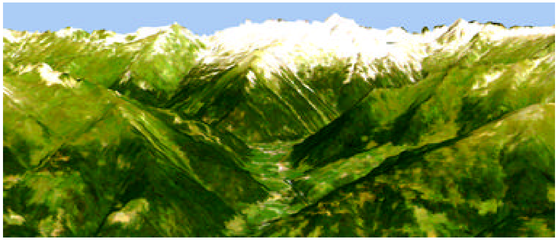
ALPMON

INVENTORY OF ALPINE-RELEVANT PARAMETERS FOR AN ALPINE MONITORING SYSTEM USING REMOTE SENSING DATA

Contract ENV4-CT96-0359



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1 Introduction

The Alpine environment, one of the most sensitive of Europe's terrestrial ecosystems, is exposed to immediate and considerable environmental threat. The International Convention on the Protection of the Alps demands comprehensive counter-measures and recommends that an Alpine information system should be implemented. The goal of the project was to compile a basic landscape register for an Alpine Monitoring System (ALPMON) by means of combined analysis of diverse satellite sensors of Alpine landscapes selected for their typical characteristics. This system shall serve as the basis for planning proposals. The feasibility of the Alpine Monitoring System was tested using specific applications in the fields of disaster management, tourism management and national park management as well as by merging the results with CORINE-Landcover. These applications were carried out in close co-operation with the responsible experts so that the procedures developed can be put into practice.

1.1 Objectives

While the Alps represent one of the most sensitive ecosystems in Europe the pressure on them, due to an aggressive development drive in the past, huge numbers of tourists as well as environmental damage, is far greater than on other environments. Forests have recently been subjected to particularly damaging natural as well as human influences. New kinds of damage to forests, the catastrophic storms of 1990 and 1999, and the resultant, and lasting problem of the bark beetle, and global climatic changes have weakened the resilience of alpine forests. Far-reaching changes have also been anticipated for agricultural land. Intensive farming and the excessive use of fertilisers, overgrazing, forest grazing, and grass-cutting adversely diminish the potential of the alpine regions as agricultural patrimony. Concurrently with this development we also find that more and more alpine pastures are no longer being grazed or cultivated, so that the pastures are gradually taken over by spreading forest. The resultant change in the face of the landscape typically associated with the Alps has a negative impact on tourism, an important economic factor. A third area of concern is the use of alpine land for tourism which increasingly is at odds with the aims of nature and landscape preservation. The cumulative effect of all these factors often proves disastrous, resulting in irreversible changes in the composition and distribution of regional plant communities as well as in agricultural and forest areas.

The International Convention on the Protection of the Alps (short: Alpine Convention) thus concluded that alpine environment is under imminent threat, and demands comprehensive counter-measures. Far-sighted national and cross-border planning, considering the manifold and often competitive land use claims, is necessary to ensure that preventive measures can be implemented by nature conservation councils, regional planning departments, tourist boards and forestry and agricultural authorities. The success of such measures crucially depends on the availability of information about the land cover/land use patterns found and their development dynamics. It is not sufficient to record alpine subsystems using high-resolution equipment. Rather, information concerning the development of regional structures over wider areas needs to be included. Some inventory projects undertaken today at least partly meet this requirement (e.g. Berchtesgaden National Park), yet due to the high cost and labour intensity associated with the processing of aerial photographs and ground analyses these investigations are generally restricted to small areas.

Satellite remote sensing represents an ideal instrument for objective, large-scale and updateable data acquisition. This is especially true for data related to regional structures which are used as a basis for the planning of corrective measures and their monitoring. Moreover, compared to other inventory systems it offers a highly cost efficient alternative. One further advantage of this instrument is the fact that satellite images can synoptically record wider areas. By use of this data it is possible to observe the same areas repeatedly which permits monitoring over many years. The latter is essential when dealing with a sensitive ecosystem such as the Alps.

1.2 Aim and Context of ALPMON

The project aimed at the compilation of a basic landscape register for an alpine monitoring system (ALPMON) which shall serve as the basis for planning purposes. The components of the alpine monitoring system were, firstly, derived from the results of a classification of Landsat-TM, SPOT and high resolution satellite images and, secondly, extrapolated from thematic maps. The remote sensing data results represent the most up-to-date GIS level, which can provide information about the alpine environment be updated after predetermined periods of time. This information was classified in such a way that, using ALPMON, the basic information, necessary for major planning projects in the alpine regions, are made available. The feasibility of the alpine monitoring system was tested using specific applications in the field of hydrological modelling, disaster management, tourism management, national park management and by merging the results with CORINE landcover. These applications were carried out in close co-operation with the responsible experts so that the procedures developed can be put into practice.

To realise the aims of ALPMON the following tasks were carried out:

Remote Sensing tasks

Primary information on the nature and state of vegetation and of residential areas for ALPMON were compiled mainly by means of remote sensing, as this data is an optimal information source for the production of small-scale maps or information systems. An important objective, therefore, was the testing of operational and semi-operational processing methods which permit a maximally precise compilation of the specified parameters. This applies to the following steps:

- Definition and harmonisation of parameters needed by the customers (requirement study)
- Establishment of permanent reference/training areas in the different test sites by means of aerial photo interpretation and field assessments
- Geometric correction of the data; operational tools exist for this purpose and only were adapted to high resolution data
- Radiometric and atmospheric correction of the data to an extremely high level of accuracy; existing methods and algorithms were applied and, if necessary, improved
- Testing existing classification procedures which can be applied to the actual conditions found in the Alps (high relief energy and small units).

GIS tasks

Topographical, hydrological and geological parameters were extracted from information contained in existing maps. They were integrated as auxiliary information in the processing of the satellite images. Furthermore, the analysis of these data provided the basis for diverse applications. In order to integrate and network the various types of information sources (remote sensing, thematic maps, digital elevation models, meteorological information) different GIS- analysis techniques were adopted to the specific tasks and performed:

- Accuracy assessment and merging of data of varying scales
- Combination of classification results with digital map information
- Harmonisation of the information content by means of operations in the GIS data base.

Feasibility Studies

Since one of the expected results of the project was to gain information concerning the general applicability of satellite images for the compilation of alpine-relevant parameters, specific applications were performed in close co-operation with national customers. The feasibility of the alpine monitoring system was demonstrated in the following fields:

- Hydrological modelling of water run off
- Production of landslide risk maps
- Support of avalanche risk assessment
- Remote sensing and tourism
- Supporting national park research and management

Due to different climatic conditions, vegetation types and geological conditions of the alpine environment different test sites, located in Italy, Germany, Austria and Switzerland, covering to a large extent the various conditions found in the Alps, were selected for these investigations. In all proposed test sites scientific investigations already have been performed, which the new investigations were based on. The geographic location of the test sites is shown in Figure 1.

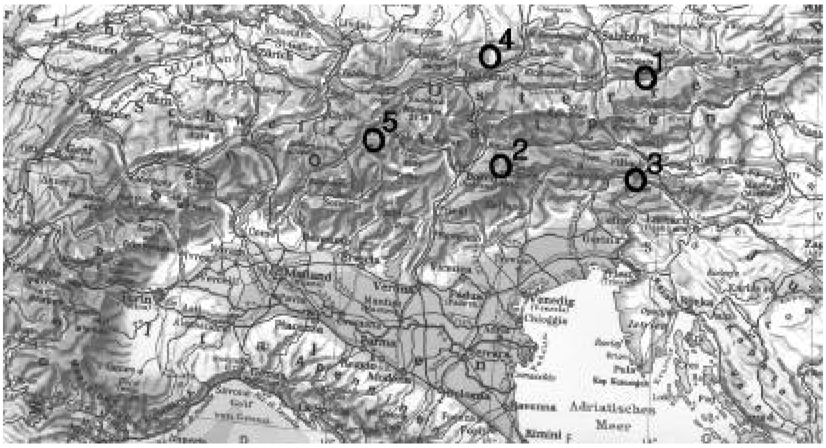


Figure 1: Test sites: (1)=Dachstein Mountains, (2)=Cordevole, Region of Veneto, (3)=Tarvisio, (4)=Northern Kalkalpen of Bavaria, (5)=Engadine.

In order to achieve the complex task an integrated approach was necessary, which takes account of developments in areas as diverse as alpine forestry, agriculture and residential developments. Solutions to such a complex problem necessitated an interdisciplinary approach, which involves the various specific disciplines of remote sensing, GIS and experts from the user/customer side.

A further result of the project is a concept for the establishment of a remote sensing based alpine information system introduced to the Alpine Convention (Customer on the European level). In order to meet the requirements and needs of the Alpine Convention and the involved national administrations an intensive execution of the customers needs was carried out. Another application task is to aggregate classified parameters of ALPMON into the CORINE-nomenclature of level 3 in order to make both data sets compatible.

1.3 Consortium

The project team is built of the following institutions:

Project co-ordinator:

- JOANNEUM RESEARCH (**JR**); Institute of Digital Image Processing, Graz – Austria

Project partners:

- R.S.D.E. Srl (**RSDE**), Milano - Italy
- University of Freiburg (**ALU**), Department of Remote Sensing and Land Information Systems, Freiburg, Germany
- University of Munich (**LMU**), Institute for Landuse Planning and Nature Conservation, Department of Remote Sensing, Freising, Germany
- Austrian Research Centre Seibersdorf (**Seibersdorf; SEIB**), Department of Environmental Planning, Seibersdorf, Austria
- Swiss Federal Institute for Forest, Snow and Landscape Research (**WSL**), Birmensdorf, Switzerland

Sub-contractor:

- Sachverständigenbüro für Luftbildauswertung und Umweltfragen (**SLU**), Gräfelfing, Germany

Full information on the project partners with contact persons and address is given in Annex 1.

1.4 Project Structure

To realise the aims of ALPMON the work was subdivided into the following thematically demarcated work packages (WP; WP co-ordinator):

WP0: Project management (JR)

WP1: Requirement study of the customers (JR)

WP2: Interaction with CEO (JR)

WP3: Set-up and harmonisation of parameters to be included in the information system (WSL)

WP4: Collecting of ground information for classification of the satellite data and verification of classification results (WSL)

WP5: Geometric rectification of remote sensing data (JR)

WP6: Topographic normalisation of satellite data (SEIB)

WP7: Atmospheric correction of satellite data (test site responsibles)

WP8: Data preparation for classification (texture analysis and image fusion; SEIB)

WP9: Classification of the satellite data due to the requirements of the national as well as European customers (JR)

WP10: Verification of the classification results (WSL)

WP12: Data integration and harmonisation of representation (ALU)

WP12: Feasibility studies on ALPMON

- 12.1 Remote sensing and tourism (ALU)
- 12.2 Modelling of water run-off (LMU)
- 12.3 Support of avalanche risk assessment (JR)
- 12.4 Erosion risk assessment (RSDE)
- 12.5 Integration into CORINE (SEIB)
- 12.6 National park management and planning (WSL)

Figure 2 demonstrates the logical interdependencies between the project tasks and the final project results.

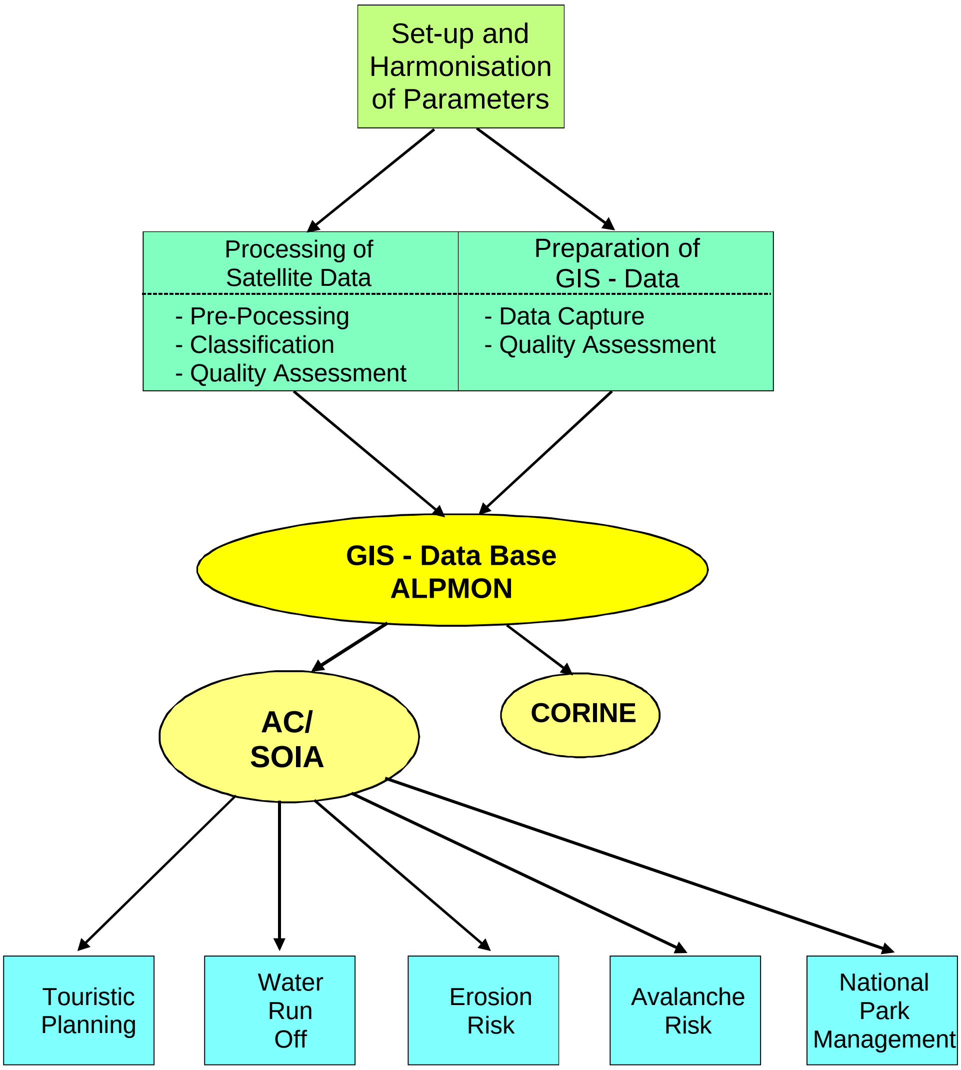


Figure 2: Project structure.

2 Work Performed

2.1 Main Customer Requirements (WP1)

The development of ALPMON was conducted in close co-operation with the Alpine Convention, in particular the *Alpine Monitoring Group*, and national administrations (for a list of the customers see Annex 2). Preliminary discussions with the customers clearly established that remote sensing data, in conjunction with other information compiled in a GIS, are perceived as useful tools in developing the kind of applications envisaged. In order to ensure, however, that the work is maximally geared to the needs of the clients, their requirements and expectations with regard to ALPMON were analysed in detail in the starting phase of the project. This has been done in workshops which were organised for each customer-service provider group.

Existing data bases and contribution of remote sensing

According to the data availability at the customers two groups can be distinguished in general:

1. Group: no data available

For many of the applications in the specific test areas no spatial information over larger areas existed at all. For example at the Austrian Institute for Avalanche and Torrent Research, the Centre for Avalanches and Hydrological Defence, Arabba, the Tourism Office of Tarvisio and the Bavarian State Office for Water Resources Management spatial data only was available in the form of some hazard zone maps. Most of the information is restricted to point measurements and empirical data. To identify potential hazard zones it is necessary to apply the criteria which have been derived from the measurement results to larger areas. So far, however, the kind of information that would fulfil the requirements outlined has not been available. High resolution remote sensing data permitted the compilation of ground cover parameters. The digital terrain model further made available topographical parameters, such as slope, aspect and elevation. Thus, remote sensing classification in combination with GIS analysis enabled the establishment of new data bases on which the divers application models could be based.

The Alpine Convention started to develop methods for data collection and did not have any data in the data base envisaged by the working group "Monitoring of the Alps".

2. Group, data available, RS needed for updating and completion

For those customers who already had spatial data on the Alpine environment, the remote sensing results of the project were used to update and/or complete their existing data bases. For example, in the Swiss National Park an update of the data base was needed. There was a lack of actual spatial comprehensive information which should be acquired by means of remote sensing methods. It is also expected, that remote sensing can help to extrapolate spot data to greater areas.

Also the Forest Administration of the Tarvisio region already had a forest classification based on Landsat TM data. However, this classification only existed for forested areas, and here was restricted to the forest owned by the state. Thus, the forest administration looked for the extension of information to non-forest areas, the increasing of spatial resolution and the updating of existing information.

Five national feasibility studies have been performed which first can be seen as independent applications since there are different national customers with their specific requirements. On the other hand all the applications contribute to issues addressed by the Alpine Convention. The following section outlines the customers and the factors and criteria which were specified during the workshops in detail.

2.1.1 Alpine Convention, the Customer on European Level

In order to achieve the required information as stated in section 1.1, the Alpine Convention consequently set up the working group "Monitoring of the Alps" on the 27th of February 1996 in Brdo. The main task defined in the programme of this working group is to develop methodologies for the establishment of an "Alpine Monitoring and Information System" (ABIS). This Information system should provide information on

- the condition of the alpine environment
- the type of pressure on the alpine environment
- the condition and development of the alpine economy and population.

This information system should be used to control and support the realisation of the aims of the Alpine Convention. Additionally, this information should be made available to the public and national or international bodies.

Due to the advantages of a remote sensing based approach, as listed in section 1.1, the results of ALPMON can on one hand be used as information source for the ABIS-system and on the other hand contribute to technical and conceptual aspects of ABIS.

The products to be generated and the information to be collected by the working group "Alpine Monitoring" can be summarised by six activity lines listed in the following:

1. Environmental indicators
2. Socio-economical indicators
3. Information system on research related to the Alps
4. Catalogue of data sources and thesaurus
5. Cartography
6. Computer aided communication system

Due to the fact that remote sensing is an appropriate tool for providing cartographic information on the type, condition and distribution of the vegetation and that the results of remote sensing can easily be integrated into GIS systems, ALPMON could mainly contribute to the activity lines 1 and 5. Additionally, ALPMON could support activity 6, since one of the objectives of the project was to clarify to what extent this activity of the working group could be adopted by CEO.

A detailed parametric description of the environmental indicators to be integrated into ABIS was established by experts. For this purpose the environmental indicators are grouped into specific thematic topics listed in the following:

- Nature and landscape reserve
- Forest
- Water
- Air
- Risks
- Soil and waste
- Climate change

Indicators for each of these topics were suggested or are under discussion. As one example the indicators for topic 2 "Forest" are listed in the following:

<u>1. Forest area and types of stands</u>

Forest area
Area of coniferous, broad-leaved and mixed stands
Coppices and coppices under standards: area in conversion to high forest

<u>2. Pressure / Threats on forests</u>

Area of forest clearings
Acidification of forest ecosystems
Areas with damages caused by biotic agents and game
Forest fires: breaking points, area burnt
Balance between removals and increment

<u>3. Function of the forests</u>

Natural hazards: causes, number, extend/area
Forest area managed for protection against natural hazards and for protection of soil/water
Area managed for recreation purposes

As far as the indicators were already set up, the nomenclature was compared and aligned with the nomenclature of ALPMON. As the nomenclature system developed within ALPMON is a modular system consisting of very detailed parameters rather than final classes it is, at present, so flexible that it can be adopted to the future requirements of the Alpine Convention’s nomenclature.

2.1.2 National Administrations, Customers on National Level

To demonstrate the potential of the ALPMON system applications were carried out which have relevance both for the Alpine Convention and, in particular, for national administrations dealing with environmental issues.

2.1.2.1 Forest and Tourism Administration at Tarvisio

The Department of Remote Sensing and Landscape Information Systems at the University of Freiburg is working together with the Forest Administration and the Tourist Administration of Tarvisio, Italy. The test site is located in the upper most of Italy on the border to Austria and Slovenia and covers an area of about 46 000 ha, around the main valley Val Canale.

In this region most of the people are interested in promoting tourism. Investments in new hotels, new infrastructure for downhill skiing, new streets and railways were made and will be made in near future. The area around Tarvisio is also applying for the winter Olympic games. Therefore it is to be expected that the construction of buildings and the opening to tourism will be even more intensified and following to that the pressure on nature will increase.

For the Forest Administration the topics are mainly "land cover" (classification results of the satellite data) and the analysis of the landscape with regard to suitable habitats for the ibex that has been reintroduced in this area some years ago. These topics are also interesting for the Tourism Administration. Furthermore, landscape modification, infrastructure analysis and the already mentioned subject areas publicity and tourist information. On this subjects - advertising, presentation (and tourist information), landscape modification and sensitivity of fauna and flora - it should be tested how remote sensing data can be used.

In the field of tourist information and publicity the processed remote sensing data can help the tourist to appreciate the beauty and uniqueness of the landscape. They can simplify the interactive planning of his stay and his activities in the landscape. The attractiveness of a region can be represented in this way, what may have positive effects on the support of tourism. For this purpose, the following items should be developed: production of thematic maps; visualisation of the landscape with the aid of digital data in realistic 3D-views; development of a landscape-related information-system for tourists.

The “asset landscape" should be observed for a long time in order to obtain information about its state and modification tendencies. Not only the natural landscape but also the man-made landscape with its particular mosaic of forest and open areas is of a particular interest for tourism, especially hikers.

Also in this case, the limited use-capacity of alpine nature and the sensitivity of fauna and flora should play a decisive role in the planning of landscape-related tourism right from the start. Possibilities on this will be included. These should go beyond pure incorporation of data from other disciplines and show, through systems analysis, how sensitive landscape areas can be pinpointed, excluding thus, the conflict-ridden areas. These and other areas of interest can be observed over a longer period. In this way changes can be detected which could be an important information. This project should show how to monitor the changes of the extension of alpine pastures in the last 40 years.

In the field of the mentioned tourism planning, methods should be developed by the effort of geographic information systems in order to provide information about the considered region, and to use them in analysis, concerning the present situation and the previous development of the landscape and the touristic infrastructure. This information is the basis for the estimate of future trends of development. They offer the possibility to arrange the planning more efficiently. The monitoring of landscape changes was already mentioned as a method. Also a systems analysis for the topic of the sensitivity of flora and fauna. But some possibilities should also be demonstrated for the analysis of the infrastructure.

All methods that are to be developed can not guarantee a solution for the conflict between nature and tourism. But they may offer the possibility of comprehensive and efficient spatial planning to the responsible authorities: the Tourism Administration and the local politicians as a rule.

2.1.2.2 Bavarian State Office for Water Resources Management

Today hydrological planning in river basins needs prognosis and forecasts to describe current water and material movement in a high spatial resolution. In co-operation with the Bavarian State Office for Water Resources (Bayerisches Landesamt für Wasserwirtschaft) the University of the German Federal Armed Forces in Munich/Institute for Water Management (Institut für Wasserwesen) developed a mathematical, GIS-based model to calculate grid-orientated runoff process, solid matter and nutrient fluxes in hydrologic meso-scaled catchments. The programming system was named ASGI, which means in German **A**bfluß-(water run-off), **S**tofftransport- (material displacement) Modellierung (modelling), using **G**eographical **I**nformation Systems.

The programming system ASGI consists of the 4 main modules

- Datenmanagement (Data management)
- Präprozessor (Data preparation)
- Prozessor (Data processing)
- Postprozessor (Data presentation).

The module "Data Management" includes

- the project- and variant specific database management
- the fast input of external data (including data check) and
- the optional data storage and restoration.

In this module we have the interface to ALPMON caused by the need for grid-based data. The Bavarian State Office for Water Resources has the opinion, that the requirements can only be satisfied by using remote sensing data. These shall provide the basis for a detailed land use classification.

The ASGI-project also includes the scaling aspects that exist in hydrological process grid modelling with GIS, with respect to selecting the optimal grid width.

To fulfil the requirements of the customer a multi-temporal and a multi-seasonal remote sensing approach was planned:

- a multi-seasonal approach to investigate the advantages and disadvantages of different times of taking satellite data within the summer period in the alpine region (e.g. shadow effects, phenological effects),
- a multi-temporal approach for change detection purposes to demonstrate the possibilities of using satellite data for monitoring purposes.

2.1.2.3 Austrian Institute for Avalanche and Torrent Research

The Institute for Avalanche and Torrent Research is a subdivision of the Federal Ministry of Agriculture and Forestry, Federal Forest Research Center. Avalanche research is in charge of preparing improved guidelines for active and passive protection from avalanches, a function also important for the Austrian economy. The work includes the development of new control techniques, for example, forestry measures for the management of avalanche hazard zones and hazard zone planning. Avalanche documentation, including accident files, is an essential contribution to the improvement and standardisation of training and education programs.

To identify potential hazard zones it is necessary to apply the criteria which have been derived from the measurement results, such as critical degree of crown closure, critical degree of gaps in the forest, etc., to larger areas. In order to adapt these criteria to regional variation, information is needed which covers all the variables which cause avalanches over extensive areas. Another requirement is that this information be available in digital form in a Geographical Information System in order to ensure that by means of automated processes the different information levels can be integrated and cross-referenced.

So far, however, the kind of information that would fulfil the requirements outlined has not been available. While adequate data has been compiled for some areas, it is generally too heterogeneous to permit the integration of data into other databases. Moreover, the data only covers small areas and is thus not easily applied to the analyses of larger areas. The aim of ALPMON is therefore to compile standardised information for larger areas. High resolution remote sensing data permits the compilation of vegetation parameters from which surface roughness can be indirectly deduced. These parameters include forestry-related variables such as the distribution of different tree species, tree age, crown closure and gaps as well as alpine pastures, scree and rocks. The digital terrain model further makes available topographical parameters, such as slope, aspect and elevation.

Two different types of avalanche risk models are currently developed at the Austrian Institute for Avalanche and Torrent Research:

- Empirical models, which are based on the Austrian avalanche register (restricted to slab and gliding avalanches).
- A fuzzy model based on actual laser measurements.

All models need similar parameters from remote sensing and DEM sources. Among these, the actual information on land use/land cover can be derived from remote sensing data. Additionally, the topographic information (e.g. slope, aspect, inclination) can be computed using the digital elevation model (DEM).

2.1.2.4 Centre for Avalanches and Hydrological Defence, Arabba

The Avalanche and Hydrogeological Defence Experimental Centre of Arabba is a structure of the Veneto Regional Council, and is under the authority of the Department for Forests and Mountain Economy. The Avalanche Centre has developed, in the frame of the EROSLOPE project (No. EV5V-0179), a system for the real time monitoring of the solid, fluid and nutrient transport, in the pilot basin of Cordon River, a small sub-basin (5 km^2) of the upper Cordevole river basin. The system has been conceived to investigate in-depth the transport phenomenology in relation to runoff and environmental parameters under well controlled conditions. All environmental parameters used in the system have been gathered by means of very detailed ground surveys. Besides this important experience which has strictly scientific aims, the Avalanche Centre is strongly interested to improve its operational capability to monitor periodically the erosion phenomena over very wide alpine areas. To carry out this task in a cost-effective way the Avalanche Centre wants to minimise the use of ground surveys, exploiting as much as possible remote sensing technologies and the information about environment already existing on the Region of Veneto, and in particular on the Forest Department.

2.1.2.5 Swiss National Park Administration

The Swiss National Park was established by Act of Parliament on 3.4.1914 and its present boundaries confirmed by Act of 7.10.1959. The Park now covers an area of about 17000 ha. Its lowest point is at 1400 m, the highest peak just over 3100 m. Beside the ecological and touristic aspects, the Park serves for scientific research conducted by a committee set up by the Swiss Academy of Sciences. The aim of the National Park is to provide Swiss natural scientists with an immense field laboratory, in which research can be pursued unhindered over a prolonged period of time, in order to study the changes occurring within an area that had previously been influenced by man. A huge amount of scientific research has been done over the last 80 years, thus gathering a lot of documentation of this area.

In order to reconcile the legitimate interests of visitors with those of Science, only certain parts of the National Park are accessible to tourists, who moreover are not authorised to leave the specified paths. Researchers are allowed to leave paths only in specific areas, for which they have to request a permission. A lot of detailed spot data are available. Because of the restricted accessibility in the Park, there is a lack of actual and proved information concerning the spatial pattern of characteristics in the whole area. For this reason, remote sensing techniques are of great interest. They shall support investigations in the following fields:

- Monitoring of grazing areas of red deer
- Changes of the alpine timberline
- Geomorphologic processes
- Avalanches
- Snow depletion
- Forest fire research
- Extrapolation of spot inventories
- Extension of the park boundaries

Current research needs a spatially comprehensive inventory of the type of areas without vegetation (boulder, rock, soil, rock and land slides, rock glaciers), type of non-forest vegetation(grass areas, shrubs), forest stand density and structure, tree species composition, natural age class of forest stands, type of soil coverage in forest stands (grass, shrubs, regeneration, gravel, soil), avalanche events, and monitoring of snow depletion. The required minimum area is 20x20 m (10x10m), required location and boundary accuracy is 10 m. Additionally, a spatially comprehensive inventory and monitoring of land use is needed. Beside main vegetation categories also use-intensity classes are of interest. To meet the customers requirements, information on these parameters shall be derived from satellite data.

In the last few years, a GIS has been established to store geocoded basic data and the results of current research. This GIS-SNP (GIS-Swiss National Park) is managed by the „Department of Geography, Division of Spatial Data Handling“ of the University of Zürich. This GIS contains data sets covering the entire area of the National Park as well as data sets covering only sub-areas. All data were available for ALPMON.

2.1.2.6 Interpretation of Classification Result in CORINE-Landcover

The CORINE land-cover project is part of the CORINE programme (Co-ordination of information on the environment) of the European Commission and is intended to provide consistent localised graphical information on the land-cover of the Member States of the European Community. The information is derived from visual interpretation of satellite images, supported by ancillary data such as topographic maps or aerial photographs. The analogue interpretation maps are false colour images on a scale of 1: 100.000 derived from geocoded Landsat TM or SPOT HRV images. The nomenclature for interpretation consists of three hierarchical levels, of which the third one comprises 44 land-cover classes (Table 10). The outcome of the project are digital vector layers representing borders of homogeneous land-cover units.

In 1994 a related land-cover project was started at the Austrian Research Centre Seibersdorf. The image data used in this project comprise 12 Landsat TM scenes acquired between July and September 1991. In contrast to the methodology of CORINE it concentrated on the semi-automatic production of a land-use map of Austria. In order to allow a comparison between this land-use map and the CORINE data set, the CORINE nomenclature was used in the project.

In general it can be stated that automatic procedures are a valuable alternative to visual interpretation. Major conclusions to be drawn from the comparison are:

1. The spatial resolution of Landsat TM images limits the recognition of certain classes (in the visual interpretation approach these classes were recognised by means of ancillary data)
2. per pixel classification and subsequent spatial post-classification of Landsat TM images limits the precise delineation of certain objects, or even suppresses narrow objects.
3. adequate pre-processing of digital images, such as topographic correction, improves the classification accuracy in mountainous areas significantly.

This leads to the basic requirement of image data with a higher geometrical resolution in order to solve for conclusions 1 and 2. At the same time conclusion 3 will still be valid as long as the image data are digital. Within ALPMON these requirements will be fulfilled, as high spatial resolution image data will be used for analysis and appropriate pre-processing will be applied. It is therefore expected that for the ALPMON test areas level III classes will be detectable.

A particular interest of the customer lies in the high alpine regions which are considered the most crucial areas for visual interpretation. This includes above all the 'Forests and semi-natural areas' classes of the CORINE nomenclature. A clear distinction of bare rock, sparsely vegetated areas, natural grassland and different forested areas is of major interest for the customer. In addition separation of dwarf-pines from other coniferous forests would significantly improve the available information.

The requirement of the customer is to get land cover maps of the test sites according to level III of the CORINE nomenclature. If it is possible to increase the thematic subdivision, a level IV nomenclature will be established. The major motivation of the customer is to estimate the feasibility of an automatic derivation of CORINE land-cover maps from high resolution satellite imagery for updating the existing CORINE data base. In order to fulfil this task image data with a high spatial resolution are indispensable, thus increasing the costs for data acquisition. On the other hand these additional costs might be compensated by a significant reduction of processing time compared to the visual interpretation. Therefore the interest of the customer includes an estimation of time and costs of the ALPMON approach with regard to the derivation of CORINE land-cover maps.

2.1.3 Requirements Fulfilled by ALPMON

Due to the diverse customers and their to some extent very different requirements it would not be useful to compile a complete list of the parameters to be derived from remote sensing and additional sources. However, an aggregated list of parameters, which indicates the parameters required for each feasibility study and test site respectively, is given in Annex 3. This list represents the parameters which were required by most of the customers and which are also relevant for the Alpine Monitoring System. The parameters merely distinguish in their further subdivision into subclasses such as number of age classes or crown closure classes within the forests and their recording accuracy. The hierarchical nomenclature developed in WP3 (Set up and Harmonisation) can be used as a link between the different customer requirements and the Alpine Convention. Additionally, a list of classes (Table 1) was suggested as a minimum standard for all applications within ALPMON. That means, each partner tried to delineate at least these classes, supplemented by the classes relevant for the respective application. Some classes have been taken into consideration because they are relevant for the Alpine Convention (AC), other classes due to their ecological importance.

Table 2 shows the benefits of the national applications to the *General Obligations* defined in *Article 2 of the Alpine Convention*. All subsequent tasks were matched with the requirements investigated within this work package.

Table 1: Common classes.

Parameter	**Definition/Classes**	**Important for AC**
Forest area	crown closure >10 to 100 %	x
Forest type	broad-leaved (<25% coniferous)	x
	mixed (25-75% coniferous)	x
	coniferous (<25% broad-leaved)	x
	greenalder	
	dwarf mountain-pine	
Coppice (Niederwald) area		x
Crown closure	>10 to 30 %	
	>30 to 60%	
	>60 %	
Forest age	clear cut	x
	thinning to pole	
	timber and old timber	
Non-forest	rock/gravel/soil	
	swamp	
	meadow/pasture	
	water	
	rhod.sp./junip.sp	
	sealed surface	

Table 2: ALPMON applications contributing to the General Obligations of the Alpine Convention.

Particular fields of the Alpine Convention	Corresponding ALPMON case study
Population and culture	
Regional planning	Touristic planning, Tarvisio Avalanche risk assessment, Dachstein
Maintaining air cleanliness	
Soil conservation	Erosion risk maps, Cordevole
Water economy	Modelling of water run off, Mangfall
Protection of nature and maintenance of the landscape	National park management, Engadine
Mountain agriculture	
Mountain forests	Forest administration, Tarvisio Avalanche risk maps, Dachstein National park management, Engadine
Tourism and recreation	Touristic planning, Tarvisio National park management, Engadine Avalanche risk assessment, Dachstein
Traffic	
Energy	
Waste management	

2.2 Methods for Building up the Alpine Information System

One of the aims of the project was to gain information concerning the general applicability of satellite images for the compilation of alpine-relevant parameters and their further usage as a base for different environmental planning and analyses tasks. Therefore, research in several test areas was performed, which cover, to a large extent, the various conditions found in the Alps. In the following the methods and procedures are described, which were applied in order to meet the objectives of the project. This comprises operational methods as well as new developed algorithms. A comparison of the different methods and their evaluation are given in section 3.3. Finally, the methods recommended for building up an Alpine Information System are described in section 4.

2.2.1 Set-up and Harmonisation of Parameters (WP3)

ALPMON envisaged a basic supra-national landscape register for an alpine monitoring system. To ensure the comparability of the information content for different test sites and later on for different regions, the parameters worked at in ALPMON were harmonised.

The elaboration of this work package started with a workshop on June, 24th. 1997, attended by all partners and some of the customers. Followed by a discussion via mail, a list of parameters (Annex 4) and a guideline for their use during ground truth collection were established. Every partner had close contacts with his customer during this discussion. Parameter list and guideline were used in the collection of ground information.

All partners agreed on a comprehensive list of single parameters and their classes. The assignment of areas, characterised by these parameters, to main vegetation or land use types (e.g. forest, non-forest, non-vegetation) could be done with respect to the specific requirements in each test site or of each customer. The assignments differed, but the common parameters and classes with common definition ensured comparability, regardless of the further assignment.

To improve comparability, emphasis was laid on information concerning the sources of date and their genesis. For this purpose, the guideline specified meta data, which had to be stored together with each information collected.

The successful use of the parameters in the collecting phase of ground information demonstrated the practicability of the results of this work package. For all of the AMS-indicators (defined for the **A**lpine **M**onitoring **S**ystem of the Alpine Convention) there are relevant ALPMON-parameters. Not all AMS-indicators can be assessed with remote sensing alone. For some of them, additional information is necessary. ALPMON worked out a list of data sets, which should be available in a GIS together with the classification results of satellite date for these indicators. Some ALPMON-parameters are not addressed in AMS, although they cover important types of alpine surfaces needed both for the Alpine Convention and the national customers. As the nomenclature system developed within ALPMON is a modular system consisting of very detailed parameters rather than final classes it is so flexible that it can be adopted to additional future requirements of the Alpine Convention.

2.2.2 Collecting of Ground Information (WP4)

For the classification of satellite images detailed information about the condition in the field is indispensable. This information was used for training of the classifier as well as for the verification of the classification results, using separate reference data sets for each purpose. The ground information within this project was mainly derived from aerial photographs for two reasons. Firstly, because there are sufficient suitable photographs available and secondly, because these are very well suited to bridge the gap between satellite images and the actual situation on the ground.

For the ground truth survey, the following methods were available:

1. interpretation of Colour Infrared aerial photos (1:5.000 - 1:20.000)
2. interpretation of Colour aerial photos (1:5.000 - 1:20.000)
3. interpretation of Black/White aerial photos (1:5.000 - 1:20.000)
4. field survey
5. processing of existing forest maps (1:5.000 - 1:10.000)
6. processing of existing topographic maps (1:10.000 - 1:50.000)
7. processing of existing orthophotos
8. processing of existing digital databases

Main sources of the collecting of ground information were aerial photos and field surveys. The ground information for all test sites was collected following the guidelines defined in the previous WP 3 including the harmonised parameters and definitions of the common nomenclature. This ensured that the classification results in the different test sites become comparable respectively compatible. By Joanneum Research a form-sheet for the data sampling was created for the

Dachstein Mountain test site. This was also used by other partners, thus improving the harmonisation of the procedures in the different test sites.

