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MID-TERM REPORT

SNOWPOWER

INNOVATIVE IN-SITU SNOW PARAMETER SENSING SYSTEM ALLOWING ACCURATE CALIBRATION OF REMOTELY SENSED DATA FOR IMPROVED FORECASTING OF HYDRO POWER RESOURCES

Novembre 2003

MID-TERM REPORT

CONTRACT N° : ***NNE5/2000/251***

PROJECT N° : ***NNE5/251/2000***

ACRONYM : ***SNOWPOWER***

TITLE : ***'Innovative In-situ Snow Parameter Sensing System Allowing Accurate Calibration of Remotely Sensed Data for Improved Forecasting of Hydro Power Resources'***

PROJECT CO-ORDINATOR :

- **FZK - Forschungszentrum Karlsruhe GmbH, Germany (partner 1)**

PARTNERS :

- **KTH - Kunglia Tekniska Högskolan, Sweden (partner 2)**
- **SLF - Swiss Fed. Inst. for Forest, Snow, and Landscape Research as Part of Swiss Federal Research Institute WSL (partner 3)**
- **HQ - Hydro-Québec, Canada (partner 4)**
- **INRS - Institute National de la Recherche Scientifique, Canada (partner 5)**
- **SOM - Sommer GmbH & Co. KG, Austria (partner 6)**

REPORTING PERIOD : FROM ***2001-01-09*** **TO** ***2003-28-02***

PROJECT START DATE : ***2001-01-09*** **DURATION :** ***36 Month***

Date of issue of this report : ***2003-11-02***

Project funded by the European Community under the 'FP5-EESD' Programme (1998-2002)

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1. EXECUTIVE SUMMARY

The objective of the SNOWPOWER project is to increase the precision of filling prognosis of hydro power stations to at least 20% by calibrating remotely sensed data with ground truth data determined by new snow measurement methods. Potential benefits are high, and e.g. only a 10% gain in forecast precision for Switzerland would correspond to a yield of 1,6 TWh or 32 M€.

By now a new electromagnetic cable sensor and prototype device for snow moisture and density measurements allowing a monitoring of an area of up to 2000 m² and evaluation software has been developed in the laboratory. The software integrates an air gap correction algorithm and a reconstruction code of the electromagnetic signal that allows the determination of a moisture and density profile of the snow pack along the cable sensors.

Laboratory and field measurements in the first winter period 2001/2002 were carried out both at measurement sites in Switzerland (Davos) and Canada (Quebec) with a prototype field system, consisting of a time domain reflectometry cable tester and an impedance analyser. Preliminary data od moisture and density were evaluated and compared to reference measurements in the concerning snow packs with excellent and promising results. Based on the experiences of the first winter campaign, a second campaign (winter 2002/2003) was launched and is currently running. A bench scale instrument, which will finally replace the prototype field system is currently being developed and will probably be available for measurements at the end of the second campaign. An important output of the project will be an industrial device suitable for field application.

The measurements already help to improve snow hydrological models. Furthermore additional hydrological models and the corresponding forecast strategies for hydro power optimisation are currently being developed, so that the measured snow pack data on the ground can be used to calibrate remote sensing data (RADARSAT) and thus will significantly improve the water reservoir filling predictions.

2. OBJECTIVES AND STRATEGIC ASPECTS

The main objective of the SNOWPOWER project is the efficiency enhancement of hydro power stations, which generate an ecologically very desirable type of energy. Thus it belongs as the central relevance to Key action 5.2.5 '*Other renewable energies*', because of its technical novelty, economic, environmental and social impact. It will contribute to the increase of the share of renewable energy in the European and global energy balance in producing electricity at a cost considerably under 0,15 €/kWh. Seven countries of the EU plus Switzerland and Norway operate hydro power stations where the catchments are under snow cover in winter. Several other countries of the world have the same situation, especially in Canada where some of the world largest hydro power stations are fed with snow melt.

Electricity from water is the cleanest energy transformation among the renewable sources. So, it addresses also the Key action 6.5.4 '*Improving the efficiency of new and renewable energy sources*'. Hydro power generation avoids emissions, any kinds, especially green house gases. Their efficiency enhancement is the best contribution to the global CO_2 reduction as required by the Kyoto agreements. The project will contribute to the consumer satisfaction and quality of life with more electricity without air pollution. The hydro power stations already have a high technical efficiency without severe consequences to the environment. This potential will be remarkably enhanced by the water management improvement as result of the project.

The proposed solution for efficiency enhancement will be suitable for new and existing plants without any restrictions. There is no need of any hardware installations in the power plant itself. By this way the sustainable management and quality of water can also be improved. In this sense it contributes to the EU policy of sustainable use of water resources at catchment scale. A certain synergy effect will be expected to this policy. In case of project success Europe will have a good competition position for the industrial marketing of the technology and the Canadian partners will benefit directly from use of the technology and from exploitation in North America. In addition a new market will be created for the equipment and Europe will benefit by the increased demand for skilled employment. The Society will also benefit from better flood prediction and avalanche warning as well as better management of the water flux both for energy generation and for environmental needs. Drinking water resources that are fed by snow covered catchments will benefit from improved prediction methods. This situation is relevant in the alpine regions of, Austria, France, Germany, Italy and Switzerland as well as in the Nordic regions of Scandinavia.

The proposed method is innovative not only on the level of each single sensor but on method and system levels also. Beside the enhanced remote data calibration and better snow water equivalent (SWE) prediction, we expect an overall improvement of the satellite data driven hydrologic computation.

Advances in hydrological modelling can be expected also. We want to get a better understanding of the start and development of snow melting processes and a better conversion of the measured physical data into snow properties distribution. It is obvious that we will get synergy results for the avalanche warning and flood prediction as well as a better prediction of drinking water resources from snow covered areas. Finally the intended field installations and instrument fabrications including a remote control network will help to make data collecting much easier.

3. SCIENTIFIC AND TECHNICAL ASSESSMENT

3.1 CRITICAL OVERVIEW OF THE TECHNICAL STATE OF THE RESEARCH

In the first half of the project six work packages were started, of which three could be finished successfully. Another three WPs are still open and running according to schedule. One WP (2) was a little delayed due to personnel shortage of one partner, but work could be compensated due to subcontracting and work could be finished with a little delay. The two WP concerning the field campaigns (3 and 6) had to be started a little bit earlier as planned, due to seasonal reasons, but this could be managed successfully.

WP 1 'Sensor development' – The design and modelling of the sensor was carried out according to plan. Calculations describing the electromagnetic field of around the sensor structure were made for different moisture and air gap conditions with a numerical calculation code. This allowed to chose an optimal cross section of the cable sensors and the sensor cables could be fabricated by a cable manufacturer specialised on the production of high quality cables for low temperatures and harsh environment conditions. In the course of the field measurements of WP 3 it turned out, that it would be advisable to also have a thicker, more wind-resistant cable; therefore an alternative cross section was additionally evaluated, designed and manufactured. At FZK the cables were configured and the cable sensors were built and tested in the laboratory.

