ASSESSMENT OF RESEARCH QUALITY

Research Assessment Geosciences 2008–2014

Delft University of Technology

QANU March 2016

Research Assessment

Geosciences 2008-2014

Delft University of Technology

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Report on the Research Assessment of Geosciences at Delft University of Technology

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Foreword by the committee chair

This review has examined the research quality, relevance to society and viability of Geosciences research over the past seven years (2008-2014), at two departments and six research units of the faculty of Civil Engineering and Geosciences at Delft University of Technology.

The review committee consisted of six professors from renowned universities in Europe, the Kingdom of Saudi Arabia and the United States of America, and a chairman from the Netherlands. We have enjoyed working together, drawing on our different backgrounds and research traditions to examine the strengths and weaknesses of the Dutch university we visited. It has been an intellectually stimulating experience and as chair I greatly appreciate the commitment and high quality contributions of my fellow committee members.

We would like to thank the research leaders, the academic staff and the department secretaries at Delft University of Technology. They compiled detailed quantitative and narrative documentation in their self-evaluation report, and we recognise how time-consuming it is to create such reports. On the site visits, we found our meetings with staff and PhD candidates engaging, lively, revealing and thought-provoking, with much to discuss and explore.

Finally, we thank Kees-Jan van Klaveren, the secretary to the review. Kees-Jan helped us to overcome the initial apprehension which is common in newly formed teams that have to perform a complex task in a short period of time and provided guidance throughout the process, from the very beginning to the completion of the report.

The goals of the review are to contribute to the improvement of the quality of research and to provide accountability for the use of (public) money for the research organisation's board, funding bodies, the government and the European Union, as well as for industry and society at large. We hope that our comments on each research unit as well as the more general comments will be useful, in our role both as quality reviewers and as 'critical colleagues', to aid further development and ensure a bright future for Geoscience research in Delft and for Earth Sciences research in the Netherlands in general.

Hessel Speelman
Chair of the committee

1. The review committee and the review procedures

Scope of the assessment
The committee was asked to perform an assessment of the research in Geosciences at Delft University of Technology (TU Delft). This assessment covers the research conducted in the period 2008-2014.

In accordance with the Standard Evaluation Protocol 2015-2021 for Research Assessment in the Netherlands (SEP), the committee's tasks were to assess the quality of six research units on the basis of the information provided by the institutes and interviews with management, the research leaders, staff members, PhD programme management and PhD students, and to advise on how it might be improved.

Composition of the committee
The Geosciences committee consisted of the following seven members.

- Dr. H. (Hessel) Speelman (chair), vice-chairman of the Waddenacademie KNAW, the Netherlands;
- Prof. L. (Louis) J. Durlofsky, Otto N. Miller Professor in the Department of Energy Resources Engineering at Stanford University, USA;
- Prof. A. (Andreas) Macke, Director of the Leibniz Institute for Tropospheric Research TROPOS in Leipzig and Professor for Atmospheric Physics at the University of Leipzig, Germany;
- Prof. A. (Alberto) Malinverno, Lamont Research Professor and Adjunct Professor at the Department of Earth and Environmental Sciences of Columbia University, USA;
- Prof. M. (Manuel) Pastor, Full Professor and Head of Department at the Department of Applied Mathematics of Universidad Politécnica de Madrid, Spain;
- Prof. G. (Gerard) T. Schuster**,** Professor of Earth Science and Engineering at the King Abdullah University of Science and Technology (KAUST) in Thuwal, Saudi Arabia and Adjunct Professor in Geology & Geophysics at the University of Utah, USA;
- Prof. M. (Michael) G. Sideris, Professor at the Department of Geomatics Engineering and Associate Dean (Engineering) at the Faculty of Graduate Studies of the University of Calgary, Canada.

Short curricula vitae of the committee members are included in Appendix 1.

Dr. K.J. (Kees-Jan) van Klaveren of Quality Assurance Netherlands Universities (QANU) was appointed secretary to the committee.

Independence
All members of the committee signed a statement of independence to safeguard that they would assess the quality of Geosciences and its research programme in an unbiased and independent way. Any existing personal or professional relationships between committee members and the programme under review were reported and discussed in the committee meeting. The committee concluded that there were no unacceptable relations or dependencies and that there was no specific risk in terms of bias or undue influence.

Data provided to the committee
The committee has received the self-evaluation report of the units under review, including all the information required by the Standard Evaluation Protocol (SEP), with appendices.

The committee also received the following documents:

- the Terms of Reference
- the SEP 2015-2021;
- Copies of the key publications per research unit;
- Copies of the key societal output per research unit.

Procedures followed by the committee
The committee proceeded according to the Standard Evaluation Protocol 2015-2021 (SEP). Before the start of the site visit, each research unit was assigned to two reviewers, who independently formulated a preliminary assessment. The first reviewer was chosen on the basis of his expertise in the domain of the unit; the second reviewer was chosen to provide a more general, complementary perspective.

The interviews took place on 28-29 October 2015 (see the schedule in Appendix 3) at Delft University of Technology. Preceding the interviews, the committee was briefed by QANU about research assessment according to SEP, and the committee discussed the preliminary assessments and decided upon a number of comments and questions. The committee also agreed upon procedural matters and aspects of the assessment.

After discussing the self-evaluation report, key publications and its preliminary findings, the committee conducted interviews with representatives of (1) the Faculty Board, (2) the department management, (3) the management of the research units, (4) a selection of academic staff working in the research units, (5) a selection of PhD candidates and (6) representatives of the Graduate School responsible for PhD training. The schedule for the site visit is included in Appendix 3. The first reviewers led the interviews, with the second reviewer and the other committee members having opportunities to ask questions.

After the interviews the committee discussed the assessments and comments. The final version was presented to the Faculty of Civil Engineering and Geosciences, for factual corrections and comments. The comments were discussed in the committee. The final report was printed after formal acceptance.

At the end of the site visit, the committee took some extended time to discuss the comments and scores of all the research units under review. The final assessments are based on the documentation provided by the research units, the key publications, and the interviews.

The texts for the committee report were finalised through email exchanges. The first reviewer was responsible for writing the draft assessment and for sending it to the second reviewer for amendment and/or approval. After all reviewers approved the assessments, the secretary compiled the report and returned it to the committee for a final approval. The approved version of the report was presented to the Faculty of Civil Engineering and Geosciences for factual corrections and comments.

The final report was sent to the University Board, and published on the website of Delft University of Technology and the QANU website.

2. General Remarks

Scope of the evaluation of research in Geosciences
This Geosciences review covers the research of six research units spread over two departments of the Faculty of Civil Engineering and Geosciences of Delft University of Technology. In this section of the report the Geosciences review committee addresses some of the common themes across the six units under review.

Earlier this year (2015) a review committee evaluated the research in Earth Sciences at Utrecht University, encompassing two research institutes (each consisting of two research programmes) and at Vrije Universiteit Amsterdam, encompassing one research institute (consisting of three research programmes). Its chair and one of its secretaries overlap with the committee involved in the present review at TU Delft. This overlap allowed for a more complete overview of current research in Earth Sciences at Dutch universities. The committee's chair has therefore taken the lead in drawing up the general remarks, putting the committee's findings in the broader context of Earth Sciences research in the Netherlands. The committee as a whole has read and commented upon a draft version of the General Remarks.

It must be noted that some institutes and universities remained out of scope of both committees. The Institute for Marine and Atmospheric Research, which covers important fields in Earth Science and is a component of the Faculty of Science of Utrecht University, is evaluated separately in the framework of the UU Faculty of Science. The University of Amsterdam, which hosts an Earth Science component in the Geo-Ecology theme of the Institute for Biodiversity and Ecosystem Dynamics, the University of Twente, which hosts the Faculty of Geo-Information Science and Earth Observation (' ITC'), and Wageningen University, which hosts Earth Science chair groups at the Department of Environmental Science, will organise the evaluation of their research in Earth Sciences as a component in more general research reviews.

The two Evaluations of Research in Earth Sciences/Geosciences carried out in 2015 cover the majority of research carried out at Dutch universities for the period 2007/2008-2013/2014. Yet, as the two committees could not obtain a full picture of the research in Earth Sciences at Dutch universities for the period 2007/2008-2013/2014, the Geoscience review committee has focused its general evaluation on the two departments and six research units of Delft University of Technology that were involved in this review.

In the paragraphs below, the committee will elaborate on the way it has used the Standard Evaluation Protocol, particularly on some of the limitations of the protocol. Furthermore, the committee aims to address some of the common themes across the two departments and six research units and raise some points for consideration and debate.

Gaining a clear picture of each department and research unit
Prior to the site visits, the committee received a self-evaluation report, publication lists and key publications of the departments and research units that participated in the review. These formed the starting point of the review and were forwarded to the members of the committee in time to be able to study them closely. The committee appreciates the considerable efforts invested in the writing of the self-evaluation report. Nevertheless, it obtained valuable insights through its discussions with staff and PhD candidates during the site visit. The committee noted that the self-evaluation report that closely followed the Standard Evaluation Protocol

proved to be a valuable point of reference for the review. It must be noted, however, that the units under review rather resembled the research programmes of SEP 2009-2015 than being 'units' as defined by SEP 2015-2021. Therefore, the units' options to develop and independently fund strategies of their own were rather limited. On the other hand, this made the units at Delft University of Technology more comparable to the research programmes at Vrije Universiteit Amsterdam and Utrecht University.

Given those restrictions, the committee has endeavoured to closely follow the Standard Evaluation Protocol instructions concerning research quality, relevance to society and viability and their respective sub-criteria.

Prior to the geoscience review the two departments (Geoscience & Engineering and Geoscience & Remote Sensing) decided to benchmark themselves against the Faculty of Engineering at Imperial College (London, UK), and the Department of Earth, Atmospheric and Planetary Sciences of the Massachusetts Institute of Technology (Cambridge, USA), respectively. The committee considers this a very worthwhile exercise. The benchmarks were also well documented.

Sliding panels in research funding
The SWOT-analyses of the research units reveal that in the current Dutch funding system, research programmes are becoming increasingly dependent on external funding. Regardless of the growing numbers of students, the amount of base funding provided by the government is declining. This decline has a number of consequences. First, there is added pressure to acquire external funding from national or European funding agencies and/or bring in contracts from industry. Although the research units have mostly been successful in their efforts, this practice does add to the considerable workload of staff members, who have to somehow combine their research work with project acquisition, heavy teaching loads, supervision of PhD candidates and time-consuming administrative duties. In the long run this multitude of duties may jeopardise research productivity and, more importantly, research quality.

