REMOTE SENSING AND GEO-INFORMATION SYSTEMS AS TOOLS FOR SUSTAINABLE DEVELOPMENT BY INTEGRATED LAND USE PLANING IN CHINA

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Commission 7, WG VII/3.4

KEY WORDS: sustainable development, remote sensing, spatial database, data fusion, land use planning

ABSTRACT:

Sustainability has been discussed for a long time now, not only in the field of land-use planning. Still achieving a sustainable development isn't easy. The complexity of the nature makes it impossible to pay attention to all the various factors affecting the sustainability. Giving the planning authorities and politicians guidelines in form of useable and understandable information is an important milestone on the way to a sustainable land-use planning. The joint German-Chinese research project SILUP (Sustainable Development by Integrated Land Use Planning) tries to achieve this. This means simultaneously respect the ecological and the socio-economic value of land, judging the different values and finding suitable areas for the development needs. This cannot be achieved by only collecting and delivering as much data as possible. The data has to be classified, generalized and simplified. The information has to presented in an understandable way and it's not useful if too much single pieces of information are delivered. The project aims for a map containing simplified categories. This categorized map shows the land use planners in an easy and understandable way, which areas should be protected and which area could be used for further development. The first phase of the SILUP project could be finished successfully and was highly acknowledged by the German BMBF (Federal Ministry for Education and Research) and the UNESCO.

1. INTRODUCTION

1.1 The Situation in the Jiangniang County

Since 1980 the fast transition process from a centrally planned economy to a socialist market economy has a significant impact on every aspect of the society in the Peoples Republic of China. In this transition the short-termed economical benefits seemed more important than the complicated and long-termed effects of the fast development on society and environment. The very fast growth leaves just a small space for a sustainable development. But the resulting problems become more and more obvious. The fast economical growth is accompanied by the destruction and over-exploitation of the nature. A sustainable development is necessary to transform the fast and overheated growth into a long and steady development suited for the economy, the people and the beautiful nature of China.

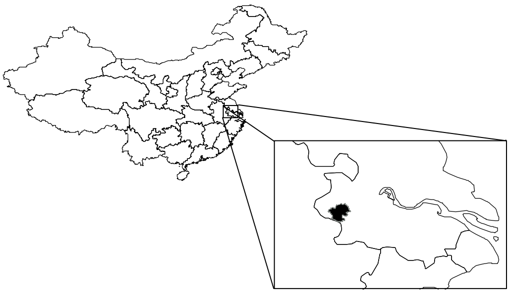


Figure 1. Geographical location of the project area

To develop and test the ideas and methods a small test area was chosen. The chosen project area was in Jiangniang County near Nanjing. Nanjing is located at the Yangtze river, about 300km west of Shanghai. The city has expanded every year at an tremendous speed since the reforms of 1978 until now. Coexisting to this development is a terrible waste of land resources and destructions of ecological systems.

The new Development Zone, new towns, highways and the new airport are occupying a considerable amount of former farmland. Since 1985 the farmland in Jiangniang county has been reduced by 150km². Because this fast development still keeps going on and more and more land is being developed, the need for a sustainable land use planning in Jiangniang county is getting obvious.

1.2 Is sustainable development suited for the needs of the people in China?

For the future development of the county, it's necessary to canalise the growth, to secure important parts of the landscape for flood-protection, to keep a high bio-diversity in the region, to take care of the agriculture and to protect the nature as whole. These important needs are now being more and more recognised by the local planning authorities throughout China. The ecological problems coming from the very fast development are getting obvious to everyone. Therefore the question is not: "Do the people need a sustainable development." The question is: "How can we achieve a more sustainable development."

Achieving an sustainable development is not a trivial problem. The aspect of a sustainable development is the field of interest for many different sciences and the scientists working on sustainability come from a broad range of different scientific backgrounds. Sustainability is a complex matter and cannot be reached by creating one perfect solution. It's also impossible to view the whole complexity of sustainability by looking from just one scientific discipline. The borders of the sciences are too small for the broad range problem of sustainability.