Important cable characteristics for snow moisture and density determination such as the different capacities of the sensors were determined, so that conditions for exact calibrations were given.

Concerning the air gap correction algorithm, literature studies about quasi-TEM mode propagation on multi-conductor transmission lines led to a semi-analytical approach relying on the assumption that the flat conductors are embedded in an elliptically stratified environment so that the boundaries insulation-air and air-snow are confocal elliptical surfaces around the conductors. The size of the air gap was defined as the distance insulation-snow at the middle of the broadside of the cable. Using quasi-TEM analysis, the reactive transmission line parameters for different values of the air gap and the dielectric constant of the snow could be calculated. It was demonstrated successfully that the influence of the air gap increases with increasing dielectric constant.

Also a reconstruction code for determining snow profiles along the cable sensors was developed. Both frequency and time domain methods were investigated and the so-called inverse problem was solved. An exact algorithm with Greens functions and an optimisation approach was considered. The possibilities and limitations of a Fourier transform of the measurement data from time to frequency domain and back were investigated. The reconstruction algorithm was coded and tested with artificial measurement data.

Finally new software for the evaluation of the measurement data was written (*GetMoisture*). The algorithm for the air-gap correction and the reconstruction of the moisture profile of the cable sensors was integrated, so that the WP could be finished as planned.

WP 2 'Laboratory trials' - A laboratory test set-up was built, which included the mechanical design, writing software for instrument control and data acquisition and the selection of materials with dielectric properties comparable to snow such as glass beads, sugar, sand, and salt. The cable sensors were calibrated and then they were buried in a tank in these materials simulating an inhomogeneous snow profile. A computer program was written to control a time-domain reflectometer, acquire the electromagnetic impulse response of the sensor, and process the data with the reconstruction code prepared. Measurements under various conditions (a number of inhomogeneous profiles) were taken. Calibration functions for the cable sensors were established. Dielectric properties of the materials in the laboratory test set-up were measured with small-scale sensors developed at FZK. The reconstructed profile in the test tank was compared with the actual material distribution. The *GetMoisture* software was optimized with the calibration data.

The calibration procedures and refinement of the codes turned out to be more complex and needed more time than planned and due to personnel shortage of the Swedish partner this WP was delayed but could finally be finished successfully.

WP 3 'Field test' – Since start of the winter season was already 3 months after project start, this WP had to be started earlier than planned but with great enthusiasm of the Swiss and Canadian partners this could be managed successfully. Four flat band cable sensors were set up at Davos, Weissfluhjoch (WFJ)-test site (CH) at an elevation of 2550 m. The cables were placed on the snow cover in the course of the winter to measure the spatial variability of the liquid water content and snow density, and especially for detecting water conducting zones during the main snowmelt.

The technical prototype field system ran almost without interruption during the whole winter 2001/2002 in Davos. Additional monitoring of snow pack properties was carried out every two weeks. The measurements were stopped at the end of the melting period in June, when all the snow on the measurement site was gone.

The signal traces resulting from the cable sensor were evaluated using the new '*GetMoisture*' software. The following snow parameters were determined and compared to different reference methods: Bulk dielectric constant, bulk snow density and liquid water content (all mean values along the cable).

For distinct situations, the reconstruction code was tested and some moisture profiles of the snow pack could be established.

In general, the field test 2001/02 at WFJ/Davos showed that the measurement system has potential to become an automatic, unattended tool enduring harsh winter conditions (thick snow pack, low temperatures). The measurements yielded very good and plausible results. The correspondence with reference measurements on the site was excellent.

However, the design and building of mechanical sensor supports turned out to be more complex, why additional experiments will be carried out within the second big field campaign of WP 6. It is also not clear if these cables possibly interrupt or influence the natural water flow in the snow pack. This issue shall be better investigated in the second field test too.

Although not planned in WP 3, INRS and HQ started preliminary field tests in December 2001 as an opportunity for the Canadian partners to get more familiar with the SNOWPOWER sensor and the measurement methodology and to prepare for the big field campaign in WP 7.

The low- and high frequency measurements were conducted on 9 different days during the winter. Snow properties were characterized regularly in the vicinity of the cables. Meteorological data were acquired continuously by an automatic weather station. The first data sets revealed the need for some technical adjustments. After that, the measurement system was satisfactorily operational under our environmental conditions.

The low frequency measurements are quite different from those made by FZK and SLF at WFJ/Davos, which still need to be investigated in the next field campaign.

The high frequency measurements from the TDR showed the expected variations from dry to wet snow. The air to snow transition zone is generally visible. However, the data could not be obtained in a format compatible with the '*GetMoisture*' program. Therefore a new set-up, identical to Davos has been established in the new winter campaign of WP 6 and data will be acquired in an adequate format for the new '*GetMoisture*' program.

Another thing the measurements in Quebec revealed was an instability of the low-frequency measurements at around 25 kHz. The reason for this still remains unclear, we suppose it could be the influence of some coastal navigation system. We will also check this within the presently running field campaign of WP 6.

Observations in Quebec also showed the need to consider different ways to obtain an optimal cable installation for next winter, since test-sites in Northern Quebec will be very remote and cannot be visited regularly.

All together, this WP was a great success, so that the partners are eager to start the second field campaign.

WP 4 'Hydrological modelling' – Although this WP will last until the end, progress is significant and although the Swiss participation was planned for a later point of time, they already made important contributions. After intensive discussions, the Canadian partners INRS

and HQ proposed that the hydrological model likely to be used with the future SNOWPOWER instrument and EQeau (RADARSAT-1) spatial distribution of snow water equivalent is HYDROTEL. Comparison will be eventually made with the global hydrological model presently used by HQ, as mentioned in the description of the work to be done. The HYDROTEL model is a distributed model which is able to update its spatial distribution of SWE from a network of snow survey stations. So, SWE and thickness of snow pack derived from SNOWPOWER data can immediately be used instead of the actual snow survey data or in conjunction with them. A new SWE updating option will be added to the model to accept the spatial distribution as estimated from SNOWPOWER and EQeau (RADARSAT-1 data).

Besides, using data in the same Northern Quebec environment as it is hoped to use the SNOWPOWER probes, we have been able to obtain a very good calibration of the CROCUS hydrological model. As a matter of fact, the model was able to simulate accurately the temporal evolution of the snow pack thickness as measured by a laser probe at three sites for three winter periods. Also, for each field campaign (twice a year) we were able to get good comparisons of measured and simulated values for SWE. The comparison of density and temperature profiles for each field campaign was also good. There is good reason to be confident to use the CROCUS model to simulate the SNOWPOWER data. The CROCUS model will also be used as a reference to verify new options to be added to the snowmelt sub-model of the HYDROTEL model.

