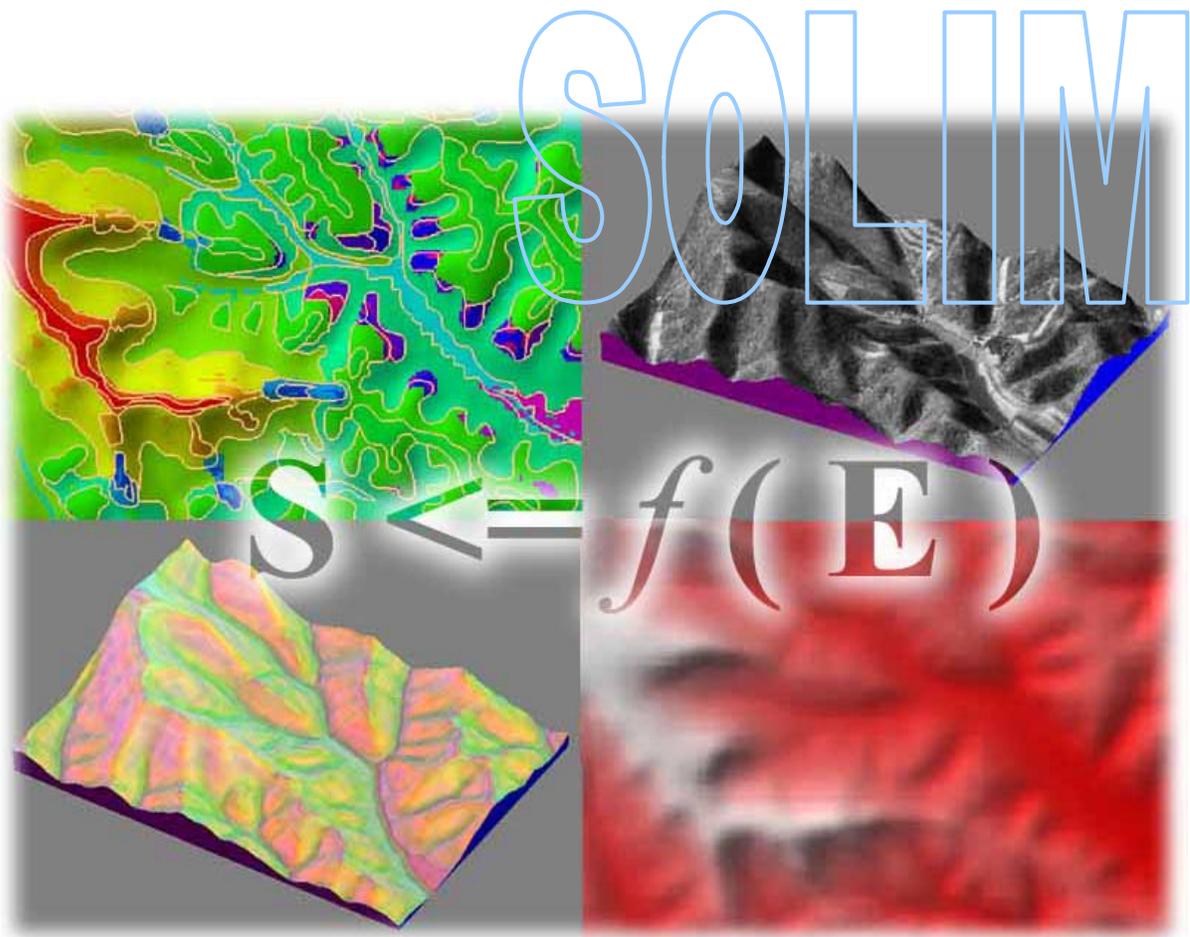


# SoLIM: A new technology for soil survey

---

Soil Mapping Using GIS, Expert Knowledge & Fuzzy Logic



**September 25, 2002**

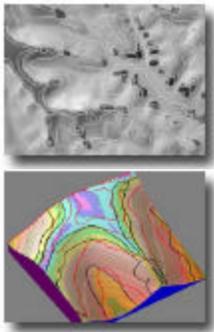
**Department of Geography, University of Wisconsin-Madison**