In the SILUP (Sustainable Development by Integrated Land Use Planning) project team, scientist from different disciplines are working closely together. The scientists from Germany and China are researching in the fields of Regional Development, Land Use Planning, Hydrology, Geography, GIS and Remote Sensing. Each project partner brings his special knowledge into the team.

2. TOOLS TO ACHIEVE A SUSTAINABLE LAND USE PLANNUNG

2.1 Helping the planning authorities

Collecting a huge amount of data and giving the planning authorities an easy access to terrabytes of raw data can't be the solution. Politicians and planning authorities have to make decisions and the data has to be presented to these users in a form they can manage and understand. This makes data management a main task in the project and this is still a vital field of research. The decision making authorities should get the chance to really make a decision out of different options. So they should be able to get different possibilities from which they can chose the best one for their region and situation. Data management consists here of more than just putting the data together. Bringing the optimal data to the right user is the challenge.

2.2 Generalisation and Simplification

One crucial step in the right direction is the simplification of the data. To decide what part of the land should be used for building a development site, no one can overlook all the different aspects of socio-economic and ecological impact at one time. Even the most sophisticated model is able to include all the different aspects of the reality. Land Use Planning always includes an idea of the future, because the plan developed now is used in an unknown and uncertain future. Therefore you can't expect a perfect Land Use Plan. The aim is a process of Land Use Planning which tries to achieve a more sustainable development for the future.

The basic idea of integrating all available information is expressed in the use of a matrix aggregation scheme as proposed by Ju (1998). The matrix aggregation tree leads to a so called Final Classification Matrix. With the FCM a systematic approach, for obtaining a objective information basis for land use planning taking simultaneously the natural resources and the socio-economic needs in account, is available.

Every parcel of land, exceeding a minimum size, is classified according to the FCM (Figure 2). The idea behind the FCM-approach is that each parcel should be classified with regard to its "ecological value" and the "socio-economic needs". The land use restrictions are derived out of these two values. According to these classifications a map for the planning authorities is created. The "ecological value" of an parcel is a combination of different aspects like flood-prevention, natural resources, bio-diversity, etc. "Socio-economic needs" is defined from the existing or forecasted pressure to use this parcel of land as, for example, a industrial or settlement area.

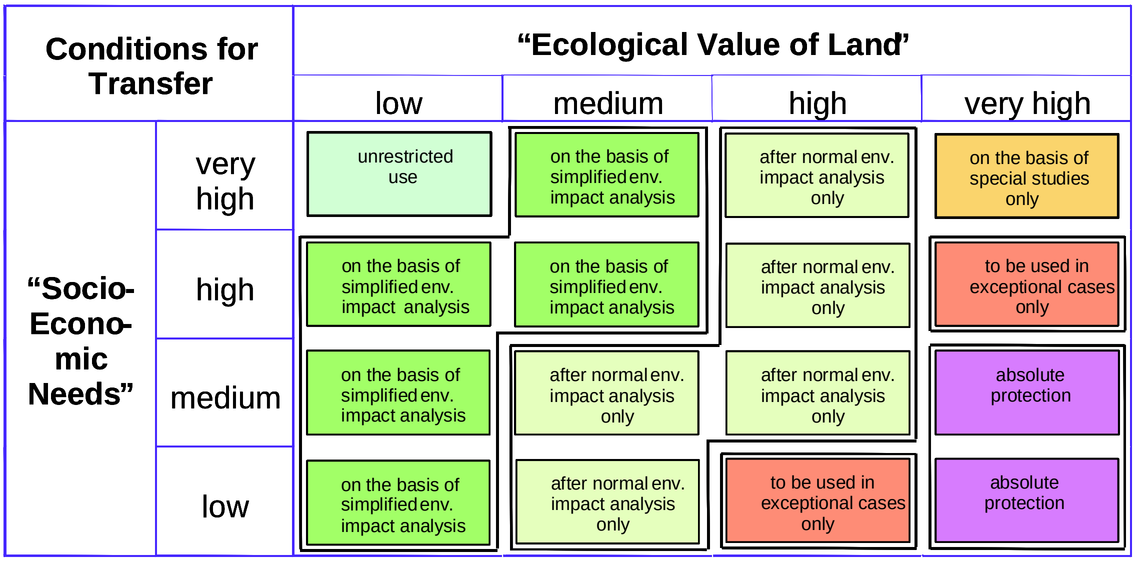
The values for "socio-economic needs" and "ecological value" are also derived from other "feeding" matrices. The "economic value" is derived from a matrix of "Value of Land for Human Needs" and "Value of Land for Biodiversity". These values are again derived from other matrices. To get the FCM a FCM-tree consisting of a range of different matrices has to be created.