Preliminary work of the Swiss group focused on calibrating models of different sophistication and the evaluation of the long-term performance of one of these models using a 25-year long data series. The results from the different model tests can be summarised as follows:

A purely statistical regression model, including attributes of topography and forest density, as well as snow precipitation and positive air temperatures was not able to reproduce the temporal development of a sub-alpine snow pack accurately enough. For the WFJ site, the temperature-index model did not significantly improve the snow melt simulation by including albedo due to the fact that the albedo was quite uniform during most of the winter. The two models with a more detailed physical description (COUP, SNOWPACK) performed pretty well the accumulation and ablation of the snow pack at WFJ/Davos. For the three winter seasons 1999-2002, COUP was able to simulate the snow depth with a coefficient of determination (R^2) of 0.95 (daily measured snow depth; $n = 950$) and timed the end of melt season very well. These simulations also showed that with regard to snow depth and snow pack outflow the multiple-layer approach (SNOWPACK) was not superior to the single-layer approach (COUP). This snow-vegetation-atmosphere transfer model was tested against snow-data from 15 long-term snow courses in the Alptal-watershed. 8 of these snow courses were on open meadows, whereas 7 were located in the forest having different canopy densities, altitudes and aspects. The main objective was to test the models long-term performance (various seasons) and its ability to represent the spatial variability encountered in this valley due to topography and vegetation. The results from this model test have been summarized in a scientific paper that will be submitted to *Hydrological Processes.* The overall performance of the models to this complex landscape was positive; especially, we are convinced that the representation of the forest was an improvement towards a more realistic

description of snow interception processes, which is a key-process in hydrological modelling of such catchments.

In addition, a 2-d simulation of the water transfer in a melting alpine snowpack has been initiated and will be carried out in 2003. This 2-d model will be directly validated against the snow pack layering and horizontal distribution of liquid water flow paths detected with the snow cables at Weissfluhjoch.

WP 5 'Development of bench scale instrument – Based on experiences of the first winter field campaign, this WP was started according to schedule. After assessing the theoretical aspects of the technical realisation of measurements in the snow (i.e. low-frequency impedance analysis and high frequency time domain reflectometry analysis), a measurement system was designed to especially fulfil the requirements that are necessary when dealing with snow: wide range of temperature, low energy consumption and adequate for field use, i.e. easy and portable.

The first step for the development was the start of the design and configuration of the low-frequency impedance analyser. After investigation of different measurement methods for low-frequency impedance analysis, the following concept was established:

Concerning the mode of operation, the measurement frequency will be adjustable by software command and is generated by the DDS-method (direct digital synthesis). This measurement frequency is transformed to a measurement bridge, which is connected to the sensor cable. In the control unit, the magnitude and phase of the resulting voltage in the bridge is evaluated, digitalised and calculated and displayed via an interface.

After the compilation of the concept of the measurement principle, the development of the impedance analyser was started. A test set up for experiments for the signal processing are being conducted. Also experiments with the measurement bridge in relation to measurement object-frequency-measurement are carried out.

A suitable TDR module was chosen and tested for application for the bench scale instruments.

Although it was impossible to have the bench-scale instrument ready at the start of the second project winter (2002/2003), we are optimistic to test the device at the beginning of the melting season at the end of this winter.

WP 6 'Field test of bench scale instrument - This WP, which contains the 2nd field campaign was started earlier again due to seasonal reasons. Although the bench-scale instrument of WP 5 is not ready yet, we prepared the infrastructure of the test field, so that the bench-scale instrument can be connected as soon as it is ready. Furthermore the typical properties of the natural snow covers, which are important for WP 4 can be also studied with the technical prototype field system of last year. Also some additional results that were found in the first field campaign of WP 3 such as the proper installation especially of the sloping cable sensors need to be investigated further.

Based on these experiences, a new suspension was constructed at SLF during October 2002. The cable is now mounted onto a cylinder with a mechanical break (Fig 1; left), which will keep a constant pressure on the cable. The suspension is adjusted continuously when the snow load increases, by releasing the cable. It was also decided to install the sloping cable in a steeper angle of approximately 45°, and to skip the supporting poles totally (Fig 1; right). Two identical suspensions were constructed, the second one to be used for a dummy cable.

The new set of 4 flat-band cables was installed by FZK and SLF/WSL in November 2002, and the system has been running without any severe problems since December 2002. It is visited once a week. To date, the new set-up of the sloping cables looks very promising. In addition to the new sloping cable, 2 horizontal cables have already been placed on the snow surface, and one more is planned. Sloping dummy cables have been installed, which will be used during spring to study the influence of the cables on the liquid water flow by tracer experiments.

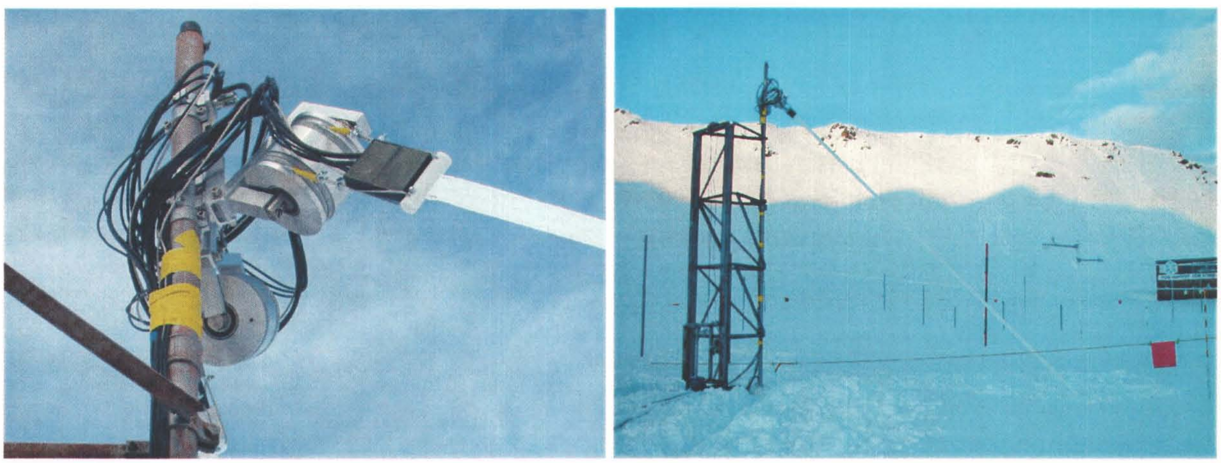

Figure 1 : The cable sensor system at Weissfluhjoch Davos (2550 m): the new suspension of the sloping cable (left), which is now installed in a 45° angle (right).