The classification of satellite images showed that all existing land cover and land use types were represented properly by the selected training areas. The statistical analysis of the ground data indicated, that a comprehensive reference data set was derived as a precondition for the successful performance of the subsequent tasks of ALPMON.

2.2.3 Geocoding of Satellite Data (WP5)

The geometry of the satellite images has to meet extremely strict requirements, firstly, because the data obtained with different sensor systems are classified multi-sensorally and secondly, because the satellite images and the classifications subsequently derived from them have to be integrated with additional digital data in a GIS. Because of the strong relief effects in Alpine terrain parametric geocoding methods were used in order to obtain the demanded accuracy levels (Raggam et al., 1999). Parametric geocoding is based on sensor-specific representation models of parameters which are generally optimised in a correction procedure, using control points and a digital terrain model.

To optimise the absolute geometric location accuracy of the geocoded image data, displacement errors caused by topographic relief have to be removed. Obviously, the amount of these errors varies from sensor to sensor, depending on the actual terrain elevation and on the sensor-specific imaging model. In the course of geocoding, these errors could be removed through the integration of a digital elevation model (DEM), i.e., the consideration of terrain relief information. This type of image data geo-referencing is called terrain correction geocoding, which is the general equivalent to ortho-photo generation in classical photogrammetry.

Based on a DEM and a consistent imaging model, geocoding was performed in two basic processing steps:

1. Map-to-image co-ordinate transformation: First, for each output pixel which defines a co-ordinate triple (easting, northing, height) in a map projection system the corresponding location in the input image has to be determined.
2. Resampling: Subsequently, a grey value for the output pixel has to be interpolated from neighbouring input image pixels following a selected interpolation criterion, i.e., either
   - nearest neighbour resampling,
   - bilinear resampling,
   - cubic convolution resampling or
   - pixel averaging.

The working procedure for the data geocoding was performed in four steps:

- Data import and definition of an initial imagine sensor model
- Ground control point measurement
- Optimising the parametric image model based on ground control points using least squares adjustment techniques
- Digital image geocoding based on the optimised parametric image model

The geocoding task has been performed for all test sites on all available data sets. Geocoding results in most cases were sufficient with sub-pixel accuracy due to parameter adjustment. Additionally, the overlay of topographic information with geocoded satellite images could demonstrate good correspondence between the data sets. However, results were not completely sufficient in the Engadine test site, where significant deviations occurred in high altitudes, mainly in the high resolution IRS pan image.

Better results in the geocoding process of high resolution digital satellite image data will be possible with a correct pre-processing of the digital image data by the data distributor, a DEM accuracy as well as accuracy of the reference data corresponding to the pixel resolution of the satellite image and a co-registration process of the geocoded images.

The quality of the geocoding results is essential for the accuracy of results of image interpretation and classification, especially when using multi-temporal and multi-sensoral data sets and auxiliary information, as was the case in the subsequent feasibility studies.

2.2.4 Radiometric Correction

Remote sensing data, from space borne or airborne platforms, of land or sea surface in the visible and near infrared portion of the electromagnetic spectrum is strongly affected by the presence of the atmosphere on the Sun-target-Sensor path. The data recorded usually do not represent the exact reflectance from the target surface. This is due to radiometric effects which are partly sensor-related such as instrument calibration, and those which are scene-related such as atmospheric, topographic, illumination and view angle effects, and target reflectance characteristics. All of these effects place limitations on the proper utilisation of the sensed data for targets recognition in the specific application.

In order to optimise information extraction from optically remote sensed data, radiometric correction is necessary to compensate for the effects of (i) illumination conditions at the time of image acquisition, (ii) image observation geometry, (iii) atmospheric phenomena and (iv) relief variations on the spectral signatures of the targets, on the spectral signature of the objects. To correct for these effects, normally, three prerequisites are to be met, namely (i) a radiometric calibration, (ii) an atmospheric model, and (iii) a target reflectance model.

The above mentioned pre-processing requirements are applicable to remote sensing data used in all applications that involve multi-temporal or multi-sensoral imagery. These pre-processing steps are also necessary to the mere conversion of digital counts to radiance or reflectance units.

From the above mentioned facts, it is clear that radiometric correction is a pre-requisite to any accurate quantitative interpretation of remote sensing data. It is one of the basic elements in the image analysis data flow. The major processing categories in it are (i) radiometric calibration, (ii) atmospheric correction and (iii) topographic correction.

2.2.4.1 Topographic Normalisation (WP6)

Since the project focused on applications within the alpine area, pre-processing of image data required the correction of topographic effects. Topography does not only affect the geometric properties of an image but will as well have an impact on the illumination and the reflection of the scanned area. This effect is caused by the local variations of view and illumination angles due to mountainous terrain. Therefore, identical land-cover might be represented by totally different intensity values depending on its orientation and on the position of the sun at the time of data acquisition.

An ideal slope-aspect correction removes all topographically induced illumination variation so that two objects having the same reflectance properties show the same digital number despite their different orientation to the sun's position. As a visible consequence the three-dimensional relief impression of a scene gets lost and the image looks flat.

In order to achieve this result several radiometric correction procedures have been developed. Besides empirical approaches, such as image ratioing, which do not take into account the physical behavior of scene elements, early correction methods were based on the Lambertian assumption, i.e. the satellite images are normalized according to the cosine of the effective illumination angle (Smith et al. 1980). However, most objects on the earth’s surface show non-Lambertian reflectance characteristics (Meyer et al., 1993). Therefore the cosine correction had to be extended by introducing parameters, which simulate the non-Lambertian behavior of the surface (Civco 1989, Colby 1990). The estimation of these parameters is generally based on a linear regression between the radiometrically distorted bands and a shaded terrain model. A comparison between four correction methods, including the non-parametric cosine correction, confirms a significant improvement in classification results, when applying the parametric models (Meyer et al. 1993).

By applying different topographic normalisation procedures in the different test sites, the satellite image quality could be significantly improved with respect to the subsequent classification of the images. In particular the Minnaert correction produced useful results.

2.2.4.2 Atmospheric Correction (WP7)

Generally, the atmospheric effect in optically remote sensed data is characterised by the molecular and aerosol absorption and scattering, other absorption gases like ozone, and clouds. The interaction of light rays from the sun in a ground-atmospheric model consists of the radiance reflected from the atmosphere without reaching the ground, the radiance reflected by the target (it contains the useful information about the pixel of the image), the radiance reflected by surrounding pixels (normally called adjacency effect), and the radiance due to the angular structure of the target surface (i.e. the relief aspect). All the above reflectance are measured by the sensor as the radiance of a pixel element.

For a non-uniform surface sensed by a high-resolution satellite, e.g. Landsat TM, under cloudless conditions the atmosphere reduces the apparent spatial variations of the upward radiance. This reduction is caused by atmospheric diffusion of photons reflected from over bright areas to the field of view over dark areas. If sub-pixel clouds are present they will tend to increase the apparent brightness of the ground-atmosphere system and, hence, the brightness of the image. It is to be noted that thick clouds and cloud shadows are difficult to correct, if not impossible. Land cover classification is affected by these two atmospheric effects, namely, reduction of the apparent spatial resolution and changes in apparent brightness.

These atmospheric effects can be corrected approximately, if the ground-atmosphere interaction system can be modelled accurately enough. Presently two major atmospheric modelling software packages are available: MODTRAN or LOWTRAN (Berk et. al., 1989; Kneizys et. al., 1988) and 6S (Vermote et al., 1995). They compute either radiance or reflectance. Radiance is the quantity that is measured by the sensor in units of Watt per square meter per sterradiance per micrometer and normally scaled to digital numbers (DN) between 0 and 255. Reflectance is a dimensionless quantity and is the radiance normalised. To correct the image for the atmospheric effect, the radiance reflected from the atmosphere, the radiance reflected by surrounding pixels, and radiance due to the angular structure of the target surface are estimated with parameters computable from any one of the above atmospheric modelling software packages. These two software packages do not make the atmospheric correction but only allow the estimation of the atmospheric loading. The actual correction can then be carried out with the estimated atmospheric loading in a separate software code.

Different strategies have been followed within the project to achieve the atmospheric correction. Additionally to the above mentioned software, two methods not relying on local atmospheric measurements, i.e. the *Point Spread Method* and the *Tasseled Cap Method* (Lavreau, 1991; Crist et al., 1986) have been tested. None of the methods provided satisfactory results in the alpine test sites (see discussion in section 3.3.5).

2.2.5 Data Preparation (WP8)

Today's remote sensors offer a wide variety of image data with different geometric, radiometric and spectral resolution characteristics. Although the information content of these images might be partially overlapping the complementary aspects represent a valuable improvement for information extraction. To exploit the entire content of multi-sensoral image data appropriate techniques for image fusion are indispensable.

Within ALPMON two methods were applied that allow the inclusion of features derived from very high resolution panchromatic images into multi-spectral classification. The first method uses object edges from the panchromatic image to sharpen the multi-spectral image, the second method computes texture images to be used as additional bands in classification.

Image Fusion

Examining existing methods for fusion of panchromatic and multi-spectral images, the most common approaches are pixel based techniques. These techniques apply numerical combinations of pixel values (spectral reflectance values), and are often referred to as image merging (Chavez et al. 1991). They include Intensity-Hue-Saturation and Principal Component substitution merging, linear combinations and multiplication of image bands. A comprehensive review on these techniques can be found in Pohl (1996). All these methods enhance the local texture of the multi-spectral image, thus improving the visual interpretability of the fusion results. At the same time they distort the spectral properties of the multi-spectral bands by combining spectral reflectance values of different image bands.

In order to avoid the spectral distortion it is necessary to perform image fusion on a higher level of abstraction. Instead of using the spectral reflectance values represented in the single pixels, the fusion process can be based on image features, such as edges or segments. Within the project a new approach was developed, applying adaptive filters for feature based image fusion. The adaptive image fusion (AIF) method allows the fusion of geometric (spatial) and thematic (spectral) features from multi-source raster data using adaptive filter algorithms. If applied to multi-resolution image data, it will sharpen the low spatial resolution image according to object edges found in the higher spatial resolution image. In contrast to substitution methods, such as Intensity-Hue-Saturation or Principal-

Component Merging, AIF preserves the spectral characteristics of the original low resolution image. The AIF algorithm was implemented as a C program.

A major prerequisite for successful data fusion is the geometric and temporal accordance of the input images. A geometric displacement will lead to undesired artefacts, independent from the fusion method applied. Differences in the time of data acquisition are another source of artefacts because of changes that might occur between the two dates. However, these changes are less critical when applying AIF, as long as they only reflect changes in the spectral characteristic but not in the size of objects.

Assuming no geometric or temporal variations between the images the quality of the fusion process depends on the information content of the images. Low quality of the panchromatic data might lead to poor results because the fusion algorithm will not be able to detect the features necessary for the merging procedure. However, applying substitution techniques to such a low quality image will not significantly improve the results either. The major limitation of AIF lies in the loss of local texture that is present in the panchromatic image. This local variation of grey values cannot be reconstructed in the multi-spectral image without distorting its spectral characteristic. Only edges that appear clearly in both images will be sharpened.

An additional suggestion was the combination of AIF and substitution techniques for visualisation. AIF would then sharpen object edges and thus eliminate the blocky pixel structure of the low resolution image. Next the local texture could be added by applying a substitution technique onto the AIF processed image, thus leading to a sharpened high resolution multi-spectral image product. However, this product is not considered an appropriate input for numerical classification but offers an excellent visual impression of the area. The latter approach was successfully applied to the Tarvisio test site.

Texture Features

Very high spatial resolution panchromatic images contain a large amount of objects. In order to recognise these objects the human visual system does not only rely on the intensity of single pixels but on the spatial variation of these intensities, in general called texture. In contrast to the parameter tone, which is defined by the intensity of a single pixel, texture has a higher degree of dimension. This degree is not limited by the two dimensions of the image matrix but also includes the different characteristics of texture. Using human language texture might be described as rough, smooth, granular or by similar expressions. But these lingual descriptions lack a formal definition of texture. Therefore most methods for its characterisation are based on the intuition and perception of the individual investigators (Irons and Petersen 1981).

This task concentrated on the use of second order statistics using grey-level co-occurrence (GLC) matrices. This method was originally proposed by Haralick et al. (1973) who presented a set of textural features that can be derived from GLC matrices. These textural features have been successfully applied in order to improve automatic classification of remotely sensed imagery (Franklin and Peddle 1990, Webster and Bracken 1992, Pyka and Steinnocher 1994). In order to transfer the information content of the GLC matrix to one representative value so called texture features have been defined. Haralick et al (1973) present 14 different texture features that can be derived from GLC matrices. We concentrated on two of these texture features which have been used successfully in various applications: the Inverse Difference Moment (IDM), which uses the grey-level differences for computing the weighted sum of the elements, and the Contrast (CON), which leads to similar results except for the inverse use of the weight factor. Both are not too sensible to image noise.

In order to obtain a texture feature image texture is computed in a moving window. In every position of the window the GLC matrix of the local neighbourhood is computed and a texture feature value is derived that is written to the new image. The result of this operation is a digital image where the single pixel values represent the degree of texture in the local neighbourhood. Undirected texture images were derived by combining such texture feature images computed in 4 directions of the basic image. The resulting texture image is rotation invariant, differentiates homogeneous and heterogeneous objects but does not represent edges This image represents a valuable input to any classification algorithm.

The algorithms for computing the four texture features in the four main directions were implemented as C programs. The texture analysis process was implemented in the Modeler of ERDAS Imagine™. It could be successfully applied to the alpine test sites, providing valuable information especially on settlements, roads, rivers, ravines, non-vegetated area and snow.

2.2.6 Classification (WP9)

Numeric, computer-based classification methods take aim to group the pixels of a grey value image into spectral signatures and mark them as thematic classes quantitatively and/or in thematic maps (Hildebrandt, 1996). A large number of investigations demonstrated that simple classification algorithms, such as maximum-likelihood and threshold-level procedures, represent a highly efficient and solid method for the compilation of land utilisation data and vegetation forms, even in high relief terrain (Schardt 1990, Schardt and Schmitt 1996). In order to ensure that classification procedures are maximally efficient and effective it was, however, necessary to employ only common classification techniques which have been tested and proved suitable for use in alpine environments.

Classification in the test sites had to fulfil the requirements of the local as well as the European customers. This was taken into consideration with the selection of special classes for each application (compare WP12, section 2.3). However, classes which had been defined as common classes within ALPMON (compare Table 1) turned out to be not existing in some test sites and therefore could not be classified. This is true for example for broad-leaved forest, which in some test sites only occurs in form of green alder shrubs. In some test sites age classes could not be separated, as the natural type of forest has mixed age, whereas e.g. in the Dachstein area the managed forest is generally dominated by a common age category.

Due to the different customer needs, the main focus of the classification effort was quite different in the test sites. Whereas the needs of the local customers of the Tarvisio test site concentrate on value added satellite image products and classification was performed mainly with respect to the Alpine Convention and CORINE requirements, in other test sites the outcome of satellite image classification is essential for the local customers. Here, main focus was put on the categories required by the local customer, such as tree species composition in the Engadine National Park, or different non-forest vegetation density in the Cordevole test site.

According to the heterogeneous test site characteristics and the varying reference data sets also different classification methods were chosen. A Maximum Likelihood classification was performed for the Tarvisio, Mangfall, Dachstein, and Engadine test sites. Thresholds were applied in nearly all test sites, partly for classification of the forest border, partly for the entire classification. Furthermore, in the Cordevole and the Engadine test site diverse unsupervised classification algorithms were used. Some classifications were performed in hierarchical manner. A forest / non-forest separation preceded the separate classification of forest parameters and non-forest categories respectively in the Tarvisio, Dachstein, and Cordevole test sites. For the Mangfall test site a completely hierarchical approach was applied. Most classifications were based on detailed signature analyses.

Additional information, such as a DEM, GIS data layers, or digital map layers, was integrated in the classification process in some test sites. On one hand classes, which could hardly be classified with sufficient accuracy from the satellite data, where substituted by the auxiliary information sources. For example in the Dachstein test site the water layer of the digital topographic map was used instead of classification of water bodies, as these would partly get mixed up with purely illuminated coniferous forest. Furthermore, streams could not be classified due to their representation in mixed pixels together with bank vegetation. On the other hand the auxiliary data supported classification itself by establishing rules for selected classes (e.g. sealed surfaces do not occur on steep slopes).

Partly, additional features derived from the high resolution satellite data sets (see WP8) were integrated in the classification process. Texture features were used for the delineation of sealed surfaces in the Dachstein and Cordevole test sites. The forest / non-forest separation in the Dachstein test site was based on a fused Landsat TM/Spot pan image.

2.2.7 Verification of Classification Results (WP10)

The verification phase was intended to give evidence on the quality of the classification results (Congalton, 1991). The results of the verification are confusion matrices for each classification giving true error rate estimates for each class and for the total classification. The accuracy of the classification results was determined for all classified parameters based on the ground information collected at each sample plot. The statistical analyses of accuracy included Kappa statistics, confusion matrices, regression analyses of observed versus estimated values, etc.

All analyses of classification results were based on the use of an error matrix or contingency table. It is a very effective way to represent accuracy, in that the accuracy of each category is plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the classification. Error matrix can be used for a series of *descriptive* and *analytical* statistical techniques.

The applied verification methods varied somewhat from partner to partner. During the Partner Meetings in Freiburg (December 1998) and Munich (June 1999), it was decided to carry out pixel- and stand-wise verification. In general, better statistical accuracy measures were produced for the stand-wise verification method. There was one exception though, were this was not the case, which could be due to the selectively small number of stands available.

All in all, the forest stand and non-forest classification accuracy differed from test site to test site (Table 3). For example in some test sites, tree species, age classes and crown coverage could not be differentiated as the forest composition was very heterogeneous as to allow a satisfactory forest stand extraction. Specifically, most partners had problems classifying dwarf mountain pine with the satellite imagery available and their respective spatial resolution.

Table 3: Variation of mean classification accuracy and Kappa coefficient in the different test sites.

Parameter	Mean classification accuracy		Kappa coefficient	
	worst result	best result	worst result	best result
Forest / non forest	70 %	97 %	0.47	0.93
Forest type (3 classes)	52 %	93 %	0.33	0.78
Forest canopy closure (3 classes)	52 %	86 %	-0.02	0.75
Forest age (3 classes)	47 %	80 %	0.24	0.60
Non forest land cover	52 %	92 %	0.47	0.89

With this, a statement on the general accuracy of the resulting maps could be made and the maps finally could be compared across the test sites. However, subjectivity is induced in the verification results by the choice of reference data sampling size and strategy (Smits et al., 1999).

2.2.8 Data Integration into ALPMON (WP11)

To ensure the accessibility of the results of ALPMON some efforts have been made to set up a common database for the different processing steps of the remote sensing data.

The parameters of the training regions for classification are stored in a MS ACCESS database with additional meta data which describes the interpreter as well as the accuracy of the data. These parameters were harmonised for all partners during the first project meetings and can be found in the report of WP3. There is one database for each test site which stores the corresponding data.

To set up a common system for the results of classification for each test site a general colour and numbering scheme was set up and can be seen in Annex 7. This enables the comparison of the classification results respectively maps from all test sites, which is especially valuable for the customer on European level, i.e. the Alpine Convention.

All results of the ALPMON project are registered to the local co-ordinate system of the corresponding test site. Additional transformation parameters to the UTM co-ordinate system are given by each partner for their data.

A CD-ROM will be compiled which will store a description of the project, all reports and the resulting data as GIF- or JPEG-images with short descriptions. This CD-ROM will be delivered soon after delivery of the final report.

2.3 Implementation of ALPMON (WP12)

All previous tasks were performed with respect to the results required by the Alpine Convention as well as the requirements of the national customers. In order to test the performance of the remote sensing based alpine monitoring system and demonstrate its potential for divers alpine questions, specific applications have been performed in close co-operation with the national customers in the following fields:

- Tourism and remote sensing
- Hydrological modelling of water run-off
- Support of avalanche risk assessment
- Erosion risk assessment
- National park management and research.

Another application task was to aggregate the parameters classified in ALPMON to the CORINE land cover nomenclature in order to make both data sets compatible. With the previous work packages an advanced basis has been established, thus, enabling proper application in the test sites according to the customers needs. The feasibility studies are described in summary in the following. A detailed description of these applications is given in the report on WP12.

2.3.1 Remote Sensing and Tourism, Tarvisio Test Site (ALU)

2.3.1.1 Introduction and Objectives

The test site is located in Italy on the border to Austria and Slovenia and covers an area of about 46 000 ha, around the main valley Val Canale. In this region most of the people are interested in promoting tourism. Investments in new hotels, new infrastructure for downhill skiing, new streets and railways were made and more will be made in near future. The area around Tarvisio is also applying for the winter Olympic games. Therefore it is to be expected that the construction of buildings and the opening to tourism will be even more intensified, which again will result in an increased pressure on nature.

The Department of Remote Sensing and Landscape Information Systems at the University of Freiburg is working together with the Forest Administration and the Tourist Administration of Tarvisio, Italy. According to these two customers, there are different tasks to be fulfilled. The requirements of the Tourism Administration can be divided into three topics. Number one is the use of remote sensing and geographic information systems (GIS) in tourism information. Number two concerns the use of remote sensing and GIS for some planning tasks and number three is related to advertisement and publicity.

In the field of tourist information and publicity the processed remote sensing data can encourage the tourist to appreciate the beauty and uniqueness of the landscape in this region. The data can simplify the interactive planning of his stay and his activities in the landscape. The attractiveness of a region can be represented in a way, which may have positive effects on the support of tourism. For this purpose, the following items were developed: The main task was the development of a landscape-related information system for tourists. For tourist information and for publicity purposes the visualisation of the landscape with the aid of digital data in realistic 3D-views and virtual fly throughs were generated. Additionally, thematic maps were produced.

With respect to planning tasks methods were developed by means of geographic information systems in order to provide information about the considered region. They should be used in analyses concerning the present situation and the previous development of the landscape as well as the touristic infrastructure. This information is the basis for the estimate of future trends of development. It offers the possibility to arrange the planning more efficiently.

The feasibility study shows how to monitor the changes of the extension of alpine pastures in the last 40 years. The 'asset landscape' should be observed for a long time in order to obtain information about its state and modification tendencies. As already mentioned, not only the natural landscape but also the man-made landscape with its particular mosaic of forest and open areas is of big interest for tourism, especially hikers. Therefore, this kind of change detection can be a valuable input for tourism planning.

In the same way, the limited use-capacity of alpine nature and the sensitivity of fauna and flora should play a decisive role in the planning of landscape-related tourism right from the start. This aspect was treated in the current work. The investigation had to go beyond pure incorporation of data from other disciplines but show, through systems analysis, how sensitive landscape areas can be pinpointed. By using the above method conflicts with other interests can be foreseen and excluded in the process of tourism planning. Additionally, the possibility for the analysis of the infrastructure should be demonstrated by way of example for roads and trails.

All developed methods can not guarantee a solution for the conflict between nature and tourism. But they may offer the possibility of comprehensive and efficient spatial planning to the responsible authorities: the Tourism Administration and the local politicians.

The second customer of our department, as mentioned above, is the Forest Administration. For the Forest Administration the main requirement is to have information about "land cover" (classification results of the satellite data) and the analysis of the landscape with regard to suitable habitats for the ibex that has been reintroduced in this area some years ago. Additionally they wanted information about aspect and slope of their region. Furthermore, they showed interest on thematic maps that were created on the basis of satellite data.

During the project the Department of Remote Sensing and LIS could gain the Comunità Montana at Pontebba as a third customer. They were very interested in the monitoring of the alpine pastures that originally was carried out for the Tourism Administration.

The use of remote sensing for these tasks was various. Not only satellite image classification results were needed but also a fusion image that is able to represent the complexity and, at the same time, the beauty of the landscape. The specific requirements and the differing use of remote sensing to fulfil them is described in the following chapters.

2.3.1.2 User Requirements

Since the Department of Remote Sensing and LIS at the University of Freiburg has more than one customer the requirements will be presented according to the single customer.

During the project a new customer was interested in the work of ALPMON. The Comunità Montana at Pontebba, Italy, was very interested in the landscape monitoring that was one of the requirements of the tourism branch. Therefore, a new customer is considered in the following list of the requirements.

Tourism Administration

- information: ideas for a tourist information system (hiking)
- publicity / advertising
- analyse landscape:
  - land cover classification
  - monitoring of landscape changes
  - information about sensitivity of landscape - as example 'potential habitats for the alpine ibex - a systems analysis
- Analyse the infrastructure
- planning recreation activities (hiking)

Forest Administration

- land cover classification
- aspect grid
- slope grid
- Potential habitats for the alpine Ibex - a systems analysis

Comunità Montana, Pontebba

- monitoring of landscape changes

2.3.1.3 Applied Methods and Implementation of Remote Sensing

For the different user requirements the classification results of the Landsat 5 TM scenes were used: first of all to describe the land cover that was of interest for forest and tourism tasks. Furthermore the classification of forest, meadow/pasture, rock/gravel and others were used in the systems analysis concerning potential habitats for the alpine ibex. For the tourist information system the crown closure classification was of interest.

To meet the other requirements a fusion image was processed. The first three channels of Landsat 5 TM were combined with the panchromatic KVR-1000 image that shows a ground resolution of 2 m. The result looks like an aerial photograph without the tiles of the Landsat pixels:

STEINOCHER (1999) developed a new fusion method that is described in the report to work package 8. This fusion method shows the visual effect that the pixel-structure of - in our case - Landsat 5 TM images were resolved and the form and extent of the objects is fitted to the high resolution (KVR-1000) image objects. The combination of this AIF-filter and the known IHS-Transformation is a perfect possibility to get photo-realistic images of the landscape. The combination of these methods is described in the report to WP12. It is roughly illustrated in Figure 3.

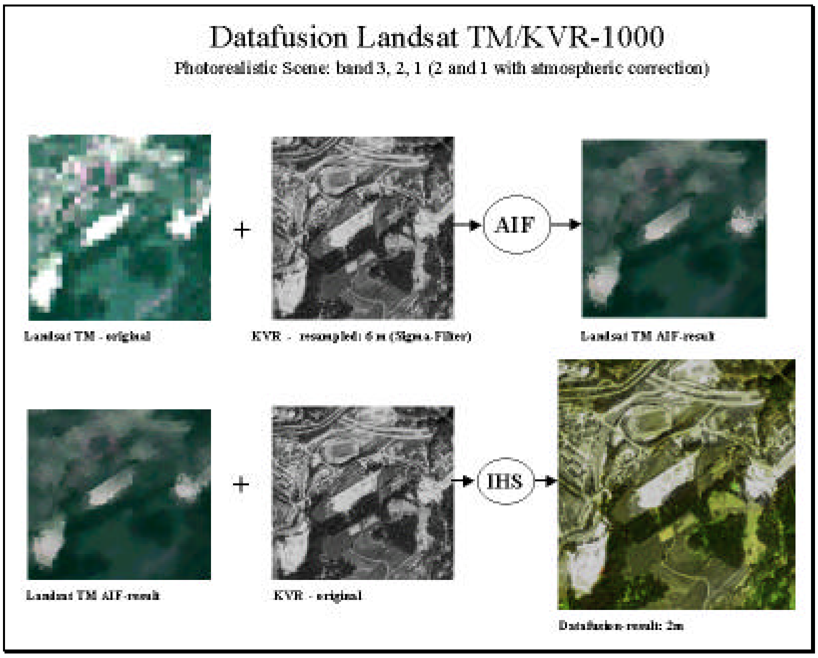


Figure 3: Overview of the used fusion method; original data: Landsat 5 TM and KVR-1000

Together with pre-processing (report to WP 8 or 12) a photo-like image is developed. This fusion image was used for visual interpretation (monitoring of landscape changes), as background (visual information) in the tourist information system and for visualisation tasks like a 'fly through'.

2.3.1.3.1 Task: tourist information system for hikers

Tourists who come to the area of Tarvisio are mostly hiking tourists. The main season for visits is the summer. Therefore, the main attention was given to "hiking-tourism". For hiking-tourism it is shown how remote sensing data and GIS technology can be used for tourist information. An information system was developed that allows the tourists to choose routes freely and get further information for these. This additional information is the altitude profile of the trail, how much of the trails length lies on ground with a particular aspect, and how much of the route goes through forest or open area.

A tourist information system is an open system: More ideas can be added. Further ideas, also with regard to local public transport service, are given by FISCHER (1998) and FISCHER et al. (1998). For example, the Swiss hiking trails SAW asked a company to develop an information system that allows management and analysis of their hiking trails. As a result, this information system is used not only by the administration but also for tourist information (KROMER et al. 1999). ZIPF (1999) attempted to interest the tourists in the history of the city of Heidelberg with three-dimensional city sceneries from different eras.

Such an information system can be used in a variety of ways and places: It can of course be made available at the Tourist Office in the region itself; it could be used via Internet or in travel agencies. The presentation in the Internet or travel agency would demand different software. These would have to be "stand alone" solutions.

The example introduced in this report was developed in order to show up some possibilities. In this part of the application study for ALPMON, both the fusion image and the classification result 'crown closure' were used. The information system was build up with ArcView 3.1. The surface adaptation was created with the dialog designer, the programming was done with the ArcView-inherent language AVENUE. Further information can be requested with the persons responsible at the University of Freiburg.

Result:

Figure 4 is meant to give an impression about the possibilities of the developed hiking information system. A hiker has now the possibility to choose a hiking route by himself. For this purpose, he touches the button "Routen wählen" (choose route). A menu then appears that helps the hiker to lay out his route and get further information about that route. Several routes can be chosen. These hiking routes can be chosen freely. Points wished to be reached should be marked here. At least a starting- and an end point must be chosen. Additionally as many intermediate points as desired can be set. In this way some routes can be tried out by the tourist. The chosen routes are listed behind the item 'Routen:' (routes:) in a dropdown menu and can be called again separately. Under the dropdown menu in which the individual routes are listed, the routing distance is announced for the selected route. The routes are tracked in the background with the network analysts function 'Find Best Route'. This function searches the shortest connection between the chosen points.

After a route has been laid out further information about it can be asked. In our example, the following possibilities were programmed: Profile chart, exposure and shares of forest / open land. Latter describes how long the route leads through closed forest, open land and so forth. The same is computed concerning exposure. The altitude profile gives a view of gradients, differences in levels and its distribution on the route (Figure 4).

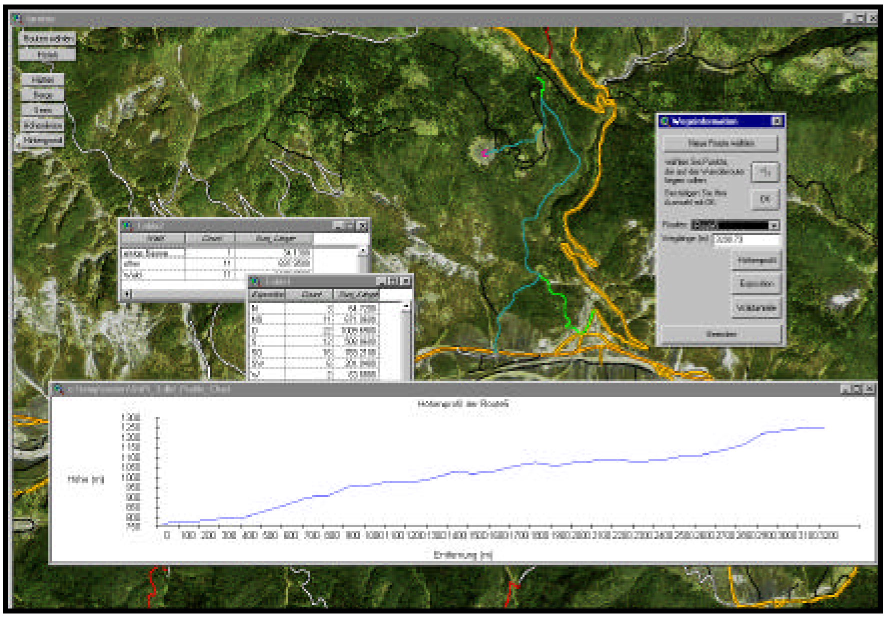


Figure 4: Information about the selected hiking route: Length of the way, altitude profile, aspect and density of the forest along the route

Further possibilities were included into the tourist information system. For different vantage points, landscape photographs which show the view from this point in a specific direction were imitated virtually and three-dimensionally. This is a possibility to give the tourist an idea about morphology and landscape of a smaller area.

These 'photographs' can be called up via a hot link theme. The three-dimensional photos were constructed with ER-Mapper and stored in tiff format. Without larger effort digital photos from the landscape can be made. The angle of view can be chosen freely. Whether the stand-point is the ground or a helicopter flight view is desired is unimportant for this technique.

Information on the places of excursions was also linked via Hotlinks. As an example, information about the huts can be obtained. Photographs can be viewed as well as possibly the opening hours and the menu.

Another possibility exists for hotels, restaurants or businesses. It would be possible to have a direct link to the homepage of this companies so that booking a hotel room may be done directly. With these parts of the tourist information system, advertising can be done. These are possible sources of revenue in order to finance such an information system.

2.3.1.3.2 Task: publicity / advertising

A good possibility to put forward the tourism region and to give a first impression of the landscape is to show a 'fly through'. The viewer can enjoy the local landscape as though he was flying over the region by helicopter. At present there are several software packages available that can generate a 'fly through'. Such a 'fly through' was computed for Tarvisio. The computer simulates the area of interest with the aid of the fusion image and the digital elevation model and computes a virtual flight over this image. For this purpose, the fusion image was resampled to 6 x 6 m ground resolution in order to reduce the required storage space without loosing too many details. The design of the 'fly through' was made by a marketing company. Here it was possible to install effects such as a slow change-over from one sequence to another. The video lasts about 3 minutes and requires as an avi file 100 Megabyte storage space.

Through producing virtual landscape photographs and 'fly throughs' remote sensing data can be used for publicity purposes. They provide a very good impression of the landscape and, together with a digital elevation model, the morphology. However, the remote sensing data can also be used very well as background for hiking maps and other thematic maps. Satellite images increase the attractiveness of these maps and, with a suitable print quality, can at the same time represent the various structures of the landscape. For the Forest Administration analogue maps were printed which show the fusion image as background. As additional information, the streets, trails and the place names were added. A survey map of scale 1:50 000 and a more detailed map of scale 1:25 000 have been produced.

2.3.1.3.3 Task: land cover

A description of the present land cover was required by both customers: the Tourist and the Forest Administration at Tarvisio.

The satellite image classification has already been described in detail (reports to work packages 9 and 10). The customers were satisfied by the results of the classification. Though there have been some lacks: the shaded areas could not be classified; sealed surface could not be separated from rock. However the classification results show a good view of the present situation in the test site.

2.3.1.3.4 Task: Monitoring of forest /open land - example: alpine pastures

For landscape related tourism, open areas are very important. They liven up the forest areas, they give the possibility to rest on blooming meadows and last but not least they give the chance to admire the panorama. However, natural open areas only occur in high areas (alpine meadows). Below the timber line, nearly all open areas were made through agricultural use and therefore build a man-made landscape. The difficult situation of agriculture in the Alps resulted again and again in areas that are given up. The result of giving up these areas is the recovery of forest.

In order to see, whether modifications occurred in the last decades, the fusion image of 1992 is compared with black and white aerial photos of 1954. In this way a period of four decades could be investigated. As an example the evolution of the alpine pastures were chosen. This example interested all of our customers: the Forest Administration at Tarvisio (concerning the increase of forest) and the Tourism Administration (concerning the loss of open land). In addition the Comunità Montana at Pontebba was very much interested in the changes of the alpine pastures.

Three different classes were measured: pasture, succession and forest. The succession and forest areas have to have at least 0.1 hectare. Areas with 10 to 30% of tree stocking were defined as succession. Forest is defined as area which are at least 30% covered by trees. Within succession and forest there areas without stocking were delineated if this area has at least a size of 0.1 hectare.

Result:

In fact there occurred a clear landscape modification in the last 40 years. Almost on all alpine pastures, a clear increase of forest could be observed. An increase of pasture did nearly not occur. Only on single plots there is an expansion of the pasture. A good example is the alpine pasture "Goriane". The increase of forest is clearly to be seen. In the northern part there is a slight increase of the pasture to the east and west: an exception as mentioned before.

In total the pasture has lost approximately 170 hectares. That corresponds to 35.5% of the pasture area of 1954. The entire area of successions only increased insignificantly. It is to be found on about 65 hectares 1992 and on 62 hectares in 1954. That means the decrease of the pasture area has almost gone completely for the benefit of the forest.

The ortho-rectification of the aerial photos would have been more precise if the original photos could have been used. Using a specific scanner would minimise the distortion. However, it is considerably more economic to use normal scanners. For the aim 'monitoring of landscape modifications', this low-cost method is sufficient since no highly precise measurements are necessary. The problem of the missing camera calibration and the lack of older topographical maps for getting control points has been considerably more seriously. Due to the inaccuracies, clear differences have to be proved in order to be able to talk about landscape modification. Therefore, all information was only given in hectares. More precise statements are not possible on the basis of the available data. However, the landscape modifications are engraving in the last 40 years. This could be clearly proved in spite of the not optimal data basis.

Sometimes forest stands could not be seen in the KVR-1000 image. Because of the bright lime and dolomite subsoil there situated vegetation was over reflected. In some parts of the alpine pasture M. Piccolo and Lussari this problem did occur. Here the delineation of forest and succession areas could only by achieved by the additional use of CIR aerial photos.

2.3.1.3.5 Task: Alpine Ibex - a systems analysis

The ibex (Capra ibex L.) was reintroduced in Tarvisio some years ago. The Forest Administration does not have sufficient information about the habitat quality in the high mountain areas and therefore, it can not be said whether the ibex already inhabits all suitable areas or if an expansion of the population is still to be expected.

To carry out a systems analysis which shows suitable areas for the ibex the main data sources are the classification results and the digital elevation model. The classification results supply information about the vegetation and the non-vegetation areas. The CIR aerial photos available from 1992 were used in addition to check whether there is vegetation in the rocky areas. With the digital elevation model, aspect, slope and exposition to sun were calculated.

