

Training needs for the next generation of soil surveyors

G R Hennemann¹, D G Rossiter²

International Institute for Geo-Information Science and Earth Observation (ITC)
Enschede, the Netherlands

1. Introduction

During the past two decades, soil survey as many other applied scientific disciplines has been dealing with a rapidly changing society and consequent shifts in public and private information needs for planning and management. Concurrently, soil survey has been faced with the advent of a whole range of new technologies, many of them highly relevant to the planning and execution of soils resource inventories (SRI).

Concerted efforts have been made to meet these challenges, in order to maintain and further strengthen SRI quality, timeliness and resource efficiency. However, soil survey programmes and SRI training in many countries have come under increasing financial and institutional pressure. This paper explores key questions pertaining to

- (a) The general nature of changing SRI demand vis-à-vis the combination of new relevant technological advances and limited SRI resources and
- (b) Their implications for SRI educational and training in the new century.

2. External and internal threats to SRI

The past decades have seen a steady decline in soil survey activities in both developed and developing countries. Many *external* factors have been responsible for this decline.

The economic recession in the 1980 and 1990s was a critical setback; another aggravating factor in this respect has been the general difficulty to quantify and evaluate the immediate and long-term benefits of SRIs for the region concerned or for the country as a whole. This puts SRI programmes at a disadvantage in the priority setting at the national planning level (Zinck, 1994a). A third negative factor is the economic liberalization policies widely adopted during the 1980s and 90s resulting in increased market control over land. This has led to a further reduction of the government-led land use planning and supporting SRI activities. Finally, in many developed countries soil mapping at the scales required has been completed or nearly so, resulting in priorities and funds being shifted away from SRI. This has led in some countries to drastic cuts in both SRI manpower resources and associated training and educational infrastructure.

In addition to external threats, soil survey is weakened by *internal* deficiencies relating to the surveyor-user interface. These may range from poor accuracy and substandard technical and visual presentation of survey results to prohibitive levels of survey staff requirements and equipments and related survey costs.

A particular problem is the increasing timeliness requirement: requests often come at short notice. In most cases the soil information required cannot be provided instantly, so that

¹ E-mail: Hennemann@itc.nl

² E-mail: rossiter@itc.nl ; WWW: <http://www.itc.nl/personal/rossiter/>

major, not well-founded land management decisions are taken, often in the complete absence of adequate and up to date soil information.

There is also increasing demand for specialised soils information that is not collected in routine or 'general purpose' soil survey, but which is needed for specific problems. A good example is heavy metal contents of soils in urban and peri-urban areas as risk factors for human health (Pouyat and McDonnell, 1991). Another is soil carbon, both organic and as carbonates, and the detailed fractions of each, for use in climate studies (Batjes, 2001). Traditional survey training does not provide the skills for these sorts of surveys.

A specific new breed of soil survey constraints is related to the rapid development of the GIS technology and soil-crop, land degradation, ecological modelling. Many of these models are rather 'data hungry' techniques requiring more and better-quality soil data. Using pedotransfer functions often can fill existing data gaps but these too require complete sets of high quality primary soil data. Yet, prediction models are often run without adequate data sets, thus generating misleading results and subsequently, poor land use and soil management decisions (Ibañez *et al.*, 1994).

3. New challenges and threats in the 21st century

3.1 The rising tide of land degradation and its impact on SRI demand

A major development affecting the need for SRI is the dramatic rise of human-induced land degradation in both developing and developed countries during the past decades. Main causes of land degradation are deforestation, overgrazing and over-utilization land. It is estimated that globally nearly 20 million km² has been affected by some kind of land degradation. Out of this more than 50% consists of water erosion, almost 30 % of wind erosion and the remainder being physical or chemical land degradation (Oldeman, 1994). Production losses and economic costs incurred as a result of land degradation are quite alarming: in South Asia, for instance, annual productivity loss is estimated at 36 million tons of cereal equivalent valued at US\$5,400 million by water, and US\$1,800 million due to wind erosion (Eswaran *et al.*, 2001). The total annual cost of erosion from agriculture in the USA is about US\$44 billion per year, i.e. about US\$247 per ha of cropland and pasture. On a global scale the annual loss of 75 billion tons of soil costs the world about US\$400 billion per year, or approximately US\$70 per person per year (Lal, 1998).