These tests are also important because it turned out that installation methods used so far are not very well suited for the very remote test fields of Northern Quebec. In this case, the cable sensors must be preinstalled carefully before the start of the winter and cannot be laid out manually at certain snow depths.Another point that needs more intensive investigation is the interaction of the cable sensors with the snow pack and especially how the water transport in the pack is influenced by the sensors. At the sub-alpine field site Alptal a dummy snow cable sensor was mounted at an angle of 45° (without supporting poles) for inspecting the size and shape of an air-gap during the snowmelt. Due to rather mild temperatures in the beginning of this winter at that site, the cable was not snow-covered to the end of January. In the first week of February a snow pack of more than 1 m formed, which will allow us to conduct the planned inspection in February.

Again WP 6 is completed by a field set-up and measurements in Quebec. Although not planned in this WP, this again shows the high motivation of our Canadian partners.

This time we installed the same technical prototype field system we had in Davos (including TDR, impedance analyser, and multiplexer) and measurements are taken automatically with the designed software. The evaluation with the *GetMoisture*-software (deliverable 6) is now possible. The problem of instabilities with the low-frequency measurements is still persistent, but we are now sure that it must be a locally limited problem, since reference measurements in Montreal did not show these instabilities.

The physical installation at the Chapais farm experimental site in 2003 was developed around three objectives:

- test different support types to find the most suitable one for our environment;
- acquire data on a larger surface for inputs into hydrological models and comparison with remote sensing images
- get a diversified dataset in order to better validate the measurements

This year, a permanent heated shelter was installed to keep the instruments (and the scientists) in a warm and stable environment. Design and installation was a collaboration between Hydro-Quebec and INRS. Supports and other parts were fabricated by Hydro-Quebec. To get data on the largest possible area, we designed a "star shaped" installation using three sloping SNOWPOWER cables starting from a central point and oriented in opposite directions at a 120° angle (Figure 2). The covered area would be of approximately 300 m² (with 10m long cables). One cable is oriented in the direction of dominant winds (cable #1: thick), the other two are therefore almost perpendicular to this wind direction (cable #2: thick and cable #3: thin). 30 m coax cables are necessary to keep a good distance between the sensors and the shelter.

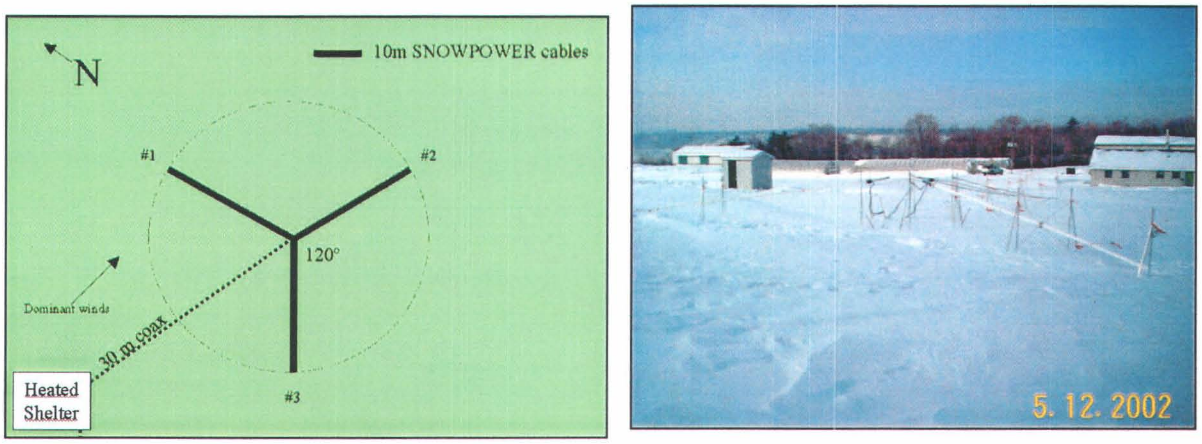

Figure 2 : Star shaped installation of the SNOWPOWER cables

The support system is designed to achieve a compromise between the strength and flexibility of the cables and the impact of the hardware on the snow cover (accumulation, transformation and melting).

3.2 COMPARISON OF ACHIEVED OBJECTIVES AND STATED OBJECTIVES

Achievements in the WPs are as follows:

In WP 1 the development and laboratory production of the snow moisture and density sensor was carried out, which represents the first milestone. The work included the development of an air gap correction algorithm and of a snow profile reconstruction code.

In WP 2 the measurement accuracy especially in case of air gaps and inhomogeneous snow profiles was assessed. The performance of the reconstruction code under various disturbing conditions was evaluated. Due to personnel shortage of partner KTH, finalisation of this workpackage was delayed, but due to subcontracting of partner FZK, the WP could be finished until month 17. The laboratory experiments confirmed a sufficient accuracy of the measurement system (e.g. not more than 2% uncertainty in the volumetric water content for air gap sizes less than 2 mm).

In WP 3 the technical prototype system was tested in the field and the results were compared to point sensor measurements. Furthermore the measurement algorithms were improved and refined with these real data of snow properties (dry and wet snow). The field campaign proved the suitability of the snow sensor system. Comparison with other measurement methods confirmed the measurement accuracy, which was the second milestone.

Some experiences in this field campaign revealed new questions concerning the installation of the sensors and their interactions with snow during settling and melting processes. To clarify these questions, some additional experiments will be carried out in the currently running field campaign of WP 6.

In WP 4 the hydrological models and the corresponding forecast strategies for hydro power optimisation are developed. This WP will last until the end of the project. Mainly the measurement results of the field campaigns, especially in WP 7, will be the input for the models and comparisons. It is expected that the extended hydrological model developed during the project together with the ground and RADARSAT data will significantly improve the water reservoir filling prediction. In the beginning the focus of this WP is mainly on the study of the hydrological models that are likely to be used with the future SNOWPOWER instrument.

In WP 5 the bench-scale instrument including a sensor network is developed. Currently tests with a prototype impedance analyser for the low-frequency measurements are underway. A commercially TDR-module for the high frequency measurements was tested and will be integrated in the bench-scale instrument. Options for an integration into data acquisition networks by remote data transmission are currently developed. We think that the bench-scale instrument will be available until the start of the melting period end of April, which is in project month 20. So there will be a slight delay of 2 months.

Similar to WP 3, WP 6 has been started earlier than planned due to seasonal reasons. Although at the beginning of this WP the bench-scale instrument is not yet available, we started the measurements with the existing technical prototype field system, but test field infrastructure has already been updated for an application of the bench-scale instrument. This way, a parallel field test of the devices is also possible. Due to some new questions that originated from experiences of the first field campaign, mainly concerning the proper installation of the cable sensors and the interaction of the cables with the snow, WP 6 was extended to investigate these points. Also a second field test was started in Canada with a set-up identical to the tests in Switzerland. Two goals are being approached by this way: first the Canadian partners are prepared for the larger scale field campaign. Second, differences in snow pack characteristics (moisture, density, etc.) between alpine (Swiss) and tundra (Canadian) snow packs will be investigated.