The analysis is made with the support of Prof. Dr. SCHROEDER (1999), Ludwig Maximilian-University at Munich and of Dr. PEDROTTI (1999), Italian Wildlife Institute at Bologna. In addition the description of HINDEL and NIEVERGELD (1995), OHLAND (1993), ELSNER-SCHACK (1982), BAUER (1982) and KOFLER (1982) were used to find the requirements of the ibex. WIERSEMA went into the use of remote sensing and GIS for the habitats analysis for ibex (STEFANOVIC and WIERSEMA, 1985; WIERSEMA 1983 (a); WIERSEMA 1983 (b)). GENTILLI (1964) could supply general information on the climatic factors in the Test site of Tarvisio. The Forest Administration at Tarvisio gave information about the areas in which they observed the ibex in the last years (RUDOLFI, 1998).

Result:

Areas that are good or very good for winter and summer habitats can be found inside the test site. Bigger areas can be found outside because the border of the test site is mostly formed by mountain ridges. In the south the south exposed side of the mountains are outside the test area. It is to be expected that the ibex will cross these borders.

There are some areas that could not be evaluated. These areas resulted out of the classification of 1984. They represent shaded areas that could not be classified. Therefore no information concerning the land cover are available.

These results show that the ibex has the possibility to expand, most likely to areas outside the test site. The smaller areas in the north will not be occupied because they are separated by the main valley Val Canale that most likely will not be crossed by the ibex.

The comparison with the observations of the foresters of Tarvisio showed that this landscape evaluation tends to be right. It can be used to get a view of the situation in the test site concerning possible ibex habitats. But, because of the resolution and the accuracy of the classification of the Landsat 5 TM scenes, it should only be used in a small scale (max. 1:25 000). It will not be detailed enough for a scale of 1:10 000.

Another problem is the lacking literature about the temperature the ibex prefers. The evaluation of the altitude - decreasing temperature with height - is only an approach. It would need some more discussion to find a good evaluation. Therefore the evaluation concerning the summer habitat shows the right tendency but not a final delineation.

2.3.1.3.6 Task: Analyse infrastructure

For the construction of the hiking information system all roads and trails were digitised. In the report on work package 12 it is shown how these trails can be analysed with the aid of GIS. Information will be given for example about the density of the road and trail network and if settlements and huts can be reached by hiking trails and/or roads or not. To meet this requirement no remote sensing data were used. It is based on the digitised information and GIS analysis.

2.3.1.3.7 Task: Planning Recreation Activities

The data described up to now allow a landscape assessment to find suitable areas for different tourism activities. For example, the information about aspect and slope together with additional geological information can help to find new places for ski runs or ski lifts.

In our area we took a closer look at the hiking tourism. A hiking information system was created. New hiking routes can be chosen and described with the aid of GIS and remote sensing data. This hiking information system can be used by the Tourism Administration to find out new route advises or it can be used by the tourists themselves for planning their tour for the day. Hiking tourists can choose new routes independently of the suggestions of the Tourist Office and get information like way length, altitude profile, aspect or forest or open area along the trail.

2.3.2 Modelling of Water Run Off, Mangfall and Sulm Test Sites (LMU, JR)

2.3.2.1 Introduction and Objectives

All land utilisation changes, irrespective of whether they are the result of set aside policies, or damage to forests, e.g. uprooted trees due to gale-force winds, are likely to effect the hydrological cycle and the quality of the water. Liebscher (1991) further stated that regional climatic changes may also have an impact on the hydrologic balance of surface waters in Central Europe. In alpine areas increases in temperatures are expected to affect snow melt periods and also the altitudes up to which snow is likely to melt, which again is likely to represent an additional hazard potential, as e.g. due to higher volumes of runoff.

The hydrological problems to be solved or at least bypassed are identified by Braun et al., (1997) to be related to the extreme heterogeneity of surface and underground to be handled. Consequently hydrological models require very different parameters like duration, intensity and sequence but also the cluster and cell size for precipitation, water net structure, topography/relief, land use, soil and geological characteristics.

Alpine conditions represent a special challenge for water run off modelling. The complexity of the interrelations between interception by vegetation coverage, infiltration into the soil, surface run off, precipitation history, temperature, snow coverage and snow melt u.s.o., as well as the effects of soil condition changes (e.g. soil pore volume changes) following the defined reduction of crown coverage by selective logging have been studied in detail over a time period of around ten years in the frame of a research project funded by the German Ministry of Research and Technology (Breitsameter et al. , 1993, Breitsameder, 1996, Moeschke, 1998).

Further important aspects are data acquisition and processing as well as data preparation (analysis, filtering, regional adaptation), i.e. the entire range of tasks from pre-processing to the development of files for model-specific parameters and records. One of the reasons for this emphasis on the availability of data is that many of the available models have proved unsuitable for practical applications because data was not sufficiently available. It would therefore be advantageous if in future only models were used which can be easily adapted to any given catchment area and do not require lengthy and costly periods of data measurement and acquisition before each new application.

Generally, precipitation-runoff-models like TOPMODEL (Beven, 1994) or WaSiM-ETH (Schulla, 1997) are used to describe run-off patterns as well as material displacement caused by erosion-inducing precipitation in medium-scale catchment areas (AGNPS 3.65 - Agricultural Non-Point Source Pollution Model (Young et al., 1989); GAME - GIS - supported run-off model based on precipitation events; Bayerisches Landesamt für Wasserwirtschaft, LfW). They are employed to describe current water and material movement, to predict future movement patterns and to forecast specific events (floods).

ASGI, german **A**bfluß (water run-off), **S**tofftransport- (material displacement) Modellierung (modelling), using **G**eo **I**nformation Systems, is a complex, modular based hydrological model which is based on the TOPMODEL approach and is integrated in a GIS environment. It belongs to the group of "distributed models". ASGI is developed to calculate run off processes and solid matter fluxes in meso-scale hydrological catchments with high temporal and spatial resolution. ASGI describes in grid elements the components of water cycle and facilitates to model decisive processes of the precipitation run off as following (Molnár & Kasper 1998), e.g.:

- interpolation of point coded meteorological input data to be implemented in grid data model
- storage of water by soil and vegetation and the resulting reduction of evaporation
- storage of water by snow cover
- snow melt induced water run off
- infiltration of water into soil and formation of land surface run off due to surplus of infiltration run off concentration in the drainage water network.

The ASGI model can be applied for river catchment areas with a size of 1 km² to several 1000 km².

For running the ASGI model topography and land use are of particular importance. While the topography parameters can be derived from digital elevation models (DEM) within GIS (Braun et al. 1997), the present land use should be extracted from operational satellite data classification.

ALPMON thus provides the land utilisation data and entry parameters that can subsequently be integrated into the ASGI model or a global model derived from it. It also specifies all requirements with regard to the model parameters. ALPMON data represent a relatively cost-efficient system that makes available initial parameters for regional hydrological and sedimentation analyses, and even takes into account changes in vegetation cover and land utilisation patterns over time (monitoring aspect). No additional digitalisation is necessary to prepare data and classifications derived from satellite images so that they can be directly entered into the model.

2.3.2.2 User Requirements

Two customers have been involved in the feasibility study of water run-off modelling, the Bayerische Landesamt für Wasserwirtschaft (LfW; Bavarian State Office of Water Resources Management), and the Styrian government, Section of Water Resources (Steiermärkische Landesregierung, Referat für Wasserwirtschaft). Subsequently, the feasibility study has been performed in two test sites: the Mangfall test site in Bavaria, Germany, (by LMU) and the Sulm test site in Styria, Austria, (by JR), each concentrating on specific aspects of the ASGI model application.

The ASGI model requires many different parameters describing local climate variables (precipitation, temperature, irradiation), topography, geology, soil (type, pore volume, etc.), land use / land cover, etc.. These factors influence the amount of water run off in a different way in temporal and spatial distribution. The following data are at least requested for the complete simulation of the water run-off / material transport simulation with the ASGI model (Kleeberg & Becker, 1998):

1. precipitation/water run-off process
    - area related data (grid format):
        - digital elevation model (DEM)
        - land use
        - soil type
    - time series (daily mean values)
        - precipitation
        - temperature

- run off amount from pour points (for result verification)

2. material transport model disconnected from the water run-off model:
   - area related data (grid format):
     - DEM
     - land use
     - soil type
     - boundaries of administrative units
   - time series
     - precipitation (hour values from meteorological stations)
     - fertiliser distribution data and crop rotation information on community level
     - sediment and phosphorus load (for calculation control)

Mangfall test site

In the Mangfall test site the aspects of data preparation, data analysis, and data input were treated. The data requirements of the customer LfW to be delivered in the frame of ALPMON covers the two parameter groups: topography and land use. The topography parameters to be extracted by GIS data evaluation are slope, exposition, catchment area, elevation as well as the shading by mountains, which is limiting the fPAR and affecting the evapo-transpiration and in general the radiation flux. To provide the land use input parameters for the ASGI, the project started with the maximum demand of the 19 land use classes as resulted from the investigations of the LfW in the hilly environment of the Vils test site (Molnár & Casper, 1998).

Sulm test site

In the Sulm test site, main emphasis was put on the preparation and implementation of additional information, such as meteorological parameters and soil maps, as well as the performance of ASGI for a selected time period. The Section of Water Resources of the Austrian Province of Styria was interested in testing whether the ASGI water run-off model is appropriate for integration into the flood information service of Styria. An important additional prerequisite of this customer was, that the model requires only data which are already available for the whole province of Styria, or data which can be acquired with limited financial and time effort for the whole country (total area of Styria: 16.400 km^2).

The result of the Sulm test site study is a complete demonstration of the ASGI water run off model including a comparison of modelled and measured water run off.

2.3.2.3 Implementation of Remote Sensing into the Model

The programming system ASGI consists of the 4 main modules

- Data management (Datenmanagement)
- Data preparation (Präprozessor)
- Data processing (Prozessor)
- Data presentation (Postprozessor).

The module "Data Management" includes

- the project- and variant specific database management
- the fast input of external data (including data check) and
- the optional data storage and restoration.

This module offers the interface to ALPMON caused by the need for grid-based data. The Bavarian State Office for Water Resources has the opinion, that the requirements can only be satisfied by using remote sensing data.

The implementation of remote sensing into the model is provided for the present land use / land cover information. Looking forward to the high resolution satellite data of the future and the resulting need on high precision DEM for pre-processing this data, DEM generation from stereo satellite image data is a second link between ASGI (or more general, water run off models) and remote sensing.

2.3.2.4 Run-off Modelling with ASGI (Sulm Test Site)

The methods described below were selected based on the user requirements and the data layers needed for the water run-off model. In ASGI a so called ‘pre-processor’ module is used for the preparation of the spatial and temporal data. This comprises in a first step the conversion of the various data layers into the formats required by the model.

The structure of ASGI is modular (based on the methods of the WASIM-ETH model), and often several calculation methods are offered to the user. In the project performed for the Section of Water Resources of the province Styria following approaches have been used:

- Interpolation of meteorological input data by application of Inverse Distance Weighting Interpolation (IDW);
- Calculation of potential evaporation after Hamon (Federer & Lash, 1983)
- Estimation of the interception storage capacity dependent on leaf area index and degree of vegetation coverage, based on the landcover classification results
- Infiltration model after Peschke (1987), based on Green and Ampt (1911)
- Soil model: saturated area approach using the topographic index after Beven and Kirkby (1979).
- Runoff separation into surface runoff, interflow, and baseflow
- Routing of surface runoff by subdivision of the basin into flow time zones combined with a single linear storage routing.

2.3.2.5 Results from Mangfall Test Site

The results of the investigations delivered to the customer LfW are of two categories:

- Methods, applied to derive the information needed to run ASGI from remote sensing data, and
- the results of data analysis, ready to be implemented into ASGI.

The second point covers remote sensing as well as GIS data evaluations.

In Table 4 land use classes as requested for the ASGI model of the Bavarian State Office of Water Resources Management are compared with the classes delivered by the ALPMON classification:

Table 4: Requirement of the Bavarian State Office of Water Resources Management versus distinguished land use / land cover classes in the Mangfall test site, Bavarian Alps.

Requirements Of the Bavarian State Office of Water Resources Management	**Distinguished Land use / land cover classes from satellite data evaluation in the frame of ALPMON**
Forest type:	**Forest type:**
• coniferous forest	• coniferous forest (inclusive dwarf mountain pine)
• deciduous forest	• broad-leaved forest
• mixed forest	• mixed forest
Non forest type:	**Non forest type:**
• fallow shrub land	not present in test site
• summer grain	not present in test site
• winter grain	not present in test site
• maize (normal)	not present in test site
• special maize (German: Mulchsaat)	not present in test site
• row crops	not present in test site
• fallow farmland	not present in test site
• grassland permanent	• meadow
• grassland temporary	• meadow
• grassland poor	• meadow
• grassland fair	• meadow
• grassland good	• meadow
• water	• water
• moor	• swamp
	• non vegetated areas, natural (rock/boulder/gravel)
	• green urban area
	• trees in urban area
Artificial surfaces:	**Artificial surfaces:**
• light built up area	• settlement low sealed

• densely built up area	• settlement high sealed
Additionally:	• non vegetated areas, artificial (e.g. parking lots)

Some land use classes are missing in the Alps, e.g. cultivation of grain, other land cover types have to be introduced, especially the natural non vegetated classes rock, boulder or gravel.

Grid size simulations show no significant changes in the percentage of land cover statistics up to a cell size of 300 by 300 metres. By larger cell sizes land cover classes which usually consist of small patches are over- and underestimated. Overestimation is the case, if by the nearest neighbour algorithm a single pixel of a land cover class surrounded by other classes is chosen and transformed to the higher cell size. On the other hand a class is underestimated, if pixels of the dominating land cover class are chosen and extrapolated. So far the results are only empirical, no resuming conclusions should be made like "a grid of 300 by 300 metres is sufficient". The resampling was performed with the data set derived from the LANDSAT-TM data from 13th August 1985 for the Bavarian State Office for Water Resources.

ATKIS (Administrative Topographic Cartographic Information System) data layers as well as the ***DEM*** have been purchased from of the Bavarian State Cadestral Office. The digital elevation model supplies data to calculate parameters for the ASGI water run off model as elevation, slope, exposition and illumination but also other data layers important for water run off modelling like: drainage system, catchment areas, water accumulation, etc.. The digital data layers already existent at the Bavarian Cadestral Office (Bayerisches Landesvermessungsamt) have been completed by additional data layers according to the needs for analysis. One of the most important GIS layers implemented into the ALPMON database is the forest management map. The forest management plan including the statistics data base (German: Forstbetriebsbücher) is connected to this map. Information about stands, age, crown closure, function of the forest stand, treatment, etc. are important hints for the development of knowledge based classification rules and for the verification too.

The result of ***GIS data accuracy study*** showed error sources of technical and/or fundamental nature which directly influence the accuracy of parameter estimation. The technical error sources are connected to data conversion from one format to another as well as to different result output from different software packages. The fundamental problems are connected to the accuracy of topographic base data as well as of the forest management maps which show errors of 40 m and more. For pixel based GIS-analysis as developed in the frame of ALPMON, the geometric accuracy of different thematic layers is a basic request. Each mismatch leads to erroneous parameter determination and as follow on effect, to erroneous criteria estimation. In an automated procedure this may lead to conclusions which do not match the real situation. Especially knowledge based advanced evaluation procedures applied on high resolution remote sensing data of the future generation of Earth observation systems may be severely affected by such error sources.

Data layers and data bases created in the frame of ALPMON

In addition to the already implemented data layers of the administrative level the following data layers have been created and are available as output of the ALPMON investigations.

Aerial photograph interpretation:

- pass-points data set for geo-rectification of new aerial photograph series
- stereo models for the aerial photograph series from 1960 (B&W), 1994 (B&W) and 1997 (CIR)
- pass-points data set for satellite data geocoding
- training and verification area selection (250 selected, 172 considered)
- statistics of training and verification areas
- detailed change detection data between 1960 and 1994 in a sub-test site

Satellite data

Satellite data have been evaluated according to the requirements of the customer Alpine Convention, Corine land cover and the application customer Bavarian State Office of Water Resource Management.

- Radiometric corrected, geocoded data sets of the Mangfall test site :
    - Landsat TM, 13th of August 1985
    - Landsat TM 09th of August 1992
    - Landsat TM 28th of June 1994)

  - Landsat TM 03rd of May 1997
  - IRS 1C, 07th of February 1997 LISS
  - IRS 1C, 07th of June 1997 LISS
  - IRS 1C,11th of September 1997 LISS
  - IRS 1C, 05th of October 1997, LISS, PAN
  - ADEOS data set from 7th of May 1997

- Land cover / land use classification according to the customers
- Simulation of grid sizes 75, 200, 277,312, 416, 500, 625 and 833 m

<u>GIS data</u>

GIS data evaluations have been restricted on the core test area Spitzingsee. In addition and on base of the ready to use GIS layers from the Bavarian State Cadestral Office a series of other application relevant data layers have been created as follows:

- The official DEM of the Bavarian State Cadestral Office has been used to derive the following data layers:
  - Map of slope classes
  - Map of elevation classes
  - Map of exposure classes
  - Illumination mask with respect to the acquisition time and date of satellite data
  - Mangfall river watershed and sub-watersheds of tributaries
  - Water accumulation on drainage pattern base
- Forest management map (Forstbetriebskarte) of the forest office Schliersee (Forstamt Schliersee) has been digitised and attributed with the data of the forest management plans (Forstbetriebsbücher).

The requirements of the customer LfW have been fulfilled. Methods for the extraction of information from remote sensing data as well as data layers needed to run ASGI have been delivered to the customer. Furthermore, it was possible to discuss the problem of water run-off modelling in the alpine region with the representatives of the LfW and so to prepare all requested data layers for the application in the Alps by the LfW in the future.

2.3.2.6 Results from Sulm Test Site

The Sulm test site study demonstrates the full evaluation chain with the ASGI water run of model. To operate the model with the methods described above, time series of precipitation, air temperature and runoff were prepared. Besides the time series data, spatial data on various parameters are required for the model. For the methods given above, following spatial source data sets were derived in a first step: Landcover from Landsat TM data, DEM from the 1:50.000 scale national map series, and soil type information estimated from the digital geological map 1:50.000 and already available point-wise analysed soil profiles.

The test area which is located south of the main ridge of the Eastern Alps of Austria covers an area of 1.100 km^2. The basin extends from the mountainous Koralm region with its highest peak, the Speikkogel with 2140m a.s.l. in the west to the city of Leibnitz in the east.

Landsat Thematic Mapper data from 10th September 1992 were used for the ***landcover classification***. The applied maximum likelihood classification is based on ground truth derived from aerial photograph interpretation.

The ***DEM*** of the study area has been built using the digital contours acquired from the Austrian Topographic Map of the 1:50.000 scale national map series. The Graz Terrain Model GTM software package, which was developed at the Institute of Digital Image Processing, was used to create the DEM. The GTM model is based on the so called 'sequential steepest slope algorithm' (Oswald & Raetzsch, 1984). As also ridge and drainage lines are integrated in the interpolation, the model delivers a DEM which is well suited for hydrological modelling (e.g. no erroneous sinks).

Meteorological time series data for precipitation and temperature were delivered from the Section of Water Resources. As these data were stored up to now mainly for documentation purposes at the

Section of Water Resources, no plausibility checks were applied to the data so far. The delivered data could therefore, not be processed directly in the ASGI environment, but shell script programming was done to check for various errors (e.g. negative precipitation values, revised time order). The remaining plausible time series data were then pre-processed in the ASGI environment. As only 7 precipitation stations remained with reliable data, IDW-Interpolation was selected as interpolation method (no height dependent regression because of statistical uncertainty). Here, significant improvements can be expected when weather radar data are integrated into the model as foreseen for the near future. Also temperature time series data were interpolated with IDW (with three stations delivering reliable measurements in the catchment).

The ***potential evaporation*** was calculated after Hamon (Federer & Lash, 1983). This model includes in addition to the temperature (IDW-interpolated as described above), an empirical monthly correction factor f_i.

Estimation of the ***interception storage capacity*** is based on leaf area index, degree of vegetation coverage and height of water stored on the surface. Leaf area index LAI (based on Thompson et al., 1981) and degree of vegetation coverage were derived from the landcover classification results.

For the Sulm catchment (and Austria in general), soils of agricultural areas are mapped with high level of detail in a scale of 1:2.500. Forests and alpine regions, however, are in general only mapped at 4km by 4km sample points. Up to now, no full area covering ***soil information*** is available which would be an appropriate basis for hydrological modelling in meso-scale catchments. To generate an appropriate full area coverage soil type map, digitisation of hundreds of soil maps as well as field work in areas not yet ascertained (forests and alpine regions) would be necessary. This cannot be performed within the framework of a hydrological modelling project because of economic and time constraints. For this application, therefore, following procedure was applied to derive the soil type information. As the basis for the estimation of soil-types, the soil-type map of Styria 1:1.000.000 (Krainer et al., 1998), the geological map of Styria 1:50.000 in digital format, and point-wise available soil analysis data (Krainer et al., 1998) were used. The result is an “estimated soil type distribution” of the catchment area, with the 1:50.000 scale of the geological map and the soil type information of the 1:1.000.000 scale soil type map. The so derived parameters can only give a rough estimate of the actual soil parameters. However, major improvements on the soil type distribution information, e.g. detailed delineation of valley bottoms, alluvial cones etc. result from this procedure.

The applied ***TOPMODEL approach*** is based on the saturated area approach using the topographic index after Beven and Kirkby (1979). This statistically based model differs from earlier soil-vegetation process models by including spatial variations in the main driving processes and uses topographic HRU’s to calculate lateral soil water transport. The recession parameter m was determined by slope hydrograph analysis. The main parameter of the TOPMODEL approach, the soil-topographical index, has been derived from the DEM. According to the saturated area theory, a higher index indicates a higher chance to contribute to the direct runoff. Thus, the areas with the highest indices simultaneously represent the river network.

The first model output results for the Sulm gauge in Leibnitz are displayed in Figure 5 for the time period from April until September 1999. Figure 5 shows the measured and simulated hourly runoff of the basin Sulm.

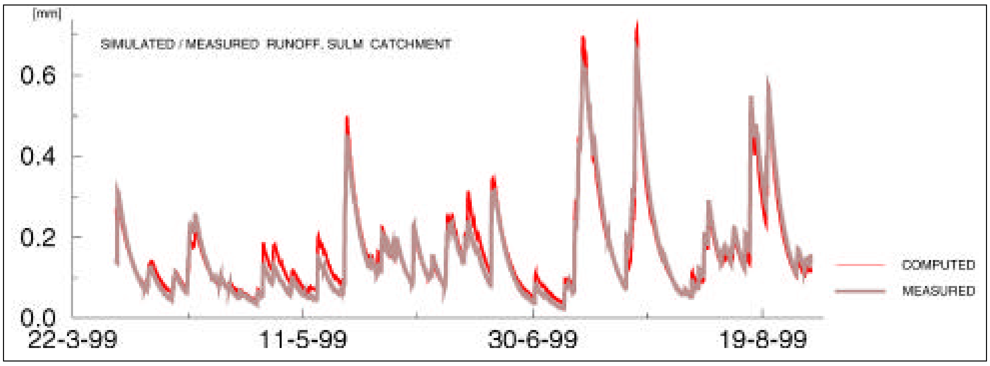


Figure 5: Measured and simulated runoff for the basin Sulm from April to September 1999.

For the period April to September 1999 the Nash-Sutcliffe coefficient was determined (Nash & Sutcliffe, 1970). The calculated "Explained Variance Coefficient" of 0.7 indicates a fair representation of the hydrology of the Sulm catchment.

2.3.2.7 Conclusion

Distributed models such as ASGI require land cover data for parameterisation. The use of earth observation data can be seen as an important pre-requisite for such models, as the spatial data demand for large area applications could hardly be satisfied without earth observation derived data sets (compare e.g. cost-estimates for land-cover mapping given by Konecny, 1995) . This leads to the conclusion that earth observation data support the application of distributed models, thus extending the toolbox of hydrologists.

2.3.3 Avalanche Risk Assessment, Dachstein Test Site (JR)

2.3.3.1 Introduction and Objectives

Increasing public and private construction activities have led to increased pressure on the valleys of the Alps. In order to prohibit uncontrolled building activities in torrent and avalanche danger zones, hazard zone maps were prepared. Moreover, close examination and monitoring of avalanche tracks led to the identification of regular patterns which may trigger avalanches. To identify potential hazard zones it is necessary to apply the decisive criteria, such as critical degree of crown closure, critical size of gaps in the forest, etc., to extensive areas. Information on the regional variation of all relevant variables should be available in a GIS for automated processing. So far, however, this kind of information has not been available. The aim of the present feasibility study was, therefore, to compile standardised information over a larger region. High resolution remote sensing data permitted the compilation of vegetation parameters from which surface roughness can be indirectly deduced.

Different types of avalanche risk models are currently developed at the Austrian Institute for Avalanche and Torrent Research, who is the national customer of this study. All models need similar parameters from remote sensing and DEM sources. Among these, the actual information on land use/land cover could be derived from remote sensing data. These parameters included forestry-related variables such as the distribution of different tree species, crown closure and forest openings as well as small bushes, alpine pastures, scree and rocks. Additionally, topographic information (e.g. slope, aspect, profile curvature, flow length) could be computed using the DEM. However, within the course of this study no avalanche risk model was available, in which the resulting data layers could have been integrated.

The aim, therefore, was to demonstrate the potential of satellite remote sensing as a relatively quick, cheap and stable tool for deriving the surface related features which are relevant for avalanche risk estimation. These parameters can be introduced to divers avalanche risk models, which require information on the land cover respectively the vegetation. They also can be used in an hierarchical approach for filtering out those areas, which are potentially endangered. This knowledge can significantly reduce the effort applied to conventional methods, which then can be restricted to the pre-selected areas.

2.3.3.2 User Requirements

The conditions and release mechanisms of different types of avalanches have been investigated in detail at the Institute for Avalanche and Torrent Research (Höller 1996, 1997 & 1998). Recently, special attention is put on the conditions within and near mountain forests, as avalanche release in these zones increases with the decreasing forest canopy density (Kleemayer 1993). In the present study two types of avalanches are considered, the slab avalanche and the snow gliding avalanche. The input parameters for the regionalisation of the avalanche models, due to different release mechanisms, are varying. The respective parameters were made available by the Institute for Avalanche and Torrent Research. Out of those

The release mechanism of slab avalanches can be described as a critical stability of the snow pack which is defined by the relation between stress and strength. The slab avalanche formation is influenced by topography (aspect, inclination, type of forest stand, canopy density, ...), meteorology (temperature, precipitation, wind, ...), and snow pack (temperature gradient, weak layers, ...). The critical parameters with regard to slab avalanches are

- A *critical diameter of openings* (> 50m^2; about 7m in diameter) enables the formation of surface hoar as a necessary condition for snow slab release:
- A *critical canopy density* also enables the formation of hoar as a necessary condition for snow slab release. It depends on the forest type with:

< 70-80%	for pure larch stands
< 40-70%	for mixed larch - stone pine stands
< 40%	for spruce or stone pine stands

- *Inclination* >30%
- *Aspect* probably in the North sector (WNW to ENE)

The snow gliding avalanche is a subtype of the slab avalanche. The release mechanism can be described with high gliding rates (snow gliding) due to increasing snow temperature and increasing water content. The snow gliding is influenced by the roughness of ground surface and the wet snow content near the snow-ground interface.

In open terrain snow gliding must be *expected* on
- abandoned pastures and meadows,
- long bladed grass mats,
- homogenous slopes.

Snow gliding is *possible* (but not as high as mentioned before) on
- slopes with small steps (from cows),
- small bushes (rhododendron, vacc.) with a height not exceeding 30 to 50cm.

Snow gliding is *very small* on
- dwarf pine stands,
- bushes > 50 cm,
- rocks > 30 cm.

Within forest snow gliding must be *expected* in larch stands with a very low canopy density and openings > 10m x 10m in diameter.

Additional Parameters are the
- *Inclination* >30-35%
- *Aspect*: south facing slopes.

From these rules the following parameters, that are detectable by means of remote sensing and DEM, could be extracted in agreement with the customer:

- Forest related parameters:
  - Forest type:
    - coniferous (mainly spruce)
    - coniferous with larch 25-75 %
    - coniferous with larch >75 %
    - dwarf mountain pine
    - mixed coniferous
    - mixed broad-leaved
    - broad-leaved
  - Forest age: three natural forest age classes
  - Canopy closure: three classes
  - Forest gaps/openings > $50m^2$
- Non forest vegetation:
  - Shrubs
  - Grassland: poor and rich
- Morphological parameters:
  - Slope
  - Aspect
  - Curvature
  - Slope/flow length

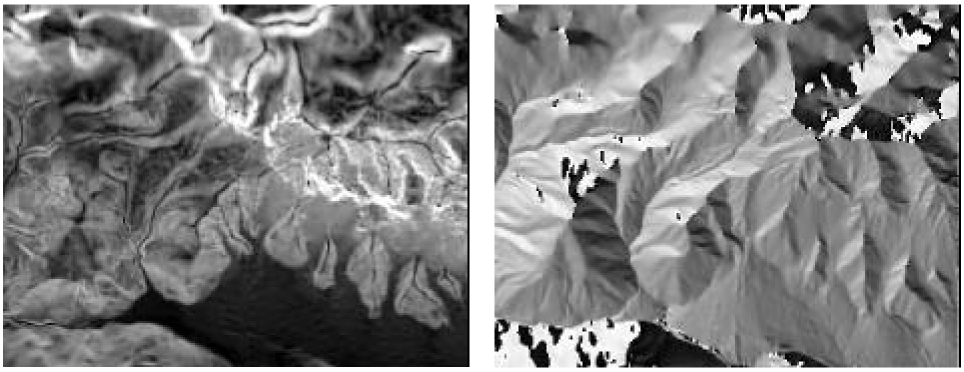
As the investigations of the customer (Austrian Institute for Avalanche and Torrent Research) on avalanche risk are restricted to mountain larch forest in the central Alps and the relevant parameters for avalanche release, and therefore concentrate on this special vegetation characteristics, additionally a literature review on further avalanche release investigations was undertaken. This review was restricted to the conditions of avalanche release and its dependency on vegetation parameters. Weather and snow conditions were not considered, as these parameters cannot be derived from earth observation data on an actual base.

The feasibility study subsequently concentrated on the detection of those parameters which were required by all reviewed avalanche models with special respects to those required by the national customer. For the customer it was essential to get detailed knowledge on the share of broad-leaved tree species as well as larch trees. Another requirement of very high importance was to accurately separate the low growing tree species (dwarf mountain pine and green alder) from high growing tree species.

2.3.3.3 Applied Methods

The information required as input for diverse avalanche risk models on one hand was derived from classification of satellite images and, on the other hand, from a digital elevation model.

Some parameters required with respect to the avalanche risk assessment are related to the topography of the landscape. The parameters comprise elevation, slope, aspect, and information on the shape of slopes. All these parameters in general can be derived from digital elevation models. But the detail of information is strongly depending on the accuracy and resolution of its data source, the DEM. Within the ALPMON project a DEM with 25m resolution was available for the Dachstein test site. All data derived from this model thus is restricted to the resolution of 25m. However, the methodology used to derive the information can be applied to any model with higher resolution, that might be available in the future. The parameters calculated from the DEM for the test site are slope and aspect (Figure 6), shape of slopes (profile curvature), and length of slopes (flow length). All calculations have been performed in ARC/INFO.



Slope Aspect

Figure 6: Slope and aspect calculated from DEM (for a subset of the test site).

2.3.3.4 Implementation of Remote Sensing

Land cover is only one out of several parameters that plays an important role in the assessment of snow avalanche risk. But, compared to the other parameters (such as weather, snow depth, etc.), it is a feature of relatively slow development, additionally being the most sensitive to the human pressure. Satellite remote sensing currently is the only tool which allows a regular investigation of the actual landcover and its changes for larger areas with justifiable time and cost effort, even more in an alpine landscape which is not easily accessible.

The aim of this study was to derive those land cover parameters, which significantly affect the risk for avalanche release, from satellite images using operational analysis methods. These comprise the forest, the land cover outside of forest, and morphological parameters. Following data sets were employed to fulfil the users requirements for avalanche risk assessment:

- Satellite data
- Landsat 5 TM
- SPOT 3 panchromatic
  - IRS-1D panchromatic, winter scene

- Other data
  - CIR aerial photos (37)
  - BW aerial orthophotos (9)
  - DEM with 10m resolution
  - Digital topographic maps
  - Avalanche register and police reports on avalanches

The investigation was mainly based on Maximum Likelihood classification of multi-spectral Landsat TM data with a ground resolution of 30m. Panchromatic SPOT 3 data (10m resolution) have been introduced to delineate the forest border, and IRS-1D data (6m resolution) have been introduced for a more detailed classification of the requested forest parameters. A multi-sensoral and multi-temporal classification approach was chosen to receive the necessary parameters from the satellite data. The accuracy obtained by the classification of the land cover parameters ranged from

68% (Kappa 0.59) for the detailed forest types over

80% (Kappa 0.60) for natural forest age,

85% (Kappa 0.62) for forest canopy closure,

87% (Kappa 0.84) for non forest classes to

95% (Kappa 0.91) for the forest border.

In more detail for some most relevant parameters: shrubs reached a mean class accuracy of 89%, for grassland it amounted to 92%. Furthermore, the mean deviation for the share of coniferous trees was only 7%, whereas the share of larch trees varied with 12% and tended to be underestimated.

Additionally, visual interpretation of the classification results showed quite a realistic image, thus confirming the quality of the output.

Implementation of a High Spatial Resolution Winter Image

The separation of typical Alpine low growing tree species such as dwarf mountain pine and green alder (in general not higher than 2-3m) from high growing forest stands could not be reached with the classification of Landsat TM data from the vegetation period, because their spectral characteristics are very similar. For improving these results, a high spatial resolution IRS-1D panchromatic winter scene was analysed by way of example for a small sub-set of the Dachstein test site.

The data acquisition time was from a period, where snow was covering the low growing tree species but has already fallen from the crowns and branches of the high growing trees. Through multi-seasonal classification it was possible to separate high growing from low growing trees with high accuracy. The classification accuracy of the high growing forest border was very high with a mean of 98% and a Kappa value of 0.95. With this approach also the dwarf mountain pine and green alder itself can be separated from each other.

The data was also investigated with regard to their potential for detecting small gaps (approx. $50m^2$) within the forest, which has been defined as one important parameter for the assessment of avalanche risk. Due to the better spatial resolution of the winter-IRS-pan image there was also an advantage in detecting gaps/forest openings down to a size of 25-30 m^2. In classifications of the summer Landsat TM and SPOT data only a detection down to approximately 240 m^2 can be reached.

In conclusion, the big advantages of the forest border derived from the IRS-1D panchromatic winter image are:

- the separation of dwarf mountain pine and green alder from high growing forest stands,
- the detection of small gaps within the forest due to the high ground resolution of 6m.

2.3.3.5 Results

The main outcome of the feasibility study on avalanche risk assessment are maps of the single parameters as defined in the requirement study. These parameters can be implemented in a region based avalanche risk model which requires information on land cover, especially vegetation and forest, and on topography. As no avalanche risk model was available within the course of this study, the implementation, unfortunately, could not be tested. Although many parametric requirements, and to some extent also their interdependencies, could be ascertained, the information yet is too heterogeneous, and in most cases too much related to a specific investigation area, to establish a comprehensive avalanche risk model.

The classification results were plotted as maps with a scale of 1:50 000, corresponding to the Austrian Topographic Map, sheet 127 *Schladming*. They were overlaid with contour lines in order to enable a good orientation within the map. Areas affected by shadow in the satellite data were masked out and not classified. They covered 2% of the entire test site. Four maps were generated for land cover (including forest type and non forest classes), forest canopy closure, natural forest age, and more detailed forest types as required for the avalanche risk analysis. Additionally, for the area which was covered by the IRS-1D winter image, an even more detailed forest type classification is available, revealing dwarf mountain pine and green.

To show an example for the possible combination of diverse risk parameters, in Figure 7 the forest canopy closure is shown only on slopes between 25° and 50°, as these are the slopes with potential for frequent avalanche release. As stated before, no rules for the combination of risk parameters were available, thus no risk analysis could be performed within the duration of this project. For assessing the potential avalanche risk zones, an hierarchical approach could be suggested, e.g. by first selecting only those areas with critical slope steepness, then within these areas the forests with critical canopy closure, and so on.

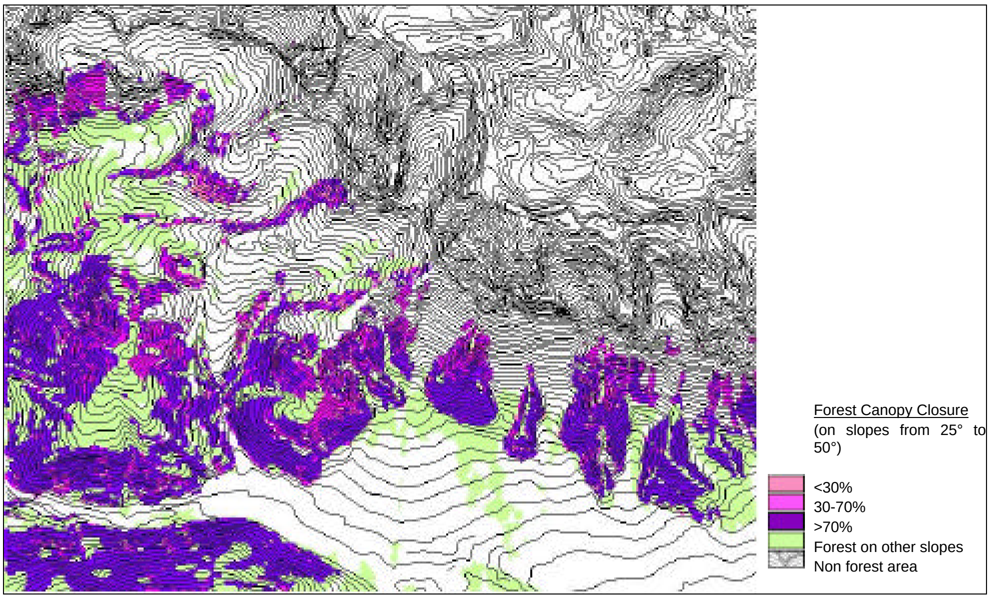


Figure 7: Classified forest canopy closure, only shown on slopes between 25 and 50 degrees.