**<http://solim.geography.wisc.edu>**

# Table of Contents

---

|  |    |
|--|----|
| The Problems SoLIM Addresses .....         | 2  |
| Overview of the SoLIM Approach.....        | 3  |
| Products 1: Map Products.....              | 4  |
| Products 2: Knowledge.....                 | 6  |
| Using SoLIM in Soil Survey 1: Process..... | 7  |
| Using SoLIM in Soil Survey 2:              |    |
| Requirements and Implications.....         | 9  |
| Current and Future Efforts.....            | 10 |
| Acknowledgement.....                       | 10 |
| Appendix: The SoLIM Group.....             | 11 |



# The Problems SoLIM Addresses

---

## Overview of issues on soil survey

Current soil survey is based on the classic concept of soil-landscape relationships. To conduct a soil survey for a given area, soil scientists first build a soil-landscape relationship model through analyzing the landscape and through extensive fieldwork. Traditionally, the spatial distribution of soil landscape units were identified through photo interpretation and manually delineated to form soil polygons.

## Challenges in conducting soil survey

There are three major challenges in conducting soil survey. The first is the polygon-based model used in soil maps on which only soil bodies of certain size are shown and small soil bodies are omitted. Consequently, the level of details is limited by the scale of the map, not by what the soil scientists know. Also, the soils in a given soil polygon are often treated as the same, and changes of soil properties only occur at the boundaries of polygons.

## Polygon-based model

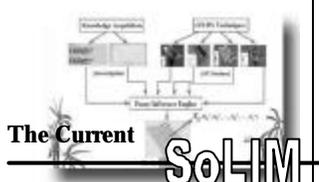
## Manual mapping process

The second challenge is the manual mapping process, which is not only tedious and time consuming, but also error prone and inconsistent. In addition, it is very difficult for soil mappers to identify soil-landscape units using more than three different environmental data layers. As a result, the delineation of soil-landscape units may not be as exhaustive as soil-mappers hope. Subtle and gradual changes in environmental conditions are often difficult to be discerned visually, and so it is easy to misplace the boundaries of soil polygons in the manual delineation process.

## Documentation of soil-landscape model

The third challenge is that the soil-landscape model for a given area is often not explicitly documented. Knowledge of the soil-landscape model of a given area is often lost when the soil mapper retires or moves out of the area. The new soil mapper thus has to 'start from scratch'.

Due to the above limitations, soil survey is currently updated at a 100 year cycle. This rate certainly cannot meet the needs of Information Age land resource management and other geographical analysis. A radical change is needed to move soil survey to a more acceptable update rate and to a product that can be continuously updated efficiently and accurately.



# Overview of the SoLIM Approach

**Overcoming the polygon map model**

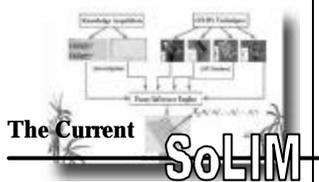
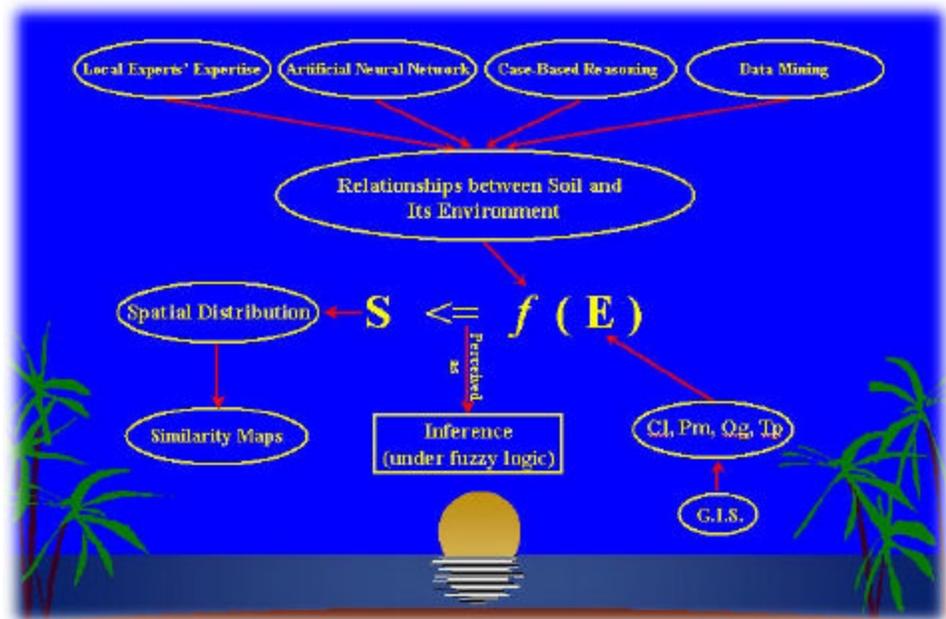
SoLIM overcomes the polygon map model by employing a similarity scheme, which represents spatial variation of soils by small pixels (dependent on the resolution of environmental data, not the map scale) and the soil at a given pixel as a vector of similarity values.