As a result, land degradation has rapidly become a major threat to the livelihood of millions of people making food security a key issue in rural development. The goal of food security, however, can only be achieved with the full cooperation of all parties involved, i.e. governments, NGOs, the private sector, and the farmers (Bridges and Oldeman, 2001). It also requires a thorough analysis of the specific conditions under which land degradation has been taken place and to establish current and future degradation trends in the particular area. This calls for specific soil information and special-purpose SRIs.

Land degradation analysis requires regular monitoring of the environment in order to detect cover changes. This means an increasing importance of multi-temporal and spatio-temporal analysis. Also, timeliness of surface soil data is often crucial as degradation studies may deal with recently developed surface features. Spatial resolution is another critical issue in degradation studies as individual features are to be recognized for a full understanding and analysis of the predominant degradation processes (Hennemann and Nagelhout, 2004).

3.2 Increasing land scarcity & multifunctional use of land and their impact on demand for SRIs

The amount of productive land in the world is limited and most of it is already in use. Due to land degradation, in combination with ever increasing rural populations, and rapidly expanding urban areas, competition among different uses of land is likely to increase as well as land scarcity (Dumanski, 1994; Schargel, 1994). These developments too have a bearing on the kind of soil information required. Soil survey of urban and industrial areas is increasingly requested by municipalities, health agencies, and planning authorities; the techniques of rural survey must be radically adapted for such areas (Bartsch *et al.*, 1997; Effland and Pouyat, 1997; Short *et al.*, 1986). The importance of these soils has been recognized by the establishment of the Soils of Urban, Industrial, Traffic and Mining Areas working group (SUITMA) of the International Union of Soil Science.

This implies that SRIs should be able to provide relevant soil information for non-agricultural uses and multi-functional use of land. Secondly, there is a need for a more customer-oriented attitude and greater user friendliness of the SRI end products. The customers may require information about data uncertainty and probability, especially when large land investments are to be made. Also, there is the changing institutional position of SRI as soil survey is often increasingly being incorporated in interdisciplinary contexts (Dumanski, 1994; Ibañez *et al.*, 1994; Schargel, 1994).

3.3 The challenge of environmental studies

Finally, SRI has to meet the challenge of environmental studies in which problems ranging from soil pollution at the detailed scale to biodiversity loss and global change at the regional of global scale predominate. All these new environmental challenges require a wider conceptual basis for SRI as well as the application of relevant new tools including the development of integrated, multi-functional GIS-based soil data sets (Dumanski, 1994).

4. The rise of the new RS/GIS technology

4.1 New developments with impact on SRI

Concurrent with above changing trends in SRI requirements and demand, some new important technological developments took place during the same period. One of them was the spectacular rise of the RS/GIS technology. ITC was founded in 1951 and by the mid-1950's was already giving courses on soil survey with a major emphasis on the use of aerial photographs. Then, satellite remote sensing for earth observation started in the early 1970s with the launching of the Earth Resources Technology Satellite (ERTS). With a general ground resolution of 80 m and a multi-spectral capability restricted by its broad channels ERTS was of limited value in regular soil survey work. This would change, however, in the 1980s with the launching of Landsat TM, with 30 m ground resolution and SPOT, with 20m and 10 m ground resolution, in the multi-spectral and panchromatic bands, respectively. Also, spectral resolution improved substantially during this period with narrower, much more 'discerning' bands and a wider overall spectral view. Consequently, satellite imagery gradually became a valuable tool in small-scale soil and land resource inventories.

Air photos did not thereby diminish in importance, but in fact became easier to integrate into GIS with the advent of low-cost, high-quality scanners and GIS (such as ITC's almost-free ILWIS) to orthorectify and mosaic them (Rossiter and Hengl, 2001). The days of the slotted templates and semi-controlled mosaics are gone forever, but the soil survey organisation is now expected to work digitally even with air photos.