For better interpretation the results additionally were draped over the DEM, thus producing perspective views (Figure 8). The background for these images was the panchromatic SPOT data, which allows good orientation in the presented landscape.

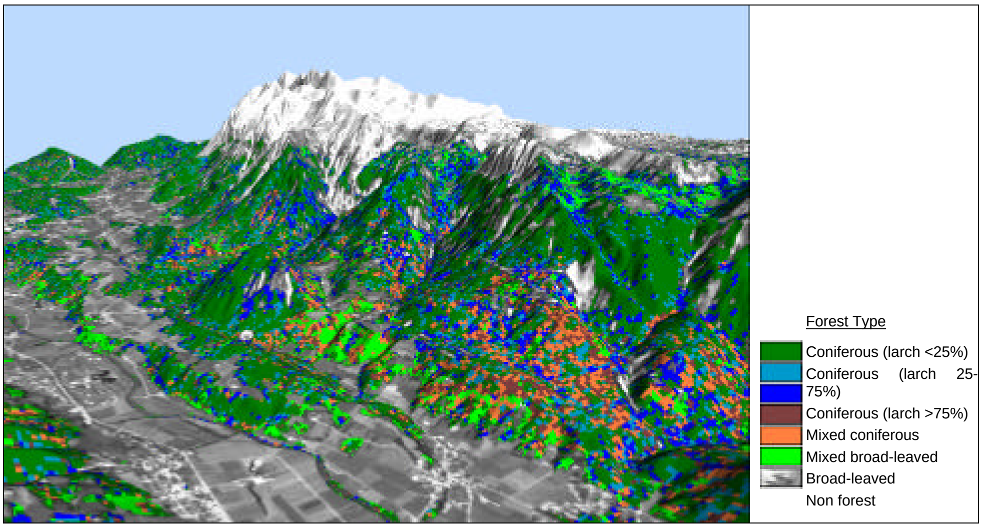


Figure 8: Perspective view of forest type classification from Enns valley to Dachstein (WNW).

2.3.3.6 Evaluation and Outlook

In general it can be stated that earth observation data proved to be a useful tool for supporting snow avalanche risk assessment in the Alps. The results of this study were mainly based on the investigation of Landsat 5 TM data. Another EC study performed in the Austrian Alps (SEMEFOR, 2000) could demonstrate, that with the availability of SPOT 4 data the classification accuracy of forest parameters can be improved significantly. The SPOT 4 sensor delivers images with 20m resolution in the multi-spectral bands and 10m resolution in the panchromatic band. Furthermore, the middle infra-red spectrum has been added, compared to the former SPOT sensors. The combination of the higher resolution and the availability of a middle infra-red band proves to be a big advantage with respect to the classification of alpine vegetation parameters. SPOT 4 data are available on request since 1999. It is strongly recommended to use these data instead of Landsat TM images for a detailed investigation of forest parameters as well as other Alpine vegetation with respect to the parameters required for avalanche risk models.

Some constraints have to be mentioned concerning two non forest land cover categories. The requirement of the customer to separate different types of grassland with respect to their use could not be fulfilled with the available satellite data. The only separation could be made between rich and poor grassland, which in most cases is related to the meadows in the valleys vs. the alpine pastures above the forest border line. Furthermore, the rock size could not be classified with these data. This might become possible with the high resolution sensors, having in mind texture features and the amount of shadow within a pixel.

In general it can be stated, that areas outside the forest can be classified due to their spectral variation if they occur on large areas. Smaller areas, which are covered by a mixture of vegetation categories, such as rhododendron, dwarf mountain pine or smaller moor areas that do not exceed 1 ha, cannot be classified definitely because of the mixed pixel problem. Simulations have proved that a geometric resolution of about 5 to 10m in the infrared spectral range is necessary to assess the typical small-area distribution pattern of vegetation outside of forests. The future sensor systems will provide data in this resolution range.

Other decisive criteria related to the morphology (slope, aspect, curvature, and flow length) could be derived from a digital elevation model. However, the currently available DEM resolution (25m) is too rough to detect morphological surface characteristics, that might affect avalanche release, such as shape of slope (convex/concave) and length of slope in non forested areas or areas with critical forest canopy density, in sufficient detail. Here, high resolution laser scanner models could deliver valuable information. But due to the high costs for these data the information should be restricted to the areas that have been defined as (very) critical in the first steps an hierarchical risk assessment, including the aspect of vulnerability.

The time resolution is another crucial factor for information extraction. A yearly update in general seems to be possible with the currently available satellite systems. The bottleneck might be the availability of images from winter with the specific snow situation required. On the other hand, the distribution of dwarf mountain pine and greenalder shows no extensive variations. Therefore, an update of this information within a 5 years period seems to be sufficient and practicable.

Finally, it should be taken into consideration that satellite image classification in general could also be used as a tool for updating the information on infrastructure that is exposed to avalanche damage, implemented in a GIS.

2.3.4 Erosion Risk Assessment, Cordevole Test Site (RSDE)

2.3.4.1 Introduction and Objectives

The assessment of erosion risk is a primary problem in mountainous regions. The purpose of this feasibility study was to develop a proper methodology for the production of erosion risk maps in these regions exploiting information derived from remote sensing technology.

The review of the existing studies on soil erosion indicates that current basic methodologies have been established primarily to assess soil erosion risk over agricultural and hilly areas in temperate climate. These methodologies therefore cannot be directly applied to a much more complex system, such as the alpine environment. Further, the use of a single methodology could hardly account for all the features of the alpine erosion phenomena. In fact, besides common erosion processes, other relevant processes increase the transformation rate of the alpine landscape. The most widespread erosion models like USLE/RUSLE or CORINE EROSION cannot be successfully applied to the alpine areas because they have been conceived to work on hilly terrain for agricultural purposes where sheet and rill erosion processes are prevailing. Mass erosion processes typical of alpine environment like debris flows are not taken into account in these models. Further, CORINE EROSION is not considered a suitable model for regional planning applications at scale 1:25.000 as required by the customer.

2.3.4.2 User Requirements

The different mass erosion phenomena present on alpine environment are influenced by a set of static and dynamic factors that can be summarised in the following categories (Table 5):

Table 5: Classification of main factors affecting mass erosion on alpine environment

Category	Factor
Static	• Morphologic/Topographic (slope, aspect) • Environmental (land cover, soil type, soil depth, presence of impermeable sub-soil)
Dynamic	• Climatic/Meteorological (critical rainfalls)

One of the most critical parameter is land cover, entering both as land cover typology and vegetation density (canopy cover). Canopy cover is estimated both in woodland and grassland. Table 6 summarises the general requirements of the erosion risk model while

Table 7 lists the land cover parameters in detail.

Table 6: General requirements

Parameter	***Description***	***Unit***	***Source***
CN	SCS Curve Number.	adimensional	ALPMON Land cover classes geology, soil
P	Critical Rainfall Volume.	mm	Climate
COVER	Canopy Cover. Percentage of canopy according to ALPMON classes.	%	ALPMON Land cover classes
SLOPE	Average slope	degrees	DTM
DEPTH	Estimated Soil/Debris depth.	m	GIS
TYPE	Prevalent Soil/Debris type (as cohesive, incoherent etc.).	Boolean	GIS
IMPERV	Presence of impermeable subsoil.	Boolean	GIS

Table 7: Land Cover requirements

Type	***Class***	***Fullfilled***	***Integrated***	***Notes***
Forest	*Crown Cover 10-30%*	X		
	Crown Cover 30-60%	X		
	Crown Cover >60%	X		
Non Forest	*Pasture Cover 10-30%*	X		
	Pasture Cover 30-60%	X		
	Pasture Cover >60%	X		
	Meadow	X		
	Rhododendrum/Junip.	X	DTM	
	Rocks /Gravel /Soil			Not used in this implementation of the model
	Water/Snow /Ice			Not used in this implementation of the model
	Sealed Surfaces			Not used in this implementation of the model
	Swamp			Not present

2.3.4.3 Applied Methods

2.3.4.3.1 Overview of the FSTAB Erosion Risk Model

The erosion model, called FSTAB (Fuzzy Stability) is composed by two sub-models, DA (Discriminant Analysis) and SCS-CN (Soil Conservation Service – Curve Number), running in parallel to account for the different factors influencing soil erosion processes and slope instability. The DA sub-model, specifically built for this study on statistical basis, accounts for static factors affecting mass erosion while the SCS-CN sub-model, an already available and well known potential infiltration and runoff model, accounts for the dynamic effects of rainfalls. These sub-models run independently using a shared database of geographically referenced information on land cover, soil, geology, geomorphology and climate. The output from the two sub-models are integrated in an inference engine, based on fuzzy logic, which gives a reasoned erosion risk index, called MEHI (Mass Erosion Hazard Index). The inference engine, for the assessment of global risk, uses a set of predefined decision rules.

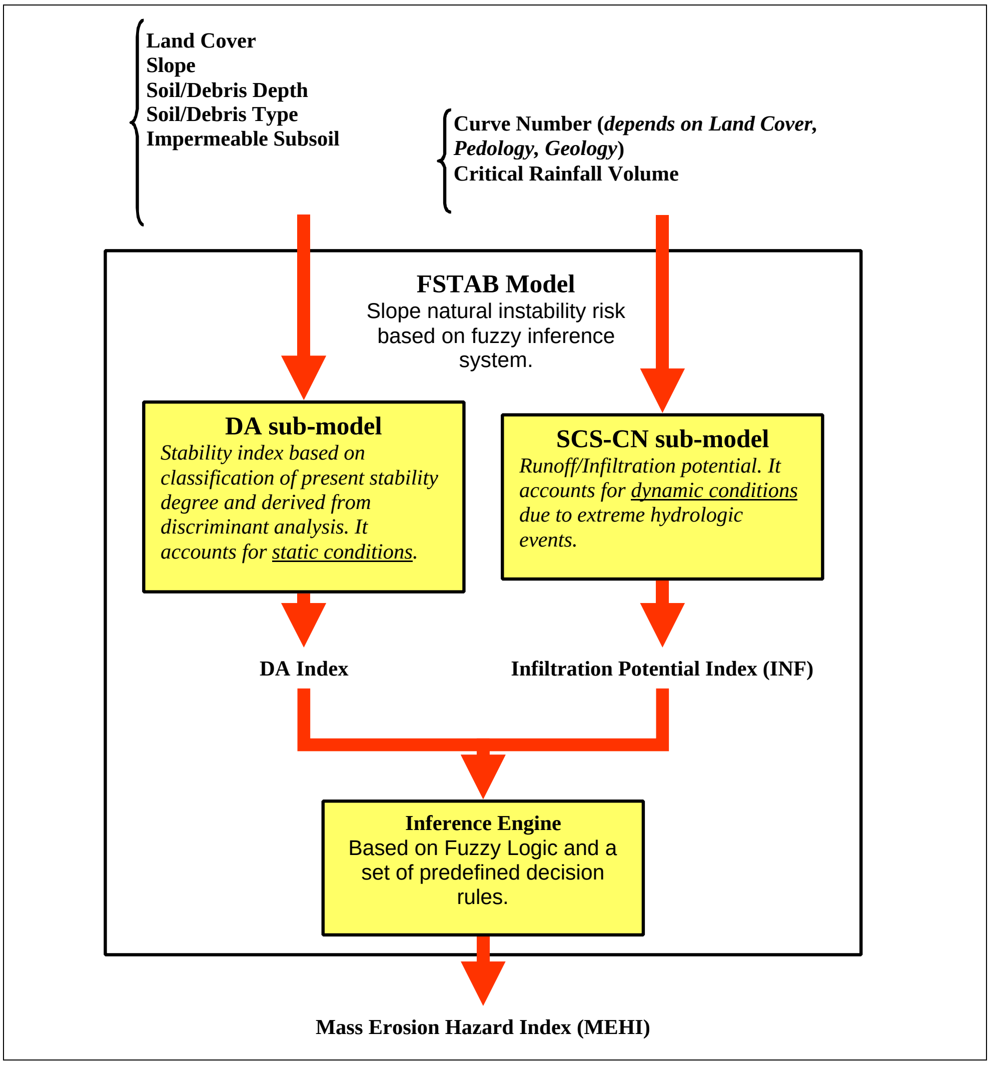


Figure 9: Overview of the FSTAB Erosion Risk Model

2.3.4.3.2 SCS-CN sub-model

The runoff/infiltration component of the FSTAB model is based on the SCS-CN (Soil Conservation Service – Curve Number) sub-model (USDA, 1986, Boughton, 1989; Hawkins et al. 1985). The applications domain of SCS-CN are: Urban, Agricultural, Forest and Rangeland.

Input data of SCS-CN are: soil characteristics, land use an land cover, antecedent moisture conditions, slope (in the EPIC and SWRRB implementations), daily rainfall volume (for direct runoff and infiltration volume computation).

In the present use of the SCS-CN sub-model, the main output data is an adimensional index for daily runoff or infiltration potential.

2.3.4.3.3 DA sub-model

The DA sub-model is derived from an assessment of the most relevant instability factors present on scientific literature on landslides, debris-flows and mud-flows, analysed by means of the Discriminant Analysis, a multivariate statistical methodology already applied on this field by other authors (Carrara et al.,1991, Busoni et al., 1995; Rowbotham and Dudycha, 1998).

The Discriminant Analysis approach can be summarised on the following steps:

I. Identify from a-priori knowledge of the phenomenon a set of parameters which could affect stability.

II. Measure the above parameters over a significant number of ground truth points on the test site area.

III. For each ground truth point assess the stability from field evidence using the following classification: Stable / Unstable / Uncertain.

IV. Apply the Discriminant Analysis to the dataset to find out the Discriminant Function i.e. the axis which better discriminates the three clusters of ground truth points classified as Stable, Unstable and Uncertain. The Discriminant Analysis gives a quantitative assessment of the contribution of each parameter to the stability.

Once the Discriminant Function is computed over the ground truth points, it is possible to use it as a model to process any point of the distributed dataset (i.e. data over a regular grid derived from ALPMON land cover and other auxiliary sources) and to assign it a stability index.

2.3.4.3.4 FSTAB Model

The FSTAB (Fuzzy Stability) model integrates the output from the DA and SCS-CN sub-models by means of an inference engine, based on fuzzy logic, which gives a reasoned erosion risk index, called MEHI (Mass Erosion Hazard Index). The inference engine for the assessment of global risk, is based on fuzzy logic and uses a set of predefined decision rules.

There is an increasing number of fuzzy logic based methodologies for slope stability assessment in the last decade (CHOWDHURY, 1988; OKIMURA et al.,1993; YOSHIMURA, 1996). The reason for this interest in fuzzy logic is the possibility to model complex phenomena and at the same time manage the uncertain nature of some model parameters and processes. Model and data uncertainty play a special role in hazard assessment and non-deterministic nature of the processes needs of a combined approach.

The DA sub-model allows to define a degree of stability based on static conditions depending on geomorphological and soil features. However, infiltration potential, storm intensity and amount are important triggers for instability processes. In fact, different infiltration potentials in adjacent areas may give an explanation of the great variability on mass movement generation in similar morphological situations. The SCS-CN sub-model accounts for the dynamic component related to infiltration potential.

2.3.4.4 Implementation of Remote Sensing into the Model

The data flow (Figure 10) illustrates all the of parameters involved in the erosion risk model. The primary parameters (violet) have been processed to derive secondary parameters used input for the sub-models DA and SCS-CN. It is evident that all the required soil parameters have been completely estimated indirectly because no primary information over soil were available. Geological field survey has been used for the calibration of the DA sub-model while geomorphology has been used for the tuning and validation of the FSTAB model.

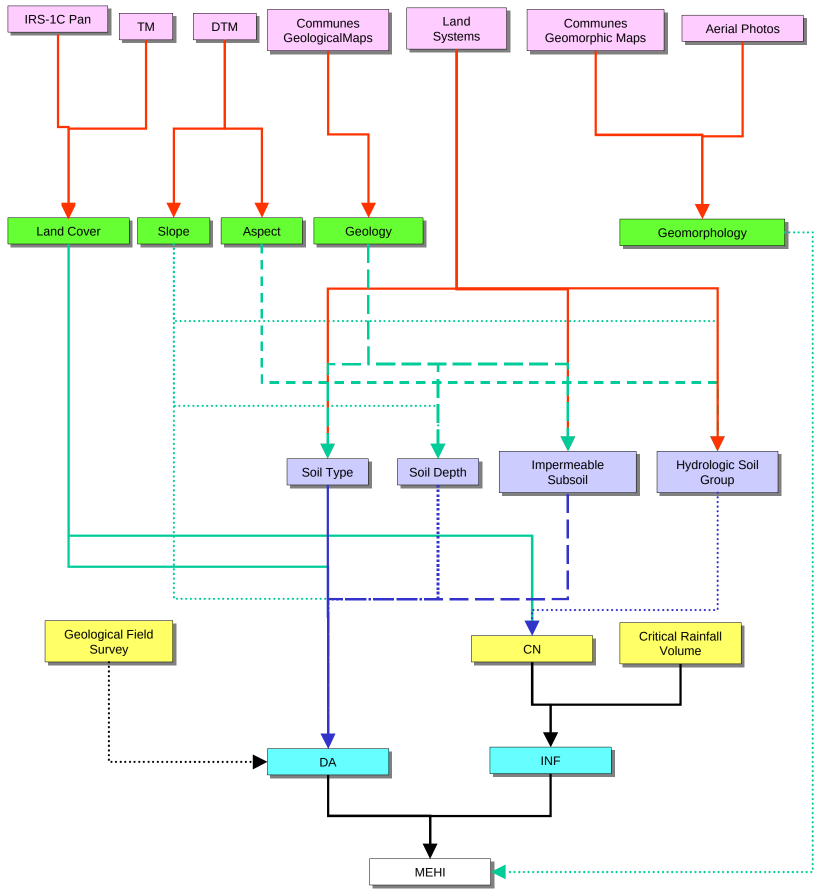


Figure 10: Erosion risk data flow

2.3.4.5 Results

The main issue of the FSTAB model is the Mass Erosion Hazard Index (MEHI). MEHI was computed at a pixel resolution of 30 metres over all the test site a part from pure rocks areas and slopes deeper than 45% because on these areas rock falls are prevailing over mass erosion and these two phenomena are too different to be modelled by the same tool which models the mass erosion risk.

It must be pointed out that the FSTAB differs from other erosion models because it does not provide an erosion rate index, which would not in any case help preventing natural disasters, but a parameter representing the propensity towards the generation of mass erosion. The assessment of results was therefore based on comparisons both qualitative and quantitative of MEHI vs. the geomorphology because it was the most significant available information about the actual and potential erosion risk in the test site area.

The qualitative assessment of MEHI was based on a visual comparison of the MEHI map and the geomorphological map, supported by aerial photographs, over five areas representative of the main geomorphic processes present in the test site (Figure 11). Four areas out of five obtained a “good” result.

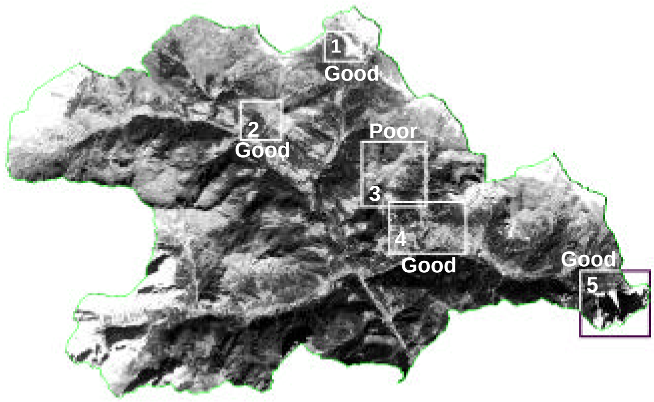


Figure 11 : Areas chosen for the qualitative assessment of MEHI

Figure 12 illustrates the assessment over Area N° 2. Talus slopes (see the geomorphologic map) are correctly represented on the MEHI map with high risk (red) and good geometric detail.

Figure 13 illustrates a case of poor correlation between MEHI and the risk expected by the examination of the geomorphologic map. The wide violet hatched polygon in the geomorphologic map represents a complex unstable area where both landslides and soil erosion (surface, rills, gullies) phenomena are present. This area should be theoretically set all at high risk whereas FSTAB doesn't recognise it correctly underestimating the risk.

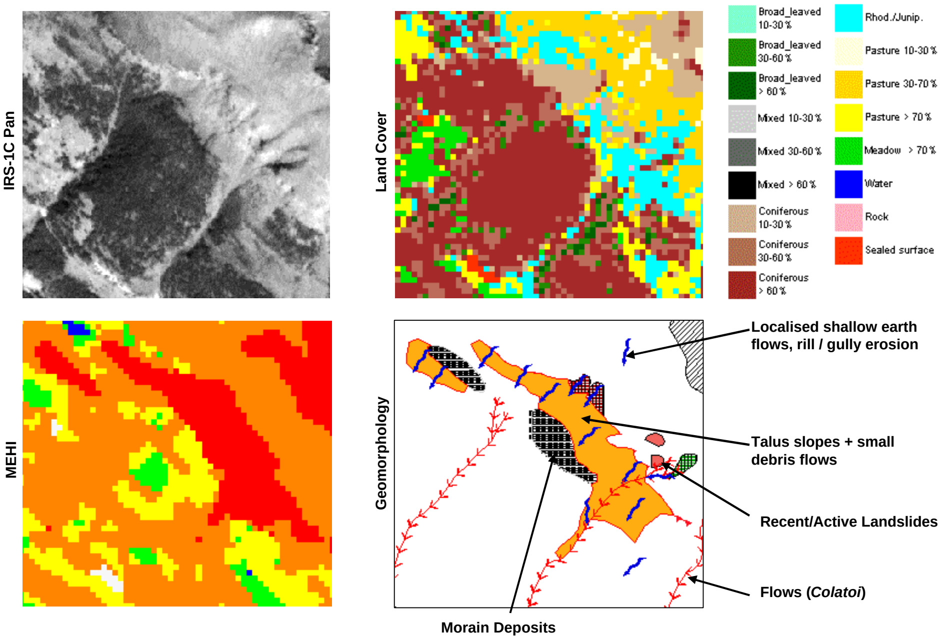


Figure 12: Qualitative assessment of MEHI over Area N° 2 (Result: Good)

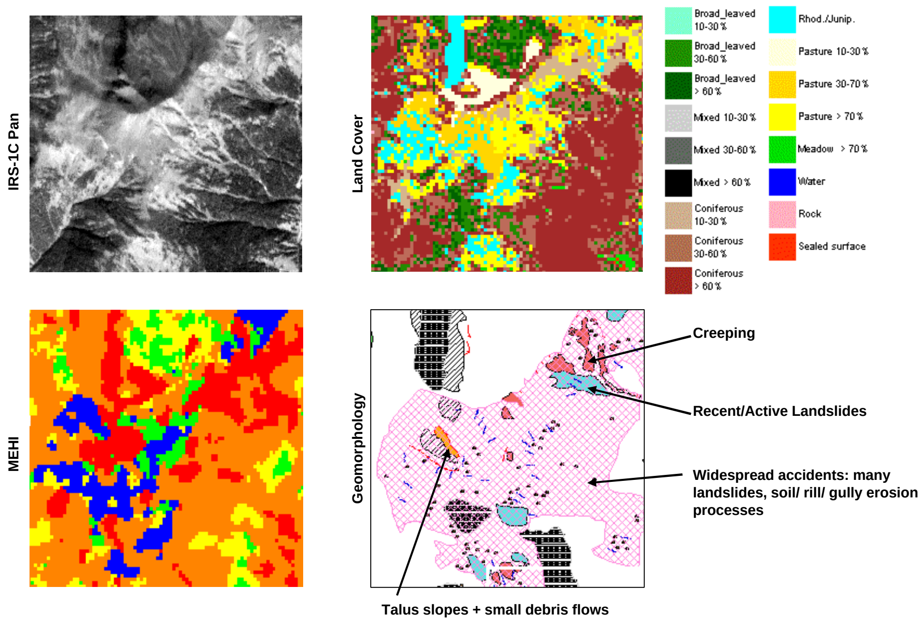


Figure 13: Qualitative assessment of MEHI over Area N° 3 (Result: Poor)

2.3.4.5.1 Quantitative assessment of MEHI

The quantitative assessment of the Mass Erosion Hazard Index (MEHI) issued by the model FSTAB was assessed in successively in two different ways. In all cases the computed MEHI was compared with the Geomorphological Map. The first assessment consisted in assigning a constant and "reasonable" MEHI value to each geomorphic type (i.e. "observed MEHI") and then computing the confusion matrix between the observed MEHI and the computed MEHI. The resulting correlation was very low because two reasons:

- Geomorphic objects (e.g. talus slopes) are approximated on the map by regular polygons while they actually have very complex features. As a consequence the actual mass erosion hazard inside the polygon is not a constant.
- The above mentioned intrinsic variability of mass erosion hazard is amplified by rapid the variations of slope.

Therefore it was decided not to take strictly into account the "observed MEHI" because it resulted to be too approximated and probably subjective. The computed MEHI was instead compared with each principal geomorphic phenomenon separately taking into account slope. The scatter diagrams obtained in this way turned out to be much more interesting. Figure 14 illustrates the scatter diagrams of computed MEHI vs. slope for Active and Inactive Alluvial Fan: the result fully agrees with the degree of morphological evolution and risk of the two types. In fact the average computed MEHI for the Active Alluvial Fan is 0.5 whereas it takes nearly 0.1 for Inactive Alluvial Fan. In these two cases the slope distribution doesn't affect significantly the MEHI.

Figure 15 illustrates the scatter diagrams of computed MEHI vs. Slope for Active/Recent, Ancient Landslide Toe. In this case the distribution of MEHI is strongly influenced by the slope: in fact for the Active/Recent Landslides the risk reaches the absolute maximum for slopes deepest than 67%.

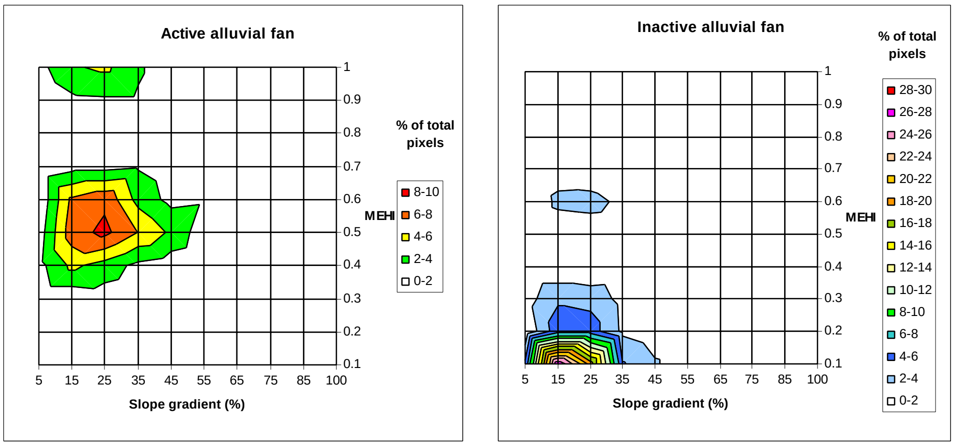
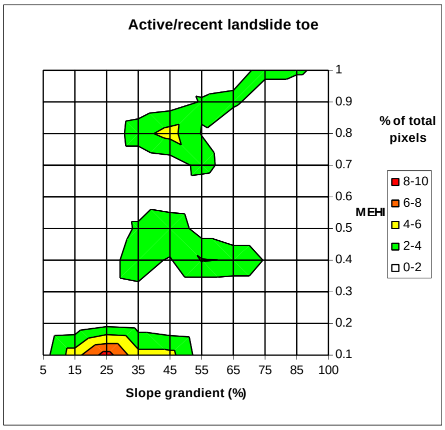


Figure 14: Scatter diagrams of computed MEHI vs. Slope for Active and Inactive Alluvial Fan



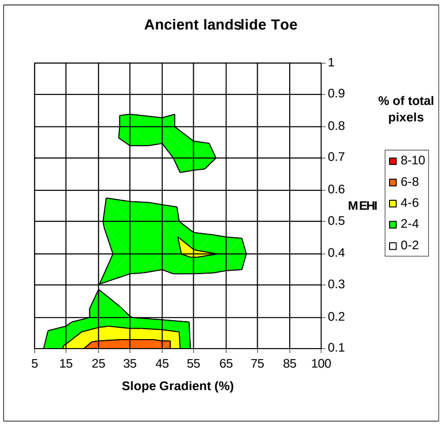


Figure 15: Scatter diagrams of computed MEHI vs. Slope for Active/Recent, Ancient Landslide Toe

2.3.4.6 Conclusion

This feasibility study was aimed to assess how remote sensing can give contributions to the evaluation of erosion risk in Alpine environment. Satellite remote sensing, supported by aerial photography and ground truth, has been used to create up-to-date land cover information. Land cover parameters have been selected to satisfy both the general requirements of ALPMON and the specific needs of erosion risk assessment, like the estimation of pasture density, which was classified into three density classes: 10-30%, 30-60%, > 60%.

These density classes were generally suitable for the erosion risk assessment, a part from the case of very low vegetated areas which created some problems that became evident only after the calibration of the erosion model. This was the case of talus slopes with very low vegetation which in many cases were classified by remote sensing as rocks. Talus slopes play an important role in the genesis of debris flows, therefore their confusion with rocks produces a fake decrease in erosion risk. The use of very high resolution satellites will certainly improve the accuracy of the quantitative assessment of the density cover in very low vegetated natural areas.

Besides land cover, other auxiliary information over morphology, geology, soil and climate resulted to be of paramount importance for the development of the erosion risk model. A part from morphological information (i.e. slope, aspect, elevation) computed from a Digital Elevation Model (derived from topographic map at scale 1:25.000), the quality of the other auxiliary information turned out to be highly heterogeneous over the test site of Cordevole but this situation can be considered quite representative of Italian Alpine regions. Geological information were collected from 5 different sources (communes) and needed to be harmonised in nomenclature and revised in geometric accuracy. The most critical information was anyway soil: no soil maps were available, then soil parameters necessary to the erosion model (type, depth, presence of impermeable subsoil) were indirectly estimated trough algorithms taken from literature crossing land unit map, geology and morphology.

However, the land cover information derived from remote sensing, even though accounting for nearly 20% of the total information required for the erosion risk assessment, is one of the most critical parameters because it changes very quickly as compared to other auxiliary information, being the parameter most sensitive to human pressure. In fact morphological and geo-pedological information can be considered quite stable along time and could be acquired once a time over a reasonably long period (nearly 20-50 years), while climate information should be updated more frequently (nearly 10–20 years) and finally, land cover information should be updated very frequently (1–5 years). What's more, land cover accuracy is, for obvious reasons, much easier and less expensive to assess, as compared to soil and geology parameters. Thus, the significance of land cover changes can be rigorously assessed with statistic tools. As a consequence, the significance of changes of the computed erosion risk along short periods (1-5 years), inducted by changes in land cover, can be even assessed.

The costs of acquisition of homogeneous morphological, geological, soil and climate information over the Alpine regions should be certainly huge but they could be paid off along several decades because these information are durable and, like land cover, they could be applied for the assessment of other critical environmental risks like run-off, floods and avalanches.

From this point of view the periodical use of remote sensing technology every few years (1-5) for land cover updating over Alpine areas is surely the most cost-effective approach even though some limiting factors to the use of satellite imagery in mountain areas last for the moment, like a significant percentage of shadowed areas (e.g. in Cordevole test site nearly 10% of areas are permanently shadowed) and a rather low probability to have fine weather conditions during satellite acquisitions (e.g. in Veneto, only 20% of Thematic Mapper imagery is cloud free).

The erosion risk model FSTAB developed during this feasibility study was aimed to take into account a wide range of mass erosion phenomena specific of Alpine areas. It must be pointed out that the FSTAB differs from other erosion models because it does not provide an erosion rate index, which would not in any case help preventing natural disasters, but an index (MEHI) representing the propensity towards the generation of mass erosion.

To allow the model to represent the erosion risk inside the test site area of Cordevole with a level of detail (scale 1:25.000) compatible with the customer requirements, which deal with the regional planning of hydro-geological defence, were necessary both a calibration based on a geological ground survey and a quite complex tuning of the fuzzy inference engine. The ground survey consisted in 115 points spread over 265 Km^2 with an average density of 0.43 points per Km^2 . The density of ground points is a function of the complexity of the geomorphological features present in the study area as well as of the required accuracy for the final erosion risk index. The tuning of the fuzzy inference engine must be carried out by an expert geologist with the following skills: 1) sound background on mass erosion phenomena; 2) general knowledge of the geomorphic processes present in the study area; 3) good knowledge of principles of fuzzy set logic.

The FSTAB model was not conceived to work over bare rocks and slopes deeper than 45° because on these areas rock falls are prevailing over mass erosion and these two phenomena are too different to be considered by the same model. Therefore the full modelling of both mass erosion and rock falls phenomena should require the integration of a further model.

The application of Discriminant Analysis in sub-model DA provided good results for the land zoning giving a stability index which is strictly representative of the local intrinsic features. The value of DA index could be even used alone as local stability index, anyway it cannot account for changes in infiltration potential related to critical run-off events and needs therefore to be integrated to the SCS-CN sub-model.

Fuzzy methods provided a good solution to the integration of the two sub-models. After a first integration, the implementation of two separated sets of fuzzy inference rules was tested: the first for debris flows and the second for all the other areas. Debris flows areas were discriminated using the geomorphological map. This approach can be justified by the time difference which normally differentiates debris flows from other slower mass movements. The problem of two different time scales was solved introducing two diverse run-off thresholds.

In order to assess the erosion risk over the whole Alpine area, the erosion model should be flexible to fit input data with very different accuracy. FSTAB has demonstrated to be a rather flexible model, as compared to other erosion models like RUSLE, because some input parameters potentially affecting the mass erosion risk can be even discarded, when their accuracy is not enough good, without prevent the model from working. This was the case of the parameter ‘surface convexity’ which can significantly affect the dynamics of surface water flow. In fact the surface convexity in Alpine areas characterised by complex morphology must be estimated with high accuracy from a very high resolution Digital Elevation Model. The pixel resolution of DEM should be around 5 metres i.e. the source topographic map should be at scale 1:5000. In the test site area of Cordevole the DEM was derived from a topographic map at 1:25.000 scale so it was non accurate enough to estimate surface convexity, therefore this parameter was not taken into account.

2.3.5 National Park Management, Swiss National Park, Engadine (WSL)

2.3.5.1 Introduction and Objectives

The Swiss National Park (SNP), first established in 1914, is the largest protected area and the only national park of Switzerland. It is located in the high-alpine region of the Engadine and covers an area of nearly 170 km^2. According to the International Union for the Conservation of Nature (IUCN), the SNP is classified as a "wilderness area" (category 1). It is especially known for its abundance of alpine fauna, such as red deer, ibex, chamois, groundhogs, and bearded vultures. Also, its characteristic landscape forms and rich alpine flora make it a tourist attraction of approximately 150'000 people a year.

Besides the ecological and touristic aspects, the SNP serves as a field laboratory for diverse nature scientists. The park enables research to be pursued unhindered over a prolonged period of time in an area, that previously had been influenced by man. A huge amount of scientific research has been achieved over the last 80 years, adding to a lot of documentation of this area. A number of long-term monitoring programs have been set up, especially in the field of vegetation monitoring: development of vascular plants has been studied since 1917 (Braun-Blanquet 1931, Stüssi 1970, Krüsi et al. 1995, Schütz et al. 1998), the growth and succession of lichen since 1923 (Frey 1959), vegetation development in lavinars since 1939 (Lüdi 1954, Riederer 1996) and in fenced areas without the influence of mountain ungulates since 1987 (Camenish and Schütz in prep.), development of moss communities since the 50ties (Geissler 1993), reforestation on burnt areas since 1951 (Hartmann und Geissler in prep.), etc. In non-vegetation areas, studies of geomorphological forms such as rock glaciers (Barsch 1996, Graf et al. 1995) and processes (solifluction) have been under study.

In summary, a lot of detailed spot data has been collected for different areas in the park, but no area-wide data coverage is available for any specific characteristic, since researchers are allowed to leave paths only in specified areas for which they have a permit. Thus, there is a lack of actual and proved information concerning the spatial pattern of various objects and processes for the entire park. For this purpose, the feasibility of remote sensing techniques has been tested. There is a need to obtain a complete inventory, especially of the most inaccessible and remote corners of the park. Also in respect to the planned park extension, information on the use and type of landscape outside of the park boundaries is of vital interest.

The Swiss National Park is in need of a spatially comprehensive inventory of grassland, forest stand characteristics (tree species composition, stand type, stand density, natural age class) and non-vegetation areas. In the latter respect, the extension and spatial distribution of soil erosion, especially of debris flows, rockslides, lavinars and active rock glaciers greatly influence the vegetation succession and the accessibility of the park in general. This basic data is needed for various applications, which can be used as a planning instrument for national park management.

2.3.5.2 User Requirements

Table 8 lists the applications of interest and the types of data required by the SNP management (WP1 Customer Requirements).