4. LIST OF DELIVERABLES

Deliverable No	Deliverable title	Delivery planned	Delivery issued	Nature*
1	Sensor for use with laboratory instruments	6	3	Eq
2	Air gap correction algorithm and code	5	5	O
3	Snow profile reconstruction algorithm and code	5	9	O
4	Laboratory test set-up	5	4	Eq
5	Measurement accuracy assessment report for air gaps, inhomogeneous profiles	9	9	Re
6	Improved air gap and snow profile reconstruction codes	9	9	O
7	Sensor system for field use with laboratory instruments	9	5	Eq
8	Data set of field campaign (sensor measurements, point measurements, weather conditions, snow conditions)	12	11	Da
9	Evaluation report of the measurement results	12	12	Re
10	Installation guide for the sensor system	12	Presumably 21	Re
11	Refined measurement algorithms and codes	12	17	O

**Nature of deliverable O means computer code, Eq means equipment, Da means data, Me means method, Re means report*

Deliverables 1, 4, and 7 are equipment from which pictures can be found in the Annex of the Progress report I.

Deliverable 2, 3, and 6 are integrated in a computer code called `GetMoisture´, the program manual can also be found in the Annex of progress report I. The program is available on request as well as deliverable 8, which is the data set of the first winter field campaign.

The reports of deliverables 5 and 9 can also be found in the Annex of progress report I.

Deliverable 10 exists in preliminary version but requires experience from an additional winter field campaign for completion. This will be done in WP 6. Completion is envisaged for month 21.

Deliverable 11 was delayed due to personnel shortage and was finished in month 17.

5. DISSEMINATION AND USE OF THE RESULTS

5.1. FUNCTIONAL ANALYSIS OF THE MAIN DELIVERABLES

Within this period, 11 deliverables were planned, of which 10 were issued up to now. Only deliverable no. 10 is still open ('Installation guide'), since it requires some more investigation during the second field campaign (WP 6). The deliverables can be summarized in 4 main groups:

5.1.1 *Laboratory cable sensor system* (Del. 1 and 4)

This is mainly Deliverable no. 1 and 4 and Milestone 1. The potential applications of this group are experiences and data concerning the realisation of dimensions and geometries of cable sensor based on the measurement of dielectric properties. We established a laboratory measurement test set-up suitable for the determination of complex dielectric properties. This can be used for characterisation of dielectric properties of a broad variety of capillary porous materials both in liquid and solid state in a frequency range between 100 MHz and 2 GHz. The experience gained and the developed codes can be used for modelling of electromagnetic fields to assess e.g. penetration depth or shape of the field. This is also useful e.g. for the assessment of interactions between electromagnetism and porous materials (such as soil, biomaterials, building materials).

5.1.2 *Technical prototype field system* (Del. 7)

The prototype field system is capable of delivering continuous measurements with automatic data acquisition and it delivers more precise and more representative measurements of snow dielectric properties, snow moisture, and snow density. The prototype equipment is also applicable for moisture measurements of several other capillary porous materials. The system is tested at the moment for application as a surface state detection sensor.

5.1.3 *Air gap correction and snow profile reconstruction code* (Del. 2, 3, 5, 6, and 11)

The Software is already used in process for operational data evaluation. It is also applicable for other measurement tasks such as soil moisture profiling, but for this purpose the hardware must be developed.

5.1.4 *Data sets of field campaigns* (Del. 8 and 9)

The data sets are already used for large-scale snow hydrology modelling and are envisaged for use in the prediction of formation of wet-snow avalanches. The data may also be useful in operational flood prediction and may contribute to verify other hydrological and climatologic models of especially Nordic regions.

5.2. VALUE ANALYSIS STUDY (RATIO FUNCTIONS/COSTS);

It is expected that the automatic and continuous snow state monitoring will save costs of at present 200 k€/y , because less manpower is needed. The potential savings, that are possible due to improved hydro power management were already estimated at the beginning of the project and yield amounts of 45 M€/y only for the 'La Grande Riviere' Catchment in Northern Quebec. This can be compared with an estimated 1 M€ for 10 systems including operating costs for a three year period.

5.3. PROTECTION OF THE RESULTS

A patent for the cable sensor configuration and for the air gap correction algorithm has already been granted. For the new developments, the present patent is regarded as sufficient. It will be investigated, if it makes sense and if it is necessary to further protect and register the developed software.

5.4. TARGETED AUDIENCE/RECIPIENTS FOR DISSEMINATION/TRANSFER OF INFORMATION.

The targeted audience and potential customers are primarily hydro power management and water resources authorities. But also hydrological research institutions, weather and climate services of both public and private origin, environmental consulting companies, civil engineering and agricultural institutions are worth looking at for dissemination. Especially the last group has great application potential for example in soil moisture measurement in irrigation techniques.

Users of remote sensing techniques are also a very important audience for transfer of information. Furthermore space agencies are a potential group for our improved remote sensing evaluation techniques.

The results of the proposed project will be disseminated, used and exploited in many different ways, from the consortium as a whole and from the individual partners in their particular fields.

The consortium exploits the results of SNOWPOWER especially by contacting local hydro power companies. Each of the partners will consult the local power companies and present the advantages of a better forecast. FZK already started to discuss the expected results with German power companies such as Bayernwerk, which is operating several hydro power plants in Bavaria.

They are very interested in increasing the efficiency of the hydro power plants by using the instrumentation and forecast methods developed in this project.

In a wider prospective SNOWPOWER will improve forecasting of avalanches and floods. In each winter avalanches occur with many victims and severe damage to buildings, roads and forests. The reliable prediction of avalanches is still an unsolved problem. One reason is the insufficient instrumentation for measuring snow parameters like water content and density in-situ. The proposed sensor will provide a solution to this problem. The partners of the consortium promote further research in this area. SLF is responsible for these activities. Floods are an even greater problem in many parts of the EU and Canada. Loss of life and enormous damage to buildings and agriculture areas are common. The hydrological models and prediction strategies for run-off developed within SNOWPOWER will be applied for forecasting floods as well. INRS, HQ and SLF, supported by the other partners of the consortium, will form a team to assess a possible exploitation of the outcomes of the project in regard to flood prediction.

Further potential for the dissemination and use of the technique, data and experiences can be found in the fields of water management of drinking water resources with snow covered catchments and in the field of soil moisture measurements and remote sensing over bare soil, for example for agricultural applications.

The activities for each participant in detail are as follows:

FZK will exploit more effectively their development by licensing their patents and know-how to the other partners as well as to other companies. Two license contracts were already concluded. Dissemination activities include presentation of non-confidential aspects of the technology through publication in international journals and presentation at selected international conferences. An active licensing policy attempts to interest potential users throughout the EU and in other areas of the world. Deliverables will include a concept for installation of the system in different conditions as well as results achieved in the larger-scale field trials.