Obviously a lot of data is needed to classify an area according to the FCM approach. To get this data remote sensing techniques are useful, especially because the data used to fill these matrices should be

1. up to date
2. from a wide area
3. collected fast and at low cost

The collected data has to be stored and managed using a spatial database system. All spatially related input data had to be corrected, updated and homogenized. The data was brought to a common reference system. The chosen dataset format was Arc/INFO coverage. Raster data are stored as georeferenced images or grids.

GIS and remote sensing play a major role in keeping actual data in the database and deliver the data needed by the different scientists in a way they can easily use it for their purpose.



Conditions for Transfer		"Ecological Value of Land"			
		low	medium	high	very high
"Socio-Economic Needs"	very high	unrestricted use	on the basis of simplified env. impact analysis	after normal env. impact analysis only	on the basis of special studies only
	high	on the basis of simplified env. impact analysis	on the basis of simplified env. impact analysis	after normal env. impact analysis only	to be used in exceptional cases only
	medium	on the basis of simplified env. impact analysis	after normal env. impact analysis only	after normal env. impact analysis only	absolute protection
	low	on the basis of simplified env. impact analysis	after normal env. impact analysis only	to be used in exceptional cases only	absolute protection

Figure 2. Prototype of a Final Classification Matrix (Ju 1998)

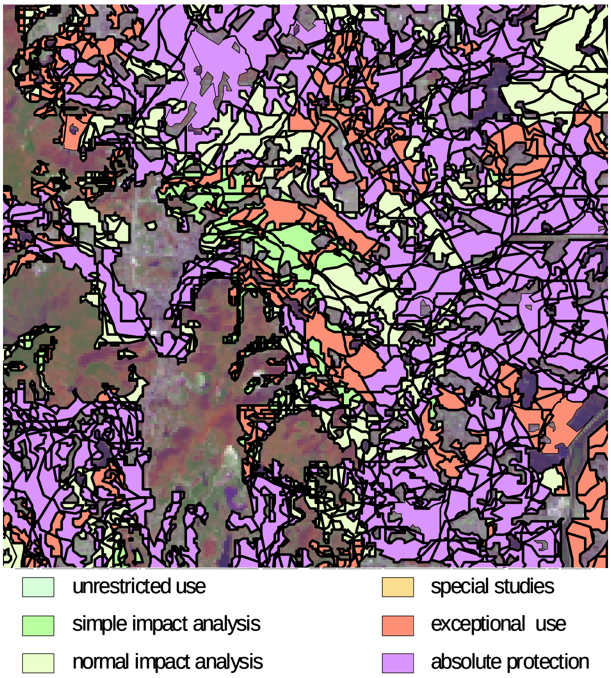


Figure 3. Part of the preliminary FCM-map

3. SILUP – SUSTAINABLE LAND USE PLANNING

3.1 The SILUP project

The SILUP (Sustainable Development by Integrated Land Use Planning) was started 1998. Three institutes from the University of Stuttgart (Institute for Landscape Planning and Ecology, Institute for Photogrammetry and Institute of Hydraulic Engineering) are working together with the Chinese project partners from the Nanjing Institutes of Geography and Limnology and of Soil Sciences of the Chinese Academy of Sciences, from the Department of Urban and Resources Sciences of the Institute of Geography and Ocean Sciences of Nanjing University, from Hohai University and from the Nanjing Hydraulic Bureau.