Table 8: Swiss National Park requirements and the respective categories extracted from satellite image data (applications in grey have been the focus during WP12 - Feasibility Studies)

Application	**Spatially comprehensive inventory of ... [minimum area (accuracy)]**	**Extracted Categories from Satellite Image Data**
(1) monitoring of grazing areas of red deer	• grass areas • trees species composition • low forest stand density • type of soil coverage in forest stands 20x20m (10m)	• grassland type • tree species composition • low forest stand density
(2) changes of the alpine timberline	• grass areas • tree species composition • forest stand density • forest age class 20x20m (10m)	• grass areas • tree species composition • forest stand density
(3) monitoring of geomorphologic processes (erosion, rock slides) and vegetation development	• areas without vegetation 20x20m (10m)	• rock, gravel, soil • detection of geomorphological forms (rock glaciers)
(4) avalanche research	• vegetation type • forest stand characteristics (stand density, tree species composition, natural age class) • avalanche events 20x20m (10m)	• tree species composition • forest stand density
(5) snow depletion monitoring for models of seasonal animal movements and energy balance models	• monitoring snow-free areas 20x20m (10m)	
(6) forest fire research (development of fuel models)	• forest stand structure • forest stand density • under cover vegetation • forest age class 25m	• forest stand density
(7) extrapolation of spot inventories	• land cover 50m	• tree species composition • forest stand type • forest stand density • grassland type • rock, gravel, soil • water • sealed surface
(8) extension of the park	• land use and use-intensity 25m	

2.3.5.2.1 Unconsidered user requirements

In the course of the project, it became clear that some user requirements could not be fulfilled. The most significant reason was the lack of high resolution satellite data of the new sensor generation, which was expected to be available in the lifetime of the project. Many parameters could not be extracted due to the insufficient spatial resolution or the inability to detect them at all (i.e. type of soil coverage in forest stands). The following categories were not investigated:

- forest age class,
- forest under-cover vegetation,
- use of non-forest vegetation,
- mass movements (avalanches, rock, and land slides).

2.3.5.2.2 Considered user requirements

Since the various wildlife management applications necessitate similar classified satellite information, four different classification results were presented to the customer, addressing many of the categories of interest. From the user requirements listed in Table 8, the following parameters were derived from satellite data:

- forest: tree species composition, stand density;
- non-forest vegetation: type of non-forest vegetation (type of grassland);
- non-vegetation: type of areas without vegetation (rock, gravel, soil), rock glaciers;
- other areas: settlements (sealed surface), snow, water bodies.

2.3.5.3 Applied Methods

Since the new generation of high resolution sensors was not available during the course of ALPMON, image data had to be chosen from commercially available satellites. For the fulfilment of the user requirements, Landsat TM data was used for all investigations concerning forest and grassland inventories. The detection of geomorphological forms was carried out on IRS-1C pan data.

The commonly used supervised parametric classification method, Maximum Likelihood, and the unsupervised non-parametric algorithm, Narendra-Goldberg Clustering, were used for the majority of classifications in ALPMON. Even though high relief terrain increases the spectral variance of an object in a satellite image, investigations have shown that simple algorithms like the Maximum Likelihood have produced very satisfactory results (WP9 Classification). Furthermore, the Narendra-Goldberg Clustering algorithm proved to be a very simple method to differentiate forest from non-forest. Not only is its application very efficient, as the number of clusters do not need to be specified a priori, but also the results, which were verified visually, proved to be very good (WP10 Verification).

Table 9 lists all classification results with their respective classes, which were delivered to the customer, addressing the considered user requirements. Classification results 1 and 2 were produced in a single classification step using the Maximum Likelihood algorithm, whereas classification results 3 and 4 were classified using an hierarchical approach (WP12 Feasibility Studies).

Table 9: Classification results assessed by the customer in the feasibility study

Classification results	Categories	Comments
(1) Tree species composition and grassland type classification	• forest: larch, alder, pure pine, mixed conifers • grassland types: lowland, highland, over silicate, over carbonate • water • rock, gravel, soil • sealed surface • no data (snow)	Region Il Fuorn
(2) Forest crown cover classification	• forest: disperse stand, middle dense stand, dense stand • grassland • water • rock, gravel, soil • sealed surface • no data (snow)	Region Il Fuorn and Val Trupchun
(3) NDVI grassland (~ phytomass estimation)	• NDVI calculation of grassland	Entire SNP
(4) Forest crown cover and grassland type classification	• forest: disperse stand, middle dense stand, dense stand • grassland type: disperse coverage (little phytomass), middle dense coverage, dense coverage (high phytomass) • water • rock, gravel, soil • sealed surface • no data (snow)	Entire SNP

2.3.5.4 Results

The Swiss National Park has visually checked the classification results (Table 9) delivered to them in different parts of the park and has responded positively over the use and applicability of classified remote sensing data. The results have been implemented in the analysis of various mountain ungulate research projects and diploma theses. The analysis of the integration of these satellite classification results 1 and 2 (Table 9) has not been completed by our customer, as the work is still ongoing.

Furthermore, the grassland analysis (classification result 3, Table 9) has been compared with research work based on field observations. This analysis showed that there is a significant correlation between 'short grass' vegetation, surveyed by biologists, and the NDVI values (WP12). The result of these grassland analyses initiated further investigations to take place. The SNP voiced the need to monitor the changes of all alpine meadows and grassland areas above the tree line for an entire season and correlate them with point data from quarterly field surveys carried out by park rangers, who map the spatial distribution of all mountain ungulates present in the park. Thus, classification result 3 was further developed to classification result 4.

Classification result 4 consists of different grassland types (according to NDVI computations) and different forest crown coverages. It was classified in a similar hierarchical manner as classification result 3. At first, the forested area was discriminated with the Narendra-Goldberg clustering algorithm. Then in a second step, the resulting classified forest was discriminated further into three crown cover classes using the Maximum Likelihood method. The third phase consisted of generating a non-forest mask with the help of the forest class. Then, all non-forest classes (grassland, water, rock, gravel, soil, sealed surface) were ML-classified. In the following last step, a grassland mask was produced, wherein the NDVI was calculated analogue to classification result 3. The first part of this investigation will be published in the near future (Catalini, 2000).

2.3.5.5 Conclusion

The results produced by ALPMON cover most of the user requirements as stated in 2.3.5.2.2. From the eight required applications listed in Table 8, only one application was tested by the SNP for its feasibility. All the classification results delivered to the SNP (Table 9) have been integrated into two ongoing mountain ungulate projects. The monitoring of grazing areas of red deer is one of the applications for which classified remotely sensed data serves as input to better understand the habitat analysis of red deer. Information on the distribution of grassland at different times of the year and open forest shows potentially used grazing areas. Classification results were also used to build a virtual world for the red deer, in order to model their behaviour. Results of the feasibility of these satellite classifications have not been established yet, as the work is still ongoing.

The remaining applications have not been tested by the customer for the following reasons:

- Many applications require that the inventoried vegetation parameters have a minimum area of 20x20m. This could not achieved, since the highest spatial resolution was 30m (Landsat TM) for multi-spectral satellite data, which has the necessary near-infrared and SWIR (short wave infrared) bands for the required vegetation investigations. Unfortunately, no SPOT data (20m) was available. For the monitoring of geomorphologic processes (erosion, rock slides), 6m-panchromatic satellite data was tested.
- The spatially comprehensive inventory of trees species composition and forest stand density could not be provided with a sufficient accuracy. As a consequence of the mediocre results, the classification of forest age class was omitted. Probably for this reason, applicability of the classification results for a number of listed applications was not followed through, since all of these categories were needed.
- The research carried out on mountain ungulates is the core research topic of the Swiss National Park, thus the monitoring of grazing areas of red deer was the most important application. All other applications have lesser priority, since they are of interest by other researchers not working for the Swiss National Park, but using the park as their research field.

In conclusion it has to be summarised that the Swiss National Park Administration has been positively convinced of the use and employment of this modern technology of remote sensing data. Visual verification of provided classification results has been carried out by our customer. Also, several results have been delivered as input to different mountain ungulate research projects and diploma theses, which are still in the process of being analysed.

2.3.6 Integration into CORINE-Landcover

2.3.6.1 Introduction and Objectives

Objective of this work package is the investigation on how far the results of ALPMON can be integrated into EU activities such as the CORINE land cover project. In contrary to the CORINE land cover project, which is based on visual interpretation of analogue satellite imagery, the ALPMON approach relies to a high extent on automated processing of digital data.

The aim of the CORINE („Co-ordination of Information on the Environment“) land cover project was to map the land use / land cover of Europe within the framework of the CORINE Program of the European Union. The European Environment Agency (EEA) in Copenhagen was in charge of the CORINE Program; co-ordination and support was performed by the „European Topic Centers on Land Cover“ (ETC/LC). The Project was carried out by so called „National Reference Centres“ (NRC) in the member states.

The „Co-ordination of Information on the Environment“ for Europe offers the possibility of comparing environmental data between the Member States. Furthermore the data can be a useful tool for environmental applications and research at European level. For this reason it is necessary to have a unique methodology for collecting the same basic data on land cover / land use for all collaborating countries. The methodology was developed by the „Joint Research Centre“ (JRC) in Ispra, Italy (EUR 1993).

The methodology is based on visual interpretation of satellite data including the use of ancillary data (topographical and thematic maps, statistics etc.). The photo-interpretation was performed on the basis of colour hardcopies of geocoded multi-spectral satellite data in a scale of 1 : 100.000. The different cover types were mapped according to the CORINE land cover Nomenclature, which consists of 44 different land cover / land use types (Table 10). The surface area of the smallest unit mapped is 25 hectares. For linear elements the minimum width is 100 meters. Finally, the interpretation results were scanned and integrated into a geographical information system. The digital CORINE land cover data are stored according to the official topographical map projection system of the single member states.

2.3.6.2 User Requirements

The interest of the NRCs, represented by the Austrian Environment Agency, concentrates on the possibilities to reduce the effort of visual interpretation and thus the costs of up-dating the CORINE land cover maps. This could be achieved by applying an automated approach as performed in the ALPMON project as alternative to photo-interpretation. However, it has to be noticed that formalised methods of pattern recognition cannot currently replace the ability of a human vision system. On the other hand they provide reproducible results that are more consistent than the results of visual interpretation. In addition it might be possible to extract more detailed information to be added as level 4 classes to the CORINE nomenclature. Objective of this work package is thus an evaluation of the results of the automatic classification performed in ALPMON compared to the original CORINE interpretation including the introduction of additional level 4 classes.

2.3.6.3 Applied Methods

Compared to the CORINE land cover maps the ALPMON data base has been derived from semi-automatic classification of digital satellite imagery. According to the processing chain developed in the course of the ALPMON project the following procedures have been applied:

- Geocoding
- Topographic normalisation
- Atmospheric correction
- Image fusion (optional)
- Numerical classification

Table 10: CORINE land cover nomenclature

Level 1	Level 2	Level 3
1. Artificial surfaces	1.1 Urban fabric	1.1.1 Continuous urban fabric
		1.1.2 Discontinuous urban fabric
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units
		1.2.2 Road and rail networks and associated land
		1.2.3 Port areas
		1.2.4 Airports
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites
		1.3.2 Dump sites
		1.3.3 Construction sites
	1.4 Artificial non-agri-cultural vegetated areas	1.4.1 Green urban areas
		1.4.2 Sport and leisure facilities
2. Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land
		2.1.2 Permanently irrigated land
		2.1.3 Rice fields
	2.2 Permanent crops	2.2.1 Vineyards
		2.2.2 Fruit trees and berry plantations
		2.2.3 Olive groves
	2.3 Pastures	2.3.1 Pastures
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops
		2.4.2 Complex cultivation patterns
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation
		2.4.4 Agro-forestry areas
3. Forests and semi natural areas	3.1 Forests	3.1.1 Broad-leaved forest
		3.1.2 Coniferous forest
		3.1.3 Mixed forest
	3.2 Shrub and/or herbaceous vegetation associations	3.2.1 Natural grassland
		3.2.2 Moors and heathland
		3.2.3 Sclerophyllous vegetation
		3.2.4 Transitional woodland shrub
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes and sand planes
		3.3.2 Bare rock
		3.3.3 Sparsely vegetated areas
		3.3.4 Burnt areas
		3.3.5 Glaciers and perpetual snow
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes
		4.1.2 Peatbogs
	4.2 Coastal wetlands	4.2.1 Salt marshes
		4.2.2 Salines
		4.2.3 Intertidal flats
5. Water bodies	5.1 Inland waters	5.1.1 Water courses
		5.1.2 Water bodies
	5.2 Marine waters	5.2.1 Coastal lagoons
		5.2.2 Estuaries
		5.2.3 Sea and ocean

The resulting thematic maps refer to the nomenclature defined in the ALPMON project (Table 11). Minimum mapping unit is the single pixel.

Direct comparison between the CORINE and the ALPMON land cover maps shows three fundamental differences:

- Differences in the nomenclatures
- Different minimum mapping unit
- Different data representation (raster versus vector)

While the problem of data representation is not treated in this work package achievements have been made in setting up rules for the transition between the nomenclatures and in overcoming the problem of the different minimum mapping units.

Table 11: ALPMON aggregated land cover classes

Topic	DN	Class
Forest type	0	No forest
	1	Broad-leaved (>25% coniferous)
	2	Mixed (25-75% coniferous)
	3	Coniferous (>75% coniferous)
	99	Shadow
Forest age	0	No forest
	1	Culture
	2	No age defined (for pinus mugo, greenalder)
	3	Thinning to pole
	4	Timber and old timber
	99	Shadow
Forest canopy closure	0	No forest
	1	Crown closure >10 to 30%
	2	Crown closure >30 to 60%
	3	Crown closure >60%
	99	Shadow
Non-forest classes	0	Forest
	1	Rock, gravel, soil, sealed surface
	2	Water
	3	Meadow, pasture
	4	Shrubs (rhod.sp., junip.sp., etc.) and "open forest" (crown closure up to 10%)
	5	Wet land
	7	Snow, ice
	99	Shadow
Sealed surface	0	No sealed surface
	1	Sealed surface >75%
	2	Sealed surface 20-75%

2.3.6.3.1 Transition of nomenclatures

During the customer workshop in Innsbruck in February 1999 a discussion between the project partners and the end user from the Austrian Environment Agency was used to define the ALPMON classes in the context of the CORINE nomenclature. A table was set up that contains the corresponding CORINE land cover class for all ALPMON classes (Table 12).

As can be seen from Table 11 the ALPMON approach concentrated on the classification of different forest types, crown closure and age of forest. In addition a number of non forest classes were derived. No focus was set on the differentiation of artificial surfaces. For the integration into CORINE the forest types are aggregated to broad-leaved, coniferous and mixed forest. The forest age is not considered, but the crown closure is taken into account in order to investigate the transition between non-forest and forest areas in the CORINE land cover. Grassland comprises both natural grassland and pastures. Shrubland will be assigned to transitional woodland shrub. Rock, gravel and bare soil might comprise both rocks and sparsely vegetated areas. Wetlands and water bodies can be limited to the corresponding classes of inland marches and inland waters. The lack of most Artificial Surface and Agricultural classes can be explained by the alpine environment of the test sites – the altitude of most areas is too high for growing agricultural crops and large urban areas do not occur.

Table 12: Transition rules between ALPMON and CORINE land cover classes

ALPMON classes	CORINE classes
Sealed surfaces	1.1 Urban fabric
Broad-leaved forest (aggregated)	3.1.1 Broad-leaved forest
Coniferous forest (aggregated)	3.1.2 Coniferous forest
Mixed forest (aggregated)	3.1.3 Mixed forest
Grassland	2.3.1 Pastures 3.2.1 Natural grassland
Shrubs (juniperus, rhododendron)	3.2.4 Transitional woodland shrub
rock/gravel/soil	3.3.2 Bare rock 3.3.3 Sparsely vegetated areas
Snow/ice	3.3.5 Glaciers and perpetual snow
Wet land	4.1.1 Inland marshes
Water	5.1 Inland waters

Applying the transition rules from Table 12 allows for a direct comparison of the two data sets. In order to enable this comparison the vector based CORINE land cover maps are rasterised with the pixel size of the ALPMON land cover maps. Confusion matrices of the two raster layers give a first idea of the level of agreement between the data sets. They were also used as reference for generalising the ALPMON classification results as described in the following chapter.

2.3.6.3.2 Spatial generalisation of land cover maps

When comparing thematic maps on a pixel basis the minimum mapping units have to be considered. Areas that are composed of different land cover types in one map might be generalised to one land cover type in the other map. In the actual case the minimum mapping unit of CORINE equals 25 hectares, whereas the ALPMON results are classified on a pixel basis. Assuming a pixel size of 10m all regions smaller than 2500 pixels have to be generalised, e.g. an area composed of patches of coniferous and broad-leaved forest each being smaller than 2500 pixel might be assigned mixed forest after generalisation.

In order to perform the generalisation two aspects have to be considered. First only those pixels are processed that belong to regions smaller than 25 hectares. Second the neighbourhood of these pixels has to be investigated in order to find the proper generalised class for the pixels. This neighbourhood analysis will be performed applying a so-called post-classification algorithm (Steinnocher 1996).

The algorithm works within a local neighbourhood which is defined by a moving window. Within this window a standardised histogram of the input classes is calculated, representing the spatial composition i.e. the frequency of the input classes found in the local neighbourhood. The histogram is then compared to a set of rules which represents the expected frequency of input classes for each generalised class. As soon as a rule is found to be true the corresponding generalised class is assigned to the centre pixel of the window.

Each rule defines the minimum frequency of one or more input classes for one generalised class. When compared to the corresponding elements in the histogram the frequency values represent thresholds. If all thresholds are exceeded within a rule, it is recognised as true and the corresponding secondary class will be assigned. The rules allow for a combination of several sub-rules within one major rule. Each sub-rule defines a threshold for one or more input classes and all sub-rules have to be true to accept the major rule. Processing of the rule-set is performed step by step starting at the top of the set. As soon as a rule is accepted and therefore applied, the rest of the rule-set will not be considered any more. If no rule is found to be true a rejection class is assigned.

Apart from the design of the rule-set the size of the analysed neighbourhood represents a crucial parameter in the post-classification process. Choosing a small window size will lead to a ‘noisy’ result since only high frequency structures will be recognised. If the window is too large the smoothing effect will become very strong, thus leading to a loss of detail. At this point it has to be noted that the presented post-classification is a generalisation process and will always suppress details. However, for the actual application this effect is required for deriving the generalised representation of the CORINE land cover maps.

The post-classification algorithm was implemented as a C program (postcl.c), and can be easily implemented under any operating system providing a C compiler. The image format used by the program is the ERDAS™ *.gis format. The header of this image format is interpreted by a structure, provided in the include file head.h.

Application of the post-classification algorithm will lead to patches that might still be smaller than the minimum mapping unit (although it is likely that they will be larger than the patches in the original classification). By simply shrinking these areas a lot of information would be lost. Therefore a second generalisation process is needed after the post-classification. This is achieved by applying an iterative shrinking process that affects only the regions originally smaller than the minimum mapping unit, while the larger ones are not changed at all. First all regions smaller than a certain threshold are shrunk leading to increasing larger regions at the expense of the smallest ones. In the following iterations this process is repeated applying an increased threshold until the threshold equals the desired minimal mapping unit. Performing this iterative process will lead to a generalised map without loosing significant information.

2.3.6.4 Results

The process of post-classification and subsequent iterative shrinking was applied to the classification results of all test sites. In order to show the effect of this process both the original classifications and the resulting generalised maps were compared to the respective CORINE land cover maps. Visual comparison was performed by means of maps, while a numerical comparison was based on confusion matrices (for details see report on WP 12). Looking at the results of the comparison a general trend can be seen. While the agreement between the original classifications and the CORINE land cover maps is relatively low, it increases significantly after the application of the post-classification process (Table 13). In all test sites the post-classified images have a higher agreement with the CORINE land cover maps. This effect is due to the increased level of generalisation that is provided by the post-classified images. In addition there is a significant increase of agreement when reducing the degree of thematic detail in the CORINE land cover maps by aggregating to level 2 (15 classes) and level 1 (5 classes). This indicates that the major confusion between the maps result from detailed thematic differences, that are likely to be caused by misinterpretation/-classification and differences in nomenclatures. A detailed analysis of the confusion between the data sets can be found in the report on work package 12.

Table 13: Agreement between CORINE land cover maps and ALPMON results

Test sites	Dachstein	Tarvisio	Cordevole	Mangfall	Engadine
ALPMON classification, agreement with					
CORINE Level 3	53%	45%	62%	29%	n.a.
CORINE Level 2	62%	78%	68%	64%	55%
CORINE Level 1	79%	83%	93%	88%	68%
ALPMON post-classification, agreement with					
CORINE Level 3	64%	53%	66%	40%	n.a.
CORINE Level 2	70%	84%	72%	67%	58%
CORINE Level 1	88%	86%	93%	90%	72%

2.3.6.5 Evaluation by the customer

The agreement between the original classifications and the CORINE land cover maps of the test sites has been less than 50% in average. This “poor” agreement is partly due to the different degrees of generalisation of the land cover maps. While in CORINE the minimum mapping unit is 25 ha (= 250000 m^2), the ALPMON classifications refer to the single pixel, i.e. an area between 25 m^2 and 900 m^2 depending on the image data applied. In order to overcome this contradiction of scale the

ALPMON classification results were post-processed using an generalisation technique. This technique allows to combine neighbouring pixels of different classes to larger objects of one heterogeneous class. Generalisation of the ALPMON classifications has its clear impact on the degree of agreement that could be increased by post-processing to almost 60% in average. Although an increase of 10% can be considered significant, and proves the effectiveness of the post-processing method, there is still about 40% of confusion between the data sets that have to be explained. A part of it might be caused by the different approaches towards generalisation. Visual interpretation usually defines the dominant class in an image as “background” and “cuts out” the remaining classes. The post-processing technique is always limited to the local neighbourhood and therefore does not consider dominant classes in a larger environment.

A major reason for the confusion between the data sets can be found in the differences between the nomenclatures, despite the effort of harmonisation, or in the interpretation of the nomenclature. This is stated in the confusion between forest and shrubland or between meadows / pastures, sparse vegetation and rocks. Here the problem is a clear definition of class limits, both in terms of space and theme. Delineation of land cover types is critical, if the spatial transition is continuos, e.g. between forest and shrubland. Differentiation of land cover types is critical, if the thematic transition is continuos, e.g. between sparse vegetation and rocks. A significant difference can also be found in the interpretation of forest types. Mixed forest in ALPMON is to a high extent interpreted as coniferous forest in CORINE, while parts of coniferous forest in ALPMON are confused with natural grassland and heathland in CORINE. The latter is due to the fact that dwarf mountain pine was defined as heathland in the CORINE nomenclature. The over estimation of coniferous forest at costs of mixed forest in CORINE – as confirmed by aerial images – might be due to the differences in the original minimal mapping unit, i.e. the different approaches to generalisation.

In general it has to be noted that the confusions in the different test sites do not show the same pattern. As a unique and reproducible processing chain was used in ALPMON to ensure comparable results for the test sites, it is likely that the CORINE data sets are not totally compatible. This becomes evident when comparing the single CORINE land cover maps from the different countries involved – Germany, Austria and Italy. For Switzerland the situation is different, as the standardised CORINE land cover map is not available. Final conclusions lead to the impression that the different approaches cannot be directly combined, at least not on level 3 of the CORINE nomenclature. Comparing the land cover maps on level 2 could lead to spatial indicators that might help the interpreter to concentrate on areas that are likely to have changed, or have been incorrectly assigned in the first version of the CORINE land cover map. The final decision on the land cover type, however, should be left to the interpreter. Such a combined approach would help to overcome the inconsistencies that appear in visual interpretation, such as overlooking single land cover units, but at the same time would benefit from the human vision system for detailed interpretation.

The introduction of level 4 classes to the CORINE nomenclature is considered possible for forest areas. While CORINE only differentiates three forest classes – coniferous, mixed and broad-leaved forest – the ALPMON classification takes into account forest types, age classes and crown coverage. However, it is to be noted that with an increasing level of detail the reliability of these classes is significantly decreasing. No conclusions can be given for other level 4 classes, such as for artificial surfaces or agricultural areas, as these land cover types hardly occur in alpine areas and thus were not of major interest for the ALPMON project.

2.4 Resources Employed by Work Package

The resources employed for each work package are listed in Annex 5. The figures give approximate values, as the final project cost statements were not available for this calculation.

2.5 Presentation of Project Web Pages

The ALPMON project is presented in the internet. A project web page has been installed at JR. Here, the general information on the project, its goals and actual state are presented. The content of this web page was updated continuously according to the progress of the project. The ALPMON web page provides information on

- **Description** of the project
  - Introduction
  - Aim of ALPMON
  - Remote sensing tasks
  - GIS tasks
  - Feasibility studies
  - Work packages
- **Partners**: List of partners including address, contact persons, etc.
- **Customers**: List of customers including address, contact persons, etc.
- **Applications**: Short description of the applications
- **Reports**: List of reports already available for downloading as Word6 document or as pdf file.

An example of the web page design is given in Annex 8. Additionally, information on the ALPMON project may be found on the CEO as well as the EWSE web pages which are linked to the ALPMON web page.

3 Conclusions and Recommendations

In general, it could be expected that the remote sensing and GIS approach used for all applications would be able to support the customers by establishing and updating their models as well as information systems. Problems occurred with extraction of some special classes which were required by some national customers, such as selected tree species. However, in comparison to conventional methods satellite remote sensing represents an ideal instrument for objective and standardised data acquisition especially of data related to regional structures. Further advantages are that satellite images can synoptically record wider areas, and that using this data it is possible to observe the same areas repeatedly which permits monitoring over many years, as requested by all customers.

The specific outputs of the research include technical specification (e.g. timing and spatial resolution) for acquisition and processing of remotely sensed data as well as model definitions for GIS. It was investigated how the incorporation of remotely sensed data improves time and costs of the respective planning and environmental analyses. The research resulted in prescriptive methods of data analyses aimed at the operational needs of the customers. The output are guidelines with demonstrative examples which can be used by the aforementioned communities.

3.1 Project Evaluation Against Success Criteria

The results of the project were evaluated by means of the following success criteria: First, the number and accuracy of the parameters which were derived from remote sensing and other sources were evaluated with respect to the customers needs. Then the costs for the remote sensing applications addressed within this project are estimated and compared to the costs of conventional methods. Finally, a validation of the final products by the customers is given.

From the beginning of the project and the discussions with the customers it can be stated that the objectives and goals of the project meet the customers needs. The results in most cases can be directly incorporated in the criteria catalogue defined and operationally used by the customer. Furthermore, the results and methods are applicable by the customer, as far as he is equipped with image processing and/or GIS software.

3.1.1 Number and accuracy of parameters

The assessment of the results against the success criteria should be performed by the following measures:

- Accuracy levels obtained by means of remote sensing methods compared to customer requirements (taking into account tolerance ranges defined by the customer).
- Accuracy levels obtained by means of remote sensing methods compared to those obtained by conventional techniques (as far as available).
- Results of remote sensing techniques compared with conventional methods currently used by the customer.

For all applications on national level respectively test sites the number and accuracy of parameters as required by the customer vs. the parameters derived by means of remote sensing for ALPMON are compared in Annex 6. Therefore, they are not discussed in detail here. As far as applicable, the remote sensing approach is also compared to conventional methods. It has to be stated that in most cases no conventional methods, such as aerial photo interpretation or field work, have been used by the customer before – especially not for the entire area to be investigated. Therefore, a comparison in most cases was not possible.

As the land use classes required for the data base of the Alpine Convention are not as detailed as those obtained for the national applications, it can be stated that these parameters could be acquired with good spatial as well as thematic accuracy. The second requirement of the Alpine Convention, the assessment of vegetation damage, could not be fulfilled within the ALPMON project. Forest damage has been investigated in more detail in the EC-project SEMEFOR (ENV4-CT97-0398), and methods for deriving this parameter were deduced from there. Furthermore, the assessment of the succession status was of interest for the AC. This parameter can easily be deduced from comparison of the land cover classification results, as they were derived in the ALPMON project, from different years by monitoring techniques. A method for vegetation monitoring in the Alps has been developed by Gallaun et al. (1999), which can be applied to the monitoring of succession status. Mono-temporally, the satellite image classification can only give information on the actual vegetation cover, but not on succession, which is a process of several years. Finally, topographical information, which is at least a pre-requisite for satellite image pre-processing, in all test sites was provided by means of digital elevation models. Quality and resolution of the DEM in all cases are sufficient for the Alpine Convention. As no high resolution DEM (25m) is available for the entire Alps, it could even be considered to introduce the MONA DEM with 80m resolution to the AC data base.

Concluding it can be stated, that in many cases the customer requirements could be fulfilled. In some feasibility studies, some parameters required by the customers could not be extracted from remote sensing data or not with sufficient accuracy. However, even in these cases, the results derived from earth observation data represent a valuable information source which significantly improves the actual sate of available information for the customers. With respect to the new very high resolution satellite data this positive effect is expected to be even increasing, as the classification of some parameters was restricted due to the coarse resolution of the satellite data available for this study.

3.1.2 Cost estimation

Not only the potential of satellite imagery to derive certain land cover parameters, but also the costs of such an approach are decisive for the decision of various customers to introduce earth observation methods into their specific applications. With this respect, the costs for the remote sensing approach were estimated and compared to the costs of conventional methods (as far as applicable).

The cost estimation has been performed for three different investigation scales:

- Scale 1:250,000 (with respect to the Alpine Convention, using WIFS data): forest/non-forest and forest type
- Scale 1:50,000 to 1:100,000 (with respect to the Alpine Convention, using Landsat 7 TM data): Alpine Convention nomenclature
- Scale 1:50,000 and better (with respect to the national customers; with additional parameters relevant for these customers; on the assumption that higher resolution data is used).

The cost estimation for the national applications with a scale of 1:50.000 or better is given in Table 14 (in EURO) and Table 15 (in person hours). The figures concerning the person hours do not consider the data costs. The cost estimations for the European customer requirements are calculated for one entire satellite image (Table 16) as well as for the whole Alps (Table 17). The cost respectively time effort estimated for the scale of 1:50.000 to 1:100.000 varied between 1,78 EURO/0.05 hours per km^2 and 2.04 EURO/0.03 hours per km^2.

All cost estimates are performed under the assumption that the processing procedure is already developed. A further assumption was that the aerial photos (for reference area investigation) and the DEM are provided by the customer.

In general, the more satellite scenes are treated for one application, the cheaper the interpretation per km^2 becomes. However, the area of interest always has to be taken into consideration when calculating the costs for a specific application. The costs for the interpretation of one satellite scene remain more or less the same, whether the area of interest is the entire image or only one km^2. This explains the differences in costs per km^2 given in Table 16 and Table 17 for classification of one entire Landsat TM scene (32.400 km^2), all scenes covering the Alps (360.000 km^2), and the area restricted to the Alps (180.000 km^2).

Conventional methods could only be evaluated as far as they were applicable to the specific requirements and as far as they were previously used by the customers. For most applications this was not the case, as earth observation data provided additional information to the customers, which was not available in this kind before. However, two figures on more or less conventional methods can be given for comparison with the ALPMON remote sensing approach.

The first concerns CORINE land cover, which is investigated by visual interpretation of Landsat TM false colour composites. The costs for the interpretation of CORINE land cover were estimated by the Federal Environment Agency of Austria with 9.50 EURO/km^2. Compared to the cots estimated for (semi)automatic classification with approx. 2 EURO/ km^2 (Table 16) the costs of the conventional visual interpretation are nearly five times higher. However, it has to be kept in mind, that the results of both approaches are not directly comparable.

For most of the national applications the only alternative to satellite image classification would be aerial photo interpretation or field work. It has to be emphasised, that the different methods are not directly comparable, as they deal with different scales and in most cases also different nomenclatures respectively parameters and number of classes to be investigated. Only for forestry related aerial photo interpretation figures are available from an area which was investigated in Carinthia/Austria. The figures given in Table 18 apply to a very detailed interpretation of aerial photos for forest parameters using an analytic stereo plotter, including vectorisation of the interpretation results. The costs are given only for the forest covered areas, which in Austria can be assumed with approx. 50% of the area covered by the aerial photos. They were estimated with 1325 EURO per km^2. It can be expected that these costs may be further reduced by a maximum factor of 5 when less parameters are interpreted or less detail is required. This would lead to a figure of approx. 130 EURO/km^2 for a land cover interpretation down to 80 EURO/ km^2 for the investigation of only a few land cover parameters. Concluding it has to be stated that also here a direct comparison of the conventional approach with the satellite classification is not possible, as the scale and detail of interpretation in both cases is quite different. However, a tendency can be clearly read from these figures, indicating that satellite image classification for the described applications and required parameters is much cheaper than the conventional methods available, and that for this reason satellite image classification in many cases made an investigation of the required parameters possible for the first time.

Table 14: Cost estimation for national ALPMON applications for scales of 1:50.000 and better (in EURO).

Scale >= 1:50.000 Estimation for an area of approx. (in most cases one complete satellite scene):	3600 km²	460 km²			3600 km²	31.500 km²
Data sources	1 SPOT 4 scene	Landsat TM + KVR-1000			1 SPOT 4 scene	1 Landsat TM scene
Application	**Avalanche**	**Tourism**	**Ibex habitat**	**Forest**	**Water run-off**	**Erosion Risk**
Parameters	Land cover and forest details	Land cover	Forest, grassland, others	Crown closure 3 classes	Land cover and forest details	Land cover and forest details
Satellite image classification	*EURO*	*EURO*	*EURO*	*EURO*	*EURO*	*EURO*
Definition of requirements and nomenclature	750,00	750,00	750,00	750,00	500,00	3.019,00
Air-photo interpretation (reference + verification areas)	20.000,00	5.000,00	2.500,00	2.500,00	15.000,00	95.125,00
Satellite image	2.500,00	5.000,00	5.000,00	5.000,00	4.000,00	3.500,00
Geocoding	1.800,00	1.750,00	1.750,00	1.750,00	1.800,00	10.750,00
Topographic (and atmospheric) normalisation	1.800,00				3.000,00	15.570,00
Signature analysis	20.000,00	2.000,00	1.000,00	1.000,00	8.000,00	89.970,00
Classification	9.000,00	6.000,00	3.000,00	3.000,00	6.000,00	48.150,00
Verification	4.000,00	1.000,00	1.000,00	1.000,00	2.000,00	5.980,00
Reporting and results in GIS format	3.000,00	3.000,00	1.500,00	1.500,00	2.000,00	18.201,00
Total	*62.850,00*	*24.500,00*	*16.500,00*	*16.500,00*	*42.300,00*	*290.265,00*
Costs per km²	***17,46***	***53,26***	***35,87***	***35,87***	***11,75***	***9,21***

Table 15: Cost estimation for national ALPMON applications for scales of 1:50.000 and better (in person hours).

Scale >= 1:50.000 Estimation for an area of approx.						
(in most cases one complete satellite scene):	3600 km^2	460 km^2			3600 km^2	31.500 km^2
Data sources	1 SPOT 4 scene	Landsat TM + KVR-1000			1 SPOT 4 scene	1 Landsat TM scene
Application	**Avalanche**	**Tourism**	**Ibex habitat**	**Forest**	**Water run-off**	**National Park**
Parameters	Land cover and forest details	Land cover	Forest, grassland, others	Crown closure 3 classes	Land cover and forest details	Land cover and forest details
Satellite image classification	*person hours*	*person hours*	*person hours*	*person hours*	*person hours*	*person hours*
Definition of requirements and nomenclature	11	24	24	24	20	
Air-photo interpretation (reference + verification areas)	303	160	80	80	600	84
Satellite image						prep. field data 42
Geocoding	27	56	56	56	27	42
Topographic (and atmospheric) normalisation	27				45	25
Signature analysis	303	64	32	32	320	
Classification	136	124	96	96	240	84
Verification	61	32	32	32	80	
Reporting and results in GIS format	45	96	48	48	80	17
Total	*914*	*556*	*368*	*368*	*1.412*	*294*
Person hours per km^2	***0,25***	***1,21***	***0,80***	***0,80***	***0,39***	***0,009***

Table 16: Cost estimation for European customer requirements.

Scale	**1:50.000 to 1:100.000 (e.g. CORINE)**		**1:250.000 to 1:500.000 (AC)**		**1:250.000 to 1:500.000 (AC)**	
Estimation for one complete satellite scene covering an area of approx.	32400 km^2		32400 km^2		592200 km^2	
Data sources	1 Landsat7 TM scene		1 Landsat7 TM scene, geoc.		1 WIFS scene	
Parameters	Land cover and forest details		Forest cover and forest type		Forest cover	
Satellite image classification	*EURO*	*person hours*	*EURO*	*person hours*	*EURO*	*person hours*
Definition of requirements and nomenclature	750,00	11	750,00	11	250,00	4
Air-photo interpretation (reference + verification areas)	25.000,00	379	10.000,00	152	10.000,00	152
Satellite image	618,00		618,00		763,00	
Geocoding	1.800,00	27			1.800,00	27
Topographic normalisation	1.800,00	27				
Signature analysis	20.000,00	303	10.000,00	152	3.000,00	45
Classification	9.000,00	136	4.000,00	61	4.000,00	61
Verification	4.000,00	61	4.000,00	61	4.000,00	61
Reporting and results in GIS format	3.000,00	45	3.000,00	45	3.000,00	45
Total	*65.968,00*	*990*	*32.368,00*	*481*	*26.813,00*	*395*
Costs per ***km^2***	***2,04***	***0,0306***	***1,00***	***0,0148***	***0,05***	***0,0007***

Table 17: Cost estimation for the classification of the entire Alps (approx. 180.000 km^2).

Scale	**1:250.000 to 1:500.000 (AC)**		**1:250.000 to 1:500.000 (AC)**	
Data sources	15 Landsat7 TM scenes (from 7 paths), geocoded		2 WIFS scenes	
Area coverage	approx. 360.000 km^2		approx. 600.000 km^2	
Parameters	**Forest cover and forest type**		**Forest cover**	
Satellite image classification	*EURO*	*person hours*	*EURO*	*person hours*
Definition of requirements and nomenclature	750,00	11	250,00	4
Air-photo interpretation (reference + verification areas)	70.000,00	1061	20.000,00	303
Satellite image	9.270,00		1.526,00	
Geocoding			3.600,00	55
Topographic normalisation				
Signature analysis	70.000,00	1061	6.000,00	91
Classification	28.000,00	424	8.000,00	121
Verification	28.000,00	424	8.000,00	121
Reporting and results in GIS format	10.000,00	152	5.000,00	76
Total	216.020,00	3133	52.376,00	770
Costs per km^2 (entire area covered by satellite scenes)	***0,60***	***0,0087***	***0,09***	***0,0013***
Costs per km^2 (entire Alps)	***1,20***	***0,0174***	***0,29***	***0,0043***

Table 18: Cost estimation for a detailed aerial photo interpretation of forest parameters.

