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Scientific evaluation of Programme area 2 Water resources (2000–2007) at the Geological Survey of Denmark and Greenland (GEUS)

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF THE ENVIRONMENT

GEUS

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1. The evaluation process

1.1 Introduction

The evaluation panel consisting of

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Prof. Ole K. Borggaard, University of Copenhagen

was given the following task:

The panel shall undertake an evaluation of research and presentation activities within the Programme Area "Water Resources", constituted by the contents of the result contracts 2000-2003 and 2004-2007.

The panel is asked to evaluate the research activities of GEUS on the basis of

- publications, reports and other relevant material produced over the period 2000-2007
- interviews with GEUS management staff and scientists and visits to laboratories and work facilities at GEUS.

The more detailed tasks are:

- Identification of areas of high quality research
- Identification of areas where the research of GEUS should be strengthened in order to meet GEUS vision and strategies
- Identification of areas which should be strengthened in order to expand GEUS ability to provide assistance to third world countries within the broad area of water resources.
- Comments and proposals as to strategic changes, amendments and improvements to GEUS work within the programme area, in order to improve GEUS ability to fulfil its main mission with this programme area put into perspective of the surveys statues and general mission

1.2 GEUS' tasks as we see them

GEUS is a research institution which has to supply scientific knowledge and advice to the Danish Ministry of Environment and information to the Danish public. The tasks in detail are:

- Geological and hydrological mapping
- Data collection and storage
- Research projects concerning resource occurrence, management and protection
- Advisory services to the ministry
- Dissemination of geological and hydrological knowledge

The water programme should give national guidelines and standards relevant for policy in the water field including the interpretation of EU guidelines for the national context. It should be a bridge between academic research and practice, be it in environmental management or consulting. It should be the "consultant of the consultants" in groundwater related matters. It should be an early warning system for the ministry and the society in general concerning groundwater related risks.

These services should come at a high professional level. For that reason it is absolutely necessary to do high level research in its own right in order to have first hand experience, and stay competent, "sharp", and competitive. As one staff member staff put it: "You are sharp if you can compete for a post in Academia". An essential element in introducing new ideas and keeping the organization from over-aging is the presence of Ph. D. students and Master students. Research is important, but not a purpose in itself. It has to be balanced against the other tasks of GEUS. If GEUS would only do top research and forget about its other tasks, there would be no reason for its existence outside of a University. It is by doing things which are not possible in a university environment that GEUS gets its justification. One of these items would be integrated projects where expertise from different disciplines is required, which normally in a university institute is not available. Other examples would be long-term activities such as monitoring and the national groundwater model. Finally GEUS is responsible for geology and hydrology related work for Greenland.

The GEUS water programme area has seen a deterioration in its conditions of work. More than 50% of GEUS' funding in 2007 of the water programme area will be external, while 6 years back only 18 % were external. Therefore the programme has a greater financial vulnerability than in earlier times. The researchers are under the pressure to not only fund new programs but also to acquire part of their own salaries from outside.

The self-determined research is possibly less than 5% of the volume of work. Asked how much high level research would be necessary to stay scientifically sharp, a GEUS scientist answered "about 50% of the time". This percentage is not reached in practice.

It is against this background that we evaluate the Water Programme.

2. Detailed evaluation of activities

2.1 Groundwater Quality Monitoring

Activities

Activities in groundwater quality monitoring were summarized by Jeanne Kjær. Groundwater quality monitoring is a high-priority activity of GEUS because groundwater is the sole or primary source of drinking water for Denmark. This activity, which needs to be done at a national level rather than solely through ad hoc monitoring by local entities, is absolutely central to GEUS's mission.

Groundwater quality monitoring efforts have been devoted primarily to three initiatives: national scale monitoring, pesticide leaching assessment program (PLAP), and drinking water quality in small private wells. The national groundwater monitoring program has accumulated 17 years of data from some 1500 screens and is supplemented with data from Danish water supply companies that monitor about 10,000 wells at 3 to 5 yr intervals. The main analyses are major cations and anions, trace elements, pesticides and other organic pollutants.

PLAP focuses on only 5 sites nationally, but each site is highly instrumented with both vadose and saturated zone monitoring devices, and each site is carefully selected to be representative of potential pesticide sources, soil type and climate. This program is conceived to not only illuminate pesticide leaching and transport processes but also to provide an early warning system for emerging groundwater pesticide problems. Noteworthy examples are new insights into migration of the metabolite of metribuzin and estrogenic hormones from manure sources. The data and analysis of metribuzin show substantially higher concentrations than were predicted by regulatory screening models for this compound, highlighting inadequacies of simplistic models of pesticide transport. The data on estrogenic hormones is beginning to elucidate occurrence and scope of this problem as well as mechanisms of transport (e.g., effects of precipitation events).

The program on drinking water quality in small private wells has obtained data from 625 out of 50,000 households. These wells are generally very vulnerable to pollution because of their shallow depth (0-10 m) and proximity to domestic and agricultural contaminant sources. Results indicate 67% of the private wells are contaminated, where "contaminated" means the concentrations are above regulatory contaminant limits (e.g., $NO_3 > 50$ mg/L, pesticides ≥ 0.1 µg/L or coliform > 0). Contamination pathways have been estimated for 21 of the wells.

Observations

As pointed out by GEUS, the national monitoring program tracks long-term changes in groundwater quality and helps assess impacts of various regulatory measures to protect groundwater. By identifying newly polluted aquifer systems or new and emerging contaminants, monitoring provides a basis for initiation of new research projects. Moreover, monitoring provides needed data for calibration and validation of flow and transport models. Apparently as a result of the national monitoring program, and perhaps particularly due to PLAP, the number of pesticides used in Danish agriculture has been reduced significantly between 1992 and 2005. PLAP has also identified higher-than-expected concentrations of certain compounds, thereby indicating inadequacies of screening models that were used to assess risk of leaching of particular compounds (e.g., metabolites of metribuzin).