With all these scientists, from different countries and sciences, working together it’s different to reach concrete agreement on a lot of details and definitions. Although it only were details and slightly different interpretations, the project shows that it is not as easy as it should be to bring scientist from different disciplines together.

To achieve a consistent database, filled with data from different scientists, sciences and countries, the definitions have to be very exact. Only exact definitions can guarantee a consistent and homogenous database. This is very time intensive, but this time is crucial for the success. Taking this time is also useful for each of the involved scientists. They can profit from thinking again about each definition, which leads sometimes to new insights.

3.2 The tasks of the Remote Sensing and GIS project group

In the SILUP Project the main work for the Remote Sensing and GIS teams consists of:

- Creation of a spatial database (SDB)
- Studies on methods of extracting thematic information from Satellite Images (SPOT)
- Research on data fusion using SPOT, SPIN-2 and CBERS-1 data.
- Construction of a Digital Elevation Model (DEM)

3.3 The spatial database

All spatially related information which was used for further processing was organized in the SILUP spatial database. The database was designed in a hierarchically way, as seen in Figure 4. The layout of the data base was discussed and worked out jointly with Chinese and German partners. The data was organised layerwise. This organisation provided a fast and easy access for all the project partners to all relevant spatially related data.

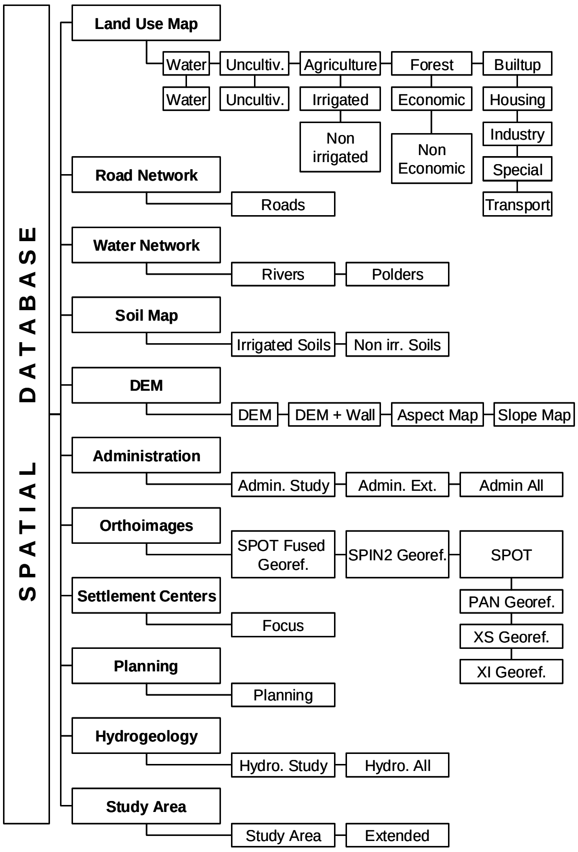


Figure 4. The design of the spatial database

In the spatial data base exclusively such data were included which are consistent to each other, i.e. all layers have the same coordinate reference and map projection. The consistency of the spatial database is fundamental to all further work. Exact definitions and a lot of discipline is required to create, update and keep the database consistent. Different standards of data coding are a big problem here. Uncertain details and definitions can still occur in the data. This has to be solved when integrating the data into the database.

Furthermore, care was taken that the single polygon layers neither do overlap nor do form gaps, in order to provide a unique and dense coverage of the whole study area.

3.4 Used methods of extracting thematic information from Satellite Images

Updating the database with remotely sensed information requires methods of extracting the desired thematic information out of the raw data.

As part of this work different techniques are used for identifying the different land-use-classes. For the identification of water bodies, which are important for the hydrological analysis of the project area, different classification methods have been tested. The most suitable method was an algorithm for a decision-tree (DT) classification. It's based on spectral values and additional information of DEM and slope.