Aerial photo interpretation	206 km^2 forest covered area
Parameters	Detailed forest interpretation with an analytic stereo plotter
	EURO
Flight costs (estimated)	43.000,00
Interpretation	230.000,00
Total	273.000,00
Costs per forest covered km^2	***1325,24***

It has to be stressed that the classification results only had a little role to play in the tourism application study. Here the fusion image (Landsat 5 TM + KVR-1000) has been very important. This fusion image could be replaced by a mosaic of aerial photographs. Table 19 shows the comparison of image fusion and aerial photo mosaicking.

Table 19: Cost estimation - Image fusion (for an area of approx. 460 km^2).

Aerial photo mosaic	person hours	EURO
Flight costs	-	25.000,00
Ortho- rectification	160	5.000,00
Mosaicking	160	5.000,00
Total		30.000,00
Costs per km^2		**65,22**

Fusion image	person hours	EURO
Satellite image (Landsat 5 TM, KVR-1000)	-	5.000,00
Geocoding	56	1.750,00
Atmospheric correction	64	2.000,00
Fusion	64	2.000,00
Total		10.750,00
Costs per km^2		**23,37**

3.1.3 Scientific Added Value

One prerequisite of the project was to use already operational methods and algorithms as far as they are applicable and sufficient for the ALPMON feasibility studies. This decision was taken due to the aim of the project that the methods and algorithms finally should be easily applicable by the customers themselves without need of special software and training apart from common commercial software products. Therefore, for data pre-processing and classification the project mainly concentrated on the investigation and application of common algorithms. Nevertheless, it was necessary to develop some algorithms which were not available yet, but needed for the realisation of the alpine applications.

From the producers point of view the scientific added value of the ALPMON investigations is connected first to the recognition of some specific problems still not solved satisfyingly and second on the evaluation of new software packages which promise to be able to solve some of the recognised problems in the near future:

1. Unsolved problems
    - The limits of conventional image processing systems for analysing the spectral feature space statistically in case of high resolution data sets of the meter range.
    - The estimation of grid size upper limits for a statistically correct calculation of water run off with ASGI. The evaluations performed in the frame of the ALPMON investigation gave only a rough approximation.
    - The documentation of inaccuracies in administrative data layers e.g. of the “ATKIS Vorstufe”, the forest management maps, the geologic maps, etc.
    - The lack of high resolution, high accuracy DEM as required for high geometric resolution data of the new generation EO systems like Space Image Carterra´s IKONOS.
2. Upcoming software and need for further research
    - In case of radiometric correction the combined topographic/atmospheric normalisation with ATCOR 3 seems to work successfully. The calculation of radiance per square unit seems to become possible, despite there are still some limitations basically due to inaccurate estimation of some parameter like the bi-directionality of backscatter. Further tests have to

demonstrate the potential of this software for radiometric correction of images from alpine regions.

- The perspectives offered by image analysis systems working object oriented like the tested eCognition from the Delphi2 Creative Technologies company, which seems to be the first step to reduce the problems connected to high resolution data and in general with data fusion. Further achievements with respect to feature extraction, shape, segmentation and object based classification are reached with the ClassTool software currently developed at JR.

Limitations of the present as well as perspectives of the future are discussed in more detail in section 3.4. The main scientific developments were achieved within the feasibility studies, where new method developments were necessary.

The development and implementation of the **image fusion** algorithm had a significant impact on the classification and visualisation of remotely sensed images. The classification of meta classes, such as the production of a forest/non forest mask, could be improved. For the visualisation of multi-resolution images the fusion method solved the problem of different pixel sizes and thus suppressed the aliasing effect in the resulting images. The methodology used for the fusion algorithm was presented to and discussed within the scientific community during several conferences (Steinnocher, 1998, Steinnocher, 1999). For example, the University of Freiburg used this method to create a fusion image as basis not only for visual interpretation but also for visualisation tasks (WP12). A photorealistic background for tourist information with a ground resolution of 2m was derived out of Landsat 5 TM data and KVR-1000 data.

For the aim 'tourist information' a **tourist information system** was programmed by using ArvView's programming language Avenue. In this tourist information system it is possible to choose hiking routes by free choice and get describing information for this route. This enlarges the possibilities of a tourist office: not only advised routes but free choice of the route with describing information like length, altitude profile, landscape factors.

For the **modelling of water run-off** using the ASGI model the estimation of soil characteristics could be significantly improved by fusion of small scale geological and soil type maps. Generally, no convenient and wall to wall soil type information is available for alpine areas. Furthermore, it was for the first time that land cover classification results could be implemented as one main parameter into the ASGI water run-off model for an alpine region.

The original scientific added value of the **erosion risk** feasibility study is summarised in the following points:

- The use of a land cover map derived from satellite as basic input for the erosion model.
- The development of an erosion model based on the concept of risk instead of the estimation of the annual amount of ablated material. The concept of risk is more suitable for land planning.
- The consideration of several mass erosion phenomena typical of Alpine environment.
- The use of two different sub-models (DA and SCS-CN) to take into account the static component of the risk, related to soil properties and slope, and the dynamic component of risk, which depends upon the intensity of the run-off.
- The integration (FSTAB) of the above mentioned sub-models by means of an inference engine based on fuzzy set logic. Fuzzy logic is viable method to manage in a rigorous way uncertain situations where: 1) data accuracy is highly heterogeneous (e.g.: land cover vs. soil map) ; 2) interpretation criteria cannot be defined rigorously because of vague definitions (e.g. the concept of risk) and lack of detailed information.

The **avalanche risk assessment** mainly made profit from the classification of winter satellite images and introduction of these results into a multi-temporal classification approach. This for the first time enabled the separation of low growing tree species, such as dwarf mountain pine and green alder, from the high growing tree species, which is not possible by their very similar spectral characteristics.

For the transformation of the classification results in the test sites to the corresponding **CORINE land cover** maps a post-classification algorithm was developed (Steinnocher 1996). Due to the large differences in scale this algorithm had to be extended by an iterative shrinking method, in order to generalise the single land cover units to the minimum mapping unit of the CORINE land cover maps. The entire post-processing has been described and published in Steinnocher et al. (2000).

Furthermore, during the ALPMON project there has been scientific technology transfer from the University of Freiburg to the local administrations in Tarvisio and Pontebba, Italy - Forest Administration at Tarvisio, Tourist Administration at Tarvisio, Comunitá Montana at Pontebba.

3.1.4 Information of the Scientific Community

The project or some of its tasks have been presented to the scientific community at diverse national and international conferences. The publications are listed in section 6.1.

3.1.5 Information of the Public

Article 4, paragraph 3 of the Alpine Convention stipulates that “the Contracting Parties shall ensure that the public are regularly kept informed in an appropriate manner about the results of research, monitoring and action taken”. This means that the dissemination of information should not be restricted to the individuals immediately concerned, or public organisations and research institutions, but that the media should be used to ensure that a wider section of the public, both within the alpine areas and outside, will be appropriately informed. In order to optimally demonstrate the potential of remote sensing it also is necessary to ensure that specified customers receive information about the results of remote sensing applications. With this respect, information on the ALPMON project is provided by the following information sources:

- CD-ROM presentation of the project:

  A promotional CD-ROM will be delivered soon after the final report. This CD-ROM will give an introduction of the ALPMON project. The results of classification will be stored as images with additional describing text. The methods of the project can be read in the project reports which will be delivered in digital format on the CD-ROM too.

  The data on the CD-ROM can be accessed via a HTML interface with a common HTLM-browser.
- ALPMON homepage
- INFEO (CEO)
- Alpine CDS
- Customer workshop (see section 6.2).

The ALPMON project consortium is still negotiating with representatives of the Alpine Convention concerning a final project workshop for presenting the project results to the European customer as well as to other interested institutions. However, as the organisational structure of the Alpine Convention has changed and no international co-ordination responsible exists any more, it is very difficult to find the right frame for such a work shop. Nevertheless, this goal will be further followed.

3.2 Project Evaluation by the End Users

The project results of each application finally were evaluated by the national end users with respect to the satisfaction of their requirements. The user of remote sensing data not only needs to know the number of classifiable categories, but also reliable information about the accuracy of the classified parameters. Such information formed the basis for assessing the quality of the applications developed from remote sensing data. The product validation was carried out in close co-operation with the customers according to the parameters set up in the requirement studies. The evaluation accompanied the whole project duration and the final results were derived after repeated consultation of the customers. All national customers (except the Avalanche and Hydrogeological Defence Experimental Centre of Arabba) sent a short project evaluation letter which is attached to this report in Annex 9.

The discussion on the results with the Avalanche and Hydrogeological Defence Experimental Centre of Arabba, which is the customer of the feasibility study on erosion risk in the Cordevole test site, can be summarised into the following issues (Table 20):

Table 20: Synthesis of the customer evaluation for erosion risk.

Item	***Strong Points***	***Weak Points***
ALPMON Land Cover mapping from Remote Sensing	• *Demonstrates the feasibility of realisation of an up-to-date land cover mapping over the whole regional Alpine area.* • *Thematic content and accuracy is generally compatible with the fundamental requirements of erosion risk assessment.*	• *The geometric resolution of the employed satellites is not enough detailed to detect the presence on the surface of potentially unstable incoherent materials (e.g. debris flows). In other words, while the satellite sensors used in ALPMON are suitable for land cover mapping, they are still not satisfactory for geomorphological mapping. Pixel resolution of 1 metre should be required.*
Auxiliary data acquisition and harmonisation (geology, geomorphology)	• *The implementation of the erosion risk model has pushed the acquisition and harmonisation of auxiliary data until now spread among several administrations and very heterogeneous. The harmonised data will turn out to be very useful also for other land planning applications of the Customer.* • *The auxiliary data, once scanned and georeferenced, have been delivered to the local administrations which previously supplied the original information on printed format, allowing them to put the information in their GIS.*	
Erosion model	• *The FSTAB model is particularly interesting for planning purposes because: 1) it accounts for several erosion phenomena; 2) unlike other models, it gives a measure of the erosion risk instead of the predicted amount of removed soil.* • *The sub-model DA, built over a statistical analysis of ground surveys and extrapolated to the whole test site area using distributed data (including land cover) seems a promising approach to the zoning on the basis of soil static conditions.*	• *The quantitative verification of a potential risk index is rather difficult.* • *In displaying the MEHI erosion risk index, the choice of the right slicing levels of the index is very critical for the correct interpretation of the map.* • *The correct choice of the threshold precipitation event for the sub-model SCS-CN is rather difficult.*

3.3 Technical Project Evaluation

In the following the technical aspects of the projects sub-tasks as well as the feasibility studies are evaluated from the project teams point of view.

3.3.1 Set-up and harmonisation of parameters

The set-up of the parameters was carried out using a comprehensive list of single parameters and the respective classes. As the requirements of the national customers were used as input for the parameter set-up, the used level of detail ensures, that all requirements of the local customers could be met. The use of single parameters instead of predefined landuse-classes enables the flexible assignment of parameter classes to user-oriented classes.

The requirements of the Alpine Monitoring System (AMS) of the Alpine Convention were included only partially in the parameter set-up, because only a first draft of AMS-indicators was available at that time. Therefore, ALPMON oriented the parameter set-up according to FIRS (EUR 16416). In some cases, AMS-indicators are fully addressed by ALPMON parameters. Some of the AMS-indicators deal with topics, which cannot be assessed with remote sensing alone. The AMS-indicators do not include the ALPMON-parameters 'crown coverage', 'vegetation coverage' and 'natural age class'. These parameters are of great importance to the protection function of the forest as well as for the planning of regeneration measures. The AMS-indicators do not address non-forest areas, which are included in ALPMON.

As the collection of ground truth information in WP 4 proved, the parameter list can be used successfully. If the AMS-indicators were ready before the start of ALPMON, they would have been considered completely.

3.3.2 Collecting of ground information and verification of classification results

Work packages WP4 Ground Truthing and WP10 Verification are summarised collectively, as they are interrelated closely. The verification of classified satellite data is very much dependent on the reference, with which the verification is done. The classification accuracy, which results from the verification, is dependent on how the reference is sampled, its spatial distribution and its representativity of the categories of interest.

Ground truth information (WP4) was collected by all partners on the basis of infrared aerial photographs, which were additionally verified with field surveys. This approach was recommended for supporting the delineation of suitable training areas for the digital classification and for verification. The parameters set up in WP 3 were applied successfully. It must be stated that the applied sampling strategies for ground truth information differed from partner to partner, which directly influences the outcome of the verification. Subjectivity is induced by the choice of reference data sampling size and strategy (Smits et al., 1999).

The verification (WP10) of classified satellite data varied somewhat from partner to partner. During the Partner Meetings in Freiburg (December 1998) and Munich (June 1999), it was decided to carry out pixel- and stand-wise verification. In general, better statistical accuracy measures were produced for the stand-wise verification method. Exceptions arose due to the selectively small number of stands available.

3.3.3 Geocoding

The integration of different sensors and the connection of the remote sensing data to ancillary information of ALPMON put high demands on the geometric accuracy of these data. Thus, the geometry of the satellite images had to meet extremely strict requirements, firstly, because the data obtained with different systems were classified multi-sensorally and multi-temporally, and secondly, because the satellite images and the classifications subsequently derived from them had to be integrated with additional digital data in a geographical information system.

With respect to the alpine terrain with high relief energy, so-called terrain correction geocoding was performed for all test sites. All the geocoding activities – except for Cordevole test site and partly Engadine test site – were carried out using the Remote Sensing Software Package Graz (RSG) of JR, implemented in ERDAS™ Imagine. This software was made available to the project partners. For the Cordevole test site Cartha for windows, a GIS system developed by RSDE, was applied. For the Engadine test site, additionally to RSG the Satellite-Ortho Module from PCI was used.

Geocoding results in most cases were sufficient with sub-pixel accuracy due to parameter adjustment. Additionally, the overlay of topographic information with geocoded satellite images could demonstrate good correspondence between the data sets. However, results were not completely sufficient in the Engadine test site, where significant deviations occurred in high altitudes, mainly in the high resolution IRS pan image.

Restrictions in the geocoding process of high resolution digital satellite image data and the quality of its results are mainly related to incorrect pre-processing of the digital image data and a DEM accuracy as well as accuracy of the reference data not corresponding to the pixel resolution of the satellite image. Implementation of a co-registration process of the geocoded images further improves the location accuracy of the geocoded images.

3.3.4 Topographic normalisation

There is a general agreement within the consortium that topographic normalisation leads to an improvement of the image data in mountainous terrain. In particular the Minnaert correction produced useful results. The C-correction seems not to be the appropriate solution, but rather tends to extreme over-correction of steep slopes. However, all corrections were based on empirical analysis thus being highly depending on the actual image data.

In spite of the good performance of the models some limitations are to be discussed. A prerequisite to topographic normalisation is an accurate DEM and precisely geocoded image data. According to Goodenough et al. (1990) and Itten et al. (1992) the spatial resolution of the DEM should be four times higher than the spatial resolution of the image data. Using Landsat TM images the required cell size would be less than 10m, for other image data such as SPOT or IRS-1C it would be even lower. In general no such DEMs are available for larger regions. The consequence of using lower resolution DEMs is the lack of topographic details within one grid cell which might disturb the correction locally.

Geometric displacements between the image and the DEM is another potential source of wrong corrections. The model performs the correction according to the DEM. If the image is slightly shifted the transition between illuminated and shadow areas will not any more correspond to the topography. This leads to systematic errors on ridges and in valleys resulting in extreme over- or under-correction of areas in the magnitude of the displacement.

The optimum result in topographic correction could be obtained if the entire area was covered by one cover type, which is indicated by a specific Minnaert constant. Then it could be assumed that a particular value of the Minnaert constant is valid for the entire area. In reality this scenario is rather rare, in particular in the alpine area. In order to optimise the model a priori information on the distribution of major cover types is helpful. This idea was considered in the implementation of the model by separating vegetated and non-vegetated areas applying an NDVI. The more cover types are separated the better the correction will be. On the other hand the recognition of these cover types is the major motivation for performing the topographic correction. So it might be useful to apply the correction and subsequent classification in an iterative way.

3.3.5 Atmospheric correction

There has been continual discussion on the meaning and quality of divers atmospheric correction algorithms within the project team during the project meetings as well as regular communication. On one hand, atmospheric correction seems to be a pre-requisite to accurate quantitative image interpretation. On the other hand, it has been stated that none of the currently available atmospheric correction models is suitable for alpine areas.

- Methods not relying on local atmospheric measurements, are too inaccurate. For example, the *Point Spread* method seems to be ineffective. Applied on the satellite data the procedure only sharpened image features. A problem that may occur by using the *Tasselled Cap* method is, that the simple linear combination of LANDSAT-TM bands may not produce in every case the desired new band which is higher correlated to dust. It is not clear to what extent the coefficients, which were derived from agricultural areas in Michigan in June are valid for other areas and seasons. Also it should be kept in mind, that haze does not only change digital numbers in a spectral band but also causes a loss of information.
- Other available atmospheric correction algorithms, like *MODTRAN* or *LOWTRAN*, implemented in *ATCOR*, strongly rely on information about the atmospheric conditions at acquisition time of the respective satellite image. This becomes a major disadvantage taking into account the poor information usually available about the atmosphere. Having different measures of the horizontal visibility within the research area at a time before or after satellite image acquisition makes estimation of a mean value necessary. The result is not very accurate and may cause over-correction or under-correction. Over-correction, additionally, results in critical loss of information in dark areas of the image.

Thus, the result of atmospheric correction is to be seen as very critical. Resulting changes appear to be not due to real correction but to errors in the correction models. The shortcomings of the available atmospheric correction algorithms are in our opinion according to the dramatic height differences in all of the test sites. These are not considered properly in the correction models. In this direction efforts have to be addressed to the scientific community dealing with atmospheric effects on satellite data especially in alpine terrain.

Further discussion concerned the order of performing atmospheric correction before or after topographic normalisation. In general, atmospheric correction is performed on original data, followed by topographic normalisation. As atmospheric correction may cause information loss mainly within the lower grey value ranges this becomes a problem for topographic normalisation. This is due to the fact that diffuse illumination is important for atmospheric correction as well as for topographic normalisation. Therefore, the opposite order was tested as well. Not being able to solve this problem by performing the correction in two separate steps, an integrated approach for both correction tasks, as proposed by Sandmeier and Itten (1997), is strongly recommended. Unfortunately, no such software is available to the public up to now.

In summary, one can say that from visual interpretation application of the described atmospheric correction algorithms in general cannot be recommended. However, the new ATCOR 3 program (Richter, 1998) seems to solve some of the problems addressed above.

3.3.6 Data preparation

3.3.6.1 Data merging

To exploit the complementary aspects of multi-sensor image data with different geometric, radiometric and spectral resolution, appropriate techniques for image fusion are indispensable. The adaptive image fusion (AIF) method allows the fusion of geometric (spatial) and thematic (spectral) features from multi-source raster data using adaptive filter algorithms. If applied to multi-resolution image data, it will sharpen the low spatial resolution image according to object edges found in the higher spatial resolution image. In contrast to substitution methods, such as Intensity-Hue-Saturation or Principal-Component Merging, AIF preserves the spectral characteristics of the original low resolution image.

The conclusions drawn from the application in the test sites are manifold. The adaptive image fusion (AIF) is considered useful for areas, that are dominated by objects larger than the low resolution pixel size. Taking the average pixel size of today's multi-spectral sensors (20 – 30m) this prerequisite is only true for certain types of image objects. Due to the size and heterogeneity of the single objects, this does not hold for forest areas. There the AIF leads to a loss of details caused by averaging the multi-spectral pixels, which is due to missing information in the panchromatic image. However, for the segmentation of forest and non forest areas the approach is considered valuable. One suggestion was to use the fusion result for first level classification, i.e. classification of meta classes that can be used as masks for detailed classification. The advantage of this approach lies in the sharp delineation of the objects to be classified, thus leading to less misclassifications caused by mixed pixels. The approach has been used successfully for delineation of the forest border in the Dachstein test site.

A second application was the combination of AIF and substitution techniques for visualisation, offering an excellent visual impression of the respective area (compare section 2.2.5).

3.3.6.2 Texture analysis

Within the ALPMON project second order statistics using grey-level co-occurrence (GLC) matrices were used to describe texture in images. A set of textural features was derived from the GLC matrices, that were assigned as grey values to the pixels of an image.

Implementation of the texture analysis algorithms and their application to data sets from the test sites show the benefits and limitations of the method. Some of the limitations are caused by quality of the data sets. Image noise will always affect texture analysis, as it produces local variation of grey values that are not related to the actual image content. This effect is particularly strong when using texture features that do not take into account grey value differences. The second parameter that has an influence on the texture analysis is the actual grey value range of the image. The smaller it is the less transitions between different grey values are possible, thus reducing the range of textural information available. Furthermore the grey value range is linked with the effect of noise. Assuming a Gaussian distributed noise with a certain standard deviation, its effect will be stronger on a small grey value range than on a larger one, as the ratio between signal and noise will decrease with an increasing grey value range.

When using texture algorithms one has to keep in mind, that texture cannot be derived from a single pixel but is always related to an area. Therefore the single pixel of a texture feature image actually represents not only the texture of itself but also of its neighbours. This leads to a spatial generalisation of the texture feature image although its nominal resolution might be the same as the one of the original image. The degree of generalisation depends on the parameters used for calculating the texture features. The larger the window size the stronger will be the effect of spatial generalisation. On the other hand a small window will only analyse a small number of transitions. As the texture features are statistical measures it is questionable if the sample derived from such a window is sufficient for an estimate.

Looking at the results of the implementation in the test sites one can get an impression of the kind of objects that could be detected by texture analysis. Settlements with their high variation of objects, linear structures such as roads or railways are clearly visible in texture feature image. In addition transition areas between two land cover types with significant different reflection characteristics appear as highly textured areas. The use of texture analysis for the discrimination of different forest stands seemed not to be possible. Taking into account the spatial resolution of the images (5-10m), the comparably low grey value range (<100) and the image noise this negative result is not surprising. However, texture images should be a valuable contribution for the recognition of major landscape elements. In particular as a complement to the results of the fusion process, that suppresses local texture, they can significantly improve the quality of image classification.

3.3.7 Classification

Classification in the test sites was performed with respect to the requirements of the local as well as the European customers. The approaches in the test sites differed in the selection of special/additional classes for each application as well as in the chosen classification method. Some main difficulties crystallised in most classifications:

- *Forest age* in many test sites could not be classified due to the natural appearance of the forest with a mixture of all tree age categories. Only the Dachstein test site is dominated by managed forest with a common age class within one stand.
- *Forest type* in some test sites is mainly mixed, with only a few pure coniferous or broad-leaved stands.
- *Tree species composition* was an important information for two applications (national park management and avalanche risk). However, some tree species could not be separated sufficiently (e.g. percentage of larch trees) or at all (spruce, pine, and stone pine). Dwarf mountain pine and green alder could not be separated sufficiently with the satellite data acquired during the vegetation period. This is on one hand due to spectral similarity with other coniferous respectively broad-leaved trees and, on the other hand, due to mixture with other tree species in one stand. However, in the Dachstein and Mangfall test sites it was possible to classify dwarf mountain pine by means of winter or spring images, where the low growing trees are covered with snow whereas the high growing trees are snow free.
- *Wet lands* were well recognised in the Mangfall test site by using the thermal infrared band of Landsat TM (TM6). However, this approach was not applicable e.g. to the Dachstein test site, as wet land areas here are relatively small and beyond the resolution of TM6 with 120m.
- *Sealed surfaces* could not be separated from rock, gravel, and soil based only on the spectral characteristics of these classes, as the spectral signatures are too similar. Additional information has to be introduced to classify this category with higher accuracy, or the information must be taken from GIS data.

On the other hand, most categories required by the customers could be classified with sufficient accuracy. In general no problems occurred with the classification of the forest type in those areas, where pure coniferous or broad-leaved stands are common. Forest age could be classified at least in some test sites, where pure age stands occur. In the Dachstein test site it was possible to separate pure larch stands from mixed spruce/larch stands and pure spruce stands (possibly mixed with pine and /or stone pine). In the Dachstein and Mangfall test sites even dwarf mountain pine and green alder could be classified by means of winter satellite data. Furthermore, some classes could be divided into subclasses (e.g. pasture and meadow, carbonate and silicate rocks) giving more detailed information. Problems with the classification of water bodies or sealed surfaces could be overcome by introducing auxiliary data into the classification process. In general, it can be stated that the outcome of classification was satisfactory with respect to the local as well as the European wide applications. This was confirmed by the customers in the first ALPMON customer work shop held from February 4-5, 1999 at Innsbruck, as well as in the final project evaluation.

3.3.8 Data integration into ALPMON

The integration of data into ALPMON worked well due to the efforts made in WP3. Nevertheless the database for storage of the parameters of the training areas was not used by all partners because some partners already had established extensive data bases for their test sites. As these included additional, test site specific parameters, it was not possible to include these data into the MSAccess data base.

With the establishment of a common class code and colour scheme as well as an extensive meta data base, the further use of the ALPMON results as well as the comparability of the data are ensured.

3.3.9 Feasibility studies

3.3.9.1 Tourism

For the tourism application the fusion image has been of central importance. The known methods like Brovey- and IHS transformation give a possibility to fuse images, but they are not able to dissolve the pixels from the multi-spectral image. So the result is an image with the higher resolution of the panchromatic image and much bigger coloured tiles of the multi-spectral scene. For visualisation tasks this kind of image is not always satisfactory.

The AIF method of STEINOCHER (1999) has been a very good pre-processing to the mentioned transformations. Visually the colour information of the multi-spectral scene is fitted to the objects of the panchromatic scene. This fact is decisive for the visual impression of an image. The fusion image is the background image of the tourism information system that has been developed during ALPMON. The tourist is able to zoom into the image, therefore the resolution is of importance. The AIF method allows to give the tourist the impression that he looks at a normal colour aerial photograph.

The tourist information system has been developed to give some ideas and possibilities to the local administrations. It has been shown how GIS technology could be used for more than analysis. A hiker information system has been programmed. Such an information system can be used in a variety of ways and places: It can of course be made available at the Tourist Office in the region itself; it could be used via Internet or in travel agencies. The presentation in the Internet or travel agency would demand different software. These would have to be "stand alone" solutions because it would be too expensive to bye the GIS software for every travel agency.

For the monitoring of landscape changes visual interpretation has been necessary, because aerial photos from 1954 and the fusion image of 1992 have been compared. In the future classification results could be used instead of visual interpretation. But for monitoring alpine pastures high resolution multi-spectral scenes are demanded.

The classification results have been used for several purposes. It could be shown that classification results are not only of interest for landscape related administrations but also for the hiking tourist. But there has been the problem that the classification of shaded areas has not been succeeded. So for the shaded part of the test site no classification information could be gained.

3.3.9.2 Modelling of water run-off

Methods for the extraction of information from remote sensing data as well as data layers needed to run ASGI have been delivered to the customer. The project work offered the opportunity to investigate the specific limitations but also chances given by the alpine environment and to discuss the problem of parameter extraction from remote sensing data with different potential.

Furthermore a review on the existing administrative data layers including accuracy assessment of this data have been performed and recommendations for the appropriated method for the divers pre-processing and processing steps have been elaborated.

The Sulm test site study demonstrates the full evaluation chain with the ASGI water run of model. To operate the model time series of precipitation, air temperature and runoff were prepared. Besides the time series data, spatial data on various parameters are required for the model. Following spatial source data sets were derived in a first step: Landcover from Landsat TM data, DEM from the 1:50.000 scale national map series, and soil type information estimated from the digital geological map 1:50.000 and already available point-wise analysed soil profiles.

Meteorological time series data for precipitation and temperature were delivered from the Section of Water Resources. Shell script programming was done to check for various errors (e.g. negative precipitation values, revised time order) in the data. The remaining plausible time series data were then pre-processed in the ASGI environment. As only 7 precipitation stations remained with reliable data, IDW-Interpolation was selected as interpolation method. Also temperature time series data were interpolated with IDW.

The potential evaporation was calculated after Hamon (Federer & Lash, 1983). This model includes in addition to the temperature (IDW-interpolated as described above), an empirical monthly correction factor f_i.

Estimation of the interception storage capacity is based on leaf area index, degree of vegetation coverage and height of water stored on the surface. Leaf area index LAI (based on Thompson et al., 1981) and degree of vegetation coverage were derived from the landcover classification results.

For the Sulm catchment (and Austria in general), soils of agricultural areas are mapped with high level of detail in a scale of 1:2.500. Soils in forests and alpine regions, however, are in general only sampled in 4km by 4km grid. Up to now, no full area covering soil information is available which would be an appropriate basis for hydrological modelling in meso-scale catchments. As the basis for the estimation of soil-types, the soil-type map of Styria 1:1.000.000 (Krainer et al., 1998), the geological map of Styria 1:50.000 in digital format, and point-wise available soil analysis data (Krainer et al., 1998) were used. The result is an “estimated soil type distribution” of the catchment area, with the 1:50.000 scale of the geological map and the soil type information of the 1:1.000.000 scale soil type map. The so derived parameters can only give a rough estimate of the actual soil parameters. However, major improvements on the soil type distribution information, e.g. detailed delineation of valley bottoms, alluvial cones etc. result from this procedure.

The applied TOPMODEL approach is based on the saturated area approach using the topographic index after Beven and Kirkby (1979). This statistically based model differs from earlier soil-vegetation process models by including spatial variations in the main driving processes and uses topographic HRU’s to calculate lateral soil water transport. The recession parameter m was determined by slope hydrograph analysis. The main parameter of the TOPMODEL approach, the soil-topographical index, has been derived from the DEM.

All these methods delivered the necessary parameters for running the ASGI model properly. Distributed models such as ASGI require land cover data for parameterisation. The use of earth observation data can be seen as an important pre-requisite for such models, as the spatial data demand for large area applications could hardly be satisfied without earth observation derived data sets (compare e.g. cost-estimates for land-cover mapping given by Konecny, 1995) . This leads to the conclusion that earth observation data support the application of distributed models, thus extending the toolbox of hydrologists.

3.3.9.3 Avalanche risk

Different types of avalanche risk models are currently developed at the Austrian Institute for Avalanche and Torrent Research, who was the national customer of this feasibility study. All models need similar parameters from remote sensing and DEM sources. Among these, the actual information on land use/land cover could be derived from high resolution remote sensing data. It permitted the compilation of vegetation parameters from which surface roughness can be indirectly deduced.

<u>Land use – forest parameters</u>

The critical parameters concerning land use are mainly forest related. Here, the forest type and crown closure were of main interest. Additionally, as described above, the separation of special tree species (larch, dwarf mountain pine, and green alder) was requested. Although the results of forest type classification (3 types) were very good with a mean accuracy of 92% and a Kappa value of 0.84, the more detailed classification into 6 types, including three different categories for share of larch tress, resulted in an accuracy of 68% (Kappa 0.59). Especially the accuracy for the percentage of larch trees could be significantly improved by the use of SPOT 4 data(see below). The forest density has a significant influence on the potential of avalanche release. This parameter has been classified in the Landsat TM satellite data with an accuracy of 85% (Kappa 0.62), for the three canopy closure categories required by the customer.

Another EC study performed in the Austrian Alps (SEMEFOR, 2000) could demonstrate, that with the availability of SPOT 4 data the classification accuracy of forest parameters can be improved significantly. The SPOT 4 sensor delivers images with 20m resolution in the multi-spectral bands and 10m resolution in the panchromatic band. Furthermore, the middle infra-red spectrum has been added, compared to the former SPOT sensors. The combination of the higher resolution and the availability of a middle infra-red band proves to be a big advantage with respect to the classification of alpine vegetation parameters. SPOT 4 data are available on request since 1999. At the moment, it is strongly recommended to use these data instead of Landsat TM images for a detailed investigation of forest parameters as well as other Alpine vegetation with respect to the parameters required for avalanche risk models.

Clearings or small openings within the forest could be detected down to a size of approx. $30m^2$ in an IRS-1D panchromatic winter image. This corresponded with the requirement previously defined by the customer to detect forest openings with $50m^2$.

Some constraints have to be mentioned concerning two non forest land cover categories. The requirement of the customer to separate different types of grassland with respect to their use could not be fulfilled with the available satellite data. The only separation could be made between rich and poor grassland, which in most cases is related to the meadows in the valleys vs. the alpine pastures above the forest border line. Furthermore, the rock size could not be classified with these data. This might become possible with the high resolution sensors, having in mind texture features and the amount of shadow within a pixel.

In general it can be stated, that areas outside the forest can be classified due to their spectral variation if they occur on large areas. Smaller areas, which are covered by a mixture of vegetation categories, such as rhododendron, dwarf mountain pine or smaller moor areas that do not exceed 1 ha, cannot be classified definitely because of the mixed pixel problem. Simulations have proved that a geometric resolution of about 5 to 10m in the infrared spectral range is necessary to assess the typical small-area distribution pattern of vegetation outside of forests. The future sensor systems will provide data in this resolution range.

<u>Roughness parameters which can be indirectly deduced from land use classes</u>

Although the scientific community agrees that surface roughness is a critical parameter for snow gliding and subsequent snow gliding avalanches, yet, there are no quantifiable measures and rules for surface roughness available, and roughness parameters of different land cover categories have not been quantified. This is due to the fact, that avalanche release is a very complicated process, influenced by the interaction of numerous factors. Nevertheless, roughness parameters such as height of small bushes and rock size have been defined by the customer as critical parameters. It was clear from the beginning of the study, that rock size cannot be classified from the available remote sensing data sources. Although the absolute height of bushes cannot be directly derived from satellite data, their distribution could be estimated by means of Landsat TM image classification. But, as stated in the conclusion to the avalanche risk study, smaller areas, which are covered by a mixture of vegetation categories, cannot be classified definitely because of the mixed pixel problem. A geometric resolution of about 5 to 10m in the infrared spectral range is required to assess the typical small-area distribution pattern of alpine vegetation outside of forests. This is also true for the classification of small alpine bush vegetation.

Low growing tree species such as dwarf mountain pine and green alder show areas with greater roughness, which indicates lower gliding rates. The distribution of these tree species could be classified with very high accuracy by a multi-seasonal approach, introducing a winter satellite image into the investigation.

Further roughness parameters are related to the litter within forest, which is depending on the forest type respectively tree species. Leaves of broad-leaved trees as well as needles of larch trees build a smooth surface on which snow gliding is significantly higher that on rougher surfaces in spruce stands. This parameter can be directly deduced from the classification of forest type respectively tree species.

<u>High precision digital terrain model</u>

Further parameters influencing avalanche release are related to topographic parameters such as slope, aspect, and elevation. These parameters were derived in sufficient accuracy from a digital elevation model with 25m resolution. The surface roughness depending on the topography would also be of great interest for the customer. E.g. cow steps on pastures was of interest to the customer. This parameter could not be assessed with the current satellite image resolution. Furthermore, the shape or homogeneity of slopes is influencing the risk of avalanche release. Generally, this can be easily calculated from the DEM with commercially available software. However, the currently available DEM resolution (25m) is too rough to detect morphological surface characteristics, that might affect avalanche release, such as shape of slope (convex/concave), length of slope, and slope homogeneity in non forested areas or areas with critical forest canopy density, in sufficient detail in the sub-meter range. Currently, only laser scanner data can deliver DEMs with the required resolution.

The <u>time resolution</u> is another crucial factor for information extraction. A yearly update in general seems to be possible with the currently available satellite systems. The bottleneck might be the availability of images from winter with the specific snow situation required. On the other hand, the distribution of dwarf mountain pine and greenalder shows no extensive variations. Therefore, an update of this information within a 5 years period seems to be sufficient and practicable.

With this, general statements on the feasibility and the constraints of satellite remote sensing based on the high resolution sensors available for this project (not taking into account the very high resolution sensors of the new generation) are given.

3.3.9.4 Erosion Risk

The feasibility study on erosion risk was aimed to assess the contribution of remote sensing to the evaluation of erosion risk in alpine environment. Land cover parameters were therefore selected to satisfy both the general requirements of ALPMON and the specific needs of the erosion risk assessment, like the estimation of pasture density, which was classified into three density classes: 10-30%, 30-60%, > 60%.

The identification of forest border was performed through a slicing of an IRS-1C pan image. This method, in spite its simplicity, turned out to be accurate (97%) and efficient in outlining sparse stands and small gaps inside the forest, which contributed to improve the detail of the erosion risk assessment. The classification was performed using a Landsat 5 TM image dated 01/06/1996 topographically corrected using the Minnaert algorithm. The criteria of selection of the image date were: to minimise the shadowed areas; to maximise the spectral discrimination between broad-leaved and coniferous forest types; to avoid the period of peak water stress on pastures (July-August) because the discrimination of the pasture density levels could become very difficult during drought.

The forest stands of the Cordevole test site, as several other Italian alpine forest stands, are highly natural therefore the tree age distribution is highly heterogeneous and spatially mixed making very difficult a spectral discrimination of the forest age on the basis of the TM image. The signature analysis over ground truth forest samples confirmed a very high spectral variability. A preliminary maximum-likelihood classification resulted into low accuracy.

Unsupervised classification, based on the Isodata algorithm with a considerably high number (20) of spectral classes and the support of ground truth samples, demonstrated to be a simple and efficient approach to account both for the high spectral variability of forest stands and for the discrimination of the pasture density levels which were suitable for the erosion risk assessment, apart from the case of talus slopes with very low vegetation which in many cases were classified as rocks producing, in the erosion model, an apparent decrease in the erosion risk.

Over non vegetated areas a texture analysis method for the extraction of sealed surfaces was tested which gave interesting results over medium size settlements whereas over the minor settlements auxiliary information from the regional topographical map at scale 1:10,000 was necessary to improve the accuracy.

Besides land cover, other auxiliary information over morphology, geology, soil and climate resulted to be essential for the development of the erosion risk model. Apart from morphological information (i.e.

slope, aspect, elevation) computed from a DEM (derived from topographic maps at scale 1:25.000), the quality of the other auxiliary information turned out to be highly heterogeneous over the test site of Cordevole but this situation can be considered quite representative of Italian alpine regions.