Contacts to the Coordinator of EU RTD-project 'EuroClim', in which climate change effects on the cryosphere are being investigated, have been established, possible co-operation is being investigated.

Contacts with Statkraft-Groner (Norway), a big consulting company with activities in the hydro power production of Nordic regions and snow hydrology have been established. Norway will be an important market for the output of this project, since it is the biggest producer of hydroelectricity in Europe (99% of its energy is made of hydro power resources). Therefore Statkraft-Groner could be a potential key customer in Scandinavia and discussions are going on concerning possible cooperation and use of the technology in their hydroelectric applications in Norway. As project advances a demonstration installation could be envisaged.

Also contacts with the Institute for Marine and Atmospheric research of the University of Utrecht (NL) have been established and the possibility for cooperative measurements are investigated.

The project was also presented to BC-Hydro, the big energy corporation of British Columbia.

KTH verifies their models and tries to extend their modelling activities based on laboratory and bench-scale tests. They will improve their understanding of electromagnetic theory of transmission lines. The new mathematical algorithms can also be used for a variety of other problems in the field of inverse methods. The advanced computer codes will improve the knowledge of KTH in optimisation and speed up of software programs.

SLF is improving their understanding of spatial and temporal variation of the large-scale hydrological processes occurring during water flow in snow. Actual measurements are already integrated in new models for snow hydrology and will be used in the operational avalanche warning of the SLF especially for prediction of wet-snow avalanche formation. Furthermore the concepts of water transport in a snow cover are improving the knowledge of SLF in predicting flood dangers.

HQ will apply the technologies to water resource prediction and improvement of remote sensing by calibration with ground measurements. The expected results of the project will have wide impact for HQ. They can significantly reduce their costs for ground measurements and get more accurate data on a wider area at the same time. An expected improvement of at least 10% in prediction accuracy corresponds to 2,2 TWh or 45 M€. HQ plans to apply the technology throughout their territory which is one of the largest hydro power areas of the world. A better water management will lead not only to an increased efficiency of existing hydro power plants but to new installations which were not considered before due to a lack of accurate run-off predictions. HQ will also disseminate and exploit the technology in different areas of North America.

INRS will improve their remote sensing forecasting models by calibration using better in-situ data. They will be able to refine their snow water equivalent algorithms and their knowledge in radar backscattering which is essential for ongoing and future satellite operations. It is expected that they can apply the hydrological models and methods developed within SNOWPOWER for other scales and other applications as well, such as remote sensing of soil moisture. Agriculture would profit from a better run-off forecast and meteorology from an estimate of stored heat capacity in the snow cover, which can be calculated from water content and density. Therefore, close connections to Agriculture and Agri-Food Canada were established, and a scientist from this organisation joined the INRS project team.

SOM expects to introduce a new range of products based on the technology developed in the project and will expand its activities internationally. This will complete its product line of instrumentation and improves its further competitiveness on the European and global market.

This will also protect and increase employment as well as economic strength for this SME. Furthermore the development of the instrumentation for SNOWPOWER will improve the knowledge of SOM in new manufacturing technologies and new electronic components. The instrument installation in Canada will open the door for SOM to the North American market. Marketing of SOM will not be restricted to the snow moisture and density sensor but cover his complete product line. The strategy is to convince potential key customers with accurate and competitive-priced instrumentation, which have proven their reliability at HQ, one of the world largest electric utilities.

Several demonstrations of the project and the objectives were given within the organisations of the different partners.

In the first half of the project, the following publications and conference presentations resulted from the project:

- Waldner, P.; Huebner, C.; Schneebeli, M.; Brandelik, A. & Rau, F. (2001): *Continuous measurements of liquid water content and density in snow using TDR*.- Proc. 2nd Int. Symp. on Time Domain Reflectometry, Sept., Evanston, Ill. (USA).
- Becker, R., Brandelik, A.; Hübner, C.; Schädel, W.; Scheuermann, A. & Schläger, S. (2002): *Soil and Snow moisture measurement system with subsurface transmission lines for remote sensing and environmental applications*.- Proc. of Open Symp. on Propagation and Remote Sensing, February, Feb., Garmisch-Partenkirchen (Germany).
- Fortin, G., Bernier, M., Jones, G.& Schneebeli M (2002). *Changes in the structure and permeability of artificial ice layers containing fluorescent tracer in cold and wet snow cover*. Proc. 69th Eastern Snow Conference, June, Vermont (USA).
- Fortin, J.P.; Bernier, M.; Savary, S.; El Battay, A. & Khaldoune, J. (2002): *New developments and results for snow cover monitoring using RADARSAT and vegetation data and the HYDROTEL hydrological model*.- Proc. IGARSS conference, June, Toronto (Canada).
- Bernier, M.; Gauthier, Y. ; Briand, P.; Coulomb-Simoneau, J. & Hurley, J. (2002): *Radiometric correction of RADARSAT-1 images for mapping the snow water equivalent in a mountainous environment*.- Proc. IGARSS conference, June, Toronto (Canada)
- Brandelik, A.; Huebner, C.; Bernier, M. & Schneebeli, M. (2002): *Vicarious calibration for remotely sensed hydro power water resource*.- Proc. of SPIE Conference (Int. Society for Optical Engineering), Vol. 4814:1-6, July, Seattle (USA).
- Stacheder, M. & Brandelik, A. (2002): *Schneefeuchtebestimmung – Methoden, Ziele, Ergebnisse*.- in : K. Kupfer & E Trinks: 11. Feuchtetag 2002, pp 197-204, Sept. Weimar (Germany).
- M. Bernier, J.-P. Fortin, Y. Gauthier, C. Corbane, J. Somma & J.P. Dedieu (2002): *Estimation de la distribution spatiale du couvert nival de son équivalent en eau à l'aide d'images VEGTATION et RADARSAT en vue d'une meilleure estimation des ressources en*

eau par le modèle hydrologique HYDROTEL.- Proc. Int. Workshop on Snow Hydrology in Mediterranean regions, Beyrouth, Lebanon.