It's possible to differentiate the spectral class of the water bodies from the land-use classes "vegetation", "road and settlement" and "non-irrigated field". This can be done using the spectral response of the classes. But as Figure 5 shows, it's not clearly possible to separate the water bodies from the shadow areas. A reliable classification depends on the separation of the water bodies from the other classes. To achieve this more information is needed, because the spectral response is not enough for the distinction of the classes for sure from the SPOT XS or from the SPOT XI scene. As additional information, used to separate the classes, a DEM was used. Analysing the slope of the possible water bodies was a great help separating the classes, because water bodies are directly related to flat slope, while shadow areas are related to more steep slope

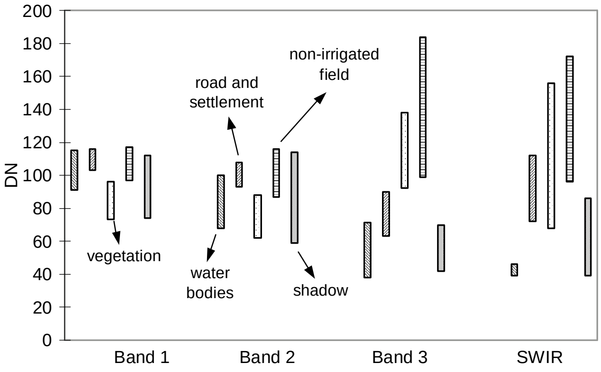


Figure 5. The spectral response range for typical object classes in SPOT2 XS rsp. SPOT4 XI multispectral data (Feng et al 2002).

This decision-tree (DT) algorithm was then compared to more traditional methods like the supervised maximum-likelihood classification (MLC) and the unsupervised ISODATA method (Lillesand, et al., 1987).

The DT algorithm showed a very high accuracy in comparison to the also tested MLC and ISODATA classifications. This is not that surprising, because additional information was used. The use of elevation data together with the sensor data was found to be able to improve land cover discrimination also by using the MLC algorithm (Haala, et al., 1999).

The extraction of the vegetation-classes was performed in two steps. Firstly, vegetation information was extracted, using a threshold method within the multispectral scene. Secondly, non-vegetation pixels were masked out and classification of the combined image from SPOT XS (10.08.1998) and the NDVI was performed on the vegetation pixels only.

For the land use/land cover classification it's important to understand the spectral response characteristics of each land use/ land cover type. The irrigated fields are distributed mainly in valley, the broadleaf, pine and shrub are concentrated in the hills. The prevention tree belts are extensively distributed over the whole county.

Two methods, supervised classification (MLC) and unsupervised classification, were performed in the classification. The classification results showed that rice and some of the woodland cannot be distinguished by their spectral response alone. More spatial parameters including the terrain factors were used to improve the classification results. This method was very effective to finally distinguish between the rice fields and the woodlands.

3.5 Improving the classification with data fusion

To further improve the classification results the high-resolution SPIN-2 data from 1995 with 1,5m resolution was fused with the mid-resolution SPOT XI data, taken 1999.

The fused data didn't fulfil all the expectations. Neither the result of the supervised nor of the unsupervised classification did improve with the fused data. The data fusion therefore did significantly improve the visual interpretability of the data. Digitising linear features and updating thematic maps with the newly fused data was easier then using just the coloured SPOT XI data or just the greyscaled SPIN-2 data. The same result was achieved by using CBERS-1 data and SPIN-2 data. There's more than one reason for these results. SPIN-2 images are analogue images made with the Russian KVR-1000 camera. The used SPIN-2 data from the Nanjing area, though offering a high spatial resolution, also suffer from a low signal-to-noise ratio. The images were taken at different times, making the fusion more problematic and less useful. Finally it's important to remember, that an higher spatial resolution doesn't guarantee a better classification result.

