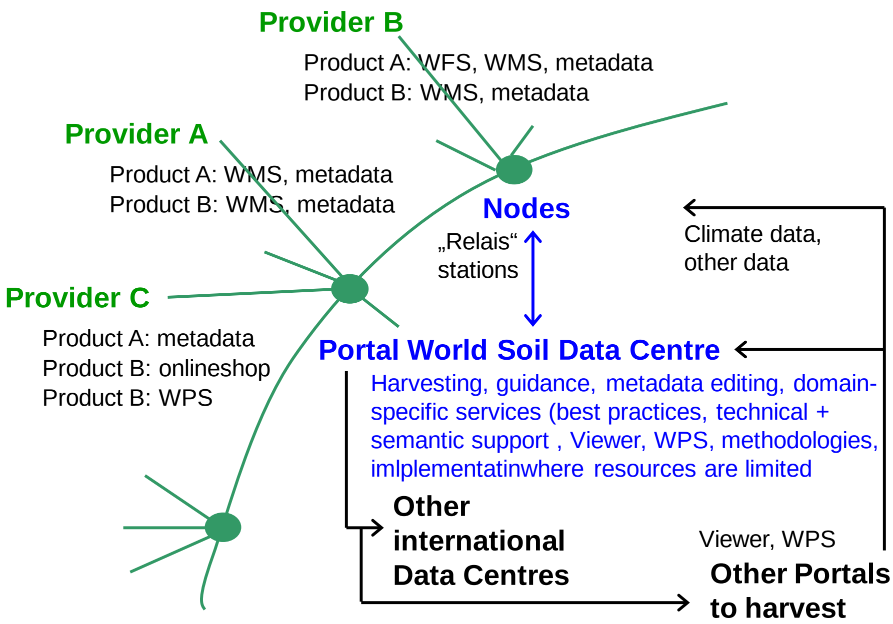

Figure 1: Distributed system of data services

2 Soil data infrastructure in GSP Pillar 4

Figure 2 presents a proposal of the components of a global soil data infrastructure. This infrastructure is targeted to implement and realize the short-, mid- and long-term objectives of GSP pillar 4. It builds on existing achievements and facilities as much as possible. It is governed by GSP IPTS and specific pillar 4 bodies (coordinator of a global soil information system and the management committee).

[10] This Appendix has been added upon review comments about possible technical components of a global soil information system.

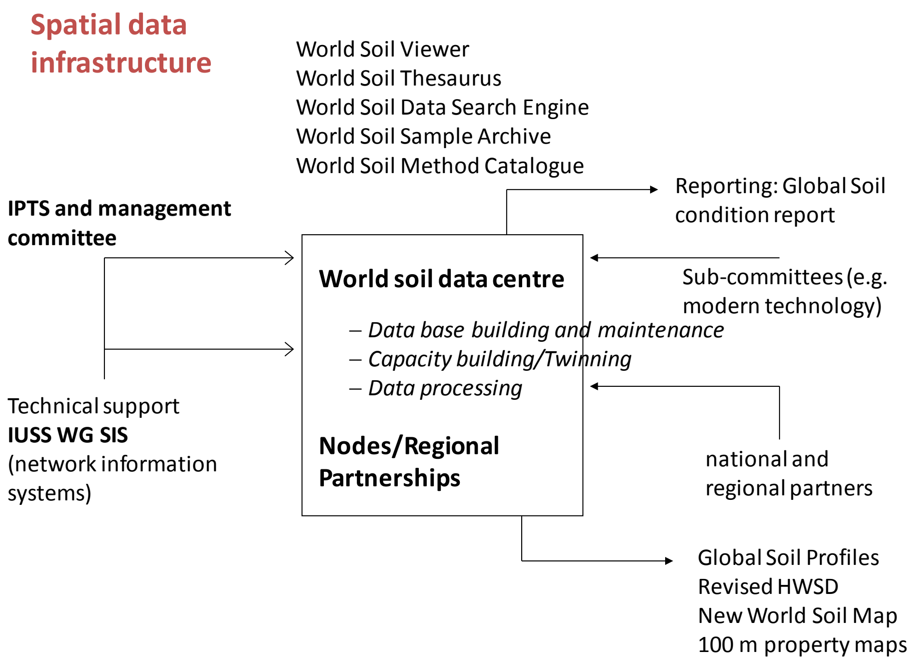

Figure 2: Global soil data infrastructure

3 Global soil data coordination

A global soil information system and global products relies on key elements in order to successfully produce representative, quality controlled global soil data products:

- Developing and maintaining specifications for data exchange; be representative, and involve the soil science community as well
- Support capacity building for local data holders and national soil information systems as needed; this includes that metadata are developed and maintained by data providers
- Design, collection, storage and provision of reference data sets to all users
- Provide a central repository of data products (metadata) across the globe, and exchange this information with other domains (e.g. in the context of GEOSS)
- Quality assurance of data and products provided and exchanged, either into a central archive or via web services
- Develop tools for knowledge transfer (e.g. world soil statistics)

These elements could be provided by a single key entity (such as ISRIC World Soil Information, or FAO data centre, or any other voluntary offer), or by a well-coordinated network of key institutions. In both cases, the Pillar 4 structure, as proposed here, overviews the development of the global soil information system and the respective global facilities (viewer, method catalogue, etc.) and products.

The following sections introduce to technical functionalities and components of a world soil data portal. Other functionalities such as reporting, news etc. will be mentioned elsewhere.