The FSTAB erosion risk model was designed to take into account a wide range of mass erosion phenomena specific of alpine areas. FSTAB differs from other erosion models because it does not provide an estimate of the erosion rate but an erosion risk index representing the propensity towards the generation of mass erosion. To allow the model to represent the erosion risk inside the test site area of Cordevole with a level of detail compatible with the customer requirements (scale 1:25.000) both a calibration based on a geological ground survey and a tuning of the fuzzy inference engine were necessary. FSTAB has demonstrated to be a flexible model because some input parameters potentially affecting the mass erosion risk can be even discarded, when their accuracy is not good enough, without preventing the model from working.

3.3.9.5 Integration into CORINE land cover

Objective of this work-package was the investigation on how far the results of ALPMON can support European activities such as the CORINE land cover project. While the CORINE land cover maps are based on visual interpretation of multi-spectral images such as Landsat TM or SPOT XS, the ALPMON approach combines and classifies image data of various spectral and spatial resolutions with numerical methods. These different approaches towards the same objective lead to significant confusions between the single results.

The agreement between the original classifications and the CORINE land cover maps of the test sites has been less than 50% in average. This “poor” agreement is partly due to the different degrees of generalisation of the land cover maps. While in CORINE the minimum mapping unit is 25 ha (= 250000 m^2), the ALPMON classifications refer to the single pixel, i.e. an area between 25 m^2 and 900 m^2 depending on the image data applied. In order to overcome this contradiction of scale the ALPMON classification results were post-processed using a generalisation technique. This technique allows to combine neighbouring pixels of different classes to larger objects of one heterogeneous class. Generalisation of the ALPMON classifications has its clear impact on the degree of agreement that could be increased by post-processing to almost 60% in average. Although an increase of 10% can be considered significant, and proves the effectiveness of the post-processing method, there is still about 40% of confusion between the data sets that have to be explained. A part of it might be caused by the different approaches towards generalisation. Visual interpretation usually defines the dominant class in an image as “background” and “cuts out” the remaining classes. The post-processing technique is always limited to the local neighbourhood and therefore does not consider dominant classes in a larger environment.

A major reason for the confusion between the data sets are the differences in the nomenclatures, despite the effort of harmonisation, or in the interpretation of the nomenclature. This is stated in the confusion between forest and shrubland or between meadows / pastures, sparse vegetation and rocks. Here the problem is a clear definition of class limits, both in terms of space and theme. Delineation of land cover types is critical, if the spatial transition is continuos, e.g. between forest and shrubland. Differentiation of land cover types is critical, if the thematic transition is continuos, e.g. between sparse vegetation and rocks. A significant difference can also be found in the interpretation of forest types. Mixed forest in ALPMON is to a high extent interpreted as coniferous forest in CORINE, while parts of coniferous forest in ALPMON are confused with natural grassland and heathland in CORINE. The latter is due to the fact that dwarf mountain pine was defined as heathland in the CORINE nomenclature. The over estimation of coniferous forest at costs of mixed forest in CORINE – as confirmed by aerial images – might be due to the differences in the original minimal mapping unit, i.e. the different approaches to generalisation.

In general it has to be noted that the confusions in the different test sites do not show the same pattern. As a unique and reproducible processing chain was used in ALPMON to ensure comparable results for the test sites, it is likely that the CORINE data sets are not totally compatible. This becomes evident when comparing the single CORINE land cover maps from the different countries involved – Germany, Austria and Italy. For Switzerland the situation is different, as the standardised CORINE land cover map is not available. Final conclusions lead to the impression that the different approaches cannot be directly combined, at least not on level 3 of the CORINE nomenclature. Comparing the land cover maps on level 2 could lead to spatial indicators that might help the interpreter to concentrate on areas that are likely to have changed, or have been incorrectly assigned in the first version of the CORINE land cover map. The final decision on the land cover type, however, should be left to the interpreter. Such a combined approach would help to overcome the inconsistencies that appear in visual interpretation, such as overlooking single land cover units, but at the same time would benefit from the human vision system for detailed interpretation.

The introduction of level 4 classes to the CORINE nomenclature is considered possible for forest areas. While CORINE only differentiates three forest classes – coniferous, mixed and broad-leaved forest – the ALPMON classification takes into account forest types, age classes and crown coverage. However, it is to be noted that with an increasing level of detail the reliability of these classes is significantly decreasing. No conclusions can be given for other level 4 classes, such as for artificial surfaces or agricultural areas, as these land cover types hardly occur in alpine areas and thus were not of major interest for the ALPMON project.

3.4 Outlook and Need for Further Research

In the frame of ALPMON inventory methods have been developed based on remote sensing data combined with auxiliary information. Different thematic feasibility studies in different test sites spread over the alpine chain have been used to test the methods.

The conclusion of our investigations is, that the general conditions for the comprehensive alpine monitoring system envisaged seems to be basically given. The concept of combining GIS and remote sensing methods has proved to be successful. The limitations at present, as observed during the investigations, are interpreted as a logical step during this transition period from the „analogue“ to the upraising „digital“ area of data holding and management. As a consequence of this development a higher degree of accuracy of the evaluations can be expected.

During the work in the frame of ALPMON a couple of general as well as methodological problems have been recognised, which are still not solved. As appeal on the responsible national and international organisations and administrations the most urgent needs for realising such a monitoring approach for the alpine region should be summarised as follows:

1. Problems of general nature:
   - GIS data layers with deficiencies in geometric accuracy
     - differences up to 70 m between DGPS measurement and map location have been registered in the test sites of the Bavarian Alps
     - the DEM grid should be in the range of 0,25 times the image pixel size for an optimal correction, best available grid size is 25 m in most test sites
   - as well as in thematic content
     - Soil maps practically not available in the Alps
     - Some data are restricted on administrative use (e.g. avalanche risk map in Bavaria)
     - attribute errors of omission or of commission
     - nomenclature and definition not harmonised
   - availability of high resolution data is not assured

2. missing of adequate evaluation methods (problems of methodological nature):
   - methodology for the automatic evaluation of high resolution satellite data
   - methodology for data fusion, data merge, image fusion, data concatenation, sensor merge, resolution merge
   - the scaling problem
   - topographic and atmospheric correction of data
   - BRDF effects elimination
   - geometric rectification, which is strongly depending on the availability of proper ground control points and DEM, which may lead to different results depending on software package used.

Maintenance and holding of area related data are duties of the sovereign. This duties are normally delegated to different administrations. ALPMON is designed to be implemented on the administration level. For reaching an operational level it is essential to work with the data bases of the official administrations. During the last years the administrations working with area related data are starting to change data holding and data management from analogue to digital systems. This process is normally combined with an update of existing data bases. On account of the large amount of data to be transformed for an area as large as the alpine chain, this process will last for a couple of years.

The topics dealing with methodology development have to be addressed from scientists working in the remote sensing and GIS domain like the consortium working together in the frame of ALPMON.

3.4.1 Satellite Sensors and Auxiliary Data

Working for ALPMON we have been forced to live with some unexpected limitations, from which the missing of high resolution RS data was one of the most sever ones. ALPMON started with the expectancy on high resolution satellite data. Most of the expected sensors failed. Only Ikonos was launched successfully in June 1999, but still today non of the test areas of ALPMON was registered. Under this conditions, the value adding effect of high resolution data sets is still an open topic.

The availability of high resolution remote sensing satellites in the near future will be an essential step forward. The investigation proved, that at the envisaged scale of 1:25.000, the most urgent need for thematic evaluations is in higher radiometric and temporal resolutions. Our hope is, that the high geometric resolution systems announced will satisfy with respect to radiometric performance also. A list of planned, failed and successful launched EO systems can be found under http://www.itc.nl/~bakker/launch-table.html .

Table 21: Status of launches planned in 1998 (EARSeL Journal, 03.98)

Date	spacecraft	country	best resolution	success
20 March	Spot 4	France	10 m	March 1998
March	Ikonos 1	USA, commercial	1 m	Failed
after March	Clark	USA	3 m	Failed
Quarter 1	CRSS 1	USA, commercial	1 m	Failed
30 June	EOS AM 1 (Terra Sat)	USA	15 m	December 1999
9 July	Landsat 7	USA	15 m	April 1999
mid	EROS A	USA/Israel	1 m	
November	Ikonos 2	USA, commercial	1 m	August 99
Late	Quick Bird	USA, commercial	1 m	Postponed
Late	NMP/EO 1	USA	10 m, 315 bands	postponed
End	OrbView 3	USA, commercial	1 m	Postponed
1998	CBERS 1	China/Brazil	20 m	

E.g. for the monitoring of alpine pastures by means of classification very high resolution multi-spectral scenes are demanded. Satellite images from IKONOS could be a solution. Yet, due to the lack of such data, for the monitoring of landscape changes in the Tarvisio test site visual interpretation of aerial photos from 1954 and the fusion image of 1992 has been necessary, as these data do not allow automatic classification due to their radiometric properties. But, as described in section 3.1.2 and Table 19, visual interpretation is more expensive and time consuming than satellite image classification.

Sensor calibration coefficients: Delivery of in-flight calibration coefficients with each band, which is needed for sensor calibration (see radiometric correction). Momentarily, this is only possible with the acquisition of Landsat 7 data.

DEM: At the starting point of ALPMON, being aware of the fact, that DEM with the grid width requested for an optimal topographic normalisation of 0,25 (4 times better) of the ground resolution of satellite data are not available from the administration for the entire alpine chain, it was planned to investigate whether this problem might be solved or at least approached by using DEM calculated from stereo on track satellite data. To normalise data of the operational satellites of the Landsat, Spot or IRS class, MOMS-2P stereo data sets have been assumed to be appropriate, promising DEM accuracy of around 6 m (pixel size of the high resolution panchromatic band). For evaluating data of the high resolution systems expected during the planning stage of ALPMON, the DEM calculation from Quick Bird stereo data sets was envisaged. Unfortunately both systems failed, so during lifetime of ALPMON it was not possible to check the real improvement by these opportunities.

Geocoding as well as *topographic normalisation* is strongly dependent on the accuracy of the available DEM. The demand of a sub-meter DEM for correcting data with 1 m pixel size like the ones from the IKONOS pan band is still an unsolved problem. In digital passive optical remote sensing at the moment only the HRSC sensor from the DLR in Berlin is able to deliver DEMs of the requested quality.

Table 22 furthermore illustrates the improvements in sensors and auxiliary data, which are expected to increase the accuracy and performances of the alpine applications in general and the of the erosion risk assessment in particular.

Table 22: Expected technological improvements useful to erosion risk assessment.

Technological Improvements	***Benefits***
1 metre satellite pixel resolution pan + multi-spectral	• Precise assessment of vegetation density in grassland particularly for low values, enabling discrimination of talus slopes. • Quantitative biomass estimation over forest. • Identification of incoherent deposits. • Creation and update of the geomorphological map. • Precise positioning of the ground truth over the image.
Satellite acquisition time close to the noon	• Dramatic reduction of shadowed areas
Digital Terrain Model pixel resolution <= 5 metres	• Improvement of topographic normalisation and consequent improvement of the classification. • Assessment of the parameter 'surface convexity' which affects the dynamics of surface water flow.

3.4.2 Methods and Algorithms

During lifetime of ALPMON some relevant methodological developments on the software market appeared, allowing to redesign the evaluation procedures used in the frame of ALPMON. Overall we wish to point out the combined topographic/atmospheric correction model ATCOR 3 (DLR, R. Richter, 1998) and the object oriented image analysis. The automatic evaluation of high resolution remote sensing data is arising problems for pre-processing as well as for classification.

Pre-processing - Radiometric Correction

ATCOR 3 shows the way how to optimise the radiometric correction of RS data under alpine conditions, delivering radiance or alternatively reflectance data which can directly be used for modelling purposes (regional and global climatic change models, etc.). ATCOR3 is a parametrical correction software which combines topographic and atmospheric normalisation. There is a need for a physically-based radiometric correction delivering image data with reflectance values and not 'at-sensor' values (**D**igital **N**umbers). There is a need for a physically-based (and not empirical) radiometric correction, combining the calibration of sensor bands with on-flight calibration coefficients, and correction for topography and atmosphere into one step. Richter's ATCOR3 builds up on this need, though limiting factors, as unavailable in-flight calibration coefficients (except for Landsat 7), and aerosol and water vapour content as well as information regarding visibility within the atmosphere during image acquisition are still a set-back. Bi-directional reflectance effects and neighbouring effects are still under study and up until now only have been modelled within the process of radiometric correction.

Additionally the problem of *directional reflection property correction* in connection with the alpine topography will be a topic of future research. At the present only ESAs CHRIS/Proba experimental system scheduled for spring 2001 seems to be appropriate to approach this problem. With nineteen spectral bands, 25 m ground resolution and five on track observation directions it will be possible to collect directional reflection properties and to grow up a respective data base which should serve to correct high resolution data sets registered with off nadir look directions.

With Ikonos the first system of the new generation of high resolution Earth observing satellites is working successfully. Space Imaging Caterra, the company operating the Ikonos, promises the coverage of any area of interest within 7 days. Apart from our fundamental doubts, growing from our experiences with data availability of operational systems of the last twenty years, Landsat, Spot but also IRS, with swath width larger for the factor 6 to 17, this is only to be realised by changing the view angle from path to path. This directly led to the necessity to adopt and improve the existing geocoding as well as topographic / atmospheric correction software.

Data preparation

Image fusion techniques as applied in the project can improve significantly the quality and accuracy of land cover classification. However, the type of land cover objects that actually benefit from fusion techniques is still somewhat limited. In particular the loss of texture information for the price of spectral preservation is a drawback. Recent research results have shown that image fusion based on wavelet transform preserve both texture and spectral information.

Image analysis with special respect to the new sensor generation

With the acquisition of high-resolution data, which with the launching of IKONOS has only been made available at the end of ALPMON, there will be an increased need of appropriate processing algorithms. High-resolution data produces increased variance of objects, thus new classification methods need to cope with this increased variance.

The problem of high pixel value variance characterising objects of interest in high resolution remote sensing data prohibits the automation of evaluation chains for data with geometric resolutions in the „m“ scale (airborne scanner data, Ikonos, Quick Bird, etc.) with conventional commercial software systems. Traditional image analysis software follows the feature space concept. Pixel by pixel the whole image is sorted into classes, according to their DN value in the spectral domain, which defines their position in the feature space. The results are X classes with Y number of pixels. Clusters of pixels of the same class are interpreted to belong to one object. The location of the objects is unknown. The statistics are calculated class-wise.

On image processing level object oriented classification approaches, based on spectral as well as on textural and shape parameters and being able to use context as well as auxiliary information in classification process wake expectations in more accurate classification results. Two new software packages shall be mentioned in this context: the ClassTool currently developed at Joanneum Research, and the Delphi2 eCognition. LMUs 20 month experiences with eCognition (Buck et al., 1999, a,b, de Kok et al, 1998, 1999 a,b, Schneider et al., 1999, 2000) proves, that this software is able to solve or at least to bypass some of the bottlenecks of conventional image processing:

- methodology for the automatic classification of high resolution satellite data
- methodology for data fusion, data merge, image fusion, data concatenation, sensor merge, resolution merge
- the scaling problem.

Furthermore, the ClassTool software currently developed at Joanneum Research, is a very flexible tool which is specialised for feature definition and extraction, shape extraction, segmentation, statistical analyses, and object based classification with various classification algorithms.

The concept of object oriented systems is different in some key positions. Object oriented image analysis systems starts with an image segmentation. Usually the segmented image is than stored as bitmap. The innovative step forward made by programs like the tested Delphi2 eCognition is to store the statistics calculated for creating a segment for each object as a attribute table. This, on the first view trivial solution, opens the door to the GIS world. First, each segment is defined by its location and becomes an object with properties stored as attribute table, and, second, the objects can now be selected by .sql queries of relational data base systems. GIS layers, respectively the connected data bases can directly be integrated into the search. This way the problem of data merge is practically solved. Additionally, the fuzzy logic classification tools of eCognition approach the week “natural” transitions in alpine environment much better than the Boolean logic of conventional image processing software packages.

The task driven definition of hierarchical evaluation rules becomes the key ability for image analysis. Which are the advantages of an object oriented system for monitoring systems ?

Having the duty to administrate area covering objects like forests (forest management), lakes, river and riverbeds (water management), agricultural plots, biotops (environmental survey), a.s.o., the most effective way is to do it object-wise. Normally for each area, defined as an object of interest, a data base has been established at the moment this object is assigned to an administration. Searching for information about an area it is sufficient to know its Id No. or geographic location.

The concept of object-wise data management is common in GIS systems like ArcView or the newest ArcInfo 8.0 release. Clicking on the object you will open the data base with the attributes assigned to this object. Looking for areas with specific properties, you will succeed starting a data base search following the rules of .sql language of relational data base systems.

The result of object oriented image analysis is a data base with information on each object distinguished during the segmentation and classification process. This allows to identify objects with statistics changed between the observations by data base .sql queries and more, to quantify the changes. An image analysis system like eCognition, which additionally is able to use existing administrative or thematic boundaries from other investigations, has major advantages for specific purposes, like they occur for example in the forest administration, which is managing the forest on stand level, for biotope monitoring, a.s.o.

Post-processing

There is still a need for advanced post-classification techniques that can at least partially compete with human interpretation skills. While the spectral classification and the recognition of land cover types can be highly automated, the interpretation of spatial context and the derivation of land use patterns is still a complex matter. Post-classification as applied in ALPMON is a first step towards rule based generalisation but is limited to simple spatial parameters. Recent developments, such as object based classification schemes or graph based representation, offer new answers to these questions, which become even more evident when the very high spatial resolution data will be used in the near future.

Concerning landscape monitoring not only satellite image classification could be an automated way. Another possibility to get cheaper results in landscape monitoring is the automatic recognition of objects. This would have to be tested in future.

Table 23 finally illustrates by way of example the improvements in algorithms and software which are expected to increase the accuracy and performance of the erosion risk assessment. Part of these parameters do also apply to other alpine applications.

Table 23: Expected methodological improvements useful to erosion risk assessment

Methodological Improvements	***Benefits***
Elimination of the over-corrections in topographic normalisation	• Improvement of the land cover accuracy. Reduction of manpower in revision of the classification.
Unsupervised classification algorithm taking into account the Mahalanobis distance instead of the Euclidean distance (like ISODATA).	• Increase in discrimination of vegetation classes.
Database containing the phenological calendars of the most common species in the study area, better if updated to the actual meteorological trend.	• Helps in selecting the best acquisition dates for the satellite images. • Useful in interpretation of spectral signatures.
Rock-falls risk sub-model.	• Accounts for the mass movements over slopes deepest than 45°. The sub-model should be integrated to the existing FSTAB.
Model tuning support system	• Should help the geologist not very expert in fuzzy set logic in the definition of the inference rules and the tuning of the membership functions.

3.4.3 Needs from Users Point of View

The inventory of actual vegetation coverage is considered as the starting point of a monitoring program to supervise local or regional changes due to global change effects. Applying the methods developed under ALPMON it will be possible to draw up an inventory of forest habitats, tree species, tree ages, stocking density, management type and intensity, erosion zones, avalanche risk zones, etc.. This should allow the identification of developments which might lead to disastrous events. The quantification of the risk potential caused by the observed trends of decreasing protection function of forests in the alpine environment should allow the administration to take preventive measures.

The research results should be used as input parameters for models, which simulate the effects of global change on alpine ecosystems. Based on the results the development of scenarios should be done, taking into account the differing predictions of models or, especially for the socio-economic sector, follow on effects of EU legal frameworks and especially the subsidies policy (Agenda 2000, etc.).

Taking into account these considerations a technical/methodological development on RS data handling and preparation as well as the resulting improvements for thematic evaluation chains can be observed these days. The final products to be offered in the future to the customers are multi-criterial evaluation procedures, able to contribute to decision finding on management level or really to propose a rank of possible alternatives for specific problems. Such multi-criterial evaluation systems should focus on the natural environment but also on socio-economic developments and their follow on effects on the functionality of alpine ecosystems.

3.5 Exploitation

The techniques and methods developed within ALPMON are of very significant interest to all customers. As all customers are environmental oriented organisations the main exploitation plans are connected to possibilities to improve environmental conditions in the Alps. Internal priorities for utilisation of the results are strong since the methods gave all partners tools to collect essential information on the alpine environment that will be of increasing importance in the future. The expertise and knowledge gained will secure the partners national role in researching and monitoring the environment.

The results of this investigation were and still will be printed in research papers. It follows that publication of results to the scientific community was a major goal. Additionally, subtask, interim, and final reports are presented on the ALPMON homepage and may be downloaded from there. The results also were and will be presented in international congresses and symposiums.

The software produced in this investigation was made available for every partner and the customers. The established databases of ALPMON were given to the customers. The customers benefit from the methods and guidelines developed in this project. These methods can now be used for practical planning tasks.

Another output of the project are maps illustrating the classes and environmental parameters for larger areas. These maps may be provided on request for administration organisations as a base for decisions.

ALU

There was very much interest shown in the results of the application 'remote sensing and tourism' by German tourist associations and nature park administrations. This led to the planning of new tourism projects with new partners where the results of the project will be enlarged and put up to practice.

One result of ALPMON is a virtual fly-through showing a combination of the different image data used for the Engadine test site draped on a digital elevation model (done with ERDAS Imagine). This fly-through will be passed on to the National Park Administration for further use in their public relations activities.

JR

One main output of the project was the detailed classification of forest parameters with special respect to the alpine protection forest. Methodologies have been developed and applied to derive these parameters from high resolution satellite images. These results will be brought into projects which are concerned with the classification and monitoring of protection forests in Austria. In this respect Joanneum Research is negotiating with the Austrian Ministry of Agriculture as well as with the

Government of the Province of Carinthia. Among others, an INTEREG project on this topic is envisaged together with Carinthia and Slovenia.

Furthermore, Joanneum Research is specialising in supporting the assessment of avalanche risks from different points of view. Negotiation with the Austrian Ministry of Agriculture are in the final phase concerning a project which shall investigate the use of laser scanner data for deriving a very detailed surface model, thus indication surface roughness as a critical parameter for potential avalanche release, and combining it with satellite image classification of the land cover.

The third field of application is concerning the modelling of water run-off. The ASGI model, on which one of the ALPMON feasibility studies was based, is tested and applied to a test site in western Styria in close co-operation with Mr. Molnar (Ingenieurbüro für Umweltmanagement u. Wasserwesen) who was involved in the development of the ASGI model. The meteorological input parameters will be further improved and the model further tested in the Styrian test site. It is expected that this model can significantly support the Styrian government with respect to the support of the Styrian flood warning system.

A main task of Joanneum Research will be to introduce the remote sensing based Alpine Information System to the Alpine Convention, following the outlined methods as described in this report.

WSL

Furthermore at WSL, ALPMON serves as a knowledge basis for the examination of a remote-sensing-based national landscape inventory, which is intended to replace, in a long-term perspective, the existing national forest inventory (LFI). WSL is responsible for the development of new methods for this purpose.

LMU

First of all the application of the ASGI water run off model in the Mangfall test site is planned for the next future. Precondition for this is that the ASGI model is running stable on the LINUX platform with the GRASS GIS software configuration as implemented during the last year.

The results of the ALPMON classifications as well as the ALPMON GIS data base of the Mangfall test site should be delivered to the Forest Offices Schliersee and Kreuth. At this Forest Offices the introduction of digital data handling is planned for the next month.

In the frame of the EU funded Interreg 2 project “Landeskulturelle Leistungen des Bergwaldes” the ALPMON classification results have been used for the predefinition of the ground truth design.

The Sections for Redevelopment of Barrier Woodland (Funktionsstellen Schutzwaldsanierung) of the Bavarian State Forest Administration plans to use the results of ALPMON for restoration planning purposes.

RSDE

Methodologies for the assessment of alpine erosion risk based on remote sensing are expected to be of great interest for several potential customers in Italy because the Italian alpine area involves five regions (Piemonte, Valle d’Aosta, Lombardia, Veneto, Friuli-Venezia Giulia) and two autonomous provinces (Bolzano, Trento), accounting for 15% of the national surface and nearly 20% of the whole alpine area, and playing a primary role on local economy. The issues of the erosion risk feasibility study represent a sound basis to develop effective demonstrations to rise the interest of regional public administrations toward the remote sensing approach to the preservation of alpine environment. However it must be considered that, while the ALPMON land cover parameters selected for the erosion risk application have a general validity over the Alps, the type and quality of auxiliary data (DEM, geomorphology, geology, soil, climate) are very heterogeneous among Italian regions, therefore the implementation of the erosion model in the other regions should require a customised approach and a specific technical and costs analysis.

SEIB

According to the results of the feasibility study for integrating automatic classification results into the update process of CORINE land cover a combined approach is foreseen. While for the final decision on the land cover types the visual interpreter is still needed, automatic processing can significantly reduce the effort of change detection. Current discussions between the Federal Environment Agency, topic centre for land cover in Austria and end user in this project, and the Austrian Research Centers are concentrating on the definition of a process scheme for a future application.

4 Concept for the Establishment of a Remote Sensing Based Alpine Information System

Based on the results derived within the ALPMON project and the outcome of their evaluation guidelines could be established for a remote sensing based Alpine Information System to be introduced to the Alpine Convention. The details for the single tasks are given in the respective work package reports. Here, only the main aspects for the establishment of the remote sensing data base shall be described.

Satellite data: With respect to the area coverage and the related processing efforts as well as with respect to the data costs it is recommended to use Landsat 7 TM data for a data base covering the entire Alps (compare cost estimation, Table 16). For a coarse estimation of vegetation or forest cover also WIFS data proved to be useful. Only for more detailed investigations of special parameters over limited areas the use of higher resolution data (Spot 4, IKONOS) is recommended, as these increase the costs per km^2 significantly.

Nomenclature: The nomenclature should be used as established within ALPMON (Annex 4), as this nomenclature is hierarchical and can easily be enhanced by additional classes or sub-classes with respect to different applications.

Ground truth: In the course of the ALPMON project detailed ground truth was collected from five test sites distributed over the Alps and representing most of the different Alpine landscape characteristics. Further investigations now can be based on this harmonised ground truth data, which, of course has to be updated with respect to the acquisition of new satellite data. Nevertheless, further ground truth will have to be collected in areas, which are not yet sufficiently represented by the five test sites. It has to be taken into consideration that at least for every satellite flight path, which may include several satellite scenes, representative ground truth information must be available. Especially, in the Western part of the Alps this is not the case at the moment.

For the ground truth survey, which should follow the common nomenclature, the following methods can be used:

- interpretation of Colour Infrared aerial photos (1:5.000 - 1:20.000)
- interpretation of Colour aerial photos (1:5.000 - 1:20.000)
- interpretation of Black/White aerial photos (1:5.000 - 1:20.000)
- field survey
- processing of existing actual forest maps (1:5.000 - 1:10.000)
- processing of existing topographic maps (1:10.000 - 1:50.000)
- processing of existing actual orthophotos
- processing of existing digital databases.

It has to be kept in mind, that representative ground truth has to be available for independent training as well as verification reference data sets. This means, that enough samples of each parameter and category have to be collected for both tasks. According to Congalton (1991), a minimum of 50 samples for each vegetation or land use category is required only for the error matrix. If more than 12 categories are classified, the minimum number of samples should be increased to 75 or 100 samples per category. Practical considerations more often dictate the sample size selection, and a balance between what is statistically sound and what is practically attainable must be found. Guidelines are given to concentrate the sampling on categories of interest and increase their number of samples, whereas reducing the number of samples taken in less important categories. Fewer samples can be taken in categories showing little variability such as water and sampling should be increased in categories, which are more variable. With this, a stratified random sampling is recommended, as a minimum number of samples are selected from each strata (stratification geometrically or by land-use).

Geocoding: The investigations have proved that the quality of the geocoding results is essential for the accuracy of results of image interpretation and classification, especially when using multi-temporal and multi-sensoral data sets and auxiliary information. Therefore, it is strongly recommended to apply a parametric, sensor-specific geocoding procedure, based on ground control points and a DEM. The co-registration of images form the same area can further improve the accuracy of data overlay. Best results within the ALPMON project could be obtained with the Remote Sensing Software Package Graz (RSG; by Joanneum Research) implemented in Erdas Imagine, the Satellite-Ortho Module from PCI, or the SILVICS software developed at the JRC in Ispra by N. McCormick (1997). Only if small scale maps (1:250.000 to 1:500.000) are envisaged, the acquisition of already geocoded Landsat 7 TM products is recommended.

Radiometric correction: At present ATCOR 3 is the only commercially available software to sufficiently optimise the radiometric correction of RS data under alpine conditions. It delivers radiance or alternatively reflectance data which can directly be used for modelling purposes (regional and global climatic change models, etc.). ATCOR3 is a parametrical correction software which combines topographic and atmospheric normalisation. With respect to the Alpine wide application this correction seems to be sufficient. For detailed investigation of specific vegetation parameters there is still a lack for in-flight calibration coefficients (except for Landsat 7), aerosol and water vapour content as well as information regarding visibility within the atmosphere during image acquisition, which could further improve the correction results. With respect to small scale maps a topographic normalisation is not urgent, as illumination differences are averaged in low resolution pixels.

Radiometric adjustment: When satellite scenes from different flight paths shall be classified together, as is likely for the entire Alps, either the radiometric adjustment of these satellite scenes or a separate classification of each flight path (including several satellite scenes) is necessary. The radiometric adjustment can be performed by linear regression of aggregated image data based on statistical analysis (Gallaun et al., 1999).

Data preparation: If an accurate update of settlement areas is required, it might be advisable to calculate texture feature images and introduce them in the classification procedure. With respect to an Alpine wide data base, for all other land cover parameters no additional image features are recommended.

Classification: Common classification algorithms such as Maximum Likelihood, Thresholding, or unsupervised classification (Isodata), are offered by all standard image processing systems. Therefore, it is recommended to apply these classification methodologies also for the Alpine data base. It depends very much on the data as well as the preference of the person dealing with this task, which classification algorithm is preferred. However, with respect to the simplicity of the approach and the necessary interaction, the Maximum Likelihood algorithm is most recommended. This is especially due to the potential that different persons deal with the classification task, but the results will still be comparable when they are based on the same training data. Once a classification methodology has been fixed, the subsequent classifications for updating of the data base should follow the same methodology to enable comparability of the results. For advanced analyses it is furthermore recommended to use the same classification methodology for the entire Alpine area, thus enabling even better wall to wall application of the results.

Verification: Verification of the satellite image classification results is essential to get a measure of reliability of the data base. As measure for the overall classification accuracy the Kappa coefficient proved to be the most suitable. However, as the accuracy of single classified categories may vary much, it is recommended to additionally calculate the mean accuracy of each class and store it in the meta data base. The guidelines for sampling were already described with the ground truthing.

Data implementation: In the Alpine Information System data from different sources shall be combined for analyses. These data may comprise raster data (e.g. classification results), vector data (information from regional information systems, such as traffic network), statistical information, a.s.o. Therefore, it is recommended to build the Alpine Information System on a software which supports all these data formats. In general, raster data also could be vectorised. With respect to pixel based satellite classification results this presupposes aggregation of the classification results to larger units in a sensible way. But common software for this procedure is not yet sufficient.

For further use of the data by various institutions it is essential to store the respective meta data in the data base. At least those data should be stored, which are described in WP11 of the ALPMON project. Furthermore, the question of data geometry has to be generally solved. For the Alpine Information System the best solution would be to store the data in a common projection which is used European wide, and additionally to provide the respective information for transformation of the data into the national co-ordinate systems.

Hardware and software facilities: If the Alpine Convention envisages, to perform the classification and monitoring of Alpine vegetation parameters themselves, at least the following hardware and software equipment is necessary:

- work station with at least 36 gigabytes storage capacity

- standard image processing software
- geocoding software, which allows parametric, sensor-specific image rectification with block adjustment
- a common GIS.

Furthermore, the persons dealing with these facilities need to be experts in remote sensing, satellite image processing, as well as GIS.

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6 Additional Information Relevant for the Project

6.1 Published Material

The project or some of its tasks have been presented at diverse conferences with the following papers:

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Buck, A., de Kok, R., Schneider, T., Baatz, M., Ammer, U., 1999: Integration von Fernerkundung und GIS zur Beobachtung und Inventur von Schutzwäldern in den Bayerischen Alpen; *AGIT 99, „Angewandte Geographische Informationsverarbeitung XI“, Hrsg. Strobl/Blaschke, ISBN 3-87907-336-8, S 94-101.*

Catalini, M., 1999. Landschaftsveränderungen im Schweizerischen Nationalpark: Was kann die Satellitenbild-Fernerkundung bieten? (engl.: How remote sensing is implemented in detecting landscape changes in the Swiss National Park), Cratschla 2 / 1999 (Swiss National Park Journal),.

de Kok, R, Buck, A., Schneider, Th., Ammer, U., 2000: Analysis of image objects from VHR imagery for forest GIS updating in the Bavarian Alps; *Procc. ISPRS Amsterdam, July 2000, Working Group III/5, in prep.*

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Schmitt, U., Schardt, M., 1999. Avalanche risk assessment by means of remote sensing and GIS. *Proc. 2nd International Symposium on Operationalization of Remote Sensing, Enschede, NL, 16-20 August 1999*, 10 p.

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6.2 Reports on Workshops

Besides the ALPMON partner meetings, which were held every six months in order to discuss the actual state of the project as well as the upcoming tasks, several workshops have been held within the course of the project which were mainly applied to the customers. The workshops (not the partner meetings) are shortly described in the following.

At the very beginning of the project, directly after the projects kick-off meeting, a workshop on the user requirements and the nomenclature was held at Joanneum Research in Graz. During this one day workshop the parameters to be assessed within the project were discussed in detail. Further topics mainly concerned the pre-processing of the satellite data and the data formats, software, media, and data exchange facilities to be used.

In January 1998 a workshop was held at the Austrian Research Centers in Seibersdorf with participants from every project team. The objective of the workshop was the presentation and discussion of algorithms, developed and implemented by ARCS, in order to enable the participants to understand and apply the algorithms within the ALPMON project. Three groups of algorithms were presented covering topographic normalisation, image fusion and texture analysis. Each presentation was performed in three steps, first giving an methodological description of the algorithm in question, next explaining implementation issues and finally demonstrating the use of the algorithm by means of examples.

A first customer workshops has been held on February 4-5, 1999 at the Austrian Institute for Avalanche and Torrent Research, Innsbruck. The goal of this workshop was, firstly, to bring all customers of the project (on European as well as on national level) together. As the interests of some customers strongly overlap, discussion on the needs as well as the approaches envisaged between these customers and the project team were essential. Secondly, the actual project results were presented to the customers and discussed. Finally, a discussion on the applications between the customers affected by the respective topic and the project team took place and the further work was co-ordinated. The workshop on one hand served for exchange of experiences and co-ordination among the customers. On the other hand it was used for preparation of the project applications in close co-operation between customers and the project team. Mr. Schaffhauser from the Institute of Avalanche and Torrent Research at Innsbruck (national customer) kindly offered to host this workshop at Innsbruck.

6.2.1 ALU

A customer workshop for the forest and tourism administration of Tarvisio was held in October 1999. The results of the tourism application were presented (as available at this date) and maps derived from classification of remote sensing data were given to the administration in analogue and digital format.

In the second part of the meeting the methods and results were discussed by the audience which consisted not only of members of the administrations but also in a lot of members of the universities of Bologna and Trieste.

The customers were very satisfied with the results of the project and will try to envisage some more projects in a partnership with ALU.

6.2.2 LMU

The customer on national level of the partner LMU, Institute for Land Use Planning and Nature Conservation is the Bavarian State Institute for Water Resources Management (LfW). Since the kick-off meeting in Graz at Joanneum three more potential customers announced their interest on ALPMON investigations and results:

- The Bavarian State Geologic Survey (Bayerische Geologische Landesanstalt, GLA)
- The Bavarian State Forest Research Center (Bayerische Landesanstalt für Wald und Forsten, LWF)

- Sections for Redevelopment of Barrier Woodland (Funktionsstellen Schutzwaldsanierung) of the Bavarian State Forest Administration.

During the proposal preparation phase all these institutions were asked for co-operation. Due to the fact, that there are no established working groups dealing with remote sensing at these institutions, the administrative act to prepare and deliver a letter of interest took more time than expected. In the meantime ALPMON was already in the working stage and the working plans were more or less fixed. On the other hand, looking forward to the final goals of ALPMON, we had a vital interest to co-operate with each of the above mentioned administrations. All of them have been identified as potential customers of remote sensing derived information and have expressed their interest in ALPMON results and methodology. For these new customers no requirement study has been undertaken. In this situation we agreed on an informal co-operation.

The following meetings have been held since the beginning of ALPMON on the 1st of June 1997:

11.07.97; 10.00 – 12.00 h: meting at the Bavarian State Forest Research Center (Bayerische Landesanstalt für Wald und Forsten, LWF) Dr. R. Mößmer, A. Troyke, R. Blaschke, Prof. U. Ammer, R. deKok, A. Buck. Discussion of the synergy between the projects ALPS, funded by the German DARA and the ALPMON activities. Agreement of an close co-operation.

24.11.97, 14.00 – 16.30h, meeting at the Bavarian State Institute for Water Resources Management (LfW) in Munich. Participants Dr. K. Martin, SLU (subcontractor), Dr. M. Becker, Dr. T. Molnar, Dr. Th. Schneider. The topic of the meeting was the establishment of the parameter as well as of the accuracy requirements for running ASG.

08.12.97, 9.00 – 11.30 h: meeting at the Bavarian State Geologic Survey (Bayerische Geologische Landesanstalt, GLA), Dr. Frank, Dr. Th. Schneider: discussion of the informal contact with the GeoRisc working group.

24.07.98, 9.30 – 11.30h : meeting at the at the Bavarian State Institute for Water Resources Management (LfW) in Munich: A. Loipersberger, Dr. Th. Schneider, W. Semmt: Discussion of the data base available at the LfW to be used in the frame of ALPMON.