Figure 6. Fusion of SPOT-XI and SPIN-2 data (Feng et al 2002)

3.6 Land Cover Map

The integrated land use map was digitised using thematic maps and other relevant data. Afterwards it was edited and updated by data processed from satellite images. Linear elements including roads and rivers, and polygon elements such as settlements, water, paddy fields, woodlands etc. were extracted. For extracting these elements different methods and means were used. The land use map was edited in ArcView. In the first step the data of settlements, water, vegetation, roads and rivers were overlaid on the basis of merged SPOT images, fused images from different sensors, referring to topographic data, administrations and DEM data from topographic maps. Then, spatial data of every element was put in and the attributes were named according to the requirements for land use data in the project. At last, topological relation of data was established in the ARC/INFO coverages.

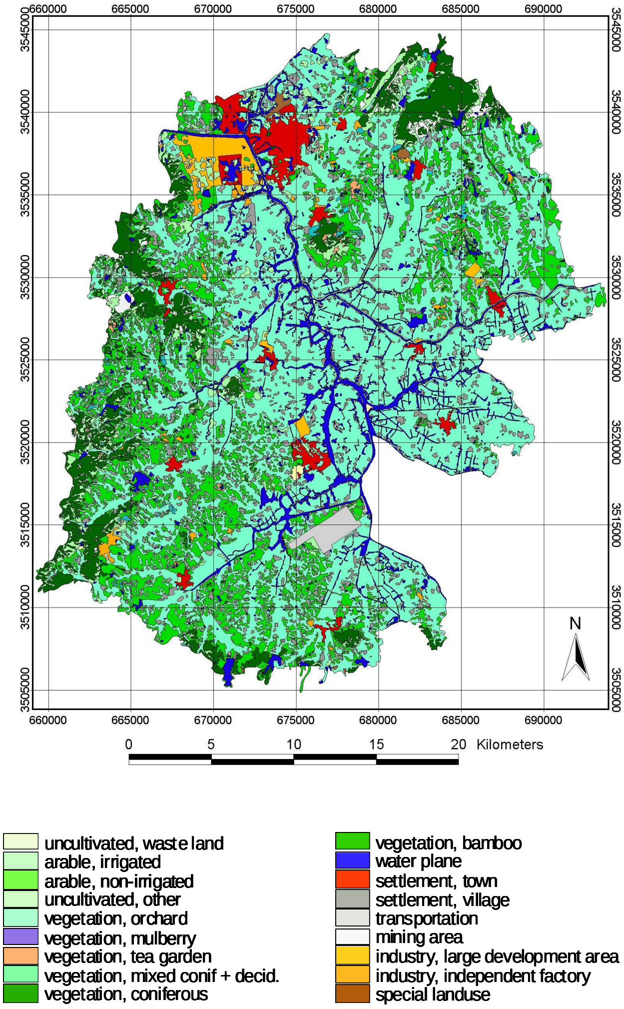


Figure 7. Land use map for the SILUP study area

3.7 Two methods for DEM reconstruction

A reliable DEM is the base for many applications of the SILUP project. All these applications would like to have a perfect DEM. Because of the known limitations this isn't possible. The different applications can tolerate different limitations of the DEM. The DEM used for orthophoto generation should be absolutely as exact as possible. For the hydrological applications this is not so important, but those DEMs have to be hydrological correct. The flowing direction of the water has to be correct for each pixel, the absolute high of each pixel is not that important. These two different expectations to a good DEM leads to two different methods creating a DEM.

For the first type of DEM, SPOT PAN Stereo Images have been used. Because of the variations in neighbouring heights, this DEM couldn't be used for hydrological applications, but for the generation of an orthoimage these small variations are not important. This DEM was generated using the Virtuozo® software package which was developed at the Wuhan University and is now being distributed by Supresoft Inc.

Ground control pixels situated near water bodies made problems in the DEM generation. This may be caused because of different water levels between the image acquisition time and the map production time. The other difficulty is that the water body areas haven't much texture in the remotely sensed data. Specular reflections do also occur in the water areas, making even more problems. Because of these problems the resulting DEM wasn't very exact and couldn't be used especially not for the hydrological applications. For further aspects on the accuracy of DEM generation from SPOT data see (Al-Rousan et al., 1998).