Second, the self-evaluation report points out that a further decrease of direct university funding could compromise the research infrastructure itself, the continuity and quality of which are difficult to secure with 'soft money'. The committee notes that a situation in which the running of laboratory and computational facilities is solely dependent on project funding is a liability. It would therefore advise the Faculty of Civil Engineering and Geosciences to earmark solid funding for the maintenance of core facilities.

A third aspect related to the increasing dependency on external funding has to do with the specific criteria that are used by funding agencies and private companies in order to decide which research proposals are fundable and which are not. These criteria may in the long term influence the type of research that is carried out within the research units, with applied work possibly gaining prominence over (fundamental) research with longer time spans. Opportunities for 'blue skies research' or 'curiosity-driven science' could well become scarce, even though the long-term socio-economic importance of such research is beyond doubt.

Lastly, the committee is particularly worried about the lack of start-up funding available for newly hired staff. The fact that the departments do not have the means to provide new staff with competitive start-up packages puts the reviewed units at an international disadvantage. Having the ability to provide promising candidates with start-up funds could prove vital to recruitment efforts and therefore for maintaining research quality.

The extent to which the participating research units are, effectively, still dependent on direct funding, varies. This could signal that some research units have more successfully adapted to the new funding reality than others.

One way to increase the level of direct funding has been through involvement with faculty and/or university-transcending research priorities. The committee has noted that, during the review period, both departments under review committed firmly to 'profiling' their research around major themes with high societal relevance. The underlying idea was to create strong, interdisciplinary research entities that would be well prepared for the increasingly selective national and international competition for research funds. Typically, these new entities connect with the so-called *topsectoren,* interdisciplinary top priority areas for research as defined by the Dutch government, which attract an increasingly large part of the available governmental funds.

The committee notes that short lines of communication and regular and ad hoc meetings between senior research staff and faculty and university board members are quite important. This ensures mutual understanding and the possibility to assist each other in pursuing the goals of departments and research units on the one hand and the objectives of faculty and university on the other hand.

Societal relevance of the Earth Sciences
Generally speaking, the societal relevance of Earth Sciences (the self-evaluation report consistently uses the term Geosciences) research by nature is high. The Earth Sciences study the system Earth. This encompasses the atmosphere (weather and climate), the cryosphere (land and sea ice), the hydrosphere (the rivers and lakes, seas and oceans, and groundwater), the geosphere (the surface and subsurface of the solid Earth and the water and the volatiles deeper in the subsurface) and the interaction of these spheres with the biosphere (the interaction of living organisms with the abiotic environment).

The social and economic importance of the Earth Sciences concerns the natural means of existence (water, energy, raw materials), the terrestrial environment (including remediation of pollution), natural hazards (such as earthquakes, volcanic eruptions, extreme weather, floods and landslides), and terrestrial space (specifically near surface and underground space), and their changes over time.

The activities of man form a significant factor in the Earth system. Therefore, the Earth Sciences also concentrate on obtaining knowledge about the influence of human activities on the Earth system along with understanding the 'natural' Earth system. The urgency and importance of this and the development of knowledge to adapt to the changing Earth are evident.

It is quite difficult for a review committee of foreign colleagues to assess all aspects of societal relevance of departments and research units, and compare it robustly with the societal relevance of research executed elsewhere in the Netherlands and in other parts of Europe and the world. Nonetheless, the committee established that the research leaders, the academic staff as well as the PhD candidates with whom it had discussions, were all very aware of the societal (including economic) relevance of their research and were eager to apply – directly and/or indirectly – their knowledge and ideas. The committee is impressed with the variety of initiatives that were employed by members of the research staff in this respect. All units have

also done remarkably well in their collaborations with industry through consortia, shared appointments and in obtaining research funding by partners from industry.

However, compared to the scientific part of the mission of the departments and research units, there seems to be much less coordination of, and reward for, the work that staff members do in the broader societal domain. While many staff members are indeed enthusiastically and successfully disseminating their research results (e.g. developing teaching material for high schools, obtaining visibility through media appearances), the initiative for such activities seems to be left primarily to the individual researcher. The committee suggests that the departments and units undertake more structural efforts in developing and monitoring strategy plans, in order to ensure that there is a more systematic and rational approach to the demonstration and realisation of public outreach, and that narrative as well as quantitative data are supplied. The committee notes that the revised Standard Evaluation Protocol that was introduced in 2015 puts more emphasis on these matters.

PhD training and supervision
The committee enjoyed meeting and talking with the PhD candidates in all the research units. They communicated high satisfaction with their roles and work in research teams and identified strongly with their respective groups.

The committee notes that Dutch universities host several types of PhD candidates. Most prominent are so-called 'standard' candidates, who are employed by the university and are financed either through first, second or third stream funding. Within the field of Geosciences at TU Delft, employment for a period of four years is the norm; PhD positions are increasingly paid for by NWO and industry, no longer by the university itself. The committee notes that their position as full employees of a university provides these 'standard' PhD students with a stable base and socialises them into the expectations and standards of academic employment. A second category of PhD students, which is as yet small, but steadily increasing, consists of 'contract' PhD candidates (*buitenpromovendi*). These are either part-time candidates who combine their PhD project with employment outside of the university or students with a scholarship from a funding body or (foreign) government.

The committee notes that agreements on supervision and training of PhD candidates are commonly formalised in an 'Education and Development' plan. Supervision is in the hands of a full professor ('promotor'), and often a daily supervisor is in charge of the quotidian supervision of the candidate. PhD candidates are expected to complete a training programme consisting of both 'skills'-courses offered at the level of the Graduate School of Delft University of Technology and of (domain-)specific courses offered either at a national research school or the Faculty itself. Training programmes with mandatory course credits (ranging up to as much as 45 Graduate School credits or 540 hours) have been formalised with the introduction of the Graduate School in 2012. Until then, the training that PhD candidates of TU Delft received consisted of CTG (Centre for Technical Geoscience) courses and otherwise could be qualified as 'training by research'. Junior researchers master the academic *metier* by being part of their supervisor's lab.

Until recently, the research in the Earth Sciences at the Dutch universities was organised in a system of well-established research schools. These were the CTG, VMSG (Veningh Meinesz Research School for Geodynamics), and NSG (Netherlands Research School for Sedimentary Geology). Components of these schools formed ISES (Netherlands Research Centre for Integrated Solid Earth Sciences), one of only six top research schools in the Netherlands. The research schools ICG (Centre for Geo-Ecological Research) and SENSE (Socio-Economic

and Natural Sciences of the Environment), and the entities Boussinesq Centre for Hydrology and the Darwin Centre for Biogeosciences were also connected to this system. The research schools connected all six universities in the Netherlands with limited (University of Amsterdam) to very extensive (Utrecht University) research in the Earth Sciences. Practically all PhD candidates in Earth Sciences were embedded in this system. CTG (Centre for Technical Geoscience, of TU Delft and UU) was the research school for all geoscience research at the TU Delft.

It appears that this scheme for cooperation in Earth Sciences research and training of PhD candidates of the joint Netherlands universities is disassembling gradually to be (partly) replaced by new graduate schools for each individual university. The review committee urges that the positive aspects of the old system (e.g. easy interaction of PhD candidates of different universities, joint scientific and educational activities, access to international scientific networks as well as to public and private stakeholders) are sustained in the newly evolving system. More specific findings regarding the Geo-cluster's PhD programme will be addressed in chapter 3.

Assessment of the Research Units

3. The Geo-Cluster: General themes

In January 2013, a Geo-Cluster was created within the Faculty of Civil Engineering and Geosciences (CEG) of Delft University of Technology (TU Delft). This cluster consists of two Departments: (1) the Department of Geoscience & Engineering (GSE) and (2) the Department of Geoscience and Remote Sensing (GRS). The six research units that participated in this review are spread across the Departments in the following way:

Department of Geoscience & Engineering

- Geology
- Geophysics
- Geo-Engineering
- Geo-Resources

Department of Geoscience and Remote Sensing (established in January 2013)

- Geodesy
- Atmosphere

The formation of the Geo-Cluster is said to offer new opportunities for cooperation between the two Geo-Departments and the underlying research units. In the self-evaluation report, the order of the units did not strictly follow their division over the two departments. In order to avoid any confusions, this report follows the order in which the units were presented by Delft. The committee notes however that this sequence does not resemble the current situation. First, the connections of the units within each of the departments are stronger and more rooted than those across departments. Second, rather than the six units specified by Delft, the committee is inclined to identify the two departments or even the Geo-Cluster as a whole as research units in the sense that they are equipped to pursue a strategy of their own in terms of size and resources. During the site visit, the committee learned that the Faculty of Civil Engineering and Geosciences will discuss and implement a new Strategic Plan.

It is difficult to assess the strategy that units have in place in order to achieve their goals in the years ahead, or the relation of each unit's strategy to the faculty-broad Strategic Plan document in development. It is recommended that each unit with enough mandate and resources to pursue a strategy of its own develops one as soon as possible for the next 5 to 10 years. There is little doubt that the units are indeed capable of meeting their targets in research and societal relevance, but without a Strategic Plan they will have to rely on the willingness and (most likely, uncoordinated) efforts of individual faculty members.

The review period comprises the years 2008-2014 for GSE and 2007-2014 for GRS. This chapter of the report discusses the overarching aspects that are the same for all research units, most notably the PhD programme and research integrity policy. The committee has identified another two general themes: the lack of female faculty and the transition in research strategy towards the American model of Primary Investigators (the 'PI model').

PhD programme

In January 2012, TU Delft established a university-wide Graduate School that is officially responsible for the supervision and training of all PhD candidates, both salaried employees of the university and those on a (foreign) scholarship.

The Graduate School plays an important role in the monitoring of the progress made by the candidate. At the start of a PhD project, a personal 'Educational and Development Plan' is drawn up, followed by a Go/NoGo assessment after one year. Thereafter, progress is monitored during yearly appraisal meetings. The university-wide Code of Good Practice aims to offer a practical guideline to supervision practices, both to supervisors and doctoral candidates. Group mentoring (in quarterly cohorts) is organised by the Faculty Graduate School. At the request of a PhD candidate, personal meetings can also be arranged.