3.1 World soil viewer

Globally, users of soil information usually first expect a quick visualisation of soil information without further usage of advanced GIS systems. A world soil viewer would provide visualizations of qualitative and quantitative soil properties from various data sources and data providers in a distributed way around the world. Its purpose in the end would be to create a dynamic soil map of the world for different soil properties with standardized legends and data exchange formats, provided by the local, regional, continental and global data providers, available to everyone via the web. In a first implementation step, services should be developed even without the necessary standardization to have quick wins.

3.2 World soil thesaurus

In a global environment and with over 6,000 languages, the translation of soil information knowledge is of outmost importance. To allow automatic translations of different terms, ontologies of interest in the Soil Science domain need to be available as a reference indexing and retrieval tool for the catalogue of data sources and other soil databases around the world.

A prototype soil thesaurus has been developed within the EU GS Soil project (gssoil-portal.eu).

3.3 World soil data search engine

Data sets, models, visualisations, soil web processing services increasingly become available online, in different formats, using various user and copyright restrictions. The products are described by the data owners using ISO-conform metadata. This information is made available through catalogue services, so that the information can found via web search. Using harvesting methods, a global multilingual repository needs to be created which allows searching for data products, therefore allowing the world soil search engine to become a one stop-location to find soil data globally for any location on earth. The interface to the outside world needs to support a variety of protocols (e.g. CSW) to allow different user communities to interact.

In this task, an overview of soil data products needs to be developed, based on metadata and additional information about important content definitions in each of the products, so that the user receives an idea about the possible harmonization needs, or uncertainties from different survey and/or sampling systems, introduced through systematic errors.

3.4 World soil sample archive

A well- maintained world soil reference collection is of outmost importance for any global efforts to support global soil information. Requirements on this collection are manifold: the samples should contain complete site and morphological descriptions, including accurate recording of the sampling position. Amount of sample material must be sufficient in order to allow further analytical analyses e.g. for quality control, interlaboratory exercises, research, development of reference methods and conversion factors needed for developing soil data transformation and harmonisation rules.

3.5 World soil profile and analytical database

Looking at the previous experiences with the WISE data base, an immense user community continues to request and to query a central digital world soil profiles database. This can be either a very comprehensive data collection containing all sorts of available soil data sets, or a quality-assured, harmonized and representative reference data set. Enabling the use of web technologies for data exchange in a global context will permit faster and new forms of soil information delivery.

Experience of the European GS Soil project (gssoil-portal.eu) underlines that data collection and exchange must be well coordinated and accompanied by domain experts. Instrumental to enhanced usability and accessibility of the data in the world soil profile and analytical database will be the harmonization of soil properties values, as well as standardization of analytical procedure descriptions.

3.6 World soil method catalogue

It was already mentioned before (soil function mapping) that harmonized methods are needed to allow data providers to develop data sets and evaluations which are comparable. This is especially necessary if data availability and exchange is based on internet services. These developments allow a large level of independence of data owners and providers, but guidance is needed to implement best practice recommendations to allow comparability of applications. For example, web processing services can offer real-time calculations with soil profile information collected during field work, like the calculation of field water capacity or other derived properties using pedo-transfer functions.

3.7 Intellectual property rights (IPR) management

It must be noted that web-based data exchange leaves data management fully in the hands of data providers. At the same time, governments realize the need and value of digital data about the environment. This leads to new data releases and pragmatic copy right agreements. For example, web security services allow for the protection of data according to the needs of the data owner, and still make this information available (e.g. meta data for all users, digital data sets to restricted users) Still, some IPR issues are still difficult to resolve, for example the spatial referencing to local data sets (land owners).

4 Regional nodes

Regional nodes (e.g. belonging to the GSP regional partnerships or other voluntarily acting data centres) do have a similar focus like the global data center; however they are specifically adapted to their regional conditions and requirements. In a global system, such nodes represent continents or groups of countries. The requirements to such regional nodes include:

→ To collect, maintain, develop soil information in a continental context:

- Identification of relevant data sets and partners;
- Analysis of metadata regarding analytical methods and soil classification applied;
- Analysis of relevant research and policy-support activities related to soil.
- Response to requests and projects by other pillars

→ To provide coordination to the regional soil science community and to the regional user community. Thus. They act as 'hubs' for the global soil information system.

→ Additionally, communication, data exchange with the global soil data center is needed.

5 Tools for data exchange – IUSS WG SIS

The International Union of Soil Science (IUSS) has observed that the process of soil data exchange is currently hampered. Therefore it initiated a working group with the mission of development, promotion and maintaining internationally recognized and adopted standards for the exchange and collation of consistent harmonized soils data and information worldwide to increase accessibility and use of soil data and information for cross-sectoral issues.

The working group wants to mobilize data sets from researchers and projects all over the globe, thus to develop a network of data providers. The web site is provided by ISIRC.

The differently constructed local data bases, managed with different software, and different export formats, need to be harmonized, exported into interoperable data sets using exchange formats/schema mapping (SoilML, SoterML, ISO25258). Guidance is needed for data providers who wish to use web technologies for data exchange. For example, a prototype open source transformation tool is available in the GS Soil project to help transporting soil data from local data bases to XML-based formats which can be used as web feature services.

→ In Support of GSP Pillar 4, the IUSS WG SIS will also develop reference material for data exchange (cookbook for data exchange)

→ Members of the WG SIS will provide distributed web processing services (interactive platforms for method applications such as PTF), but also profile data upload and download masks

→ The WG SIS is closely cooperating with the IUSS soil science community, particularly with ISRIC World Soil Information and ISO TC 190 Soil Quality.

→ Members of the WG SIS will provide data management tools such as a free soil database for users which lack infrastructure for soil data management. For example, SoDa is a free and open-source software. It is ACCESS-based, and can be easily used.