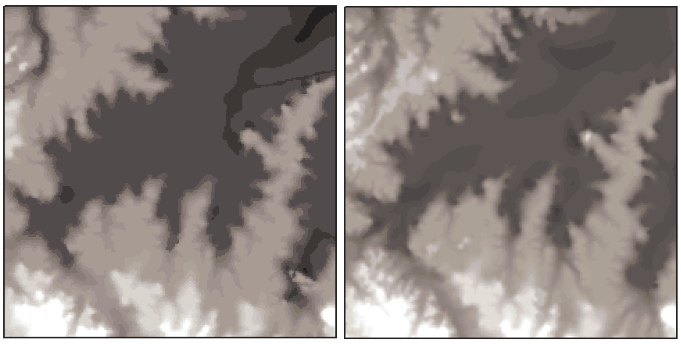


Figure 8. DEM generated from Stereo-SPOT images (right) and DEM generated with the TOPOGRID module (left)

For the hydrological applications the flowing direction of the water is important and has to be correct. As shown in Figure 8 the DEM created with the Stereo-SPOT images are not hydrological correct. In the middle of the right image of Figure 8 the river would have to climb over a small ridge. To build a DEM which was hydrological correct the TOPOGRID module from ARC/INFO (Hutchinson, 1988) was used. For generating the DEM, TOPOGRID needs input data. The input data were in detail: polder areas, water bodies and river middle axes. The river middle axes were digitised manually from a topographic map. All rivers inside polder areas were removed since polder areas were decided to be treated as closed units. All river segments were oriented downstream, which is a prerequisite for the TOPOGRID module.

The TOPOGRID module computes gradient directions perpendicular to the contour lines and then iteratively respects the oriented river network (Hutchinson, 1996). To generate the finally used DEM, 2000 iterations were calculated. After the DEM calculation the digitised lake and polder polygons were used to level all DEM cells inside the same polygon to the same height. For the hydrological applications this again was an important step, because this levelling ensures a flatness of lake and polder areas. The DEM generation was performed in close interaction with the hydraulic engineering group in order to ensure the usability of the results. The generated DEM contains 22 of the 28 GCPs used in the area. For these 22 GCPs, the standard deviation in elevation computes to 3.70 m.

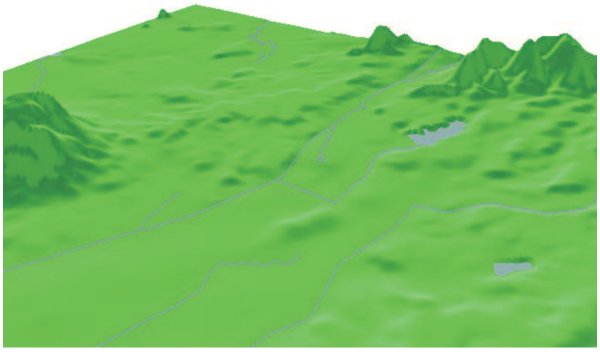


Figure 9. 3-D landscape model generated using TOPOGRID

Still the generated DEM didn't suit all the needs for the hydrological computations. The calculations of the hydrological project group showed some water flows inside the polder areas. This should not occur, but couldn't be avoided. As a workaround an artificial "wall" was build into the DEM. Around all polder polygons the DEM was rised at least 2m to avoid any further inflow into the polder areas.