Over the course of the project, all PhD candidates are required to complete a tailored training programme consisting of discipline-related skills, general scientific research skills and personal development (transferable skills). The university-wide Graduate School offers courses in the latter category, while the Faculty Graduate School of CEG is responsible for the first two categories. Discipline-related courses are often organised by research schools and the GSE Department is coordinator of the interuniversity (TU Delft and UU) research school Centre for Technical Geoscience (CTG). This school offers a large variety of introductory and advanced courses in the field of geoscience to PhD candidates of the two Delft geo-departments and of Utrecht University. PhD candidates are expected to learn general scientific research skills by the 'learning-on-the-job' principle.

TU Delft's HR department has developed guidelines to support a successful recruitment and monitoring process and therefore to help reduce dropout rates and improve lead times. The two Geo-departments aim for a mix of PhD students educated in its own MSc programmes and students from other (international) universities, who currently make up around two-thirds of the PhD student population. Recruitment is therefore both international, making use of the staff members' network, and local, by giving attention to students graduating from TU Delft MSc programmes like Applied Earth Sciences and Civil Engineering.

As part of their appointment, 'standard' PhD candidates have teaching obligations. They are also involved in the supervision of BSc and MSc students during their graduation phase.

PhD theses ideally include two to four international peer-reviewed journal publications. The average graduation rates for both departments are largely comparable with TU Delft and Dutch averages. Finishing within four years is – as yet – very rare, below ten per cent. The time required for a student to complete a PhD in any of the six research units is of concern to the committee. Apart from the low graduation rates within four years, only about half of the PhD students finish within six years. Since funding is only provided for four years, after that time students typically leave to find employment, and then work only part-time on their research.

The research units expect that the recent creation of the Graduate School will help to improve lead times. The committee was pleased to learn that the two departments have, over the review period, made serious efforts to substantially improve completion times. It is too early to comment on actual results, but the committee believes it is important to facilitate and incentivize PhD completion within a four-year time frame. This might be accomplished by

making earlier Go/NoGo decisions, requiring the development of clear research plans, and/or considering PhD student graduation statistics in faculty assessments.

Research integrity

As of October 2012, the aspirations and responsibilities of TU Delfts students and staff regarding research integrity and ethics are laid down in a university wide 'Code of Ethics'. The self-evaluation report describes this Code of Ethics as a living document. The university aims to facilitate open discussion about the subject, e.g. during faculty meetings, dilemma sessions, and courses for new employees and PhD candidates. As of March 2013, all letters of appointment refer to the Code of Ethics and new employees of the Geo-Cluster are made aware of the Code during an introduction meeting.

In order to advise and support students and staff on possible integrity and ethics dilemmas, TU Delft has developed a 'Roadmap for Matters of Integrity', and appointed a formal university committee and confidential advisers at the Faculty level. All PhD theses are checked for plagiarism before they can be defended.

In 2015, the Geo-Cluster started a pilot with regard to data management that is, according to the self-evaluation report, leading within TU Delft. The underlying principle is that data that are essential to prove the integrity and ownership of research results should be retained in a durable and appropriately referenced form for at least five years from the last publication. The procedure concerns various data types, i.e. measured, collected and/or numerical computed data, as well as source code. Its implementation is carried out in close cooperation with the TU Delft Library, which takes part in the '3TU Datacentrum'. Whenever possible, the data are uploaded in the Repository of the 3TU Datacentrum, which ensures unrestricted access for the general public and the long-term accessibility and safety of data.

The committee holds the view that awareness of and commitment to research integrity should start at the earliest stages of any academic career: in class. The committee was pleased to learn during the site visit that discussing the ethics of geoscientific research is indeed common practice within the Faculty of Civil Engineering and Geosciences. Course manuals of master courses like 'Climate change: science and ethics', the 'Journal Club on climate change and geoscience' and 'Petroleum Engineering & Reservoir Geology' clearly show that students are made aware of ethical themes regarding the research field and actively train in distinguishing myths from fact and in arguing their own position.

More generally, the committee concludes that TU Delft and the Geo-Cluster have adequate procedures in place to safeguard and maintain research integrity. Through its discussions with representatives of the different units, it did not learn of any recent incident that should call for further measures. This being said, within the context of this assessment it had limited time available to examine or discuss integrity procedures at length.

Principal Investigators and the PI-model

In the PI model, which is used at most research-focused US universities, younger faculty are encouraged to establish their own research areas, which may be quite distinct from those of senior professors within the unit/department. Young faculty are expected to demonstrate the ability to fund their research, and to generate high-quality results, within about five or six years of their initial hiring. Under this approach, hiring decisions are based on expected research excellence rather than on precise alignment with a specific research area. Although it is the intent of some of the units to shift towards the PI model, the committee did not feel that sufficient resources are provided to enable young faculty to thrive as they develop their

own research areas. Generating funding appears to be a significant challenge, with proposal success rates of below 20 per cent, according to the young faculty in Geo-Resources and other units. In US universities, it is common to award startup funds that might cover the expenses of two PhD students and/or post-docs for a period of 2-3 years. Such funding, or something similar, is important to facilitate success in the PI system, as it allows young faculty to quickly have PhD students working in the areas of their choice. The committee recommends the units to consider introducing this, or a similar funding mechanism, as they transition to the PI system.

Female Faculty

The lack of female faculty members in all units has drawn the attention of the committee. It believes that more effort should be placed on female hires. One approach for this, which is used at some universities in the United States and is compatible with the PI system, is to expand the definition of 'research fit', while not compromising on quality. This would mean potentially hiring someone whose research interests are slightly outside the unit's mainstream, but who nonetheless could still fit within the unit. It is worth noting that at some American universities, university-level funding is made available to hire female faculty who fall into this category; i.e., top-tier scientists/engineers, but not a precise fit with existing departmental research activities. Alternatively, the units might consider taking full advantage of existing programs for recruiting female faculty, such as the Delft Technology Fellowship. The committee was pleased to learn that TU Delft institutional funds have been made available in order to support efforts to hire senior female researchers.

4. Geology

4.1. Description of the research unit

4.1.1. Mission, strategy and targets

The Geology unit is part of the Department of Geoscience & Engineering. Its mission is to develop knowledge and tools to quantify and predict the multi-scale architecture, the physical properties of sedimentary bodies in the subsurface – including their uncertainties – and their flow and geomechanical behaviour. Linking curiosity-driven research to application-driven engineering methods is described in the self-evaluation report as 'a core value of the unit' and as key to solving future challenges with regard to the increasing pressure that societies are exerting on their subsurface.

To pursue its ambition of combining fundamental Geology and Engineering research, the research unit stimulates cooperation with other units such as Geophysics and Geo-Resources. Joint projects reportedly result in a strong embedding within the Department. The combined mission is also said to promote the societal relevance of the unit, which has established a number of public-private collaborations that have had an impact on industry and society at large.

A key factor in the overall strategy of the unit is a combination of observation, mostly of recent and outcropping fossil sediments, and process-based modelling. The two scientific focus points of the unit are siliciclastic systems and fractured reservoirs. Scientific, HR and funding strategies of the unit that are described in the self-evaluation report are all driven by the choice to develop both sedimentological and structural approaches. Strategies for the future mostly appear to be a continuation of existing policies.

4.1.2. Resources

Over the reporting period, staff numbers have fluctuated around an average of 18.5 fte, with a peak of 22.3 in 2011 and a subsequent low point of 15.7 in 2012. Fluctuations mostly have to do with varying numbers of non-tenured staff (post-doc researchers and PhD candidates). However, there is also a trend of decreasing tenured fte's (from 6.5 in 2008 to 4.9 in 2014), and the self-evaluation report indicates that a number of vacancies remain to be filled. As a consequence, the teaching load of staff members is described as high. The relatively limited size of the unit as compared to other Geology units outside TU Delft and the limited number of non-tenured staff as compared to the other units in the review are mentioned as weaknesses in the unit's SWOT analysis.

The unit reportedly aims for a healthy balance between first stream ('direct funding'), second stream ('national governmental funding', mostly obtained from NWO, STW and earlier the top research school ISES) and third stream ('industry/ EU funding') funding. The figures show that direct funding amounts to roughly one-third of the annual budget, while external funding streams are more variable. The total budget has gone down over the review period, from €2,114K in 2008 to a low point of €1,401K in 2013 and a slight recovery to €1,566K in 2014. In most years a substantial overspend of the budget seems to have taken place.

4.2. Qualitative and quantitative assessment of the research unit

4.2.1. Research quality

The research of the Geology unit concentrates on the formation and geometry of geological heterogeneities, which control the three-dimensional distribution of subsurface properties and the flow of water and hydrocarbon fluids. Research projects are based on a sound strategy of combining observation and modeling to quantify and predict properties of subsurface sedimentary bodies.

The Geology unit follows two general research directions: one in sedimentology, with an emphasis on siliciclastic shallow- and deep-water deposition systems, and another in structural geology, focused on fracture networks. According to the committee, these two directions are well chosen to address the goal of interfacing between geology and engineering problems. While this is a practical, applied goal, the activities of the Geology unit maintain a healthy balance between curiosity-driven research and application-driven developments.

A significant component of the Geology unit research agenda is the development of the Delft3D software and associated modules. Delft3D models the formation of three-dimensional sedimentary bodies in river deltas as a function of a number of input variables, such as sediment supply, river discharge and sea level changes. This is a significant effort that aims to understand how sediment is distributed in these complex systems starting from fundamental physical principles. In these environments, subsurface flow properties are strongly controlled by the spatial distribution and the connectivity of high-permeability sand-rich units. The committee recognizes the importance of this research to advance the general understanding of the formation of these sedimentary bodies.

The study of fractured reservoirs is another key component of research within the Geology unit. This research is driven by the quantification of fracture networks from the small scale of rock outcrops to that of kilometer-wide objects, resulting in a unique database that includes different lithologies and tectonic settings. The goal of this effort is to predict fracture apertures, a critical parameter that exerts a fundamental control on fluid flow. Fluid flow through fractured reservoirs is an open research problem, and advances are highly relevant for many applications.

The unit has also started work in geologically constrained seismic inversion. The committee agrees that this is a promising and important area of research, because geological information can provide significant prior information to reduce non-uniqueness in the inversion of seismic data. Finally, participation in the ICDP CONOSC project, which aims to obtain a complete Cenozoic stratigraphic record in the Dutch subsurface, will provide an exciting data set.