Further important advances were made during the 1990s with the arrival of Landsat 7 and TERRA-ASTER with again higher spatial and spectral resolutions and wider spectral views. Landsat 7 achieved 15 m resolution in the panchromatic bands and 60m in the thermal band ; for TERRA-ASTER these values were 15 m in the visible and near infrared domain (VNIR) and 90 m in the thermal infrared domain (TIR). Many other satellites were launched during this period including IKONOS which for the first time produced a spatial resolution of less than 1m. There were many other important developments such as the introduction of off-nadir viewing to enable stereovision on satellite images and semi-automatic generation of digital elevation models (DEM). The 1990s thus saw a continuous improvement of general satellite image quality in terms of spectral, spatial and temporal resolution. Mulders (2001) summarizes the major RS advances that were made during the period with special reference to mountainous land surveying. These allowed for further advances in a number of areas of direct relevance to SRI and land degradation studies, e.g. (a) Multi-factor approaches to spatial prediction of shallow mass movements supported by DEM and GIS, (b) Application of multiple end-member spectral mixture analysis (MESMA) to identify land cover types, (c) Enhanced spatio-temporal analysis and assessment of land degradation-affected areas.

An important concurrent development has been the ever-increasing availability of RS-data from Internet; many of these new data sources are free or low-cost, e.g TERRA-MODIS and TERRA-ASTER imagery. Also, thematic data on topography, land cover and geology have become widely available from different sources. Soils data is also coming on-line, although not without problems (Rossiter, 2004).

A new survey tool that emerged during this period is GPS. Integrated with a mobile map it allows for improved geo-location of observation points and improved accuracy of boundary mapping. GPS further allows the use of small format aerial photography (SFAP) for GIS applications in a variety of natural resource survey fields including soil degradation mapping, forestry, and wildlife and rangeland studies (Hennemann and Nagelhout, 2004; Warner *et al.*, 1996).

Other new developments include the rise of geostatistics which allowed for an entirely different way to survey: by geostatistical interpolation of soil properties or classes from point observations. This technique already has proven its value in e.g. detailed soil pollution and salinity surveys. Geostatistics is further in combination with RS an important element of the newly emerging pedometric approach to soil survey (McBratney *et al.*, 2000).

Finally, the development and application of sophisticated crop growth models as well as physically-based erosion models and other land degradation hazard models should be mentioned here. The old empirical models increasingly showed deficiencies when applied outside their original testing areas. New process-based models were consequently developed giving generally better results but also showing some distinct disadvantages: they are much more data-demanding in terms of range of parameters and data quality; they are often difficult to operate under field conditions (Lal, 1994)

4.2 Limitations of the new technologies

a) *Technical limitations of RS in SRI*

Further major advances in remote sensing technology in terms of improved spatial, temporal and spectral resolution are to be expected in the coming decades (Mulders, 1999). However, dealing with the current capabilities of RS a number of distinct limitations in relation to SRI have become apparent. Soils unlike vegetation are a largely hidden natural resource only appearing at the surface in areas with low vegetation cover such as dry grasslands and agricultural fields. As a result, mapping of soils covering a particular area, directly on the basis of satellite imagery has proved to be possible only in special cases (Hengl, 2003).

Skidmore *et al.* (1997) examining Landsat TM and Compact Airborne Spectrographic Imager (CASI) data found statistically significant correlations between certain soil parameters and eucalypt forest vegetation in SE Australia. The evidence seemed to suggest that the correlation was mainly determined by the influence of soil on the vegetation, although other factors were involved such as illumination factors caused by the terrain, and direct reflectance of soil. This and other studies show that with complementary statistical correlation techniques indirect mapping of specific *soil parameters* is well possible. Ratio indices such as the Normalized Difference Vegetation Index (NDVI) may be very useful in discriminating differences related to soil surface condition but cannot be give more than support to regular conventional interpretation techniques in current SRI.

Soil studies dealing with erosion *mapping* are often faced with rapidly changing soil surface conditions requiring timely remotely sensed data with high spatial resolution. Hennemann and Nagelhout (2004) analysing recently developed wind erosion patterns in the Central Rift Valley in Kenya found regular satellite-based remote sensing techniques based on Landsat TM and ASTER data largely ineffective for wind erosion detection and assessment. Although a fair overview of the areas currently affected by wind erosion could be obtained and also the gradual expansion of these affected areas over the past 10 years could be monitored and assessed, no distinction could be made between the individual wind-erosion features. As a result, adequate analysis of the complex relationship between the different erosion patterns, their development stage and the underlying causal factors was not possible. In view of this and lacking a recent conventional aerial photographic cover of the area, a small format aerial photography (SFAP) cover was generated within a short time and successfully used for a detailed wind erosion analysis.