Budgets for the monitoring programs have been cut substantially in recent years, and it appears that the monitoring leadership has struggled to provide convincing arguments for reversing this trend. Below the review panel will provide recommendations for justifying and reinvigorating the monitoring program. Further, perhaps the monitoring program can be used to better define overarching goals and long-term vision for GEUS water resources

The finding that 67% of the nation's private shallow wells are contaminated is startling. Importantly, this finding together with the deeper monitoring data provide the basis for defining both the future mission of GEUS monitoring and effectively communicating or defending that mission in public and scientific forums. In this context, it is worth noting that "contaminated" in this program is defined as the concentration exceeding the regulatory contaminant limit (e.g., 50 mg/L for NO_3). Therefore, the percentage of wells that are impacted by pollution (containing concentration levels higher than background) is actually much higher than 67%. This is perhaps not surprising, but it is no less alarming for a country that depends virtually entirely on groundwater. It means that recharge waters over vast regions of the country are contaminated. This raises the important question: "Given that most of the deeper groundwater is too old to have been impacted significantly by the poor quality shallow groundwater, what is the sustainability of the deeper groundwater quality?" That question can be used to both justify maintaining a vigorous monitoring program and for defining more clearly a longer-term vision for the water resources program area. Stated another way: Most of the shallow groundwater quality is poor while the deeper groundwater is still mostly too old to be contaminated; and estimating the downward transport and fate of the shallow groundwater and long-term evolution of deeper groundwater quality is one of the grand water resource questions of today – not only in Denmark but worldwide. This question can be used to lay a unifying research path not only for the monitoring area but also for the characterization, modelling and IWRM areas.

Scientific Quality

Publication output of the monitoring group in international journals has been lean although it has increased recently, apparently because of the need to keep a shrinking staff focused on data collection and because of recent emphases on publishing in ISI-citable international journals, which typically do not publish data papers. Nevertheless, the panel would like to point out that an important part of the GEUS mission is in fact data collection, which is appropriate for a national geological survey. Therefore it would be prudent to not discount the contributions of monitoring scientists who might primarily publish their work in other forms, such as internal GEUS reports. By the same token, since monitoring data are also essential for modelling and analysis in a variety of water resources investigations, one should expect that monitoring staff be co-authors on a variety of publications coming out of the water resources program area. This will happen if GEUS uses the monitoring to ask the poignant questions that form the basis for higher-level analysis of processes. For example: What is the cause or meaning of a particular trend in groundwater quality? At what rate will the poor quality shallow groundwater degrade deeper groundwater and will dispersion and dilution with clean recharge be enough to mitigate the impacts? The recent increase in publications by monitoring scientists seems to indicate that such an approach is being adopted.

Recommendations

Monitoring with both a nationwide and, in certain cases, local scope is a core activity of any geological survey, the resulting data are essential for resource management and protection, and GEUS should work to both maintain and strengthen this activity. Furthermore, monitoring program results have helped create strong political and public awareness of both groundwater contamination problems and the important role of GEUS in resource management and protection.

GEUS will continually face the lay-person's typical argument – "groundwater quality typically changes extremely slowly or perhaps not at all, so why bother to spend much effort monitoring it?" GEUS should respond with the following argument that in fact only GEUS has the experience, data and knowledge to back up: "Regional-scale groundwater quality changes on time scales of decades to centuries or even millennia. Moreover, most of our shallow groundwater is substantially contaminated and may eventually degrade quality of the deeper groundwater. We have one of the longest-term groundwater monitoring networks in the world, with 17 years of water quality data, yet future impacts on deep groundwater quality and effects of changes in contaminant source loading (due to changes in land management, including regulatory restrictions on chemical use) can only be observed with multi-decadal data. By analogy, imagine trying to prove that the globe is warming with only 17 years of data."

GEUS monitoring scientists have begun to publish more by investigating local-scale processes that could explain local-scale trends or patterns in monitoring data. GEUS

should also use the monitoring program results to justify and execute regional-scale investigations on the fate of contaminated shallow groundwater concerning the resource as a whole and what measures might be taken to mitigate this problem.

Despite the potential for GEUS monitoring scientists to expand international journal publication of process-oriented research, GEUS should also recognize the unique benefits of monitoring as a core geological survey and an admirable service to the people of Denmark. In this regard, GEUS should consider giving more-or-less equal recognition to internal publications on monitoring that are obviously highly valuable but not publishable in journals. We heard that the data available on the web site, where the public can look up the water quality of their home town or village, show 1.8 Million hits per year. This is indeed an indicator that an information need of the public is successfully addressed.

The monitoring publications produced by GEUS have been in fairly high impact journals for the environmental area (e.g., ES&T), are of high quality, and provide results that are very relevant to groundwater resources. The success stories on metribuzin, estrogenic hormones, and glyphosate are compelling. It should be emphasized that the work on private well quality should be highly publishable in North American journals, even if only presenting broad statistics and trends. This is because North American systems have been exposed to contaminants for a shorter time interval as compared to Denmark and the rest of Europe, and the notion that shallow groundwater quality could become so degraded in the future would be especially provocative news (and food for discussion) in North America. In fact, there is ongoing debate whether North Americans even know enough about shallow groundwater quality to make intelligent assessments and predictions regarding sustainability.

2.2 Geomicrobiology

Research activities

The activities in this field were presented by Carsten Suhr Jacobsen. Research in geomicrobiology at GEUS started 11 years ago and has focused on microbial degradation of selected pesticides in soil and aquifers. Investigations of microorganisms in complex environments are challenging since only a low percentage (often < 1%) of these organisms can be cultured. Rapid development of molecular techniques in recent years has revolutionized the field of microbial ecology and provided a range of tools to study also the unculturable organisms. Researchers at GEUS have made important contributions to this development and can, together with a few research groups in other countries, be considered as pioneers in developing successful techniques to extract and analyse mRNA from soils. This is a major breakthrough since it allows studies of specific microbial activities in situ, providing quantitative measures of the transcription of selected functional genes.

The degradation studies have during recent years mainly focused on the herbicide dichlobenil (2,6-dichlorobenzonitrile) and its metabolite 2,6-dichlorobenzamide (BAM), and on polycyclic aromatic hydrocarbons (PAH), but also others e.g. 2,4-D, glyphosate, 4-chloro- 2-methyl-phenoxyacetic acid (MCPA) and isoproturon.

Factors that have been studied, which affect degradation, include sorption/desorption to soil particles; aerobic vs. anaerobic conditions; clay vs. sand content; soil pH; depth in the soil profile; amendment of nutrients; addition of bioremediated soil containing large populations of degrading organisms.

Molecular techniques have been used to analyse microbial community composition by PCR-DGGE and to identify possible degraders by sequencing. Real-time PCR has been used in several studies to quantify specific degradation genes. The efforts that have been devoted to developing techniques to analyse mRNA in soil, open up the possibility of further studies of the actual activity of these genes in situ.