In summary, the research of the Geology unit is based on a sound strategy. Present faculty members are highly distinguished, have a strong international academic reputation, and maintain a robust publication record. However, the relatively small size of this unit and the high turnover experienced during the review period work against achieving worldwide excellence. Stabilizing and increasing the size of this unit would help to reach its ambitious vision (see 'Viability' below).

4.2.2. Relevance to society

The stated mission of the Geology unit is to understand and quantify the geometry and physical properties of subsurface sedimentary bodies, including uncertainties. This goal is key to predict how fluids flow in the subsurface and address hydrocarbon and groundwater production, geothermal energy generation, and underground CO2 storage. The results of geological investigations provide a unique reality check in building 3D models of the Earth subsurface. Incorporating geological knowledge is necessary to ensure results that match what is known about the overall properties of geological objects. The vision of this unit is right on target and is of the highest level of relevance to practical societal needs.

Guided by this well-targeted vision, the Geology unit is very active in addressing issues of broad societal relevance. This is demonstrated by many successful external collaborations, particularly with the petroleum industry. For example, as presented during the review meeting, Statoil is in the process of including Delft3D modeling software in their workflow. The plan to develop Delft3D into an open-source web-based tool to model reservoirs formed in the shallow marine environment will make this kind of modeling widely available for a variety of applications. Other examples of highly relevant activities are collaborations with the Geo-Resources unit to include information on fracture networks in modeling subsurface fluid flow and with the Geophysics unit on including geological constraints in seismic inversion. Geologically constrained seismic inversion has been sponsored by the Delphi consortium and offers a great opportunity for future funding to develop practical applications. Finally, the Geology unit personnel engaged in several excellent outreach activities.

4.2.3. Viability

The Geology unit has had a distinguished history of collaborations with the petroleum industry. Many PhD projects have been funded by industry, and the unit had a productive history of joint academic-industry appointments. The unit has also been very successful in securing funding from the Dutch science foundation organizations. The plan for the next five years, as stated in the self-evaluation report, is to essentially continue with the current funding model raising funds from industry and from the national government, with the addition of the CONOSC drilling project. The planned strategy follows the past success of the unit and is well grounded.

The Geology unit is currently the smallest unit in the Geo-Cluster (20.3 fte total including PhD students in 2014), and in the last few years there has been a decreasing trend in the number of tenured staff members (from 6.5 fte in 2008 to 4.9 in 2014). During the review period three staff members have transferred out of the unit, and two more have retired very recently or will do so in the near future (in 2015 and 2017). Counteracting these departures, in 2015 the appointment of the unit leader has been increased to 1 fte and a position has been offered to a new faculty member.

The Geology unit has done an admirable job in focusing their activities so that quality results can be achieved given the relatively small unit size. The committee shares, however, the concern expressed in the self-evaluation report that the possibility that future vacancies will not be replaced is a threat to the long-term viability of this unit. The risk is that the Geology unit in the future may not have the critical mass to make progress toward the ambitious and highly relevant goal of producing applications that connect Earth sciences with engineering. Compounding this risk, a substantial part of the external funding comes from the petroleum industry and may decrease in the next few years if the oil price remains as low as it is today.

The committee's recommendation to keep this unit productive and viable in the future is at least to make sure that the number of scientific staff members does not decrease due to departures or retirement. Even better, a modest increase in the size of the scientific staff would help to decrease the teaching load and free time to perform research and obtain additional external funding.

4.3. Scores

Quality	*Very good*
Societal Relevance	*Excellent*
Viability	*Very good*

5. Geophysics

5.1. The strategy and targets of the research unit

5.1.1. Mission, strategy and targets

The research unit Geophysics is part of the Department of Geoscience and Engineering. Its mission is 'to execute fundamental geophysical – seismic & EM – and petrophysical research, directed towards developing cutting-edge acquisition, imaging, characterisation and monitoring methodologies for resource exploration, and environmental and engineering applications.' Research in the unit involves three main themes, inspired by current societal needs: Exploration Geophysics, Environmental and Engineering Geophysics, and Petrophysics. The self-evaluation report accentuates the importance of cooperation with other units in the Geo-cluster for a proper understanding of multi-scale subsurface processes.

In its strategy for the 2015-2020 period, the unit's research will continue to centre around the above-mentioned themes. In addition, more emphasis will be on issues relating to the effects of production of hydrocarbons in the subsurface and the development of sustainable geo-resources. This requires continuing research efforts within the unit, as well as further cooperation with other units in the Geo-Cluster and external partners. The scientific, HR and funding strategies mirror these ambitions. They focus on further development of geophysical and petrophysical methodologies, academic visibility of the research unit and strengthening and continuation of cooperation with external partners and scientists from various disciplines. Among others, the unit intends to increase cooperation with the Delphi Consortium, a Delft-based industrial consortium established in 1983 with the mission to develop breakthroughs in the geo-imaging technology for the geo-energy industry. The Delphi research program is sponsored by more than 30 international companies, including all major national and international oil companies.

5.1.2. Resources

During the review period, staff numbers first went down from 34.7 fte in 2008 to 29.8 in 2012, after which they rose again to 32.0 fte in 2014. The decrease until 2012 can be explained by the fact that three senior staff members continued their careers elsewhere. As a result, the absolute number of PhD students dropped as well, although the ratio of PhD students per staff member remained relatively constant at 2.5. After a hire of a tenure-track assistant professor in December 2014, the situation in 2015 in terms of research staff is comparable to that in 2008. The unit's ambition is to further increase the number of PhD students (24-30 fte, from 16.8 in 2014) and post-docs (8-12 fte, from 8.5 in 2014).

The unit's finances by and large depend on second (national governmental) and third (industry/EU) stream funding. National governmental funding has shown some fluctuations (down to €358K in 2014), but has averaged in most years at about €1.0M. The unit reportedly expects to again reach this amount in 2015; in the long term, it expects a further increase, as it has been selected as one of three groups in the Netherlands that will be at the core of a NWO/FOM funded National Knowledge Centre for the Deep Subsurface, with a budget of €30.0M for a period of five years. Other options to attract funding include an application for a NWO Gravitation grant and applications for individual Veni-Vidi-Vici grants. Third stream funding has been stable at an average of €1.7M per year.

5.2. Qualitative and quantitative assessment

5.2.1. Research quality

Based on its publication records and the academic reputation of its tenured staff, the committee concludes that the Geophysics unit is the unquestioned world-leader in the development of theoretical interferometric imaging methods in both seismic and EM research. The unit complements this theoretical effort with the development of geophysical instrumentation and field collection expertise. This dual-edged sword is a potent opportunity to educate students in both theory and practical applications of geophysics. The petrophysics component of the unit provides key input to translate geophysical results into physical properties and processes of interest. The reputation of this unit will be significantly enhanced if it can successfully integrate the expertise of the Delphi Consortium into the unit. Integration is no easy task and the utmost effort should be used to make this a synergistic melding of the Geophysics unit with Delft researchers.

Compared to the other units, the Geophysics group has the highest annual paper publications at 5.43 per tenured fte and conference publications at 7.24 per tenured fte. The high H-index for a senior faculty also attests to the world-leading calibre of the unit's reputation. Two of the senior faculty have been editors of the world's leading journal in applied geophysics. The academic and research reputation of the unit has been recognized internationally, and its faculty members have received many prestigious awards and hold leadership positions at SEG.

5.2.2. Relevance to society

The Geophyiscs unit engages in activities of tremendous societal relevance, such as sustainability through geothermal energy, imaging structures and subsurface of active volcanoes, and developing and distributing modelling software used around the globe. The relevance of the unit's research to the Netherlands is further attested by the fact that Shell, one of the premier oil companies in the world, makes strong efforts to collaborate with the Geophysics unit. This is evidenced by the presence of Shell's researchers as part-time faculty advisors. Those fruitful ties with industry will be further enhanced through close cooperation with the Delphi Consortium. Undoubtedly, the unit has succeeded in creating high societal impact, based on the relevance of its research and the commitment of its staff to initiate or participate in public outreach.

Less evident is how the unit works toward valorisation in a more economic sense, or which strategies would bring about public attention to research results. Although members of the unit have provided governmental bodies with research reports and recommendations, and acted in public debates on tv and in national newspapers, the activities do not seem to be actively coordinated and in fact depend on the personal interests and qualities of individual staff members. The committee holds the opinion that a more systematic approach would allow the unit to perform even better in convincing the general audience and the market place of the societal relevance of its research. Such an approach would include certain metrics to assess the unit's performance in this respect over time, as well as incentives for its research staff as recognition for their efforts to increase public outreach.

5.2.3. Viability

The Geophysics unit is right on trail to further strengthen its already excellent research quality. Apart from the expected benefits of further collaborations with the Delphi consortium, it has already secured a major source of funding through its participation in the Dutch National Knowledge Centre for the Deep Subsurface. The committee is confident that

the unit, also thanks to its strong leadership, in the coming years will be as financially sound as it has been during the period under review. Its faculty are recognized internationally for their research excellence, and place very high amongst the top universities offering geophysics programs internationally.

The committee strongly agrees with the SWOT analysis provided by the unit. It shares the unit's worries about further reduction of open funding opportunities. Collaborations with the Geology and Geo-Resources unit however have been strong and may be expected to again be fruitful over the coming period.

A concern is that a major part of the external funding of this unit comes from the petroleum industry. This funding source will be less reliable in the next few years if the oil price remains as low as it is today. In the long term, it is uncertain what the role of the petroleum industry will be as the world moves to energy sources that do not emit CO2.

5.3 Scores

Quality	*Excellent*
Societal Relevance	*Very good*
Viability	*Excellent*

6. Geodesy

6.1. The strategy and targets of the research unit

6.1.1. Mission, strategy and targets

The unit Geodesy is part of the Department of Geoscience & Remote Sensing, and deals with four main research themes: 1) Gravity; 2) Positioning, Navigation and Timing; 3) Geokinematics and 4) Remote Sensing. In 2013, the department and unit were included in the Faculty of Civil Engineering and Geoscience to encourage strategic cooperation within the Geo-Cluster. The mission of the unit Geodesy is to advance technology and knowledge for monitoring and modelling the Earth in space and time, and to develop associated applications in science and society using opportunities offered by new observational platforms and sensors.

Research in the unit Geodesy reportedly is strongly driven by urgent major societal challenges in Water, Climate, Safety, Infrastructure, Transport, and Energy. Solutions for those challenges often require a multidisciplinary approach. Therefore, the unit strives to increase the number of multi-disciplinary projects that address particular societal challenges and to enhance cooperation with colleagues in the Geo-Cluster and other, external partners.