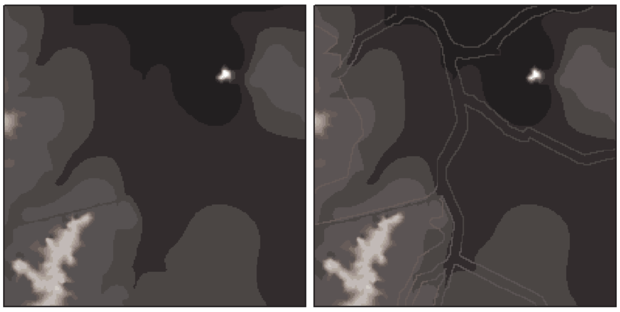


Figure 10. 50m DEM without (left) and with (right) walls at polder boundary

4. OUTLOOK

With just a few steps taken it isn't possible to say: "Going the SILUP way leads to a sustainable development." A long way lies ahead. The next goals will be to finalise the operational concept of the FCM. This should include feed-back mechanisms, impact analysis and dynamical functions. Especially adding time, as an important factor in the sustainability analysis, will be most important.

Making the system more useable it will be important to add automatic methods for classifying high-resolution remote sensing data. The high quality of the already existing data will be useful for further work in the area. The data can be used for updating the spatial database with new procedures similar to the work of Walter et al (1998) in combination with the automated image to map registration approach presented by Hild (2001). Further methods have to be developed and implemented. The now available high-resolution satellites like QuickBird-2 will deliver new data. The combination of high- and mid-resolution data requires new methods of classification. The biggest change of classifying these combined data lies on hierarchically structured classification methods. But using these high-resolution datasets also make the extraction of linear objects more interesting. Using QuickBird-2 data, the automated extraction of roads and railroads seems possible, especially when having a good data source of the road and railroads in the area which only needs to be updated.

Special regards lies on methods of fusing different data sources and sensor types. Theses methods will needed to be further developed and improved. The combination of different types of sensors will lead to new types of information, especially for ecological applications. To predict effects and side-effects of different land-use plans, a whole range of information is needed. With the combined sensor data this information may be delivered just in time to meet the needs of the land-use planers, helping them reaching a more sustainable world than today.

REFERENCES

Al-Rousan, N. & Petrie, G., 1998. System Calibration, Geometric Accuracy Testing and Validation of DEM & Orthoimage Data Extracted from SPOT Stereopairs Using Commercially Available Image Processing Systems, IAPRS, Vol.32/4, "GIS Between Visions and Applications", Stuttgart: 8-15

Feng, X., Fritsch, D., Wang, Z., Liu, X., Hild, H., 2002. Geo-Information Derivation and Management. In: Treuner, P., She, Z., Ju, J.: Sustainable Development by Integrated Land Use Planning. Final Report on a Co-operative Research Project. Stuttgart.

Haala, N., Walter, V. & Stätter, C., 1999. Analysis of Multispectral and Stereo Data from Airborne Pushbroom Systems for DTM Generation and Land Use Classification, International Airborne Remote Sensing Conference and Exhibition, Vol.I, Ottawa, Ontario, Canada, pp. 170-177

Hild, H., 2001. Automatic Image-To-Map-Registration of Remote Sensing Data, in: D. Fritsch & R. Spiller, eds, 'Photogrammetric Week '01', Heidelberg, pp. 13–23.

Hutchinson, M.F., 1988. Calculation of hydrologically sound digital elevation models. 3rd International Symposium on Spatial Data Handling, Sydney. Columbus, Ohio, International Geographical Union.

Hutchinson, M.F., 1996. A locally adaptive approach to the interpolation of digital elevation models. In: Proceedings, 3rd International Conference on Integrating GIS and Environmental Modelling, Santa Fe, NM.

Ju, J., 1998. A Primary Integration Matrices Approach to Sustainability Orientated Land Use Planning in China. Stuttgart.

Lillesand, T.M. & Kiefer, R.W., 1987. Remote Sensing and Image Interpretation, New York.

Walter, V. & Fritsch, D., 1998. Automatic Verification of GIS Data Using High Resolution Multispectral Data, in: T. Schenk & A. Habib, eds, `IAPRS', Vol. 32/3, ISPRS Commission III Symposium on Object Recognition and Scene Classification from Multispectral and Multisensor Pixels, Columbus/Ohio, USA, pp. 485-490