In addition to studies which take into account the entire soil microbial community, bacteria capable of mineralising BAM have been isolated. Other studies have investigated the fate of degrading bacteria when introduced into soil contaminated with the relevant pesticide.

Studies have generally been performed as laboratory experiments in microcosms, where degradation of ^{14}C labelled substrates has been measured as $^{14}CO_2$ production. Work recently accepted for publication also contains studies of the field scale variation of microbial activity, degradation and pesticide sorption to soil particles.

Observations

The group as a whole has a strong foothold within microbial pesticide degradation. They use, and continuously develop, relevant and highly up-to date molecular tools to analyse microorganisms in soils with respect to identification of important degraders as well as presence and activity of specific degrading genes. Close collaboration with chemists at GEUS appears to be very fruitful. There is however strikingly little collaboration between senior researchers working on microbial degradation.

Based on recent results, the group plans to devote research efforts to studies of spatial variation patterns of pesticide degraders in soil, and on the bioavailability of the pesticides. The patchy distribution of microorganisms, especially in subsurface soil layers, plays a large role for the degradation potential. This, as well as studies of the bioavailability of toxic compounds, offer new and exciting research topics that take advantage of the group´s knowledge in biodegradation, microbiology and organic chemistry but where collaboration with mathematical modellers within or outside GEUS would clearly be advantageous.

Meeting new demands

Concentrating all research on pesticide degradation might be a threat to the group in the future. Although national funding agencies apparently support this theme, it is not

prioritized internationally at present; for example the FRP7 does not include this as major subject. To meet this possible threat, the group is directing some research into studies of spread and establishment of pathogenic bacteria in soil. This appears to be a wise strategy since it is a research field that is rapidly expanding internationally due to an increased focus on health related questions, in combination with the increasing possibilities offered by new molecular techniques to track pathogenic bacteria. Such research tasks fit well with the group´s expertise on in situ detection of indigenous or added degrading bacteria and their genes.

The mission of GEUS includes Greenland, which is one reason for GEUS existing as an autonomous research institute. From this perspective, the ongoing research on pesticide degradation in permafrost appears important. Organic pollutants are transported over large distances and may threaten Greenland as well as other arctic areas due to slow degradation and thus long turnover times. This is a research field where GEUS should contribute, and it fits well in response to the attention paid to the arctic regions during the Polar Year.

Research quality

The research in geomicrobiology at GEUS is considered to be of high quality. The group is successful in obtaining funding from external sources, and attracts many Ph.D. students. Researchers in the group are well known internationally for studies on pesticide degradation as well as development and optimizations of molecular techniques applied to soil. They produce a relatively large number of articles every year, which are published in highly rated international scientific journals, as well as book chapters and a large number of presentations at international conferences. The relatively high numbers of citations, as well as h-indices of some of the researchers, demonstrate a strong and sustainable international impact of the research.

Although the major part of the dissemination of research results from this group is through scientific international publications, the group also publishes reports and articles in Danish journals, and arranges visits for school children etc., thereby fulfilling the demands for dissemination to the public.

Recommendations

- Keep the expertise on microbial degradation of pesticides
- Further develop studies on spatial variability of degrading microorganisms in subsoil; sorption/desorption; bioavailability; diffusion and develop collaboration with mathematicians/mathematical modellers in this work. Experiments will feed data into models, and models will in turn generate new questions to be addressed by experimentalists.
- Continue to be in the forefront with respect to development and adaptations of molecular techniques
- Expand the new research on spread and establishment of pathogens

2.3 Geochemistry: Analytical chemistry and soil pollution

Research activities

Activities within this area were summarized by René K. Juhler and Anders R. Johnsen followed by a visit to the laboratories guided by Carsten S. Jacobsen and René K. Juhler.

Current projects include a broad range of applied studies of various organic and inorganic compounds in different matrices: (i) Natural formation of chloroform and other halogenated organic compounds, (ii) Percolation of grey wastewater in rural areas, (iii) P-index in agricultural soils and sediments, (iv) Nitrate reduction in unsaturated zone, (v) Natural toxins (solanine, ptaquiloside), (vi) Application of geostatistics for the characterization of soil/sediment variability and heterogeneity, (vii) Remote sensing of geochemical parameters, (viii) Various comprehensive fate studies of different pesticides, (ix) Pyrite oxidation and (x) CFC groundwater dating.

Observations

The core expertise is considered to include: (i) Analytical chemistry regarding determination of various organic xenobiotics, inorganic compounds and gases, (ii) Execution of experiments at different scales ranging from laboratory to field/landscape scales, (iii) Performance of multivariate data analysis and (iv) Close contact with the 'surrounding world'. These issues were shown and explained by various examples, which also demonstrated the very broad range in geochemical subjects going from batch/column investigations in the laboratory to field and landscape studies on various contaminants, in particular organic pollutants. Focus on organic pollution in more recent projects is very much in accordance with public concern about water pollution with pesticides and other organic compounds.

The analytical chemistry, which appears to be an integral part of geochemistry and geomicrobiology, is well organized and carried out with great skill. Optimization of the methods and techniques (e.g. sample cleaning and extraction) for the purpose in question seems to be an integral part of the analytical work and awareness of good laboratory practice was demonstrated. The laboratory was demonstrated to be well-equipped with various relevant sample pretreatment equipment facilities and modern techniques used for determination of organic compounds, e.g. LC-MS and GS-MS. The laboratory lacks state-of-the-art-techniques for analysis of inorganic compounds, e.g. techniques that can be used in heavy metal speciation, but access to modern equipment is available in other laboratories at GEUS.

A rather long list of future research activities was presented including tuning and improvement of current activities in order to give better advice and services to society. Future tasks will also include new pollutants such as drugs, antibiotics, hormones and natural toxins. These activities seem logical and relevant considering the obligations of the

institution. On the other hand, the behaviour of these compounds is not very new but an integrated study on these compounds along the lines of the pesticide study might be innovative.

GEUS is performing applied and not basic geochemical research. It therefore seems logical that development of new analytical methods/techniques is not included in the plans of the future. However, it will be necessary to adapt and optimize current methodology and to take up and apply new techniques in order to support other research activities. Consequently, expertise in analytical chemistry is very important but GEUS seems well-aware of the importance of in-house analytical chemistry expertise and access to state-of-the-art techniques. However, one aspect that might attract more focus in the future is bioavailability of pollutants because it has become more and more clear that it is the bioavailable fraction of a pollutant that creates problems, not the total concentration; determination of bioavailability is important for both organic and inorganic pollutants.