6.1.2. Resources

In the period 2007-2014, staff numbers within the Geodesy unit have been rather stable. A low point of 44.3 fte was reached in 2009, when the Faculty of Aerospace Engineering proposed to terminate Delft's geodesy research. After the university's Executive Board decided to retain the Geodesy research groups and to transfer them to the Faculty of Civil Engineering and Geosciences by mid-2010, the research staff recovered and even reached a peak of 54.8 fte in 2013. The unit's personnel strategy for the coming period reportedly focuses on consolidation, and filling vacancies on geophysical geodesy, remote sensing of environment, and optical remote sensing technology. Rather than looking for perfect fits in terms of niche or seniority, the unit's strategy is to search primarily for candidates with an excellent research profile.

The unit's funding strategy according to the self-evaluation report reflects the research program, by aiming for a mixture of methodology-driven and application-inspired research. Funding for the latter category will be acquired through EU, Space agencies, STW, governmental organisations and industry. Funding for methodology-driven research will have to come from NWO programmes and personal grants. Over the review period, well over 45 per cent of research funding has consisted of direct university funding, averaging at €1.3M. In the coming period, the unit will investigate possibilities for funding of new GRS-oriented themes, whilst continuing its efforts to bring in NWO (personal) grants, STW grants, European and public-private funding.

6.2. Qualitative and quantitative assessment

6.2.1. Research quality

The Geodesy unit has set a clear mission, and has focused its future research strategy on issues of major societal impact, such as the monitoring of water and resources, climate change, land and infrastructure, safe navigation, and natural hazards, all areas of particular importance for the Netherlands. The expertise of the personnel in geodetic and remote

sensing observing systems, as well as the existing and planned multi-disciplinary projects and collaborations, will certainly enable the unit to achieve these goals. In fact tremendous progress has already been made and has been documented in high-quality theses and refereed publications in high-impact scientific journals, including Science and Nature. In addition, software and scientific models and products have been made available and used by many disciplines. The academic and research reputation of the unit has been recognized internationally, and its faculty members have received many prestigious awards and hold leadership positions in international scientific organization, such as, e.g., the International Association of Geodesy (IAG).

In terms of organization, funding and human resources, the unit has managed to survive and succeed in the midst of difficult times (internationally) for geodesy. However, it is evident that personnel turnover happens quite often and that the vacant positions are not filled as quickly as required. This is partly due to the reduction of the unit's budget from the university, which resulted in a reduction on faculty and staff positions. It is not clear from the documents provided if this also made the delivery of the academic programs more difficult but, in any case, it is recommended that the direct funding be kept at a healthy level that could guarantee the operational expenses of the unit for at least the next several years.

To their credit, the unit's research staff managed to increase the overall funds during the last few years by attracting funds from national government and EU and industry sources. Nevertheless, with these external funds becoming scarcer (e.g., from NWO), the long-term availability of internal funding should become a priority.

The publication/productivity strategy is very good as it focuses on quality rather than quantity. PhD training is also very good, although the unit should strive to increase the overall number of PhD students and take measures to decrease their time to graduation.

6.2.2. Relevance to society

It is quite clear that the research work of the Geodesy unit directly addresses challenges related to key societal topics, such as infrastructure, energy, climate, safe navigation, hazards, etc. Many such applications are documented in detail in the Self-Assessment Report 2008-2014, together with international educational activities and research collaborations, contributions to industry, government and space agencies, free dissemination of results via publications and software, advising governmental agencies and participating in public debates and information sessions. Therefore, there is no doubt about the high societal impact and relevance of the research work of this unit, or the participation of its staff in outreach activities.

What is not quite clear is whether or not the unit has a policy and a process in place on how to best promote research results and the wide expertise of its staff so that, on the one hand, it could enable and/or influence governmental policies (e.g., on monitoring and risk mitigation of environmental hazards) and, on the other hand, take its innovative research to the marketplace through the development of products and services.

So although through the efforts and the involvement of individuals the unit has increased its societal relevance, it may be able to do that at a much higher level – and at the same time increase its 'visibility' nationally and internationally – by developing and implementing an internal policy and procedures dealing with contributions to society as well as on research commercialization. This may also require collaboration with and advice from the university's research commercialization and public relations units. Some assessment metrics should also

be developed in order to measure the effectiveness of such a policy over time. In addition, it may be appropriate to develop a 'recognition or reward mechanism' for those with significant contributions to academia, government and industry in particular, and to society in general.

6.2.3. Viability

There is no question about the viability of the Geodesy unit. It is recognized internationally for its research excellence, and places very high amongst the top universities offering geodesy programs internationally. The unit has strong, yet flexible leadership, who has established strong links with leading national and international academic and governmental institutions, as well as industry, and has managed to keep the finances and the overall operations at a healthy level.

The SWOT analysis provided in the self-evaluation report has captured all the important strengths, weaknesses, opportunities and threats that the unit is facing. Particularly worrisome is the difficulty in attracting enough highly qualified doctoral students, and in supporting them to complete their studies in no more than 4 to 5 years. In addition the reduction in NWO budgets seems to create additional problems of research funding and increased administration load. The faculty turnover is certainly a problem but the unit's leadership, to its credit, sees this also as an opportunity to expand their expertise in areas they are not presently covering. One such area, for example, could be the area of Geospatial Information Systems and Big Data management and representation. With the unit's emphasis on Earth Observation research using data from geodetic and remote sensing satellite missions, such an area of expertise would complement very nicely the existing strengths of the unit.

A few issues have been identified regarding stability of staff, funding and expertise in the unit, but these are no more severe than what is occurring currently in similar institutions worldwide due to the increased mobility of individual faculty members, the availability of opportunities elsewhere, and the uncertainties in stable long-term funding of academic and research programs. Nevertheless, these issues should be carefully monitored, and proactive actions should be taken by the unit, as well as by the university, in order to mitigate such problems and to guarantee the smooth operation of the unit.

6.3 Scores

Quality	*Very good*
Societal Relevance	*Excellent*
Viability	*Excellent*

7. Geo-Engineering

7.1. The strategy and targets of the research unit

7.1.1. Mission, strategy and targets

The unit Geo-Engineering is part of the Department of Geoscience and Engineering, and aims to improve the fundamental understanding of materials and processes in the shallow subsurface, with a particular emphasis on providing engineering solutions for a delta environment. It strives to develop fundamental insights as well as innovative technologies needed to address current societal issues, thereby focusing on four interconnected themes: Soil Mechanics, Geo-environmental Engineering, Subsurface Engineering and Dykes and Embankments. Those in turn can be classified into two main areas: (i) Fundamental tools of research (Theme 1) and (ii) Application fields (Themes 2-4).

7.1.2. Resources

Over the reporting period, research staff numbers have grown significantly from 23.8 fte in 2008 to 35.7 fte in 2014, although the total number of tenured staff was lower in 2014 (8.5 fte) than in 2008 (9.1 fte). The self-evaluation report explains the rising numbers of temporary staff through its success in funding, whilst the tenured staff has had to deal with a number of retirements and transfers. The Geo-Engineering unit reportedly expects a more stable development in terms of staff numbers in the coming period. It intends to strengthen the new research themes by seeking a chair in Subsurface Engineering and increasing the number of staff at associate professor level.

The unit's funding strategy is based on its mission to execute fundamental geo-engineering research of societal relevance. During the review period, second and third stream funding combined have risen significantly, from € 698K in 2008 to 1.7M in 2014. Direct funding has decreased somewhat in absolute numbers (from € 983K in 2008 to € 886K in 2014), and significantly as percentage of total funding (from 58 per cent in 2008 to 34 per cent in 2014). In December 2014, two Top Sector Water grants were awarded, funding two post-docs and six PhD students in the coming review period. The strategy for the coming period is based on consolidating second and third stream funding through a number of programmes, industrial cooperations and personal grants.

7.2. Qualitative and quantitative assessment

7.2.1. Research quality

The mission of the unit is quite specific, focusing on engineering solutions for delta environments. This has produced a research strategy comprising the themes of soil mechanics and geo-environmental engineering, which were recently supplemented by the themes of Subsurface Engineering, and Dykes and Embankments. The latter are obvious choices and particularly important for safe construction and mitigation of risks from especially water/sea-related hazards in the Netherlands. Regarding Theme 1, the fundamental tools of research, the unit delivered the quality needed for the proposed application fields. The unit takes particular care of cultivating excellence in (i) Laboratory testing and data acquisition, (ii) Constitutive modelling, and (iii) Mathematical and Numerical modelling. All these tools are necessary for the applications it pursues. The unit values and promotes innovation. In this respect it is worth mentioning the liquefaction tank and the centrifuge machine, the constitutive modelling of soils of interest in the Netherlands, the stochastic finite element method that takes into account soil heterogeneity, and the material point model, which

complements the finite element models developed in the unit. The various areas of research work well together through regular collaboration and by generating synergies. The committee concludes that this is a main asset, because progress in theoretical aspects can lead to innovative solutions.

The unit's strategy is based on a proper selection of the targets, which include innovation and direct interest for the country. In order to achieve good results along the proposed lines, the unit has followed an interesting policy of human and material resources during the review period. Regarding human resources, the committee has found a good policy of hiring new staff at all levels, from PhD students to full professors. New staff are experts in laboratory testing, constitutive, mathematical and/or numerical modelling. Regarding material resources, the unit set two lines to follow: (i) maintaining, improving and updating the testing equipment, and (ii) hiring personnel able to design new tests and equipment. Both targets have been achieved.

As the long-term policy of funding research related to petroleum is being questioned by Administration, other units of the Geo-Cluster may suffer from it. However, Geo-Engineering, if it continues the policy of "keeping the country safe" regarding natural hazards, will be in a good position. Given that the unit attracts a high number of candidates for the posts it offers at all levels, an improvement regarding the lower level can be suggested; for example, attracting more students within double diploma schemes with other leading European universities. The average number of PhD students per scientific staff is very good, with an overall increasing trend. On the other hand, the ratio of post-docs to scientific staff is not particularly high. The Unit has already recognized this weakness and is seeking ways to increase this ratio. Such efforts should be supported by the University with direct funding, whenever possible.

According to the committee, cooperation with the other units needs to be reinforced, with results materialized in the form of scientific publications. Indeed, stronger collaboration with the Geo-Resources unit, especially on basic modelling tools such as mathematical, constitutive and numerical tools, would be both interesting and fruitful.