**Overcoming the manual mapping process**

It overcomes the manual mapping process through the use of GIS techniques and an automated fuzzy inference scheme. This inference scheme determines the similarity vector for the soil at each pixel using knowledge of soil-landscape relationships and the environmental conditions derived using GIS techniques for that location.

**Overcoming the knowledge documentation problem**

The knowledge documentation problem is overcome by explicitly extracting knowledge on soil-landscape relationships and storing the extracted knowledge in a knowledgebase. The documented knowledge is separate from the inference process.



# Map products

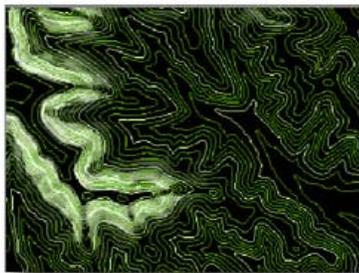
## Products 1

The products from SoLIM are of two major types: the map products (various forms) and the extracted soil-landscape model (various formulations).

Among the map products, there are fuzzy membership maps, raster soil categorical maps and its associated uncertainty maps, soil property maps, and conventional soil polygon maps.

### Fuzzy membership maps

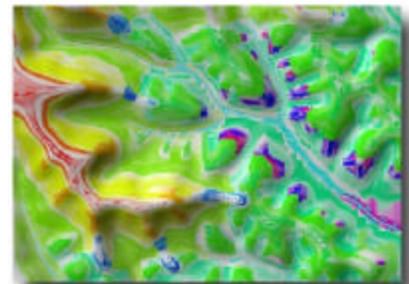
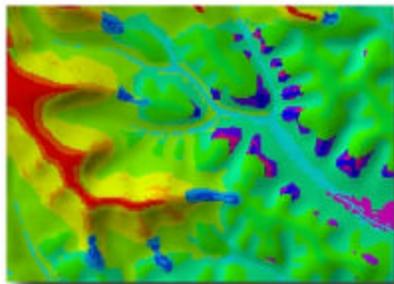
Fuzzy membership maps show the spatial gradation of soils, and preserve the intermediate nature (between types nature) of soils, thus assisting soil interpretation with more useful information than traditional means.



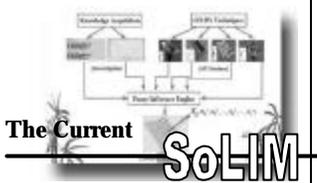
← The fuzzy membership map related to one soil series.

### Raster soil categorical maps

Detailed raster soil maps contain soil bodies as small as a single pixel. Not only is the soil map much more detailed, but also uncertainty in creating such a raster map from the fuzzy membership can be produced to assess the validity of assigning local soils to prescribed soil types.