25.11.98, 8.30 – 10.30 h: meeting at the Bavarian State Geologic Survey (Bayerische Geologische Landesanstalt, GLA), Dr. A. von Poschinger, Dr. Frank, Dr. U. Haas, Dr. Th. Schneider: The use of ALPMON results for the purposes of the GeoRisc program. Dr. Haas is delegated to the customer workshop in Innsbruck.

04.02. – 05.02.99 Customer workshop in Innsbruck, participating customers from ALPMON partner LMU: Dr. T. Molnar, Dr. P. Braun (Bavarian State Institute for Water Resources Management), Dr. R. Mößmer, R. Blaschke (Bavarian State Forest Research Center), Dr. U. Haas (Bavarian State Geologic Survey).

04.03.99: meeting at the Institute for Land Use Planning and Nature Conservation in Freising. Participants: Dr. Haas (Bavarian State Geologic Survey), Dr. Th. Schneider, W. Semmt, R. deKok, A. Buck: Discussion of the Innsbruck workshop, need of the updated geologic maps of the ALPMON test site and the intention of the Geologic Survey to set the priorities on this map sheets.

09.03.99. workshop and presentation of the final release of the ASGI water run off model at the Bavarian State Institute for Water Resources Management (LfW) in Munich. Presentations of Dr. T. Molnar, Dr. M. Becker, Dr. P. Braun and Dr. Casper with an introduction of Prof. Kleeberg from the University of the Federal Army of Germany from Neubiberg.

20.01.00, 9.00 – 13.00h meeting at the LfW in Munich with Dr. habil. T. Molnar and Dr. P. Braun from the customer LfW and Dr. Th. Schneider and Dr. W. Pohl from the Institute of Land Use Planning and Nature Conservation. The topic of the meeting was to present the final results, to discuss the accuracy obtained with the applied methods in the frame of ALPMON and to check the opportunities of running ASGI during the year 2000. The result of this discussion was, that due to an overall work overflow and the general orientation toward other, more critical, regions of Bavaria at that moment the application of ASGI with the prepared data set could not be expected within 2000. Dr. Molnar demonstrated the ASGI version with the LINUX operating system and GRASS as basic GIS system.

6.2.3 JR

Besides some short meetings between Dr. Schaffhauser (Austrian Institute for Avalanche and Torrent

Research, Innsbruck), Dr.habil. Schardt, and Mag. Schmitt (Joanneum Research) at Joanneum Research, during the whole project, the following meetings took place:

11.3.97 Discussion of the empirical avalanche model

Participants: Dr. Schaffhauser, Dipl. Ing. Höller, Austrian Institute for Avalanche and Torrent Research, Innsbruck
Mag. Schmitt, Mag. Granica, Dipl. Ing. Gallaun, Dr. Schardt, JR

Location: Joanneum Research

9.6.97 Discussion of the empirical avalanche model

Participants: Dr. Schaffhauser, Austrian Institute for Avalanche and Torrent Research, Innsbruck
Mag. Schmitt, Mag. Granica, Dipl. Ing. Gallaun, Dr. Schardt, JR

Location: Joanneum Research

18.11.97 Discussion of the Fuzzy avalanche model

Participants: Dr. Schaffhauser, Austrian Institute for Avalanche and Torrent Research, Innsbruck
Dr. Piffl, Government of Styria
Dr. Schardt, JR

Location: Styrian Government

27.11.97 Discussion of the Fuzzy avalanche model

Participants: Dr. Schaffhauser, Austrian Institute for Avalanche and Torrent Research, Innsbruck
Dr. Stefan, TU Berlin
Dr. Randeu, Mag. Schmitt, Dipl. Ing. Paar, Mag. Granica, Dr. Schardt, JR

Location: Joanneum Research

27.10.1999 Discussion of preliminary results, further avalanche parameters, and possible improvements

Participants: Dr. Höller, Dr. Schaffhauser, Institut für Lawinenforschung
Mag. Schmitt, Dr. Schardt, JR

Location: Austrian Institute for Avalanche and Torrent Research, Innsbruck

24.3.2000 Discussion of the final results and the report

Participants: Dr. Schaffhauser, Austrian Institute for Avalanche and Torrent Research, Innsbruck
Mag. Schmitt, JR

Location: Joanneum Research

6.2.4 RSDE

The following table summarises the customer meetings held by RSDE during the project.

Meeting	Contents
Arabba, August 23 1997	Discussion about Customer requirements. Acquisition of climatic data, bibliographic references over the geomorphology of the Cordevole basin and appraisal of the previous erosion studies of the Customer.
Milan, December 11-12 1997	ALPMON Meeting. The Customer illustrates his experience on solid transport control over the Rio Cordon.

Bozen, November 25 1997	Relation on the state of the work (image pre-processing).
Mestre, January 25 1998	Discussion of the architecture of the erosion model and design of the geological and vegetation survey.
Arabba, August 3-14 1998	Geological and vegetation survey. The Customer gives permission of access to forest roads. Acquisition of auxiliary data (geomorphology, geology) from communes through the support of the Customer.
Innsbruck, February 4-5 1999	ALPMON Customer Meeting. Presentation of the preliminary results of the classification.
Venice, September 21 1999	Presentation of the final results of the classification and preliminary issues of the erosion risk model.
Milan, December 17 1999	Presentation and evaluation of final results of the erosion risk model.

6.2.5 WSL

In the course of ALPMON, several meetings with the Swiss Customer (Swiss National Park) were held to inform about the actual status of the project, and discuss present classification results and further needs. The following meetings took place:

- 26. March 1998: meeting with Flurin Filli (Research Co-ordinator within the SNP Administration) at WSL in Birmensdorf; organisation of the Partner Meeting of June 1998.
- 28. January 1999: meeting with Britta Allgöwer, Ruedi Haller and Andi Bachmann (GIS-SNP group) at WSL in Birmensdorf; discussion of actual classification results and actual needs.
- 16. / 17. April 1999: SNP Research Presentations (*Zernezer Forschungstage*): Oral presentation of ALPMON requirements and results, Swiss National Park researchers and administration were invited to the National Park House in Zernez. Title: Landschaftsveränderungen im Schweizerischen Nationalpark: Was kann die Satellitenbild-Fernerkundung bieten? (German)
- 3. June 1999: meeting with Flurin Filli at WSL in Birmensdorf; further user requirements were discussed in the scope of red deer habitat monitoring (WP12 Feasibility Studies).
- 20. September 1999: meeting with Ruedi Haller (GIS Specialist of the SNP) in the National Park House in Zernez; discussion of results from Feasibility Studies (WP12).
- April 2000: meeting is planned with Ruedi Haller in the National Park House in Zernez regarding the publication of one of the applications covered during the feasibility studies (red deer habitat monitoring with satellite imagery).

6.2.6 SEIB

In September 1999 a meeting at the Federal Environment Agency (FEA) of Austria, Vienna, was held with participants from ARCS, Joanneum Research and FEA. Subject of discussions were the first results of work package 12 – Integration into CORINE – for the Dachstein test site. FEA was responsible for the establishment of the CORINE land cover map of Austria and serves as an end user in the ALPMON project. Outcome of the meeting was a first assessment of reasons for the differences between the CORINE land cover map and the ALPMON classification.

6.3 Relevant URLs Related to the Project

Not for all partners of the project team and only for a few of the customers an URL exists. The URLs relevant for the ALPMON project are:

ALPMON	http://dib.joanneum.ac.at/alpmon/
Austrian Research Centre Seibersdorf, Department of Environmental Planning	http://www.arcs.ac.at http://systemforschung.arcs.ac.at/SU/
CEO	http://ceo-www.jrc.it/
EWSE	http://ewse.ceo.org/
Federal Environment Agency - Austria	http://ubavie.gv.at/
JOANNEUM RESEARCH, Institute of Digital Image Processing	http://www.joanneum.ac.at/dib
Swiss Federal Institute for Forest, Snow and Landscape Research	http://www.wsl.ch/
Swiss National Park	http://www.nationalpark.ch
Tourism Administration at Tarvisio, Italy	http://www.tarvisiano.org
University Freiburg, Department of Remote Sensing and Land Information Systems	http://www.ruf.uni-freiburg.de/felis
University Munich, Institute for Landuse Planning and Nature Conservation, Dep. of Remote Sensing	http://www.lnn.forst.uni-muenchen.de

6.4 Definitions, Acronyms and Abbreviations

AIF	Adaptive Image Fusion
ALPMON	Inventory of Alpine-relevant Parameters for an **Alp**ine **Mon**itoring System using Remote Sensing Data
ALU	University Freiburg, Department of Remote Sensing and Land Information Systems
AMS/ABIS	Alpine Monitoring System of the Alpine Convention
ASGI	**A**bfluß-(water run-off), **S**tofftransport- (material displacement) Modellierung (modelling), using **G**eographical **I**nformation Systems
CEO	Centre for Earth Observation
CIR	Colour Infrared (aerial photography)
CN	Curve Number
DA	Discriminant Analysis
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EWSE	Information Exchange for Earth Observation
FSTAB	Fuzzy Stability
GCP	Ground Control Point
GIS	Geographic Information System
IGM	Istituto Geografico Militare Italiano
JR	Joanneum Research
LfW	Bayerische Landesamt für Wasserwirtschaft (Bavarian State Office of Water Resources Management)
LMU	University Munich, Institute for Landuse Planning and Nature Conservation, Dep. of Remote Sensing
MEHI	Mass Erosion Hazard Index
MOMS-2P	Modular Optoelectronic Multispectral Stereo Scanner 2 on Priroda
PAN/pan	panchromatic
RSDE	R.S.D.E. Srl
RSG	**R**emote Sensing **S**oftware Package **G**raz
SCS	Soil Conservation Service
SEIB	Austrian Research Centre Seibersdorf, Department of Environmental Planning
SNP	Swiss National Park
TM	Thematic Mapper
WP	Work package
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research

Annex 1: Project Team

Project Co-ordinator:

Company	JOANNEUM RESEARCH Institute of Digital Image Processing
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Tel.	+43-316-876-1735
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Project Partners:

Company	R.S.D.E. Srl.
Address	Via G. Washington, 78 I-20146 Milano Italy
Tel.	+39-2-48007912
Fax	+39-2-48012280
WWW	http://www.rsde.com
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Address	Tennenbacherstr. 4 D-79085 Freiburg Germany
Tel.	+49-761-203-3694
Fax	+49-761-203-3701
WWW	http://www.ruf.uni-freiburg.de/felis
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Company	University Munich / Technical University of Munich (since 1th of October 1999)I Institute for Landuse Planning and Nature Conservation, Dep. Of Remote Sensing
Address	Am Hochanger 13 D-85354 Freising Germany
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Address	A-2444 Seibersdorf Austria
Tel.	+43-2254-780-3876
Fax	+43-2254-780-3888
WWW	http://www.arcs.ac.at
Contact persons	Klaus Steinnocher, klaus.steinnocher@arcs.ac.at

Company	Swiss Federal Institute for Forest, Snow and Landscape Research
Address	Zürcherstr. 11 CH-8903 Birmensdorf Switzerland
Tel.	+41-1-739-2111
Fax	+41-1-739-2215
WWW	http://www.wsl.ch/
Contact persons	Harald Mauser, harald.mauser@wsl.ch, Tel. +41-1-739-2243 Manuela Catalini, manuela.catalini@wsl.ch, Tel. +41-1-739-2287 Lars Waser, lars.waser@wsl.ch, Tel. +41-1-739-2292

Sub-Contractor:

Company	Sachverständigenbüro für Luftbildauswertung und Umweltfragen
Address	Lohenstr. 14 D-82166 Gräfelfing Germany
Tel.	+49-89-851663
Fax	+49-89-8545840
WWW	none
Contact persons	Klaus Martin, SLU.Dr.K.Martin@t-online.de

Annex 2: Customers of ALPMON

Alpine Convention and Integration into CORINE:

Organisation	Federal Environment Agency - Austria
Address	Spittelauer Lände 5 A-1090 Wien Austria
Tel.	+43-1-31304-0
Fax	+43-1-31304-5400
WWW	http://ubavie.gv.at/
Contact persons	Alpine Convention: Wolfgang Mattes, Tel. +43-1-31304-5446 CORINE: Peter Aubrecht, Tel. +43-1-31304-3111

Forest and Touristic Planning:

Organisation	Ministero delle Risorse Agricolo, Alimentari e Forestali
Address	Via Romana, 21 I-33018 Tarvisio (Ud) Italy
Tel.	+39-0428-2786 / -2787
Fax	+39-0428-644017
WWW	
Contact persons	Dott. Patrizio Terlicher

Organisation	Azienda di Promozione Turistica del Tarvisiano e di Sella Nevea
Address	Via Roma, 10 I-33018 Tarvisio (Ud) Italy
Tel.	+39-0428-2135
Fax	+39-0428-2972
WWW	http://www.tarvisiano.org
Contact persons	Presidente Giampaolo Macoratti

Organisation	Comunità Montana "Canal del Ferro - Val Canale"
Address	Via Pramollo, 16 I-33016 Pontebba (Ud) Italy
Tel.	+39-0428-90351
Fax	+39-0428-90348
WWW	
Contact persons	Dott. Alessandro Oman, Valentino Volpe

Modelling of Water run-off:

Organisation	Bavarian State Office for Water Resources Management
Address	Lazarettstr. 67 D-80636 München Germany
Tel.	+49-89-1210-1530
Fax	+49-89-1210-1041
WWW	
Contact persons	Becker

Avalanche risk maps:

Organisation	Federal Forest Research Centre, Institute for Avalanche and Torrent Research
Address	Hofburg-Rennweg 1 A-6020 Innsbruck Austria
Tel.	+43-512-573933
Fax	+43-512-572820
WWW	http://www.fbva.bmlf.gv.at/inst8/lawinen.html
Contact persons	Horst Schaffhauser, Peter Höller

Erosion risk maps:

Organisation	Centro Sperimentale Valanghe e Difensa Idrogeologica, Regione Veneto, Arabba
Address	Strada P.sso Campolongo, 122 I-32020 Arabba di Livinallongo (BL) Italy
Tel.	+39-436-79227-8
Fax	+39-436-79319
WWW	
Contact persons	G.R.Scussel

National park management:

Organisation	Swiss National Park (SNP)
Address	National Park House CH-7530 Zernez
Tel.	+41-81-856 13 78
Fax	+41-81-856 14 70
WWW	http://www.nationalpark.ch
Contact persons	Flurin Filli

Annex 3: List of National Customers Requirements

Parameters		**Tourism/ Forestry**	**Water Resources**	**Avalanche Risk**	**Erosion Risk**	**CORINE**	**National Park**
Scale		1:10000			1:25000	100.000	
Units							
	min. width				25m	25 ha	20 m (10 m)
	min. length				60m		20 m (10 m)
Forest							
	high growing tree species	x	x	x	x	x	x
	low growing tree species	x		<, > 30-50cm	x	x	x
	crown closure	x		x	x		x
	natural age class	x		x			x
	openings	x		7x7m, 10x10m	x	x	x
Non-Forest							
vegetation	mire/swamp	x	x		x	x	
	rhod.sp., junip.sp.	x	x		x		x
	others	x	x		x	x	x
use of n.forest veg.	unused	x		x	x		x
	pasture/meadow	x		x, cow steps	x	x	x
	skiing area	x		x	x		
cov. of non-veg.	rock, gravel, soil	x		rocks > 30cm	x	x	x
	others	x			x		x
cov. by others	running/standing water	x	x		x	x	x
	snow, ice	x	x		x	x	x
	sealed surf.	x	x		x	x	x
Land Use	fallow shrub land	x	x		x	x	
	crops		x		x	x	x
	fallow farmland		x		x	x	x
	grassland	x	x		x	x	x
	built up	x	x		x	x	x
Topography							
	inclination	x		x	x		x
	aspect	x		x			x
	slopes	x		x	x		x
CORINE Level 4					x	x	
Soil Parameters					x		
Geomorphology	erosion				x		x
	mass movements				x		x
Climatic Parameters					x		

Annex 4: List of ALPMON Parameters

PARAMETER		CLASS											
Nr	**Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Coverage of vegetation												
1	**Crowns of potential high growing trees**	0-5%	6-10%	20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	100%	
2	**Crowns of potential low growing trees**	0-5%	6-10%	20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	100%	
	Ground vegetation												
3	Mire, swamp	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
4	Rhododendron sp.	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
5	Juniperus sp.	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
6	Others (grass, herbs, other shrubs)	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
7	**Total vegetation**	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
8	**Coverage of litter**	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
	Coverage of nonvegetation												
9	Rock	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
10	Boulders-blocks	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
11	Gravel	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
12	Soil	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
13	Mixed grain size (without soil)	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
14	**Coverage by others**	Running water	Standing water	Snow	Ice								
15	**Sealed surfaces** (by buildings, concrete, asph	0-20%	21-75%	100%									
	Tree species composition												
	Proportion of high growing tree species												
16	Broadleaved (all age classes)	0-10%	11-20%	25%	26-30%	31-40%	41-50%	51-60%	61-70%	71-75%	76-80%	81-90%	100%
17	Coniferous (culture and thinning)	0-10%	11-20%	25%	26-30%	31-40%	41-50%	51-60%	61-70%	71-75%	76-80%	81-90%	100%
18	Larch (older than thinning)	0-10%	11-20%	25%	26-30%	31-40%	41-50%	51-60%	61-70%	71-75%	76-80%	81-90%	100%
19	Scots pine (older than thinning)	0-10%	11-20%	25%	26-30%	31-40%	41-50%	51-60%	61-70%	71-75%	76-80%	81-90%	100%
20	Spruce and other coniferous (older than thinn	0-10%	11-20%	25%	26-30%	31-40%	41-50%	51-60%	61-70%	71-75%	76-80%	81-90%	100%
	Proportion of low growing tree species												
21	P. mugo	0-25%	26-50%	75%	76-100%								
22	Broadleaved	0-25%	26-50%	75%	76-100%								
	Proportion of natural age classes												
23	Clearing	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
24	Culture	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
25	Thinning	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
26	Pole	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
27	Young-medium timber	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
28	Old timber	0-10%	11-20%	30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%		
29	**Reason for opening**	unknown	stand at the alpine timberli	windfall	snow breal	biotic impact	removal						
30	**Use of non-forest vegetation**	unused	pasture	w	maize	rye	root crop	crop	area				

Annex 5: Resources Employed by Work Package (for the whole project period)

The figures give approximate values, as the final project cost statements were not available for this calculation.

	JR		RSDE		ALU		LMU		SEIB		WSL	
	man hours	EURO	man hours	EURO	man hours	EURO	man hours	EURO	man hours	EURO	man hours	EURO
Personnel:												
WP 0: Project management	2.025,0	89260,33					480,0	11.762,98			301,0	
WP 1: Requirement study	472,5	21862,19	1.268,0	36928,76	640,00	16670,46	300,0	7.351,87	105,5	3.891,69	146,0	2.193,57
WP 2: Interaction with CEO	75,0	3085,64									0,0	
WP 3: Set up and harmonisation	32,5	907,26					320,0	7.841,99			29,0	
WP 4: Collecting of ground info	960,0	27598,15	1.594,0	46424,73	520,00	13544,75	120,0	1.472,52			249,0	1.464,28
WP 5: Geocoding of sat. data	525,0	13683,38	670	19519,49	550,00	14326,18	420,0	9.274,73			538,0	15.309,47
WP 6: Topographic normalisation	180,0	4903,99	36	1055,11	240,00	6251,42	180,0	4.411,12	280,0	12.695,03	350,0	10.677,05
WP 7: Atmospheric correction	74,0	2065,77	18	527,55	200,00	5209,52	200,0	4.901,24			129,0	3.935,26
WP 8: Data preparation	99,0	2719,61	36	1055,11	336,00	8751,99	840,0	10.307,64	450,0	22.541,58	444,0	13.544,60
WP 9: Classification	950,0	28942,33	1.378	40.379,07	164,00	4271,81	1.080,0	26.466,72			834,0	25.441,89
WP 10: Verification	195,0	5924,62	1.004,0	29.137,77	192,50	5014,16	240,0	5.881,49			1.762,0	49.094,85
WP 11: Data integration	109,6	3060,50	522,0	15.095,96	417,00	10861,85	520,0	10.877,12			162,0	4.527,56
WP 12: Feasibility studies	2.200,0	66034,46	2.678,0	77.796,33	1860,50	48461,56	1.080,0	26.466,72	576,0	37.295,32	761,0	20.929,12
Total personnel:	7.897,6	270.048,23	9.204,0	267.919,88	5.120,0	133.363,71	5.780,0	127.016,14	1.411,5	76.423,62	5.705,0	147.117,66
Equipment												
Third party assistance		13.279,18						43.984,66				
Travel and subsistence		10.835,96		10089,33		9842,37		8.415,01		7.533,19		5.692,57
Consumables and computing		8.071,67		25217,85		6507,72		4.927,97		3.435,83		67.983,49
Other costs		2.543,55		0,00				12.101,87				
Overheads		233.720,99		66979,96		20286,17		30.397,44		57.625,66		34.296,60
Total EURO:		538.499,58		370.207,02		169.999,97		226.843,09		145.018,30		255.090,31

Remarks:
The column "Man hours" includes all the work carried out for ALPMON, regardless of whether it is funded by the EU (for WSL, that means funded by the Swiss authorities).
For WSL, the column "EURO" includes only those costs, which are funded by the EU.
LMU * The calculation of EURO from man hours is based on the rate for different reimbursement categories from scientist, technical employee, scientific research helper, student research worker.
The man hour costs may therefore differ between WPs, depending on the involvement of persons paid according to the respective categories.

Annex 6: Number and Accuracy of Parameters - Customer Requirements vs. ALPMON Results

Tarvisio test site (ALU) – Tourism and Forestry:

1:50,000-1:100,000		1:25,000 (national customers)			Comment
Requirement	ALPMON	Requirement	ALPMON	Conventional methods	
Forest / non forest	could be classified	-	-	-	-
Forest type	could be classified	coniferous deciduous mixed; single tree species	coniferous, deciduous and mixed could be classified; tree species could not be classified		
Forest age	could be classified	Forest age < 30, > 30 years	more classes were classified		customer agreed
Crown closure	could be classified	Crown closure < 50, 50 - 80, > 80%	the classes < 30 %, 30 - 60, > 60% could be classified		customer agreed
Rock / gravel / soil	could be classified	Rock / gravel	could be classified as one class, but not be separated		
Sealed surfaces	could not be classified	streets	could not be classified	have been digitised	sealed surface showed the same signature as rock/gravel
		settlements	could not be classified	have been digitised	sealed surface showed the same signature as rock/gravel
Swamp		Swamp	only one small area in the test site		
Water		lakes	could be classified		
		creeks, rivers	could not be classified	rivers have been digitised	
Meadow / pasture		Meadow / pasture	could be digitised		
Rhododendron sp. / Juniperus sp.		shrubs and low growing trees; (subclasses: in mountains, next to rivers)	could be classified (could be classified, could not be classified)		
		technical lines	could not be classified		

All classes mentioned above except Pinus mugo could be classified good with accuracies between 70 an 95 percent. But the Kappa-coefficient which indicates the strength of the classification is very low (as can be seen in the report on WP10). Due to the topography of the test site there was a big amount of shadowed areas, where classification was not possible (see report on WP9).

Mangfall test site (LMU) –Modelling of Water Run-Off:

1 : 50.000 to 1 . 100.000			< = 1 : 50.000 (national customer)				
Requirements Alpine Convention	**ALPMON**	**Prod /Users acc. %**	**Requirements (LfW)**	**ALPMON**	**Prod/ Users acc. %**	**Aerial photographs**	
Forest type:	**Forest type:**		**Forest type:**	**Forest type:**		**Forest type:**	
• Coniferous forest	• Coniferous no timber	26/36	• Coniferous forest	• Coniferous forest (incl. Pinus mugo)	63/81	• Coniferous forest (incl. Pinus mugo)	•
• Coniferous timber and old timber	• Coniferous timber and old timber	61/47					
• Pinus mugo	• Pinus mugo	19/37					
• Deciduous forest	• broad-leaved forest	77/62	• Deciduous forest	• broad-leaved forest	90/52	• broad-leaved forest	•
• mixed forest	• mixed forest	29/72	• mixed forest	• mixed forest	45/35	• mixed forest 5 classes	•
Other forest parameter	**Other forest parameter**		**Other forest parameter**	**Other forest parameter**		**Other forest parameter**	
	Not distinguished		• crown cover	Not distinguished		10 % classes	No age class forest
	Not distinguished		• age classes	Not distinguished		4 – 5 classes	No age class forest
Non forest type:	**Non forest type:**		**Non forest type:**	**Non forest type:**		**Non forest type:**	
•			• fallow shrub land	not present in test site		not present in test site	
•			• summer grain	not present in test site		not present in test site	
•			• winter grain	not present in test site		not present in test site	
•			• maize (normal)	not present in test site		not present in test site	
•			• special maize (German: Mulchsaat)	not present in test site		not present in test site	
•			• row crops	not present in test site		not present in test site	
•			• fallow farmland	not present in test site		not present in test site	
• meadow	• meadow	87/86	• grassland permanent	• meadow	90/97	• grassland permanent	•
•	•		• grassland temporary			• grassland temporary	•
•	•		• grassland poor			• grassland poor	•
•	•		• grassland fair			• grassland fair	•
•	•		• grassland good			• grassland good	•
• water	• water	100/100	• water	• water	100/100	• water	•
• moor	• swamp	67/99	• moor	• swamp	44/100	• moor	•
• soil	• soil	68/90		• soil		•	•
	• non vegetated areas, natural (rock/boulder/gravel)	63/23		• non vegetated areas, natural (rock/boulder/gravel)	88/87	• non vegetated areas, natural (rock/boulder/gravel)	•
	•			• green urban area	94/63	• green urban area	•
	•			• trees in urban area	57/95	• trees in urban area	•
Artificial surfaces:	**Artificial surfaces:**		**Artificial surfaces:**	**Artificial surfaces:**		**Artificial surfaces:**	
• sealed surface	• sealed surface	37/73	• light built up area	• settlement low sealed	87/67	• settlement low sealed	•
•	•		• densely built up area	• settlement high sealed	38/70	• settlement high sealed	•
	•		Additionally:	• non vegetated areas,		• non vegetated areas,	•

				artificial (e.g. parking lots)		artificial (e.g. parking lots)	

Dachstein test site (JR) – Avalanche risk assessment:

Requirements				Results			
Parameters	Specification	ALPMON	Inst. f. Avalanche and Torrent Research	Spatial resolution	Mean classification accuracy (%)	Conventional methods	Comment
		1:100,000-1:250,000	1:50,000				
Forest area	**canopy closure >10%**	**x**	**x**	**10m**	**98**		
Forest type		**3 types**	**4 types**	**25m**	**92**		
Broad-leaved	<25% coniferous	x	x		96		
Mixed forest	25-75% coniferous	x			69		
Mixed broad-leaved	25-50% coniferous		x		0		too less ref. areas
Mixed coniferous	50-75% coniferous		x		67		
Coniferous	>75% coniferous	x	x		96		
Trees species			**x**	**25m**	**68**		
Dwarf mountain pine	>50cm		x		very good (n.q.)		
Green alder	>50cm		x		very good (n.q.)		
Share of larch	larch >25% larch 25-75% larch >75%		x		81 29 59		mean absolute deviation: 11% 23% 36%
Forest canopy closure				**25m**	**86**		
>10 to 30%		x	x		75		too less ref. areas
>30 to 60%		x			57		
>60%		x			57		
>30 to 70%			x		70		
>70%			x		91		
Forest age			**x**	**25m**	**80**		
Culture		x			58		
Thinning to pole		x			72		
Timber and old timber		x			86		
Mixed age		x			n.a.		
Small forest openings	**50-100m^2**		**x**	**6m**	**<30^{m} (n.q.)**		
Non-forest land cover				**25m**	**92**		
Small bushes	mainly Rhod.sp. and junip.sp.	x			74		
Pasture		x			94		only *rich* and *poor* grassland could be separated
Meadow		x					
Grassland used	with/without cow steps		x				
Grassland unused			x				

Water		x				from dig. maps	
Rock, gravel soil		x	x		93		
Rock	rock size >30cm		x		not classified		Class. not possible
Sealed surfaces		x			n.q.		additional rules incl.
Wetland		x			75		
Snow, ice		x			100		
Skiing areas			x		not classified	visual interpretation	
Topography				**25m**	**n.q.**	**from DEM**	DEM resolution too week for avalanche application
Inclination			x				
Aspect			x				
Slope type	convex, concave, homogenous		x				

Cordevole test site (RSDE) – Erosion Risk Assessment.:

Customer			**ALPMON**			
User requirement	**Minimum Area**	**Positional Accuracy**	**Category**	**Spatial Resolution**	**Positional Accuracy**	**Classification Accuracy**
Forest border	50x50 m	25 m	**classified**	30 m	16 m	good 97 %
Forest type	50x50 m	25 m	**classified**	30 m	16 m	good 98 %
Forest stand density	50x50 m	25 m	**classified**	30 m	16 m	good 85 %
Vegetation type (grass areas)	50x50 m	25 m	**classified**	30 m	16 m	unsatisfactory 70 %
Vegetation cover (grass areas)	50x50 m	25 m	**classified**	30 m	16 m	good 79 %
Areas without vegetation	50x50 m	25 m	**classified**	30 m	16 m	good 89 %
Land cover	50x50 m	25 m	**classified**	30 m	16 m	good 84 %

1:50,000-1:100,000		**1:25,000 (national customers)**		
Requirement	ALPMON	Requirement	ALPMON	Conventional methods
Forest / non forest	could be classified	-	-	-
Forest type	could be classified	Coniferous, deciduous, mixed	coniferous, deciduous and mixed could be classified	
Crown closure	could be classified	Crown closure < 30%, 30–60%, > 60%	the classes < 30%, 30-60, > 60% could be classified	
Vegetation cover (grass areas)	could be classified	Pasture cover <30 %, 30 –60 , > 60%	could be classified	
Rock /gravel / soil	could be classified	Rock / gravel / Soil	could be classified as one class, but not be separated	
Sealed surfaces	could be classified	Streets/ settlements	some could be classified	some small settlements should be digitised
Swamp	could be classified			
Water		Lakes	could be classified	
		Creeks, rivers	could not be classified	rivers have been digitised
Meadow / pasture		Meadow / pasture	could be classified	
Rhododendron sp. / Juniperus sp.		Shrubs and low growing trees;	could be classified	

Engadine test site (WSL) – National Park Management:

Customer			**ALPMON**			
User requirement	**Minimum Area**	**Positional Accuracy**	**Category**	**Spatial Resolution**	**Positional Accuracy**	**Classification Accuracy**
trees species composition	20x20m	10m	**classified**	30m	23m	unsatisfactory (50-60%)
forest stand density	20x20m	10m	**classified**	30m	23m	unsatisfactory (60-70%)
forest age class	20x20m	10m	not possible			
forest stand structure	25x25m		not possible			
under cover vegetation	25x25m		not possible			
type of soil coverage in forest stands	20x20m	10m	not possible			
vegetation type (grass areas)	20mx20m	10m	**classified**	30m	23m	good (80-90%)
areas without vegetation	20x20m	10m	**classified**	30m	23m	good (80-90%)
avalanche events	20x20m	10m	not available			
monitoring snow-free areas	20x20m	10m				
land cover	50mx50m		**classified**	30m	23m	good (80%)
land use and use-intensity	25x25m		not possible			

All Test Sites - CORINE Integration (SEIB):

Customer		**ALPMON**	
User requirement (CORINE nomenclature)	**Minimum Area**	**Class**	**Comments**
1.1.1 Continuous urban fabric	5 ha	sealed surface > 75%	*not classified in all test sites*
1.1.2 Discontinuous urban fabric	5 ha	sealed surface 20-75%	*not classified in all test sites*
1.2.1 Industrial or commercial units	5 ha		not occuring
1.2.2 Road and rail networks and associated land	5 ha		*only occuring in one test site*
1.2.3 Port areas	5 ha		not occuring
1.2.4 Airports	5 ha		not occuring
1.3.1 Mineral extraction sites	5 ha		not occuring
1.3.2 Dump sites	5 ha		not occuring
1.3.3 Construction sites	5 ha		not occuring
1.4.1 Green urban areas	5 ha		*not classified in all test sites*
1.4.2 Sport and leisure facilities	5 ha		*not classified*
2.1.1 Non-irrigated arable land	5 ha		*only occuring in one test site*
2.1.2 Permanently irrigated land	5 ha		not occuring
2.1.3 Rice fields	5 ha		not occuring
2.2.1 Vineyards	5 ha		not occuring
2.2.2 Fruit trees and berry plantations	5 ha		not occuring
2.2.3 Olive groves	5 ha		not occuring
2.3.1 Pastures	5 ha	meadow / pasture	see also 3.2.1
2.4.1 Annual crops associated with permanent crops	5 ha		not occuring
2.4.2 Complex cultivation patterns	5 ha		*only occuring in one test site*
2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation	5 ha		*not classified*
2.4.4 Agro-forestry areas	5 ha		not occuring
3.1.1 Broad-leaved forest	5 ha	broad-leaved forest	< 25% coniferous
3.1.2 Coniferous forest	5 ha	mixed forest	25-75% coniferous
3.1.3 Mixed forest	5 ha	coniferous forest	> 75% coniferous
3.2.1 Natural grassland	5 ha	meadow / pasture	see also 2.3.1
3.2.2 Moors and heathland	5 ha	coniferous forest	includes dwarf pine

3.2.3 Sclerophyllous vegetation	5 ha	shrubs and open forest	see also 3.2.4
3.2.4 Transitional woodland shrub	5 ha	shrubs and open forest	see also 3.2.3
3.3.1 Beaches, dunes and sand planes	5 ha		not occuring
3.3.2 Bare rock	5 ha	rock / gravel / soil	
3.3.3 Sparsely vegetated areas	5 ha		postclassified
3.3.4 Burnt areas	5 ha		not occuring
3.3.5 Glaciers and perpetual snow	5 ha	snow / ice	
4.1.1 Inland marshes	5 ha		not occuring
4.1.2 Peatbogs	5 ha		not occuring
4.2.1 Salt marshes	5 ha		not occuring
4.2.2 Salines	5 ha		not occuring
4.2.3 Intertidal flats	5 ha		not occuring
5.1.1 Water courses	5 ha	water	see also 5.1.2
5.1.2 Water bodies	5 ha	water	see also 5.1.1
5.2.1 Coastal lagoons	5 ha		not occuring
5.2.2 Estuaries	5 ha		not occuring
5.2.3 Sea and ocean	5 ha		not occuring

Annex 7: Class Codes and Colour Scheme for Common Classes

Class codes are unsigned 16 BIT integer

Class	DIGITAL NUMBER	COLOR	COLOR (RGB)
Broadleaved	100	green	0,255,0
Broadleaved; 10-30%	110	very light green	128,255,128
Broadleaved; 30-60%	120	yellow green	128,255,0
Broadleaved; > 60%	130	green	0,255,255
Mixed forest	200	light brown	255,128,64
Mixed forest; 10-30%	210	dark red	128,0,0
Mixed forest; 30-60%	220	red brown	128,64,64
Mixed forest; > 60%	230	light brown	255,128,64
Coniferous	300	dark green	0,128,0
Coniferous; 10-30%	310	very dark blue green	0,64,64
Coniferous; 30-60%	320	very dark green	0,64,0
Coniferous; > 60%	330	dark green	0,128,0
Rhododendron sp./Juniperus sp.	400	brown	128,64,0
Pasture	500	light yellow	255,255,128
Pasture; 10-30%	510	very light brown	255,200,128
Pasture; 30-60%	520	yellow green	225,255,128
Pasture; > 60%	530	light yellow	255,255,128
Meadow	600	yellow	255,255,0
Water	700	blue	0,0,255
Rock/gravel/soil	800	light grey	192,192,192
Sealed surface	900	grey	128,128,128
Wetland	1000	bright brown green	192,192,128
Snow/ice	1100	bright cyan	192,255,255
Shadow	99/999	black	0,0,0
CROWN CLOSURE			
Crown closure >10 to 30%	10	light magenta	255,128,192
Crown closure >30 to 60%	20	magenta	255,0,255
Crown closure >60%	30	dark violet	128,0,255
FOREST AGE			
Culture	1	light blue green	128,255,255
Thinning to pole	2	dark green	0,128,0
Timber and old timber	3	dark blue green	0,128,128
Mixed age	4	very light green	128,255,128

1^{st} digit: vegetation type
2^{nd} digit: crown closure/vegetation density
3^{rd} digit: age
Example: 113 = broad-leaved, crown closure 10-30%, timber

Annex 8: Example from the ALPMON Web Page

JOANNEUM RESEARCH

ALPMON

- Description
- Partners
- Customers
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ALPMON

Inventory of alpine-relevant parameters for an alpine monitoring system using remote sensing data

The Alpine environment, one of the most sensitive of Europe's terrestrial ecosystems, is exposed to immediate and considerable environmental threat. The International Convention on the Protection of the Alps demands comprehensive counter-measures and recommends that an Alpine information system should be implemented.
The goal of this CEO project is to compile a basic landscape register for an Alpine Monitoring System (ALPMON) by means of combined analysis of diverse satellite sensors of Alpine landscapes selected for their typical characteristics. This system will serve as the basis for planning proposals. The feasibility of the Alpine Monitoring System is tested using specific applications in the fields of disaster management, tourism management and national park management as well as by merging the results with CORINE-Landcover. These applications are carried out in close co-operation with the responsible experts so that the procedures developed can be put into practice.

Links to other ALPMON websites

- ALPMON web page at CEO
- ALPMON web page on the EWSE
- CEO PROJECTS

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Annex 9: Project Evaluation by the National Customers

Feasibility study	Responsible project partner	Customer
Tourism	ALU	Ministero delle Politiche Agricole e Forestali, Tarvisio
Forestry	ALU	Azienda di Promozione Ruristica del Tarvisiano di Sella Nevea
	ALU	Communita Montana Canal del Ferro – Val Canale
Modelling of water run-off	LMU	Bayerisches Landesamt für Wasserwirtschaft
Avalanche risk assessment	JR	Institut für Lawinen- und Wildbachforschung
National park management	WSL	Schweizerischer Nationalpark, Direktion
Integration into CORINE	SEIB	Umweltbundesamt, Wien