Research quality

The research performed within this area appears of general high quality. Many results are published in international peer-reviewed journals, but probably more project results might be of interest for an international audience. According to publication record the average publication rate of senior scientists in the group is about 0.9 international (ISI-cited) publications per year over the last 7 years, which is considered acceptable. The commitment of GEUS to serve the society/ministry through reports, overviews and notes can make it difficult to find time for writing international peer-reviewed publications.

The strength of the research in most projects is the integration of two or more different disciplines such as geology, hydrology, analytical chemistry, statistics and microbiology. The investigation of natural formation of chloroform and other organic chlorinated compounds and the studies on glyphosate distribution in different soils are good, but definitely not the only examples of integrated projects.

While research quality is good and achievements are many in projects on organic pollutants, investigations on inorganic contaminants are less impressive.

The introduction of CFC-analysis into the chemistry group has given the group a new tool, opening a new area of research. It is a good example of the bridge function from basic research to application. CFC data can nowadays already be used to constrain the notoriously non-unique groundwater models. First projects on multi-tracer comparison showed that results are easily publishable, which means they are of considerable interest to the scientific community. The coupling of CFC with other pollutants for age dating has also great potential. Finally the work on degradation of CFC in anaerobic environments will lead to good publications. It clearly shows the value of having a long-term field site available (in this case Rabis Creek) on which the general conditions are well known through previous work and the behaviour of a new tracer can be easily interpreted.

Recommendations

Continuation of the integrated approach is very much encouraged in future Danish projects but it might also be very useful in relation to a stronger focus on investigations in Greenland, as is recommended, in particular with intensification of mining activities. Performed microbial degradation studies have clearly shown the importance of bioavailability of organic pollutants such as PAHs. Determination of the bioavailable fraction is also an important issue in chemical analysis of organic as well as inorganic contaminants. Up-to-date analytical chemistry support of geochemistry, geomicrobiology and related areas requires modern analytical techniques, which are often very expensive. Apart from mainly arsenic and nitrate, inorganic pollutants seem to be a less prioritized area, although affiliation of a new scientist may change this view. Strengthening of the inorganic chemistry might also include 'new' trace elements such as rare earth elements (REEs) and other elements normally not addressed in environmental investigations in Denmark but which seem to attract consideration outside Denmark. Many soils, especially urban soils, are so polluted with organic and inorganic compounds that human health and ecosystem functioning are threatened. Remediation of such soils is an important and great challenge, especially when it comes to methodologies that are environmentally safe. Apart from being very much needed in Denmark, such methodologies might also be requested in other countries suffering from soil pollution. However, steam ventilation and use of similar very technical methods used on soils/aquifers that are strongly polluted with volatile organic compounds or washing of heavy metal polluted soils deposited in landfills are considered to fall outside GEUS' commitments. Accordingly it can be recommended to address the following issues:

- Continuation of the integrated approach in future projects in Denmark, Greenland and elsewhere.
- Constant focus on international publication in peer-reviewed journals and allocation of the time necessary for writing the papers.
- More focus of importance of bioavailability rather than total content of pollutants.
- Constant awareness of keeping analytical techniques updated by regular purchase of state-of-the-art instruments as well as keeping up the analytical chemical expertise.
- More consideration of inorganic pollutants, also including heavy metals and "new" elements. Heavy metal consideration will require purchase of expensive instrumentation, especially to address the bioavailability problem. This issue will become even more important with more focus on activities in Greenland.
- Development of environmentally-friendly methodologies for in-situ remediation of soils contaminated with organic and inorganic pollutants.

2.4 Subsurface Characterization and Conceptualization

Activities

Activities in subsurface characterization and conceptualization were summarized by Klaus Hinsby following an overview of the history of activities 2.4 to 2.6 by Heidi Christiansen Barlebo.

The subsurface characterization and conceptualization group has focused mainly on regional-scale integration of geologic information into hydrologic models, a new classification framework for groundwater and surface water interaction including an ecological context, pesticide and nutrient transport including groundwater vulnerability analysis, application of environmental tracers, fractures and preferential flow tills and carbonates, and salinity and arsenic problems in Denmark and Vietnam. This group does not fall into a classical category such as modelling or geochemistry, but seems to function as a connector between disparate disciplines. For example, the MIOMOD project on regional characterization and modelling of deep Miocene aquifers is a success story in which complex, 3D hydrostratigraphy was characterized through the needed but (globally) seldom seen collaboration between hydrologists, petroleum scientists, geophysicists, and environmental tracer specialists. In other projects the group has advanced a comprehensive framework for conceptualizing different systems of interacting groundwater, surface water and riparian ecosystems; and they have overlain on that framework data on environmental tracers (CFCs and $^{3}H/^{3}He$), redox state and N and P concentrations to examine nutrient cycling in riparian hydroecosystems. The use of environmental tracers for estimating mean apparent groundwater age is a recurring theme of the group. In at least one case they are also cooperating with the modelling group for simulating both apparent mean groundwater age and environmental tracer concentrations with a transport model, thereby using knowledge of both the flow system and the environmental tracers to arrive at a stronger understanding of how the system functions. In addition to applying state-of-the-art environmental tracers, they are also researching some of the methods themselves. Examples are their work on CFC degradation and investigation of bomb-pulse ^{36}Cl transport and its utility for estimation of mean groundwater age. Another noteworthy example of the characterization and conceptualization work is research on fractures and preferential flow in tills and carbonates.

Observations

The characterization and conceptualization group brings to the table two important ingredients. Firstly, they bring powerful tools such as environmental tracers and borehole logging. Secondly, they exemplify within GEUS an ability or willingness to collaborate across disciplines. This collaboration extends well outside the Hydrology and Geochemistry Departments and into reservoir characterization and geophysics. The panel views this type of collaboration as particularly important, in light of the dire need to

produce more realistic or reliable transport analyses by incorporating geologic heterogeneity into the models. It is also important as a means of countering the tendency for scientists to sequester themselves within the administrative departments or divisions of any organization.

Although the integration of hydrology, geology and geophysics to produce better transport models is not new, doing it successfully or effectively is a still evolving area of research and development. GEUS certainly has to a degree the personnel and tools for this type of work to grow into an internationally recognized strength. That will require greater integration with the modelling group, particularly for modelling the environmental tracers.