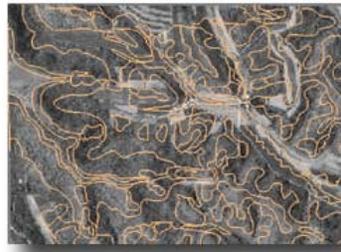
Raster categorical maps and uncertain map



# Map products

## Conventional soil polygon like maps

Conventional soil polygon like maps can also be created from the fuzzy representation. It is inevitable for a soil polygon to include some small soil bodies that are different from what the soil polygon is labeled to be. These inclusions can be reported on a per soil polygon basis, which is a great improvement over the conventional approach to reporting inclusions (often lumped into a mapping unit).

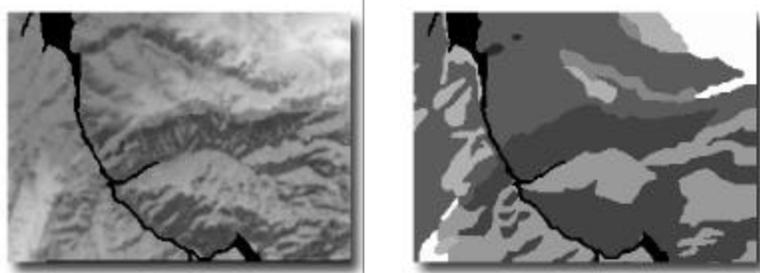


The polygon inclusion table

| PolygonID | 1 <sup>st</sup> | Pent | 2 <sup>nd</sup> | Pent | 3 <sup>rd</sup> | Pent | 4 <sup>th</sup> | Pent | 5 <sup>th</sup> | Pent | Other | Pent |
|-----------|-----------------|------|-----------------|------|-----------------|------|-----------------|------|-----------------|------|-------|------|
| 1         | 7               | 83.3 | 3               | 16.7 | NILL            | 0    | NILL            | 0    | NILL            | 0    | Other | 0    |
| 2         | 6               | 92.1 | 3               | 3.8  | 5               | 3.5  | 7               | 0.5  | 12              | 0.1  | Other | 0    |
| 3         | 7               | 88.8 | 6               | 4.8  | 30              | 4.2  | 11              | 1.3  | 23              | 0.6  | Other | 0.3  |
| 4         | 6               | 86.8 | 7               | 11.7 | 5               | 1.5  | NILL            | 0    | NILL            | 0    | Other | 0    |
| 5         | 5               | 63.3 | 6               | 36.7 | NILL            | 0    | NILL            | 0    | NILL            | 0    | Other | 0    |
| 6         | 3               | 35.7 | 5               | 32.1 | 6               | 32.1 | NILL            | 0    | NILL            | 0    | Other | 0    |
| 7         | 3               | 64.3 | 1               | 35.7 | NILL            | 0    | NILL            | 0    | NILL            | 0    | Other | 0    |
| 8         | 6               | 71.3 | 5               | 16.2 | 11              | 8.7  | 3               | 3.8  | NILL            | 0    | Other | 0    |
| 9         | 7               | 88.3 | 23              | 7.2  | 20              | 1.7  | 30              | 1.5  | 6               | 0.7  | Other | 0.6  |

## Property maps

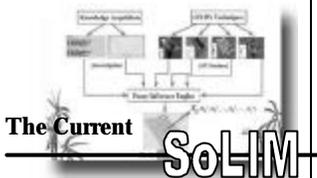
Continuous soil property maps can also be produced using the fuzzy representation. The spatial gradation of soil properties is better captured in these maps than that by conventional soil maps.



A-horizon depth derived from SoLIM (left) and from traditional soil map (right)

## Accuracy

The soil polygons produced from the SoLIM approach are consistent with the soil-landscape model due to the ability of GIS to accurately discern the subtle and gradual variation of environmental conditions (given that the data is accurate). On the other hand, the soil lines created through traditional soil surveys may not follow the landscape variation well due to the difficulty encountered by soil mappers in photo interpretation. The SoLIM approach has achieved over 80% accuracy when compared with field observations while the accuracy of conventional maps rarely exceeds 70%.