The limitations of satellite-based remote sensing techniques not only lie in their comparatively low spatial resolution but also in their limited spectral resolution in the visible light range: spectral differences between and within wind erosion features in the area typically occurred within the visible light spectral range. Such soil colour differences are readily distinguished with SFAP colour photography but much less so with satellite-based remote sensing techniques.

b) *Operational and institutional limitations of RS*

The new RS technology not only has distinct technical limitations, also it is often poorly available in regular working situations. This applies particularly to the more advanced high spatial and spectral resolution systems such as IKONOS and HYMAP which are prohibitively expensive for routine work, but also mainstream satellite RS data e.g. from ASTER, which although low-cost or even free may just not be available for the area under study or may show inadequate quality as a result of cloudiness or lighting conditions.

Mulders (1999) mentions two major constraints to the successful application of RS technology currently in geo-resource surveys: the *limited financial means* in developing countries for investments in computer, printers and digital storage capacity. This limits both the RS and GIS capabilities as required for e.g. coupling DEM data with soil data and other ground truth data. However, this limitation is becoming almost non-existent as technology advances. For a few k\$ even a local soil survey office can have immense computing power, sufficient storage including the capability to read and write optical disks (CD-ROM), and free or very low cost statistical, GIS, and RS software. ITC's own ILWIS is a good example, but there is also the free open-source GRASS and the commercial but low-cost IDRISI as excellent alternatives to expensive commercial programs. So finance and technology are *not* serious limitations for most projects.

Much more serious is the second constraint, *communication* : there is still a general lack of exchange between experts and end-users through workshops, demonstrations and refresher courses. Also, the communication between RS/GIS experts and policymakers needs improvement: the latter group need to be informed and where necessary convinced of the encouraging capabilities of the new technologies in geo-resource inventories and geo-hazards analysis allowing for spatial integration of these aspects into agricultural and rural development planning.

And of course the most serious constraint is *lack of knowledge* on how to use all this fabulous technology and these rich datasets! This is where training is more needed than ever.

c) Limitations of prediction models

The new soil erosion and crop growth prediction models as mentioned above show clear advantages but unfortunately also some conspicuous disadvantages: they are much more data-demanding in terms of range of parameters and data quality than the conventional empirical models; they are also often difficult to operate under field conditions. Spatially-explicit (distributed) models are expected to perform better, but Jetten *et al.* (2003) review the serious difficulties with the practical application of these to date.

Further, Stroosnijder (2003) warns against the commonly held view that the new erosion prediction technology makes accurate erosion measurements less important or even unnecessary. He summarizes the main constraints of the new water erosion models: (a) there is often insufficient empirical data of adequate quality to feed the new models, and (b) there is a lack of funds to improve that situation by development of better soil erosion measuring technologies, equipment and skilled personnel. Partly, as a result of this, the new 'data-hungry' erosion prediction models use much of their input from estimates and values derived from empirical pedotransfer functions making them hybrid models rather than truly process-based, deterministic models.

The major concluding point here could be that students must appreciate both limitations and possibilities of the new exciting technology. Perhaps the real challenge posed by the new tools not so much lies in the use of it *per se* but much more in finding out under what conditions and in what way, the new tools in various combinations can optimally be employed for effectively achieving high-quality SRI products at reduced costs.

4.3 Using synergy between new and existing tools in SRI

The overall picture emerging from the above is that although the new SRI relevant tools in many situations already have given excellent results and are holding much promise for the

future, the current message that synergy-based combinations of existing and new technologies is giving the best results both in terms of technical quality, methodological effectiveness and input efficiency.

Shrestha *et al.* (2004) analysing land degradation and mass movements in the Nepalese Himalaya note that a judiciously planned sequence of conventional techniques (photo interpretation techniques and use of decision trees) and new tools (use of RS techniques and erosion prediction technology) is giving optimum results. Others, similarly, indicate the importance of finding and applying complementary combinations of existing and new tools in soil and natural resources mapping and land degradation studies (Hengl, 2003; Zinck, 1994b). At ITC we strive to do exactly this.