The classical approach of using environmental tracers is to interpret the tracer data in the context of a very simple flow or transport model (e.g., piston solute transport or a simple mixing model) and then arrive at a so-called groundwater age. In reality, such "ages" can be highly biased (usually low) and merely represent a mean of a complex and broad (100's to 1000's of years) distribution of ages. Although the estimates of apparent mean ages can be important indicators of things like groundwater vulnerability, they have the potential to be even more powerful *if,* rather than fitting the data to simple models, one uses more complex, regional- or sub-regional-scale models to simulate migration of the tracers themselves. This requires not only closer integration with the modelling group, but also regional flow and transport models that have sufficient heterogeneity and spatial resolution to represent transport and fate of the tracers. Development of this research area would be consistent with this group's stated need of new researchers in inorganic geochemistry and the modelling group's stated need of new researchers in modelling of geologic heterogeneity at multiple scales. The combined use of environmental tracers and transport models is recognized by the group as a future research goal.

Additional items in the characterization and conceptualization group's future research vision are physical and chemical responses to climate change, groundwater and surface water interaction (physical and chemical) in an ecological context, reactive transport through double porosity media, and borehole logging. With the exception of the borehole logging, wherein we assume the group wants to acquire capabilities with additional logging tools, it is not entirely clear to the panel how the group sees itself fitting into these future research areas. It would be helpful, for example, for the group to identify more specific characterization/conceptualization research goals that would be needed to accomplish better models of hydrologic change related to climate change and groundwater/ surface water interaction. In general, one can foresee that if the group develops greater capabilities in both borehole logging and interpretation of environmental tracer data (through whole basin hydrologic models), they will substantially improve GEUS' ability to research groundwater and surface water interaction, climate change effects on hydrology and the like.

The group does appear to have a good network of national and international cooperation. The panel agrees that the characterization and conceptualization group could be

strengthened through the addition of research staff in inorganic geochemistry, especially if the staff includes additional expertise and research interest in environmental tracers (e.g., CFC, SF6, $^{3}H/^{3}He$ and emerging tracers). Currently there appears to be only one scientist with substantial emphasis on environmental tracers (Hinsby), and addition of at least one more would help provide needed critical mass.

This group needs and wants to collaborate more with the modelling group, but this is unlikely to happen to a substantial degree until the modelling group builds greater expertise in reactive transport modelling. The characterization group has occasionally bridged this problem through collaboration with groups at the university (e.g., Engesgaard). Such activities should continue, but because of the great importance of GEUS developing greater capabilities in analysis of long-term water quality change, the panel feels strongly that GEUS needs to add research staff in reactive transport modelling at multiple scales.

Another way for the characterization group to strengthen its research while producing better characterizations is through collaboration with inverse modellers. A very active area of research and development in the hydrologic community is the joint inversion of multiple data types, including the usual hydraulic data as well as environmental tracer and geophysical data, to produce better constrained flow and transport models.

Part of modern hydrogeologic characterization is surface geophysics (including cross-hole methods), but it appears this group's only geophysical capability is in borehole methods.

Scientific quality

Researchers within the characterization and conceptualization area are producing good to excellent research and publishing in some of the stronger hydrologic sciences journals such as Journal of Hydrology, Applied Geochemistry, Journal of Hydrogeology, and Vadose Zone Journal. Most of their publications are rich in field hydrologic data and many are strong in terms of integration of disciplines. Quality of the work could be improved by including more quantitative analysis (modelling) of the field data through greater collaboration with the modelling group and, ideally, future additions to the modelling group staff in the area of transport modelling.

Output of the group in terms of numbers of publications in international journals amounts to 20 during 2000-2007. Within this group there are 9 researchers who regard characterization and conceptualization as their sole, primary research area. Given this number of researchers, there would appear to be substantial potential for a greater rate of publication. It is possible that the substantial development time for field hydrologic studies to mature into the publication phase is partly responsible for the low publication to researcher ratio. Again, one way to strengthen the publication record in this area is to have greater collaboration with modellers. Often field data by themselves do not create enough critical mass for publication in international journals; however, by rounding out the research with quantitative analysis (modelling), often the work becomes more significant

and publishable. By the same token, modelling papers that are lacking in field data are not publishable, so the potential synergy is mutually beneficial.

Recommendations

The characterization and conceptualization group provides some of the essential tools for conducting modern hydrogeologic investigations (i.e., environmental tracers, borehole geophysical logging). In particular because of the significant potential of environmental tracers for elucidating groundwater vulnerability and for calibrating regional flow and transport models, GEUS should consider adding a research scientist in inorganic geochemistry with strong expertise in environmental tracers to complement Hinsby's expertise.

Subsurface characterization is by its nature an integrative endeavour. The group certainly understands this and has had success in integration. GEUS should nevertheless encourage or facilitate more advanced and more frequent quantitative analysis of the high quality field data produced by the characterization group. This can be accomplished by developing greater synergies between this group and the hydrologic modelling group. In particular, strengthening the modelling group through the addition of expertise on reactive transport would in turn strengthen the characterization group by providing a means for more fully using the environmental tracer data. Furthermore, modern integration of characterization data will increasingly be done in the context of inverse hydrologic modelling, wherein multiple data sets are used to jointly and quantitatively constrain the model. GEUS should consider adding this expertise to their characterization projects through research staff additions or through collaborations with outside scientists.

GEUS should try to facilitate greater incorporation of surface geophysics into its hydrologic characterizations either by addition of research staff or through greater crossover between the hydrology and geophysics departments.

2.5 Geological and hydrological modelling

Research activities:

The field was introduced by Jens Christian Refsgaard. The group's work spans the scales from plot to catchment and the country as a whole. The ambition of the group is to set standards for the modelling industry in Denmark and to be the "consultant of the consultants". Typically a project does not involve routine work but more generalizable aspects of modelling in Denmark. The subjects of modelling are dictated by the needs of the country, which involve the pollution of groundwater resources by agrochemicals, sustainability of a certain water quality, and the water balance under a changing climate.

The group has also a unique national task, which is the construction and continuous updating of a national groundwater model. This model gives a national overview over

groundwater hydrology, groundwater vulnerability and indicators for the ministry. The task is well placed at GEUS as it involves a type of work which cannot be done at a university. It requires long-term involvement, continuous updating, and the synthesis of GEUS's geological knowledge and data bases with hydrology.

The scientific aspects of the modelling group's work are various. The most important is the investigation into model uncertainty. While traditional models are deterministic, coming up with one result, a more enlightened approach admits that information on the subsurface is always incomplete and uncertain and wants to quantify the influence of this uncertainty on model results. Uncertainty relates to both model parameters and geological structure. Engineering practice is not yet really incorporating these ideas, which have been present in research for the last 20 years. The group therefore plays an important role in bridging the gap between academia and practice and finding ways of introducing methods for quantification of uncertainty into Danish engineering practice.