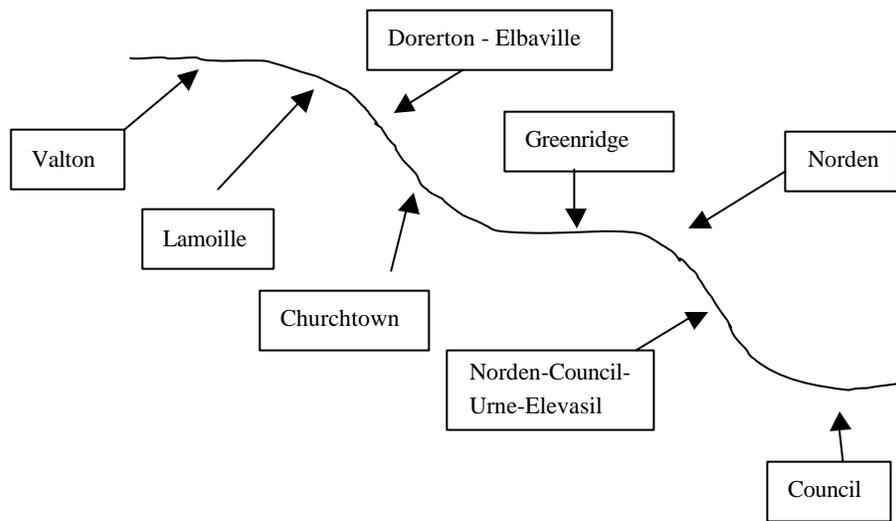
## Products 2

The extracted soil-landscape model can be documented in several different ways:

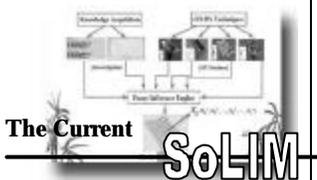
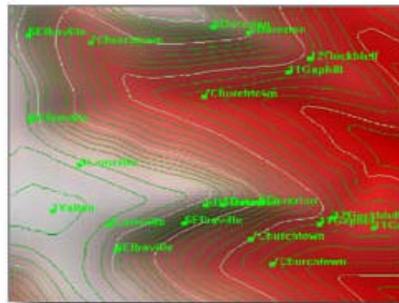
- ✍ Catenary sequences
- ✍ Dichotomous keys
- ✍ Soil-environment descriptions
- ✍ Tacit points (typical locations for each soil types)
- ✍ Fuzzy membership functions

The documented knowledge can be studied and updated by current and future soil scientists, and can also be reused in future soil survey updates.

**An example of catenary sequence**



**An image of tacit points**



# Process

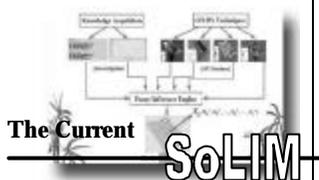
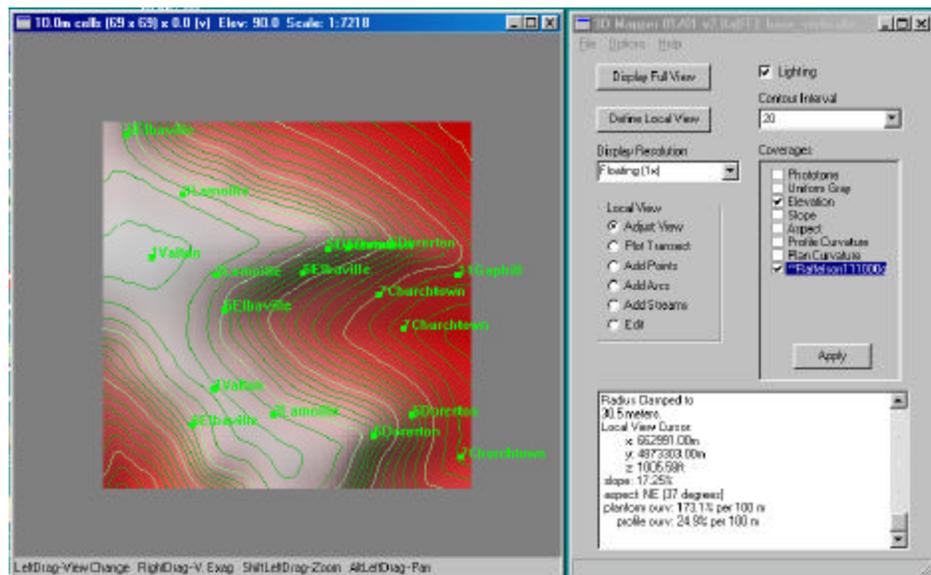
## Extract the soil-landscape model