During the period under review, important changes were taking place: new staff brought in fresh ideas and improved the funding rates of the unit, laboratories were improved, and the unit changed its publication policy by shifting attention from conference papers to publications in peer-refereed journals. Indeed, the research unit conducts very good, internationally recognised research. According to the committee, the unit is very well positioned in the scientific environment, being part of international research networks such as ALERT Geomaterials, where the unit plays an important role.

Regarding the quality of the research done in this period, a major indicator is the quantity and originality of papers, together with the journals where they were published. These journals cover a wide audience: *Computers and Geotechnics, Geotechnique*, *Georisk*, *Vadose zone*, etc. The committee suggests however to consider including journals with an even higher impact factor. The topics include some interesting applications, such as geotextiles. The number of papers in refereed journals shows a tendency to continuously increase during the last years, up to a number of 35 in 2014 – a nearly sixfold increase from previous years. The total academic output is also very good and has been consistent over the review period.

The unit is encouraged to continue working along the proposed research lines, especially the new lines where more continued effort will provide more PhDs and publications, obtaining as

a result a higher international visibility. The journals where the results are published could be widened too.

7.2.2. Relevance to society

In a country like the Netherlands, where a major threat is the sea action – one only needs to point at the flooding disaster of 1953 – strong research groups focusing on the design, construction and maintenance of dykes are a necessity. The Geo-Engineering unit is undoubtedly engaged in research of very high societal relevance. Engineering that aims at evaluating risks and reducing their impacts (e.g., flood protection), while at the same time minimizing the effects on the environment, has high societal relevance and holds the potential to improve quality of life.

Government and industry funding are a good indication of societal appreciation of the research proposed by the unit. Indeed, external funding is an excellent mechanism of self-adjustment since industry and administration will only be willing to fund those projects it believes to be relevant for society. Moreover, it is important to notice the involvement of industry in the research projects and their actual implementation. Several staff members are also advising industry, national institutes and other organizations. Furthermore, the committee appreciates the fact that most master's student projects and PhD projects have a significant industrial component, including advisors from industry.

Staff and even postgraduate students of the unit are very much involved in (i) professional committees dealing with the development of codes, standards and relevant policies, and (ii) public debate and knowledge dissemination to the general public. Such involvement should always be encouraged, supported and rewarded by the university.

Media appearance has increased last year, being estimated at 9 (to be compared with 7 and 0 in the preceding years). The committee supports the efforts to increase media attention and suggests to be more alert to media opportunities. As mentioned above the unit contributes by preparing codes that are applied by engineers and the dissemination of the results in the form of books, reports, and courses for practical engineers is of great interest and very much appreciated by the industry. The committee concludes that the research unit is indeed making an outstanding contribution to society.

7.2.3. Viability

The unit's viability is beyond any doubt. Starting with a strategy based on excellence in research tools that are applied to problems of high interest for the country, combined with good policies in human and material resources, it comes as no surprise that the unit is being funded in a harmonic manner from both public and private mechanisms. Therefore, we can conclude that the unit is robust and viable.

Regarding material resources, there are two lines to follow: (i) maintaining, improving and updating the testing equipment, and (ii) hiring personnel able to design new tests and equipment. Both targets will have to continue being taken into account in the forthcoming years. The mechanisms used to improve involvement of industry have proven efficient.

The committee concludes that the overall viability of the unit is excellent. The research the unit produces is very good and of very high societal relevance, and therefore it is anticipated that the unit will have the continuous support of the government and industry (and, hopefully, the university at times of leaner public and private funding). We can conclude here that the unit is excellently equipped for the future.

7.3 Scores

Quality	*Very good*
Societal Relevance	*Excellent*
Viability	*Excellent*

8. Geo-Resources

8.1. The strategy and targets of the research unit

8.1.1. Mission, strategy and targets

The Geo-Resources unit is part of the Department of Geoscience and Engineering. It is divided into four themes: (1) Rock-Fluid Flow Processes, (2) Advanced Reservoir Simulation and Optimization, (3) Resource Engineering, and (4) Geothermal Engineering. The first two themes are within the general area of Petroleum Engineering (though they are also relevant to other applications such as geological carbon storage), while the third theme involves mining and mineral recovery.

Over the assessment period, there have been significant changes in some of these areas. Key events within the Resource Engineering theme include the hiring of two new faculty (in August 2011 and April 2012), and the transfer of another faculty member from the Geology unit. Within the Petroleum Engineering theme, two assistant professors have left the unit during the assessment period, and two new faculty members have joined (in 2013 and 2015). Within the Geothermal Engineering theme, a new professor was recruited in 2013.

8.1.2 Resources

Between 2008 and 2014, staff numbers almost tripled from 15.3 fte in 2008 to 42.2 fte in 2014. According to the self-evaluation report, this growth has been the result of a number of successful hires based on the PI model. Two less successful tenure-track hires left after a critical review of their fundraising and publication records, yet overall the total amount of tenured fte almost doubled from 4.0 fte in 2008 to 7.7 fte in 2014. In 2015, a new associate professor was hired in the research theme Advanced Reservoir Simulation and Optimization, whilst an additional lecturer in Resource Engineering was appointed to meet the increased teaching load of the current staff and allow them more time for research. The PI model will continue to guide the personnel strategy in the coming period.

The unit's finances by and large depend on third (industry/EU) stream funding. Notably, no national governmental funding was secured during the review period, although the unit in 2015 succeeded in obtaining funds for two PhD candidates from the Dutch Ministry of Foreign Affairs. On the other hand, third stream funding has consistently accounted for three-quarters of the unit's total budget. A sharp increase in funding is visible since 2013, when the Resource Engineering group was established. Over the review period, total funding increased from €1.65M in 2008 to €3.8M in 2014. The unit's strategy for the coming period is to continue to engage in large second or third stream programmes. It reportedly expects more success in national governmental funding and funding through public-private partnerships, due to the new research themes Resource Engineering and Geothermal Engineering, and to increased focus on societally relevant research, particularly shale oil and gas, and geomechanics during gas production.

8.2. Qualitative and quantitative assessment

8.2.1. Research quality

In terms of research quality, the committee is impressed with the efforts of the Geo-Resources unit during the review period. It believes the unit has many outstanding capabilities, and indeed some of these were viewed as world leading/excellent. These include aspects of the research within the Petroleum Engineering theme, such as foam and chemical

EOR (which entails both experimental and modeling work) and closed-loop reservoir management. Much of the closed-loop reservoir management research was performed within two successful and well-established industrial consortia – ISAPP (Integrated Systems Approach to Petroleum Production) and RF (Recovery Factory). Faculty in Rock-Fluid Flow Processes are also in the process of forming an industrial consortium. Recent faculty hires should act to further strengthen the Advanced Reservoir Simulation and Optimization theme, as discussed below.

The Resource Engineering and Geothermal Engineering themes appear to be very well positioned for the future in terms of faculty, research directions, and funding. Their research activities, which include real-time mining and optimization, and the development of plans to drill a geothermal injector-producer well pair on the TU Delft campus, are exciting, novel and ambitious. The research accomplishments over the assessment period within these two themes were limited, however, due to the fact that most of the faculty in these areas joined Geo-Resources relatively recently. Neither theme area has produced a PhD graduate over the assessment period, although several PhD students are currently in the pipeline.

8.2.2. Relevance to society

The unit is involved in a variety of research projects that are directly relevant to societally-important activities on the efficient and safe extraction of energy and mineral resources. The high level of industrial funding within Geo-Resources is indicative of the practical relevance of its research output, as well as of the desirability (to industry) of the students graduating from this unit. There has also been significant uptake of some of the research results, including the use of optimization and simulation software and field implementation of EOR processes by Shell and other companies. Other noteworthy activities include participation in the Geothermal Capacity Building Programme and advising parliament on shale gas development. Expansion of the Geothermal Engineering theme will further enhance, potentially very substantially, the societal relevance of the Geo-Resources unit.

8.2.3. Viability

Within the Petroleum Engineering areas, there have been two strong new hires (in 2013 and 2015) who are capable of contributing greatly to future research in Advanced Reservoir Simulation and Optimization and other themes. These faculty, combined with existing excellent faculty in this theme and in Rock-Fluid Flow Processes, should position the unit to be in the top-tier in a range of new and existing research areas. Participation in the Delphi consortium should act to facilitate additional productive interactions with Geophysics and Geology. The committee is convinced that the Resource Engineering theme is also well positioned for excellence, given its strong new hires, novel research ideas, and great success in quickly securing research funding. It expects fruitful interactions between Resource Engineering and Petroleum Engineering in the areas of closed-loop modeling and optimization, uncertainty quantification, and possibly on other topics. Since many of the research areas within the unit involve the development of large-scale codes, the committee encourages Geo-Resources to adopt modern software-management practices.

The Geothermal Engineering theme also appears to be very well situated for future success. This theme has recruited an international geothermal leader as a new faculty member, and has secured significant funding. It is pursuing an exciting project that will entail drilling an injector-producer well pair on the TU Delft campus. If this does indeed come to fruition, it could put Geothermal Engineering in a unique position in terms of research capabilities and stature. It is important to note, however, that the theme currently includes only a single faculty member at 0.3 fte. It will be very challenging to establish a comprehensive world leading program in this area without additional faculty. This potential need has been recognized by the unit. Effective collaborations with faculty in Petroleum Engineering areas (e.g., reservoir simulation) will act to further strengthen this theme.

8.3 Scores

Quality	*Very good*
Societal Relevance	*Excellent*
Viability	*Excellent*

9. Atmosphere

9.1. The strategy and targets of the research unit

9.1.1. Mission, strategy and targets

The research unit Atmosphere is part of the Department of Geoscience & Remote Sensing. In the self-evaluation report, the unit has defined its mission as 'to perform cutting edge research and development in atmospheric modelling and remote sensing, aiming at local and regional scales.' The unit's research encompasses the study of the atmospheric water cycle, trace gases and aerosols by developing atmospheric models, simulation tools as well as new observation methodologies. The results it produces should then be used for improving climate models, and for increasing the ability to monitor and forecast urban air quality, extreme weather, wind and solar power.

The unit aims to do so by bringing together the disciplines of 1) atmospheric modelling and simulation, and 2) atmospheric remote sensing. Over the review period, it has done so quite literally: until 2012, the two disciplines were represented by two research programs housed in two different faculties. Ever since then, the groups have aligned their research agendas and reportedly started to benefit from a synergetic approach in a number of fields.