Another scientific task is upscaling, a process which allows to get from the typical point information to regionally continuous spatial data sets and large-scale effective parameter values. This would also include the characterization of the heterogeneity of aquifers.

A further important research activity is the installation – together with university research groups - of a hydrological observatory for testing modules of hydrological/ hydrogeological models. A motivation for this work is that the national water balance is inconsistent with a closure error of about 20%.

Three examples of the work were presented in more detail:

The first one was the national groundwater model. It uses the DHI software MIKE SHE/MIKE 11. It models groundwater flow on a 500 m grid with geological inputs available at a much finer resolution (100 m horizontal, 20-40 layers vertical). It uses the unique opportunity of geological knowledge and modelling knowledge being united under one roof in GEUS. The model will be used in the assessment of climate change impact. This is indeed one of the few applications for which a national model is appropriate. The model is correctly seen as a reference and not as a model for all purposes. It is a framework from which smaller regional or local models can draw realistic boundary conditions.

The second example was on the group's work in drawing up guidelines on good modelling practices. The work was triggered by an experiment in which 5 consultants were asked to map the vulnerability of an aquifer to nitrate pollution and came up with vastly varying results. The group worked out standards within a European project (HarmoniQuA), drawing up a modelling protocol. The principles stress especially two items, the stakeholder involvement and the accommodation of uncertainty. Also, an external peer review of models is postulated.

The third example weighed the geological uncertainty of models against the parameter uncertainty. It was shown that for an example the geological structural uncertainty was much larger than the parameter uncertainty.

The group is disseminating its results actively by courses, handbooks, consulting to the regional authorities and utilities, a planned new textbook on hydrogeology etc. The group was also involved in a big European effort under the name Harmoni-CA

Observations

The group is of importance and has impact in Denmark. It is probably the strongest groundwater flow modelling group in the country. It sets standards for groundwater modelling which have the potential to improve general practice. The group is well integrated into European research efforts.

The group fulfils its obligation of looking into the consequences of new EU directives and regulations and their impact on needs in modelling and monitoring.

The general tendency of the group is towards integration of models (vadose zone, saturated zone, flow and transport, even socioeconomics). No software development is undertaken. Several codes are available, mainly the codes from DHI and the USGS. This is probably a good strategy. Yet, only a group which still has the ability to write code will know what can go wrong in a calculation. Also, there may be a risk in basing the national modelling on just one single proprietary software.

While the quantification of uncertainty is stressed in the guidelines for others, the national groundwater model is a deterministic, one-solution, model. Geological as well as hydrologic uncertainty is not characterized yet. This is felt as an inconsistency in the work of the group and should be remedied in the future.

Very little modelling is done on transport including chemistry/ microbiology. The possible synergies with the chemistry group are consequently not fully used. All chemical findings can acquire more value added by interpretation within the given flow system. Not to do so is wasting a chance of getting more mileage out of the efforts of GEUS. The interesting field experiments of the chemistry group are interpreted and modelled by researchers from the university rather than the own modelling group. It seems that the modelling activities of the group are not quite in tune with the requirements of the chemistry department.

The group feels its weakness with respect to characterization of geological uncertainty. Here the synergy with the geology/quarternary geology departments could be stronger.

The work of the group is quite continuous. However, it is not seen how innovation by import of methods from the purely academic research will be ensured. Where are the new tools from airborne geophysics, in which Denmark is so strong? Where are the new tools from remote sensing, where Denmark has its excellent space center? And where are the new tools from geostatistics, which are necessary for the work on uncertainty?

Virtually every researcher in hydrology for the last 20 years has stressed the need for upscaling. Here this demand is reiterated. However, no concrete way is shown how this could be achieved in the future and especially up to the national scale model.

The plans for future activities are reasonable but basically "more of the same" except for one, the climate change impact on groundwater, which is a very promising new direction.

One would have wished to see a bit more how innovation is ensured and how possible future needs of the ministry might be anticipated and served.

Quality of research

The group is steadily publishing 3 to 6 ISI peer reviewed papers per year since 2000. This is less than the geomicrobiology group but more than the chemistry group. The group has been smaller but has now 13 researchers on a level of post doc and upward, including a department head. So the number of publications could in the future be larger. Papers are published in good journals and they are cited. The papers are often more of review type or of policy type than original and novel research. This seems okay, given the normative task of GEUS. They can be used directly by practitioners. Compared to publications of the academic institutes I would rate the publications of the modelling group a bit lower.

Recommendations

- Strengthen efforts to get heterogeneity mapping into the national groundwater model. In cooperation with other departments of GEUS, strong in characterization, the typology of heterogeneity in different aquifer environments could be mapped. Characteristic values of variability could be taken out of former projects. A map giving such characteristics would be innovative and useful. It would also create synergy within GEUS.
- Service to chemistry-microbiology groups. It is suggested to strengthen the cooperation of the modelling group with the chemistry group. While it is fine if data generated within GEUS are interpreted with models by outside groups, it might be helpful for internal coherence and development of GEUS to have also in-house interpretation capability, looking at chemical-microbiological data plus interpretation with models as an integrated product. The cohesion and ideas for a more effective utilization of internal synergies could be developed by retreats of the groups involved. In such an environment ideas for future strategy and developments could be born.
- Time and manpower should be devoted to innovation. While the group is fine for the time being, without an effort of importing new techniques the importance may decrease.

2.6 Water Resources Management

Research activities

The activities in this field were presented by Hans Jørgen Henriksen. The group is rather small and new and cannot really be compared with the others.

The activities include mainly the application of Bayesian belief networks to the management of environment and resources. The methods are not developed, but rather

applied using available software tools. Applications are in the participatory approach to assessment and management. The activities also include the definition of sustainable yield for Danish aquifer situations. The major project where all techniques are applied is the NeWater project within the 7th FP of the EU. In this project management ideas are formulated for a river basin in central Spain where agriculture and conservation of nature are in conflict. Three of the 4 current research projects were explained in more detail.

Observations

This activity is presently rather marginal. Yet, it is an activity with future potential. It is new and innovative. It covers a demand which has become more and more visible in recent years. It is also a way of turning a modelling effort into an interactive development process for a group of stakeholders. The formulation of indicators for sustainability is an important task which is still far from a final state.