5. Taking up the challenge : developing SRI-related training courses in the 21st century

5.1 Facing new threats and constraints

a) General

What are the direct and indirect implications of above societal and technical developments for soil survey education and how should these be dealt when designing SRI training courses? To adequately answer these questions, we should have a quick look at the range of technical, institutional and resource-related threats and constraints affecting current SRI-related educational development. These are briefly discussed below.

b) Dwindling societal support and financial resources for international development education

Since the early 1990s international training institutes such as ITC are faced with a steadily waning support both from the public and from the government with respect to development cooperation. This trend has already exerted a negative effect on fellowship numbers for the institute, which have stabilized and even decreased somewhat in recent years. Further, this year, a free market tender-based system will be introduced for fellowship distribution among the various educational institutions in the Netherlands. This is likely to have a general positive effect on competitiveness and educational quality but it may also lead to a further reduction of fellowships and to course fragmentation including those on SRI. Short tailor-made courses are likely to emerge which can serve the immediate needs of the customer but will lack the provision of coherent, in-depth training in the various SRI components as may be required by participants. This development and other developments mentioned earlier on may also lead to a lower visibility of SRI when incorporated in educational courses labelled e.g. 'natural resource inventories, 'management of biodiversity' and 'geo-hazard analysis'.

c) Adapting to differentiating customer demand and competitive educational markets

Ongoing differentiation of client groups with new, diverging needs and demands are posing another challenge to SRI course designers: How to accommodate the needs and wishes of these new customers? We and others can no longer offer a course simply titled "Soil Survey" and expect to be understood by the clients, let alone attract 40 students per year! At the same time, there is a growing competition between educational organisations and groups. This has increased the need for new strategic alliances among SRI educational institutions. ITC has responded to these challenges with a new strategy to decentralize its educational programme.

This will involve engaging into partnership arrangements with qualified professional organizations that will take care of part of ITC's educational programme and courses. Another strategic issue is the establishment and formalization of high-quality academic standards of courses leading to so-called course accreditation. In recent years, accreditation has become an educational necessity for acquiring and maintaining international recognition and reputation.

d) Limited time resources

Training in professionally operating and applying the new RS/GIS and other relevant technologies obviously requires a lot of extra course time. And so does training on many of the conventional SRI tools (e.g. API and field survey techniques) which continue to be indispensable for professional SRI, as we have seen above. Sound conceptual knowledge of the soil-landscape model is still a prerequisite in SRI professional work and should therefore be maintained as an intricate part of any SRI training. Then, there are the applications, without which soil survey is useless: models, land degradation processes, soil survey interpretations, and land suitability evaluation. The combined effect of all this is that modern SRI training has become even more time-demanding than it used to be.

Concurrently, general course time availability has come under increasing pressure from a number of largely organisational trends and developments. One is the decreasing individual availability of course participants in general: the professional cannot any longer easily step out of his/her organisation for a consecutive period of 1 to 1½ year as used to be the case.

Another negative factor is the general opinion in some management circles which considers the new technology as the solution to all time-resource problems: 'what took 6 months can now be done in 6 weeks, and a 6 week-job can now be completed in just 6 days. Unfortunately, this distorted principle is also held valid for SRI training; as a result, additional pressure is placed on educational managers to further reduce time spent on relatively cost-intensive yet indispensable course elements such as SRI field training.

e) How to attract promising young professionals to SRI?

The intake of young SRI professionals has seen a declining trend since the mid-1990s onward. How can we reverse this negative trend, how can we attract intelligent and motivated young professionals to SRI? This is one of the major challenges for SRI training in the 21st century.

There are the common structural constraints such as non-competitive salary levels and the relatively low status of SRI work in general: soil survey work is traditionally seen as tedious and dirty ('soiling one's hands') involving long days in the field. It may not be possible to take on the first constraint; however, the image problem of SRI can well be addressed. The currently poor image can be corrected by showing the role of the new technology as well as by emphasizing the wider environmental context of modern SRI turning it into an exciting and challenging professional undertaking. We can also emphasize the broad professional role of the modern surveyor, active not only in the survey itself, but in the needs assessment, planning, execution, interpretation, and on-going support of clients.