9.1.2. Resources

As the two constituting research groups Atmospheric Remote Sensing and Clouds and Climate only joined forces in 2012, they had no common personnel or funding strategy before that date. Nevertheless, before as well as after 2012, both programmes combined have been quite successful in attracting new research staff. During the review period, staff numbers have risen significantly, from 10.1 fte in 2007 to 27.2 fte in 2014. In the self-evaluation report, the unit mentions a strengthening of research in the chemical atmospheric domain through a new tenure track position. In the coming period, the unit aims at collaboration with KNMI and via part-time positions and a long-term commitment of at least ten years to allocate additional staff and resources to research on high resolution atmospheric modelling, model-observation infrastructures, geo-seismics and atmospheric chemistry.

Prior to 2012, the unit's constituting programmes did not keep separate track of their finances. Therefore, the unit has only reported on its funding and expenditures in 2013 and 2014. In those years, direct university funding accounted for over 60 per cent of the total budget, while third stream funding amounted to about one third. Consequently, national governmental funding provided only a small percentage of the unit's budget. In the coming period, the unit's strategy is to set the research agenda of national and international funding agencies by initiating ideas for new research programmes. It also aims to join and/or initiate international consortia in order to secure funding through programmes within Horizon 2020, ESA, ESFRI, the National Roadmap for Large Scale Infrastructure and/or NWO-Large.

9.2. Qualitative and quantitative assessment

9.2.1. Research quality

The unit Atmosphere performs high quality research in the fields of atmospheric modelling and remote sensing. The unit strongly benefits from an increasing partnership with KNMI, where high-resolution modelling and super-site remote sensing has been built up successfully over the past years and is now more and more a central topic at TU Delft. Active ground-based and satellite-based remote sensing is very strong at the unit. All together this has

resulted in the unit having established itself as an international leader in Large Eddy Simulations, in synergetic approaches in ground-based remote sensing, and in satellite remote sensing of trace gases. The CESAR atmospheric test-bed jointly operated with KNMI represents a unique world-class infrastructure for coupling high-resolution observations to state of the art modelling. Strong cooperation with ESA is reflected in the establishment of satellite remote sensing infrastructures (measurement techniques and retrieval algorithms).

The high research quality and visibility is also shown in the leadership in two EU projects. The unit includes expertise along the full process chain from technological and methodological (including models) development to final products. The cooperation with other research units within the faculty is convincing, with interesting plans on coupling the atmosphere to ice sheets or atmosphere-coastal interactions. On the other hand, solid earth physics (as in the other research units) and atmospheric physics do not have too many interfaces. However, the Atmosphere Unit has strong methodological links to these research units and a clear strategy to build on these links.

There is a potential for a somewhat higher publication rate. Furthermore, PhD tracks appear rather long. It is recommended that these issues be addressed in order to improve the unit's productivity.

9.2.2. Relevance to society

The research unit improves process understanding in weather and climate and leads activities in global and long-term remote sensing. Societal relevance is very strong in the areas of weather forecasting, understanding climate change including extreme events, air quality, and renewable energy generation. Interaction with stakeholders, space agencies, as well as an ERC grant on wind energy and commitment to solar power research represent important societal contributions. Thus, the research unit is successfully addressing major societal issues in the fields of weather, climate, health and energy.

9.2.3. Viability

The research unit demonstrates clear and promising strategic planning for the development and application of new observational and computational technologies as well as new methodologies. This suggests we can expect continued cutting-edge research from the unit. The strategic cooperation with KNMI has a very strong potential to ensure long-term research. The synergy of high-resolution modelling and remote sensing around the CESAR observatory, the national lead in the European Research Infrastructure ACTRIS, as well as the strong involvement in European satellite remote sensing programmes provide an excellent long-term perspective. The TU Delft Atmospheric Science unit is well established in the overall Dutch atmospheric science community. The benchmarking with the Atmospheric Science work at MIT hints at the need for improving communication within and outside the research unit.

With three new appointments - jointly with KNMI - the Atmosphere Unit is internally on an excellent track to address future challenges. Externally, the unit has a clear strategy to maintain and achieve a leading role in fundamental and applied research.

9.3 Scores

Quality	*Very good*
Societal Relevance	*Excellent*
Viability	*Excellent*

Appendices

Appendix 1: Curricula vitae of the committee members

Hessel Speelman (chair) received his academic education at Groningen University (BSc geology/geophysics; 1971), Leiden University (geophysics/sedimentology) and the Vrije Universiteit Amsterdam (MSc hydrogeology; 1974). Then he did geological research in Indonesia and worked as a researcher at the Vrije Universiteit Amsterdam. After obtaining his PhD (Amsterdam; 1979) he worked as a hydrogeologist in Colombia. In 1982 he was appointed geoscientific expert at TNO in the Netherlands. From 1988 to 2005 he held senior management positions of geoscientific knowledge institutions (i.e. general director of the Netherlands Institute of Applied GeoscienceTNO – National Geological Survey). In addition, Speelman held board positions from the early 90s onwards at institutions which are part of the Dutch knowledge infrastructure related to earth and life sciences (including KNAW, NWO, and universities) and at organisations related to geo-information and at European geoscientific associations and the EU. From 2005 to 2008 he worked – affiliated with the Netherlands Innovationplatform – on developing ideas for improving the public knowledge infrastructure of the Netherlands. From 2008 to 2012 he was advisor 'renewal public knowledge infrastructure', board member (portfolio: geoscience) of the WaddenAcademy KNAW and chairman/member of supervisory boards. Since 2013 he is vice-chairman and geoscientist of the WaddenAcademy, chairman of the steering group long-term subsidence in the Wadden Sea Region and chairman of supervisory boards in the field of earth and life sciences. From 1998 – 2015 Speelman participated/participates in audits and reviews to assess research programs and institutions in the EU.

Louis J. Durlofsky is the Otto N. Miller Professor in the Department of Energy Resources Engineering at Stanford University. He served as ERE Department Chair from 2006–2012. Prior to his arrival at Stanford in 1998, Durlofsky was affiliated with Chevron Energy Technology Company (from 1998–2004, he was affiliated with both Stanford and Chevron). He holds a BSc degree from Pennsylvania State University (1981), as well as MSc (1982) and PhD (1986) degrees from Massachusetts Institute of Technology, all in chemical engineering. He was a postdoctoral fellow at California Institute of Technology from 1986–1987. Durlofsky's current research interests include optimization of subsurface flow operations, general reservoir simulation, reduced-order modeling, upscaling of detailed geological models for flow simulation, data assimilation, energy systems optimization, and geological carbon sequestration. Durlofsky is the co-director of two industrial affiliate programs, the Stanford Smart Fields Consortium and the Stanford Reservoir Simulation Research Consortium (SUPRI-B). He is also involved in the Stanford Center for Carbon Storage.

Andreas Macke obtained a Diploma of Physics at the University of Cologne in 1990. He received his PhD in Geosciences at the University of Hamburg in 1994. His work is focused on light scattering and radiative transfer theory and applications with an emphasis on nonspherical ice particles and inhomogeneous clouds. From 1995 to 1996 he was PostDoc at the NASA Goddard Institute for Space Studies GISS where he contributed to the International Satellite Cloud Climatology Project ISCCP. Starting in 1997 he build up his research group as Assistant Professor at the Leibniz-Institute for Marine Sciences (now GEOMAR), where he habilitated in the field of Meteorology in 2002 and earned a permanent professorship on Marine Meteorology in 2004. Since 2010 Andreas Macke is Director of the Leibniz Institute for Tropospheric Research TROPOS in Leipzig and Professor for Atmospheric Physics at the University of Leipzig. At TROPOS he is heading the Department of Atmospheric Physics. Amongst others Macke was Member of the Science Advisory Boards of the German Weather Service and the German climate change adaption programme

KLIWAS. He is a member of the German Research Agency (DFG) - Council "Ocean and Atmosphere", the German Senate Commission on Oceanography as well as member of several boards of the Leibniz Association, amongst others the Steering Committee of the Leibniz Research Cluster "Crisis of a globalized world". Macke's scientific work deals with the investigation of aerosols and clouds and their effects on the climate system. In this context he organizes and performs regular expeditions with the German research ice breaker POLARSTERN and worldwide campaigns in key areas of climate actions. His work is aiming at the experimental retrieval and theoretical treatment of small-scale but climate relevant radiative processes in the complex aerosol/cloud system of the atmosphere. Some of the main projects he is currently involved in are the „High Definition Clouds and Precipitation in Climate Prediction HD(CP)2" project with the Federal Ministry for Education and Science, and the „Integrating Cloud Observations from Ground and Space – a Way to Combine Time and Space Information" with the DFG.

Alberto Malinverno received an undergraduate degree in geology at the University of Milano, Italy, in 1981 and a Ph.D. in geology at the Lamont-Doherty Earth Observatory (LDEO) of Columbia University, New York, in 1989. After three years at LDEO as a research scientist, in 1992 Malinverno joined the staff of the Schlumberger-Doll Research center in Ridgefield, Connecticut, where he managed a research group on the quantification of uncertainty in measurement interpretation. He returned to Lamont in 2005 as a principal research scientist at the LDEO Borehole Research Group. As a logging scientist, he participated to five scientific drilling expeditions on the US drilling vessel JOIDES Resolution (N. Cascadia margin, Bay of Bengal, Equatorial Pacific, and twice on the Costa Rica Pacific margin). Malinverno is now a Lamont Research Professor and an adjunct professor at the Department of Earth and Environmental Sciences of Columbia University. His current research interests include microbial methanogenesis and methane hydrate formation in continental margin sediments.

Manuel Pastor graduated in civil engineering at Universidad Politécnica de Madrid (UPM), obtaining his doctorate in civil engineering in 1980. He was a part-time lecturer since 1976, obtaining a professorship (Prof. Titular) in 1987. He has been researcher at the spanish Centro de Estudios y Experimentación de Obras Públicas (Research Centre for Public Works, depending on the ministry of public works) from 1975 to 2009, where he obtained a post of oceanographic engineer in 1980. He has been part of the laboratories of Geotechnical Engineering, Roads, Harbours and Coasts, and Applied Techniques, where he led the department of Computational Engineering since 1984. He obtained a full time professorship at the Department of Applied Mathematics of UPM, becoming Head of the department in 2011. He has been elected member of the Royal Academy of Sciences (Sevilla) in 2006, and president of the international association ALERT Geomaterials (2011-). Pastor's main research interests are mathematical, constitutive and numerical modelling of geomaterials and geostructures.