Scientific quality

The activity is so new that only 2 ISI publications are available in 2007. The quality seems fine.

Recommendations

This activity should not be seen as a separate from modelling. It should be at the core of the modelling group. The modelling group cannot restrict itself to make guidelines on modelling. Modelling is only a tool and the modelling group should not separate itself from the water resources management which gives the whole modelling a sense. To decouple the tool from its sense-giving goal is counterproductive and makes modelling stale.

The activity should be welcome for the group. It may open a whole new way of model application as a tool for dialogue between different stakeholder groups.

While the psychological side is somewhat covered by the competence of the group leader, the socio-economics are far from covered. It should be considered to increase the competence of the group by a resource economist.

The modelling group is looking into uncertainty. This is fine. But what is finally needed is decision making under uncertainty. This is another reason to look for a goal for the modelling on a higher level than the mere technical level of characterization of uncertainty.

3. Overall Evaluation

3.1 Observations

The vivid presentation of the review meeting showed us that GEUS is a productive place where interesting scientific work is done. It extends services to the nation, which are of high value such as monitoring, the national groundwater model, early warning of emerging contaminant threats, and risk assessment.

GEUS proves by its publications record that is scientifically sharp and competitive. The present situation is characterized by a very positive development over the last 7 years. Yet, in the long run, there is room for improvement and some reason for concern.

The strength of the group lies in its interdisciplinary character. It combines disciplines such as geology, hydrology, analytical chemistry, microbiology, geophysics. It has Denmark as a huge groundwater laboratory in which all these disciplines can be used in combination in the context of a society that is entirely dependent on groundwater. But this strength does not always unfold.

While all departments and research groups are productive taken one by one, the synergies could be better. One reason is a culture in which people are used to doing their own work without looking at what is going on in the other departments. The matrix structure of projects bringing together the groups seems not to work well, although there are some rare examples where all groups were integrated into common work (e.g. KUPA project). This problem of accomplishing integration is practically universal among academic and research institutions. In general, organizations can address this problem by taking organizational or social measures to increase the likelihood of collaboration between disciplines. Perhaps more importantly, organizations can formulate research visions based on sufficiently important problems (both societally and scientifically) that scientists are self-motivated to unify toward common goals. Some ideas for 'vision' topics are included herein.

Work for Greenland is a small component of the work at present. It could be increased. With the growing interest in mining some anticipation of pollution problems could be of interest. The special situation in the arctic provides new opportunities for fresh science. The water movement under the glaciers, the melting process, microbiological degradation processes of organics etc. provide tasks for the hydrology department. The worldwide focus on future climate change scenarios frequently leads to speculation on the future fate of the Greenland ice sheet, which is largely a geologic and hydrologic question.

Ideas for future work and a long-term vision are not very clear. This is of course a consequence of the institute being ordered by its ministry what to do. Still, the institute should be proactive in defining important new tasks which eventually will shape the

agenda given by the ministry. Much of the future work announced in the presentation is business as usual. What the water group needs is a big overarching goal which can develop a pull and unifying effect. What is needed are flagship programs or goals behind which all researchers can unite. The research on climate change and its implications for Denmark's groundwater and streams – both with respect to water quantity and quality - could be such a theme. Another potential theme concerns the unknown future status of deep groundwater quality as the poor quality shallow water migrates downward during the coming decades.

The introduction of the geomicrobiology group some years ago was a good move. It has brought new vigour into the water programme and increased the scientific standards. It shows that GEUS is a modern geological survey. Other surveys in Europe have gone through the same development of decreasing some traditional tasks and taking on new ones. This process cannot stop with geomicrobiology. Some strategic additions might bump the modelling and characterization capabilities into world-class status. Further, it might be prudent to add strength in the area of socioeconomics.

A busy research organization which has to produce income may be in the danger of forgetting to prepare for the future. It should take care to reserve some time of its work for upgrading its methods and introducing innovation.

3.2 Scientific quality

The programme can be proud to have areas of high quality research. As such we identify the following:

- **Geomicrobiology.** With two excellent senior researchers and a great publication record this relatively new field is very visible to the outside.
- **Pesticide research.** GEUS has extensive and almost unique expertise in pesticides, concerning their measurement, their behaviour in the subsoil, transport, biological degradability, etc. In this area it has also shown the strength of combining the different disciplinary forces.
- **Soil pollution research.** The original work in the field on natural formation of chloroform and the relevance of availability of PAH for its toxic activity is excellent and had an impact on legislation.
- **Modelling:** The national groundwater model and its application for assessing long-term change on the basis of a well understood past, is of high scientific quality and relevance.
- **Chemistry:** With the ability to analyze new environmental tracers (CFC) in the group's own laboratory, the environmental tracing and age dating work has been enhanced considerably and the success shows in an increased number of high quality publications in this field.

3.3 Recommendations

Areas to be strengthened

The ideas and activities to upgrade groundwater modelling by assessing its uncertainty are very relevant. Engineering practice is not yet ready to accept this task. The data basis and the tools are not yet in place either.

Inorganic pollutants (e.g. As) and inorganic chemistry are of importance both in their own right and as the background on which the organic pollutants move. Both with respect to equipment and manpower this field should be strengthened, including the environmental tracer capabilities.

The need to more fully integrate subsurface characterization efforts, including use of environmental tracers, as well as the need to ultimately predict sustainability of deep groundwater quality demands reactive transport modelling expertise at the field and regional scales.

The characterization and modelling areas need advanced geologic modelling capabilities for representing physical and biochemical heterogeneity. Capabilities in the areas of quantitative geostatistical, stratigraphic and/or process modelling of heterogeneity are needed to help keep GEUS water resources programs current and prepared to pursue problems related to transport in groundwater and surface water.

The water management component with modelling as a participatory process, creating a decision-making framework for input by multiple stakeholders, is of considerable future potential and relevance. Building new strength in the socioeconomic aspects of water seems justified.

More research and characterization initiatives in Greenland would be appropriate and, because of the uniqueness and developing nature of Greenland, would likely provide fresh opportunities. One example might be integrating subsurface and surface hydrology into models concerning future changes to the Greenland icesheet. Others would include anthropogenic water quality problems as well as effects of current and future mining.