# Using SoLIM in Soil Survey 1

The process of applying SoLIM in soil survey can be divided into four steps:

1. Extract the soil-landscape model, which is done by answering the following questions and completing the tasks below:

- ☞ What are the different types of soils in the area?
- ☞ What is their catenary sequence?
- ☞ What are the key environmental variables that are important in distinguishing these different soil types?
- ☞ Use the environmental variables to key out these soil types.
- ☞ Describe the environmental conditions under which each soil type typically occurs.
- ☞ Show the geographic locations where each soil type typically occurs.



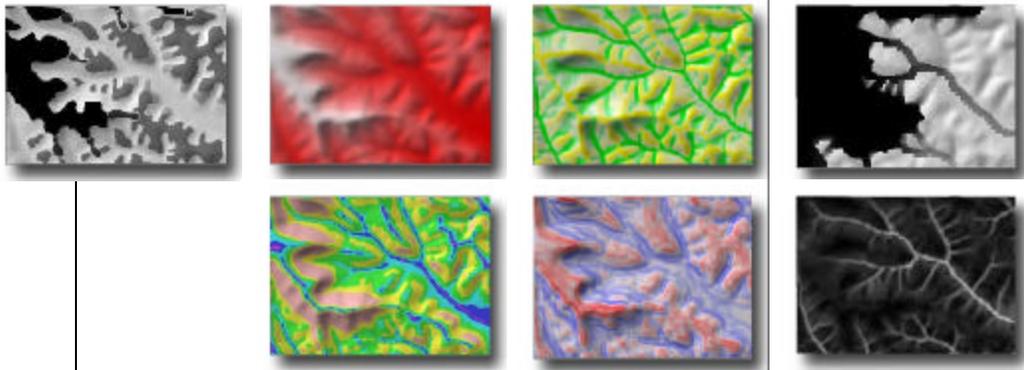
Locating tacit points

# Process

## Construct the GIS database

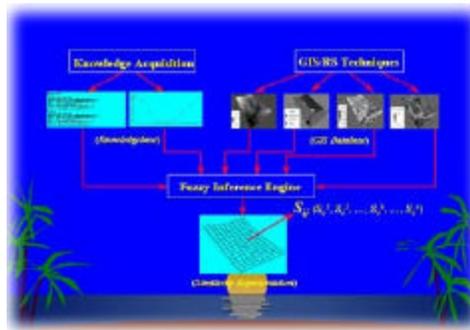
### 2. Construct the GIS database:

Based on what was learnt from the soil scientists, spatial data on the important environmental variables will be derived using GIS techniques.



## Perform the soil inference

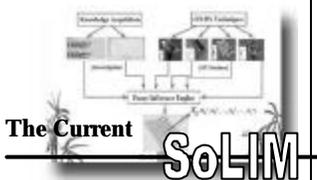
### 3. Perform the soil inference.



## Verification

### 4. Verification by soil scientists:

Soil scientists examine the inferred result to see if what produced by the inference engine matches what is expected. If not, it is necessary to identify problematic areas and the causes. The products can then be improved by updating the soil-landscape model and/or including additional environmental variables.



# Requirements

## Using SoLIM in Soil Survey 2

### Dataware

The SoLIM methodology requires two major inputs: The soil-landscape model and necessary environmental data.

The soil-landscape model

The participating soil scientists should already have a satisfactory soil-landscape model for the area under concern. If not, the soil scientists should build such a model before applying the SoLIM approach. Techniques, to assist soil scientists to quickly develop satisfactory soil-landscape models, are under development.

Environmental Data

The necessary environmental data are derived using GIS/Remote Sensing techniques. Data generally include topography, vegetation, and geology. Orthophotos are useful if available.