Improving our public relations message is therefore essential; this can be achieved by enhancing the attractiveness of the public relations message. Even more important, however, is to actually take this message out to the schools, colleges and other educational institutions

and meet there with future SRI professionals. There are web-based initiatives in soil science education (NASA Goddard Space Flight Center, 2003) which may eventually bear fruit.

Actively informing young students and promoting a particular professional field has proven to be generally quite effective. In the Netherlands some universities faced with critically low science-student numbers, started a public relations campaign to attract more science students. They found that it was only after taking the public relations campaign to the schools and contacting school students directly that science student numbers started to increase at their universities. The concluding question here is:

How to handle all this in our efforts to build modern, coherent and effective professional & academic SRI training ?

5.2 Types of SRI training

Five broad types of SRI training can be distinguished as follows:

a) *Pre-graduate training*: This is best handled by a standard university curriculum, increasingly-strong on basic science and mathematics, emphasizing soil science as such. There is not much time to train in specific survey-related subjects but a summer field program to study landscapes and soils is highly desirable. Yet, no one tries to turn out trained soil surveyors at this level. Historically, soil survey organisations have taken these graduates and done their own training.

b) *Professional graduate training* ('soil survey institutes' or field courses). This is the core of field training which can be expanded to include modern techniques such as digital field data capture, remote sensing, and GIS database integration. However, the traditional instructors may not be themselves trained in these new methods. This is where SRI is suffering the most: the traditional three- to six-month fieldwork training is almost non-existent because of budget problems.

c) *In-service training*: this kind of training is meant for working professionals who can not leave their posts, to learn specific techniques. This is ideal for introducing one specific new technique, e.g satellite remote sensing or geostatistics.

d) *Graduate academic training*: this is ITC's and similar institutions' main niche. The client group is working professionals who need a solid year of new training at an academic level. This involves field work and a group project; again, budget problems cause these to be much shorter than optimal.

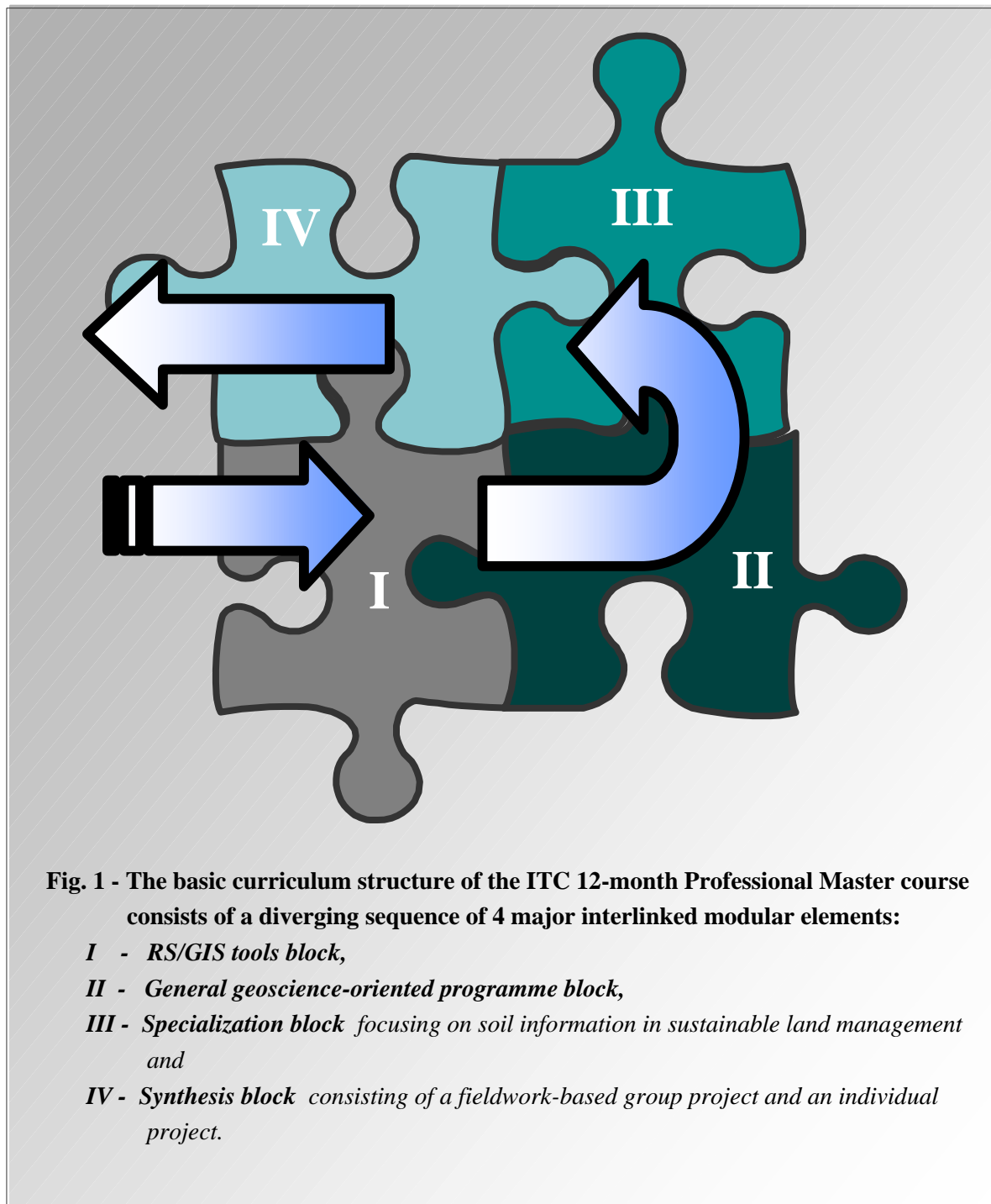
e) *Refresher training*: this type of training is intended for working professionals who can not leave their posts, and have already a second degree.