Recommendations for work in developing countries:

Before one can plan the international work its goals must be better defined. The strategy would look very different depending on whether one goes to Subsaharan Africa or to China. In any case, one can only export products that reflect strengths. We think a concentration on GEUS' counterparts in the developing world, meaning the geological surveys, would be advisable. On the one hand they could be a basis from which to do common project work, and on the other hand a strengthening of other survey's services by capacity building will enhance their contribution to the countries' development. A

successful geological survey such as GEUS certainly has the specific knowledge needed to upgrade those surveys in the developing world.

Two new researchers were hired to get CV's suitable for applying for money from DANIDA or similar to do work in developing countries.

When GEUS scientists were asked what the rational for this move was the answers were:

- to get further funding
- to fulfil a demand by the governing board
- to learn something which might be of interest for Denmark too

All these motivations seem inappropriate although we feel sympathy for the group which has to bring in money for their own survival. Yet, for an activity in developing country to make sense some more focusing and structure is required. Exports are feasible in areas where GEUS has expertise and needs in a developing country are congruent with that expertise (e.g. Pesticides, As, CFC age dating). A lot of work is done by Danish consultants in developing countries and they may come up with problems they cannot answer themselves and where they could request GEUS assistance.

It is an illusion to think that work in developing countries will lead to cutting edge results as the needs in water are often so basic that they can be solved without any further science. Other European geological surveys help in building up their counterpart surveys in developing countries. There is a large demand in hydrogeological exploration, application of new methods such as CFC age dating, remote sensing, geophysics etc. Working via a sister organization in a developing country might be a more satisfying way than to go into an arbitrary water supply or water pollution project. So while we think that an engagement of GEUS in the developing world is laudable for humanistic reasons, it should be focused and structured for synergy with present activities and not taken as a mere source for improving the economic situation of GEUS. Another reason for doing work in developing countries could be that such projects are very attractive for young scientists, they create enthusiasm and there is great potential for those projects to provide the needed glue for the water programme internally.

Other General Recommendations

- Strengthen capabilities for modelling of geologic heterogeneity with geostatistical, geologic process and/or other techniques.
- Strengthen capabilities in inorganic geochemistry, including environmental tracers.
- Greater integration across disciplines, with particular attention to integration of hydrology, geochemistry and geomicrobiology through the use of reactive transport modelling at multiple scales.
- Although there are many positive signs of integration, there is still much potential for improvement in this area. GEUS should create a strategy for increasing collaboration and integration among the disciplines. This could include organizational changes, initiation of more joint proposals, encouragement of joint proposals through use of internal matching funding, joint seminars, periodic retreats for brainstorming about

future research directions, among others. Integration is a universal problem in the sciences. Accordingly, this is a never-ending but worthwhile battle.

- As in most research institutes, there is evidence that GEUS is top-heavy with upper-level researchers but lean in mid-level researchers, i.e., those who do tasks typically too time-consuming or mundane for upper-level staff, but too involved and demanding of significant training to be handled by graduate students. The panel is aware of the disadvantages of having too many, mid-level, permanent staff. Nevertheless, GEUS's work obviously requires some optimal level of mid-level support staff, and it should deal with this issue.
- Keep the monitoring program strong and maintain as a top priority the collection of high-quality data on nationwide water quality.
- Keep the expertise on microbial degradation of pesticides.
- Expand the new research on spread and establishment of pathogens
- More focus of importance of bioavailability rather than total content of pollutants.
- Constant awareness of keeping analytical techniques updated by regular purchase of state-of-the-art instruments as well as keeping up the analytical chemical expertise.
- More consideration of inorganic pollutants, also including heavy metals.

Comments on publications

The group provided a transparent documentation on the ISI publications, citations, and h-coefficients. The panel was asked for a standard on publication requirements for a senior scientist. We think that GEUS has made big step towards publishing in internationally renowned, peer reviewed journals. This is laudable. We see a publication density of about 1 publication of this type per year and senor scientist. This is sufficient in our view. The emphasis should not be on numbers alone. The emphasis should be on quality. Optimization of the publication record in the ISI should not be exaggerated. It would have the effect that single disciplinary work would be done exclusively, as it is easier to get to publications in single disciplinary work than in interdisciplinary project work. Such a move would not be in the interest of the water programme. Time for writing of publications should be allocated in research proposals.

Annex 1 – Terms of Reference

EVALUATION OF GEUS' RESEARCH ACTIVITIES

WITHIN THE PROGRAMME AREA

WATER RESOURCES

1. Terms of Reference - The Evaluation Panel

According to the Danish Statutory Order 281 of 22/03 2006 on Evaluation of Sector Research Institutions the GEUS Board has decided that the next research evaluation shall cover the water resource programme area.

Objectives

The panel shall undertake an evaluation of research and presentation activities within the Programme Area 'Water Resources', constituted by:

- **Results Contract 2000-2003:**
  - Groundwater monitoring and mapping
  - Hydrology, groundwater pollution and protection
  - Use of groundwater and hydropower
  - Contaminated soil
- R**esults Contract 2004-2007:**
  - Groundwater resources and hydrology
  - Groundwater pollution and protection

based on a thorough examination of selected publications and reports produced by the survey in addition to two visits to GEUS in Copenhagen.

Tasks

The tasks of the panel being an evaluation of the research activities of GEUS on the basis of

- Publications, reports and other relevant material produced over the period 2000-2007 (start of evaluation).
- Interviews with GEUS' management staff and scientists, and visits to laboratories and work facilities at GEUS.

In order to

- Identify areas of high quality research,
- Identify areas where the research of GEUS should be strengthened in order to meet GEUS vision and strategies,
- Identify areas which should be strengthened in order for GEUS to expand GEUS' ability to provide assistance to third world countries with the broad area of water resources,
- Provide comments and proposals as to strategic changes, amendments, and improvements to GEUS' work within the programme area, in order to improve GEUS' ability to fulfil its main mission with this programme area put into perspective of the surveys statutes and general mission.

Time table

The panel pays a visit to GEUS for evaluation (3-4 days):	September 13-16, 2007
Preparation of report:	September/October 2007
Visit to GEUS for presentation of findings (1 day):	Early November 2007
Reporting:	November 2007
Presentation of the findings for the GEUS board:	December 2007

Reporting

The evaluation panel is supposed to report their observations and conclusions in writing.

2. Confidentiality

The experts shall not disclose to any third party information in their capacity of being a member of the evaluation panel.

3. Expenses and compensation

GEUS shall reimburse all reasonable expenses related to the visits of the experts to the institution. Additionally GEUS shall compensate each expert for his time paying a lump sum of DKK 15,000.

Copenhagen, 19 March, 2007

Johnny Fredericia

Deputy Managing Director