### Liveware

To make SoLIM work, a GIS specialist, who understands well the conceptual ideas behind the approach, the implementation and operation of the approach, is needed. The GIS specialist should not only be able to prepare the needed environmental data layers and run the inference engine, but also be able to extract soil-landscape relationships from soil scientists.

# Implications

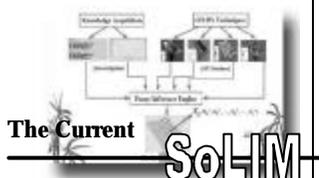
### Role of soil scientists

Clearly, the role of soil scientists in making SoLIM function is paramount since it is their soil-landscape model that the SoLIM approach relies on.

### Training

Although the SoLIM concept proves to be viable, extensive training is needed to make the approach work in soil survey production. The training is necessary because:

1. Experts need to be comfortable with the approach
2. GIS personnel need to be proficient in the SoLIM methodology



## Current and Future Efforts

---

Our future efforts will be to continue the development of the technology and to help the implementation of this technology in soil survey production.

### Development of the technology

With regards to the development of SoLIM, we currently focus our efforts on building and extracting the soil-landscape model and on development of techniques for effectively characterizing soil formative environments. Specially, we have been exploring the use of fuzzy classification techniques to assist soil scientists in initially building soil-landscape models. We are examining the application of data mining techniques to extracting soil-landscape model from non-human sources (such as old soil surveys). We are developing advanced terrain analysis techniques for accurately quantifying the spatial gradation of soil-formative environments, such as fuzzy representation of landforms. In addition we continue to enhance the 3dMapper to facilitate knowledge acquisition and soil inference.

### Implementation of the technology

With regards to the implementation of SoLIM in soil survey, we will develop training programs which help potential SoLIM practitioners to understand the theories and concepts behind SoLIM, and to conduct soil survey using SoLIM. An integrated program interface will also be developed for convenient operation of the system. In addition, we will develop visualization tools to visualize the inner working of the inference engine.

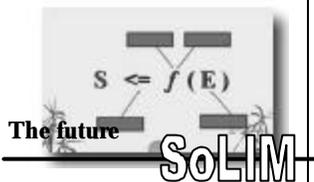
### Using SoLIM products

We will explore ways of using information products from SoLIM and integrate various SoLIM products with information from other national soil databases. We will contribute to the development of soil information delivery systems which will allow easy access to soil information products by general public.

## Acknowledgement

---

SoLIM is the result of a joint research effort by University of Wisconsin-Madison, Natural Resources Conservation Service (NRCS) of U.S. Department of Agriculture.



# Appendix: The SoLIM Group

---

## **A-Xing Zhu**

550 N. Park Street  
Dept. of Geography, UW-Madison  
Madison, WI 53706

Tel: (608) 262-0272  
Fax: (608) 265-3991  
Email: [axing@geography.wisc.edu](mailto:axing@geography.wisc.edu)

## **James E. Burt**

550 N. Park Street  
Dept. of Geography, UW-Madison  
Madison, WI 53706

Tel: (608) 263-4460  
Fax: (608) 265-3991  
Email: [jburt@geography.wisc.edu](mailto:jburt@geography.wisc.edu)

## **Feng Qi**

Tel: (608) 262-1857  
[fqi@students.wisc.edu](mailto:fqi@students.wisc.edu)

## **Trevor Quinn**

Tel: (608) 262-1857  
[trevorquinn@students.wisc.edu](mailto:trevorquinn@students.wisc.edu)

## **Rongxun Wang**

Tel: (608) 262-1857  
[rongxunwang@students.wisc.edu](mailto:rongxunwang@students.wisc.edu)

## **Amanda Moore**

Tel: (608) 262-1857  
[amoore@wisc.edu](mailto:amoore@wisc.edu)

## **Jian Liu**

Tel: (608) 262-5856  
[jianliu@wisc.edu](mailto:jianliu@wisc.edu)

## **SoLIM Homepage:**

<http://solim.geography.wisc.edu>