5.3 Underlying educational considerations & principles

a) General elements of modern SRI training

In modern professional SRI training generally four major course elements can be distinguished as follows: I - general RS /GIS tools block, II - general earth science-oriented block, III - specialized soil survey block and IV - synthesis block in which the student is to carry out a fieldwork-based project in which all previously acquired knowledge and skills are utilized (Fig.1). Some students continue with an MSc thesis on a soil survey-related topic; but this is not aimed at the professional who will continue to work as an active surveyor. The conceptual knowledge of the subject matter is presented in course elements II and III. The

overall structure is sequential in which each successive course element is building on and utilizing the accumulated knowledge and skills as acquired during all preceding course elements.



b) Important additional considerations and questions

With respect to the length and more detailed composition of each individual course element, this largely depends on the perspective and educational objectives of the course at hand. In situations with a rich SRI data environment much attention could be given to the training on the vast range of relevant GIS tools whereas in a poor SRI data environment more time is to be spent on RS-based data acquisition techniques. Other considerations on the ‘supply side’ are (a) establishing the minimum time requirement per course element and (b) focussing on SRI tools that are both technically feasible *and* accessible to SRI professionals operating under working conditions and (c) maintaining a clear problem-orientation throughout the training course so that the participant can learn how to apply the new SRI tools under real-world conditions.

Key considerations on the ‘demand side’ are (a) the average academic level and professional background of the course participants and (b) developing sufficient course flexibility to accommodate specific interests and wishes of the individual course participant.

An important general question is : Should the new SRI tools be taught as a separate block or interlaced with SRI applications? Educational theory and our experience strongly suggests the latter; most people but especially working professionals learn theory only from hands-on experience with problems in their own area of interest. The problem gives focus and motivation, and makes the theory ‘come alive’ for the learner. Unfortunately, some educators become enamoured of the technology itself, and forget this hard-won experience.

6. Conclusions

The road ahead is very difficult. The very richness of the new techniques and the diversity of clients and demands that make soil survey today so exciting and challenging require increasingly-sophisticated and well-trained soil surveyors (or should we say “soil-landscape-process specialists”?). This places a heavy educational demand both on the scientists themselves and on the trainers. We must do more with less time... how can we do this? By paying more attention to recruiting surveyors with a fundamentally sound scientific education and enthusiasm for the subject, and by providing them a learning environment for lifelong improvement in their profession. These are exciting times and we should not shirk from the challenge.

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