Submitted and accepted papers:

- A. Brandelik, C. Huebner, R. Schuhmann & M. Stacheder (2003): *Determination of Snow Density and Snow Water Equivalent for Hydro Power Generation*.- ISEMA Conference, March 2003, NZL (accepted).
- M. Stacheder, S. Schlaeger, A. Brandelik & M. Norgren (2003): *A new in-situ sensor for large-scale snow cover monitoring: I. Principle, design, and air gap correction*.- Symposium of Int. Glaciolog. Society, June 2003, Davos, CH (submitted).
- M. Stähli , M. Stacheder , D. Gustafsson, A. Brandelik, & M. Schneebeli (2003): *A new in-situ sensor for large-scale snow cover monitoring: II. Field test*.- Symposium of Int. Glaciolog. Society, June 2003, Davos, CH (submitted).
- D. Gustafsson, M. Stähli & R. Meister (2003): *Use of flat-band snow sensor data in a snowmelt run-off model*.- *Symposium of Int. Glaciolog. Society*, June 2003, Davos, CH (submitted).
- A. Brandelik, C. Huebner, S. Schlaeger & M. Norgren (2003): *State of the art inversion techniques for subsurface moisture profiles.- Conference on Progress in Electromagnetic Research*. - PIERS (submitted).
- M. Norgren (2003): *A simple approach to quasi-TEM analysis of a planar multi-conductor structure embedded in an elliptically stratified environment*") was accepted for publication in Microwave and Optical Technology Letters.
- M. Niang, M. Bernier, Y. Gauthier, G. Fortin, E. van Bochove & A. Brandelik (2003): *Integration of polarimetric SAR data and Snopower probes data into the EQeau model for snow monitoring*.- IGARRS 2003 conference, July, France

6. MANAGEMENT AND CO-ORDINATION ASPECTS

6.1. THE PERFORMANCE OF THE CONSORTIUM AND THE INDIVIDUAL PARTNERS

The work for the project started in time in Sept. 2001. Since the winter in Davos and Quebec normally begins in November we had to hurry up and field installations for the first field campaign (WP3) were started earlier as planned. Therefore the first steering committee meeting took place a little late after 3 month of the project start with all partners present.

Also in September 2001, a proposal was submitted by Professor Monique Bernier (INRS) to a Canadian R&D Institution (NSERC), for financing the scientific contribution of INRS to the SNOWPOWER project. In February 2002, Prof. Bernier received a positive answer from NSERC. For a three years period, INRS will receive a total grant of 326 666 EUR which is in the same order than the budgeted contribution of INRS (304 350 EURO) to this project.

A web site *http://www.project-snowpower.de* has been established and is maintained by FZK. Also a web page of the Swiss subproject was set up at :

http://www.wsl.ch/staff/manfred.staehli/snowpower/welcome-en.ehtml.

A project database was set up by SLF/WSL on a FTP-server to allow easy access to the Swiss field data for all project partners.

The cooperation within the project is in general excellent. Continuous communication is mainly done by email and periodic reviews of the progress by plan are carried out by coordinator. Beside the annual meetings, mutual visits of Project partners in Switzerland, Austria and Sweden were carried out. The 2nd steering committee meeting, again with all partners present was hosted by INRS and HQ in Quebec in July 2002, the 3rd and thus mid-term project meeting is envisaged for March 17th to 19th and will be hosted by SLF in Davos. The motivation of the project partners is high and especially the field tests in Switzerland and Canada are performed with great enthusiasm.

Additional cooperation between partner Sommer and FZK concerning the development of another environmental sensor and between HQ and FZK concerning the development of a Laser scanning device for snow are carried out and will thus intensify the existing mutual relationships. This is also valid for SLF, who has several other sensors from Sommer company in use for avalanche research.

Dr. Hübner, second key person of the coordinator FZK in the project, has left the company but will still be available as a consultant for the project. Dr. Stacheder, a scientist with yearlong experience in material moisture measurements was employed by FZK to work for the SNOWPOWER project.

The SLF team is enlarged by Dr. Manfred Stähli, an expert in soil and snow hydrology and employed at the Swiss Federal Research Institute for Forest, Snow and Landscape Research (WSL) of which the SLF is a part. Also a post-doc position at SLF for the work of SNOWPOWER was filled on October 15th 2002 by Dr. David Gustafsson. He will supervise mainly the field campaigns in Switzerland.

Dr Eric van Bochove, research scientist at Agriculture and Agri-Food Canada and invited professor at INRS, jointed officially the INRS SNOWPOWER team. Dr van Bochove implication will allow the Canadian partners to be involved in the development of an other application of the sensor: *Scaling-up of* N_2O *atmospheric emissions from agricultural soils by using the SNOWPOWER probe continuous snow density measurements.*

Post-Doc position at INRS for the work of SNOWPOWER was filled on July 1st 2002 by Dr. Niang Mohamed, an expert for remote sensing data evaluation, who will be in charge of the measurement evaluation in Quebec.

Dr. Brandelik (FZK) and Dr. Stacheder participated at the *2nd Int. Symposium and Workshop on Time Domain Reflectometry (TDR)* at Northwestern University in Evanston, Illinois in Sept. 2001. Dr. Brandelik presented a joint paper (partner 1 and 3) about TDR applications in snow and ice.

Dr. Brandelik (FZK) gave a presentation of the snow cable sensors at Hydro-Quebec head quarter on September 10, 2001. Members from INRS also attended that meeting. On September 11, a visit of the Chapais Experimental Farm was organized.

In preparation for the first steering committee, Hydro Quebec organized a meeting of the two Canadian partners in Montréal on November 23, 2001.

Prof. Monique Bernier gave a presentation on November 30, 2001 at the *University* of Karlsruhe, Germany. The topic was the estimation of Snow Water Equivalent using SAR data from the Canadian satellite RADARSAT.

The 1st steering committee meeting was held in December 2001 at FZK with all partners present.

SOMMER participated in several meetings with the project partners at FZK and SLF to further improve their understanding of the scientific background and the techniques applied in this project.

Dr. Brandelik gave a presentation at the Open Symposium on Propagation and Remote Sensing in Garmisch-Partenkirchen in February 2002.

One person from FZK and one person from partner SLF/WSL participated at the 3rd Workshop of the *European Association of Remote Sensing Laboratories* in Berne/CH in March 2002.

Prof. Monique Bernier gave a conference on May 3, 2002, at the CEN (Centre d'Etudes Nordiques) annual meeting presenting the SNOWPOWER project and other INRS projects related to snow and ice monitoring. The CEN is a Laval university research centre on Nordic or alpine research topics and main activities in Northern Quebec.

In June 2002, a poster paper was given by Guillaume Fortin, Dr Monique Bernier, Dr Gerald Jones (INRS) and Dr Martin Schneebeli (SLF) at the 69th Eastern Snow Conference, Vermont, USA. The paper will be published in the conference proceedings: *Changes in the structure and permeability of artificial ice layers containing fluorescent tracer in cold and wet snow cover.*

Two presentations by INRS were held at *Int. Geoscience and Remote Sensing Symposium 2002* in June in Toronto. Dr. Stacheder also participated at the IGARSS conference.

The 2nd steering committee meeting was held in July 2002 in Quebec with all partners present.

Following the meeting Dr. Brandelik participated at the SPIE-conference of the Int. Society for Optical Engineering in Seattle and gave a presentation. He also visited BC Hydro company, the biggest power production company in British Columbia and presented the project.

From Sept. 12th to 14th 2002 the Swedish partner was visited to discuss topics concerning the electromagnetic modelling and the possibilities in overcoming the personnel shortage of the partner.

On Sept. 18th and 19th 2002 the project was presented at the Weimar 'Moisture-Day-Conference', Germany.

Prof.. Bernier gave a presentation at the International Workshop on Snow Hydrology in Mediterranean regions in Beirut, Lebanon on December 16th – 19th.

6.2. MANPOWER TABLE

see table 1 at the end of this report

6.3. BAR CHART WITH WORK

see table 2 at the end of this report

7. CONCLUSIONS AND REVIEW OF THE DESCRIPTION OF THE WORK

The partners should clearly state that, in view of the achieved results to date and the potential for use, they wish (or do not wish) to continue the project. The planning of the work for the second period of the research should be reviewed based on the critical assessment of the results achieved and any new available technologies or methodologies. Possible modifications to the Description of Work (Annex I to the contract) might therefore be indicated.

All partners would like to continue the project since:

- the field tests have shown that the measurement system has a great potential in giving high quality long-term measurements of SWE, snow density and liquid water content, suitable for hydrological modelling and calibrating remote sensing data.
- the system enables a unique measurement of horizontal variation of liquid water content in the snow.
- it is planned to use further data to improve the understanding of liquid water flow in snow, which can be used for prediction of wet-snow avalanche formation. This could be of capital importance in developing strategies for avalanche early warning with attendant reduction in loss of human life and damage to infrastructure.

The detailed work for the second period will be discussed intensively at the mid-term meeting. The planning is as follows:

- WP 4: The hydrological models and the algorithm for combining ground truth data with satellite data will be permanently refined with the data of the second field campaign and new management strategies for an optimum exploitation of hydro power will be developed.
- WP 5: It is envisaged to have a bench-scale instrument ready at the beginning of the melting season of the snow pack in the Swiss Alps, which will be approximately in May. The properties of the bench-scale instrument will be compared with the field prototype system already installed.
- WP 6: Since Start of second winter season and planned completion of the bench-scale instrument differed too much, measurements of the snow pack were continued with the existing field prototype system both in Switzerland and in Canada. Infrastructure for the test of the bench-scale instrument was already established. It will be attached to the sensors as soon as it is ready. The WP was extended with some more field experiments concerning the installation methods of the cable sensors and their interaction with the melting water in the snow pack.
- WP 7 and WP 8 are at the moment envisaged as planned.

8. GLOSSARY

AAFC: Agriculture and Agri-food Canada
C: capacity
FD: Frequency Domain technique,
G: conductivity
GetMoisture: evaluation software for measurement data
GHz: Gigahertz,
HYDROTEL, EQeau, CROCUS, COUP, SNOWPACK: different existing hydrological models
IA: Impedance analyser, model HP-4192A
L: inductivity
MHz: Megahertz,
ns: nanoseconds,
NSERC: Natural Sciences and Engineering Council of Canada
PE: Polyethylene
Permittivity: dielectric constant (ε)
RADARSAT-1: Canadian radar satellite launched in 1995
SAR: synthetic aperture radar,
SWE : Snow water equivalent (depth of water that would cover ground if snow pack was liquid)
TEM: Transversal electromagnetic
TDR: Time Domain Reflectometry, model Tektronix 1502B
TWh: Tera Watt hour
WFJ: Weissfluhjoch (measurement site at Davos)

Table 1 : Man Power and Progress Follow-up Table

Task/Subtask (N°/title)	Partner (Name/ abbrev.)	--------- Man-Month ----------- Planned efforts - at start of period (MM) Year 1 a	Planned efforts Year 2 b	Planned efforts Year 3 c	Planned efforts Total d	Actual effort (MM) Year 1+2 a1	Forecast effort (MM) Year 2 b1	Forecast effort (MM) Year 3 c1	Forecast effort (MM) Total d1	*Devia-tion (MM)* *Totals* d1-d	------- Technical Progress % ------- Planned (%) Year 1	Planned (%) Year 2	Planned (%) Year 3 a+b+c /d	Assessed* (%) Year 1	*Devia-tion (%)* *Year (now)*	***Comments on major deviations and/or modifications of planned efforts.***
WP 1 Sensor development	FZK	10			**10**	10			**10**		100%	100%	100%	100%		
	KTH	6			**6**	5			**5**	*-1*	100%	100%	100%	100%		
	SLF/WSL															
	HQ															
	INRS															
	SOM															
	..															
	Total	**16**			**16**	**15**			**15**	***-1***	**100%**	**100%**	**100%**	**100%**		
WP 2 Laboratory trials	FZK	10			**10**	12			**12**	*2*	100%	100%	100%	100%		WP could be finished in month 17 with a delay of 8 month. This was caused both by personnel shortage of partner 2 and more work than planned.
	KTH	6			**6**	2			**2**	*-4*	100%	100%	100%	100%		
	SLF/WSL															
	HQ															
	INRS															
	SOM															
	..															
	Total	**16**			**16**	**14**			**14**	***-2***	**100%**	**100%**	**100%**	**100%**		
WP 3 Field tests	FZK	10			**10**	10			**10**		100%	100%	100%	100%		WP successfully finished Few work that could not be carried out mostly due to seasonal reasons transfered to field campaign of WP 6
	KTH	3			**3**					*-3*	100%	100%	100%			
	SLF/WSL	6			**6**	3			**3**	*-3*	100%	100%	100%	100%		
	HQ	2			**2**	3			**3**	*1*	100%	100%	100%	100%		
	INRS	2			**2**	3			**3**	*1*	100%	100%	100%	100%		
	SOM															
	..															
	Total	**23**			**23**	**19**			**19**	***-4***	**100%**	**100%**	**100%**	**100%**		
WP 4 Hydrological modelling and forecasting	FZK															
	KTH															
	SLF/WSL			8	**8**	3	2	3	**8**				100%	38%	*63%*	
	HQ	2	4	7	**13**	3	3	8	**14**	*1*	15%	46%	100%	21%	*-3%*	
	INRS	2	4	7	**13**	2.25	3	4.5	**9.75**	*-3.25*	15%	46%	100%	23%	*8%*	
	SOM															
	..															
	Total	**4**	**8**	**22**	**34**	**8.25**	**8**	**15.5**	**31.75**	***-2.25***	**12%**	**35%**	**100%**	**26%**	***16%***	
WP 5 Development and building of bench scale instrument	FZK	2	2		**4**	2	2		**4**		50%	100%	100%	50%		
	KTH															
	SLF/WSL															
	HQ															
	INRS															
	SOM	6	10		**16**	10	6		**16**		38%	100%	100%	63%		
	..															
	Total	**8**	**12**		**20**	**12**	**8**		**20**		**40%**	**100%**	**100%**	**60%**		

Table 2 : Overview of planned work vs. achieved

Bar chart mid-term report Sept. 2001 - Feb. 2003