Gerard T. Schuster is Professor of Earth, Science and Engineering at the King Abdullah University of Science and Technology (KAUST) in Thuwal, Saudi Arabia. He is founder and codirector of the Center for Fluid Modeling and Seismic Imaging at KAUST. Schusters holds a master's degree and a PhD in Geophysics from Columbia University. In 1985, Schuster continued his academic career at the University of Utah where he still holds a position as Adjunct Professor in Geology & Geophysics. In 2009, Schuster accepted his current chair at KAUST. Schuster's research interests are in seismic imaging, interferometry, waveform inversion, EM methods, seismic field techniques, and the use of novel methods for super resolution imaging. His geophysical lab is equipped with state-of-the-art seismographs for 624

channel recording and a 72-channel resistivity array for both exploration, engineering, and earthquake applications. Schuster has a strong interest in geophysical characterization of archaeological sites.

Michael G. Sideris has degrees in Geomatics Engineering from the National Technical University of Athens, Greece (1981, Dipl.-Ing., Honours), and the University of Calgary (U of C), Canada (1984, MSc and 1988, PhD). In 2004, he was also awarded an honorary doctorate (Dr. honoris causa) in geodesy by the University of Architecture, Civil Engineering and Geodesy in Sofia, Bulgaria. After receiving his PhD, he joined the faculty of the Department of Geomatics Engineering at U of C, where he is now a professor and Assoc. Head (Graduate Studies). He has also served as Associate Dean in the Faculties of Engineering and Graduate Studies at the University of Calgary. His research interests are in the areas of gravity field approximation, spatial and temporal geoid modeling, dedicated gravity satellite missions (GRACE, GOCE), satellite altimetry, airborne gravimetry, height systems and vertical datums, optimization, and geodetic applications of statistical, spectral, and wavelet methods. His research on efficient methods for precise geoid determination and geodetic boundary value problem solutions has earned him an international reputation, and the FFT-based software he developed is being used internationally by universities, national agencies and private industry. He has graduated over 40 MSc and PhD students, and has published over 200 articles in books, encyclopedias, scientific journals and fully-refereed conference proceedings. Sideris is a Humboldt International Research Fellow, and a Fellow of the International Association of Geodesy (IAG) and the International Geoid Service (IGeS). He is currently the President of the International Union of Geodesy and Geophysics (IUGG) and an honorary President of the IAG.

Appendix 2: Explanation of the SEP criteria and categories

The Standard Evaluation Protocol 2015-2021 asks review committees to assess three criteria:

- Research quality:
  - Level of excellence in the international field
  - Quality and Scientific relevance of research
  - Contribution to body of scientific knowledge
  - Academic reputation
  - Scale of the unit's research results (scientific publications, instruments and infrastructure developed and other contributions).

- Relevance to society:
  - quality, scale and relevance of contributions targeting specific economic, social or cultural target groups;
  - advisory reports for policy;
  - contributions to public debates.

The point is to assess contributions in areas that the research unit has itself designated as target areas.

- Viability:
  - the strategy that the research unit intends to pursue in the years ahead and the extent to which it is capable of meeting its targets in research and society during this period;
  - the governance and leadership skills of the research unit's management.

Category	Meaning	Research quality	Relevance to society	Viability
1	World leading/excellent	The unit has been shown to be one of the most influential research groups in the world in its particular field.	The unit makes an outstanding contribution to society	The unit is excellently equipped for the future
2	Very good	The unit conducts very good, internationally recognised research	The unit makes a very good contribution to society	The unit is very well equipped for the future
3	Good	The unit conducts good research	The unit makes a good contribution to society	The unit makes responsible strategic decisions and is therefore well equipped for the future
4	Unsatisfactory	The unit does not achieve satisfactory results in its field	The unit does not make a satisfactory contribution to society	The unit is not adequately equipped for the future

Appendix 3: Programme of the site visit

28 October				
		8:45	Arrival of the Committee	
	9:00	11:30	Committee Meeting	
	11:30	11:45	Welcome by dean	Prof. dr. ir. Bert Geerken (Dean)
	11:45	12:30	Meeting with institute management	• Prof. dr. ir. Bert Geerken (Dean) • Prof. dr. ir. Jan Dirk Jansen (department head GSE) • Prof. dr. ir. Kees Wapenaar (Director Research School CTG) • Prof. dr. ir. Herman Russchenberg (department head GRS) • Prof. dr. ir. Ramon Hanssen (department head GRS until September 1th 2015)
	12:30	13:15	Lunch	
unit 1	13:15	14:00	Management unit 1 - Geology	• Prof. dr. Giovanni Bertotti (unit leader/section head) • Dr. Joep Storms
	14:00	14:15	Evaluation unit 1	
unit 2	14:15	15:00	Management unit 2 – Geophysics	• Prof. dr. ir. Kees Wapenaar (unit leader/section head) • Prof. dr. ir. Evert Slob
	15:00	15:15	Evaluation unit 2	
unit 5	15:15	16:00	Management unit 5 - Geo-Resources	• Prof. dr. William R. Rossen (unit leader/section head) • Dr. Mike Buxton (section head Resource Engineering)
	16:00	16:15	Evaluation unit 5	
unit 6	16:15	17:00	Management unit 6 – Atmosphere	• Prof. dr. ir. Herman Russchenberg (unit leader / section head) • Prof. dr. Harm Jonker (section head)
	17:00	17:15	Evaluation unit 6	
	17:15	18:00	Committee Meeting	
29 October				
unit 3	9:00	9:45	Management unit 3 - Geodesy	• Prof. dr. ir. Ramon Hanssen (unit leader / section head) • Prof. Dr-Ing.habil. Roland Klees (section head)
	9:45	10:00	Evaluation unit 3	
unit 4	10:00	10:45	Management unit 4 - Geo-Engineering	• Prof. Dr. Michael Hicks (unit leader/section head) • Prof. Dr. ir. Timo Heimovaara
	10:45	11:00	Evaluation unit 4	

	11:00	12:00	Interview with staff members	• Dr. Amin Askarinejad • Dr. Rick Donselaar • Dr. ir. Deyan Draganov • Dr. Läslo Evers • Dr. Hadi Hajebeygi • Dr. Phil Vardon • Dr ir. Christiaan Tiberius • Dr. Stephan de Roode • Dr. Riccardo Riva
	12:00	12:45	Lunch, poster presentations PhD students	Venue: Exhibition Room
	12:45	13:30	Guided Tour of the Facilities	• Dr. Karl-Heinz Wolf (head of the GSE laboratory) • Prof. dr. ir. Herman Russchenberg (department head GRS)
	13:30	14:15	Interview with PhD students	• Helena van der Vegt (Geology) • Iris Hartstra (Geophysics) • Tom de Gast (Geo-Engineering) • Eduardo Barros (Geo-Resources/Petroleum Engineering) • Marinus Dalm (Geo-Resources/Resource Engineering) • Marcel Kleinherenbrink (Geodesy) • Thomas Frederikse (Geodesy) • Karolina Sarna MSc (Atmosphere) • Ricardo Reinoso Rondinel (Atmosphere)
	14:15	14:30	break	
	14:30	15:00	Interview with boards responsible for graduate schools/ research schools	• Prof. dr. ir. Kees Wapenaar (Director Research School CTG) • Prof. dr. ir. Jan Dirk Jansen (chairman of the Curriculum committee of CTG) • Ilse Oonk MSc. (Coordinator Graduate School CEG)
	15:00	16:30	Committee meeting	
	16:30	17:00	Plenary closing session / reception	Venue: Exhibition Room

Appendix 4: Quantitative data

Table A: Research staff

Research staff	2007	2008	2009	2010	2011	2012	2013	2014
	fte	fte	fte	fte	fte	fte	fte	fte
Research Unit 1: Geology								
Tenured staff	N/A	6.5	6.2	6.2	6.2	5.2	5.3	4.9
Non-tenured staff	N/A	1.5	1.6	5.0	5.1	2.3	2.0	1.8
PhD-candidates	N/A	8.5	8.6	9.3	11.0	8.3	10.2	13.6
Total research staff	**N/A**	**16.5**	**16.5**	**20.4**	**22.3**	**15.7**	**17.5**	**20.3**
Research Unit 2: Geophysics								
Tenured staff	N/A	7.8	7.0	6.9	6.1	6.6	6.7	6.8
Non-tenured staff	N/A	6.7	2.7	3.7	5.2	6.7	8.7	8.5
PhD-candidates	N/A	20.4	22.6	20.5	19.6	16.5	15.1	16.8
Total research staff	**N/A**	**34.9**	**32.4**	**31.0**	**30.9**	**29.8**	**30.6**	**32.0**
Research Unit 3: Geodesy								
Tenured staff	10.4	12.4	13.3	12.5	11.9	12.1	11.0	12.3
Non-tenured staff	14.4	10.2	5.1	7.0	5.8	2.7	10.3	13.4
PhD-candidates	25.4	24.9	25.9	28.8	32.7	33.8	33.5	26.5
Total research staff	**50.2**	**47.5**	**44.3**	**48.3**	**50.4**	**48.6**	**54.8**	**52.2**
Research Unit 4: Geo-Engineering								
Tenured staff	N/A	9.1	9.3	9.3	11.0	9.7	7.7	8.5
Non-tenured staff	N/A	0.0	0.8	3.4	2.4	3.0	2.2	3.8
PhD-candidates	N/A	14.8	15.9	19.3	21.1	26.8	25.1	23.5
Total research staff	**N/A**	**23.8**	**25.9**	**31.9**	**34.5**	**39.5**	**34.9**	**35.7**
Research Unit 5: Geo-Resources								
Tenured staff	N/A	4.0	4.5	4.7	4.8	7.1	8.7	7.7
Non-tenured staff	N/A	1.6	4.0	5.8	5.0	2.8	4.1	8.1
PhD-candidates	N/A	9.8	8.4	11.5	15.5	20.4	22.4	26.4
Total research staff	**N/A**	**15.3**	**16.8**	**22.0**	**25.3**	**30.3**	**35.0**	**42.2**
Research Unit 6: Atmosphere								
Tenured staff	2.5	3.3	3.6	4.5	4.8	5.0	5.7	5.8
Non-tenured staff	3.0	3.0	3.4	3.0	2.9	2.2	4.4	4.5
PhD-candidates	4.6	5.2	5.6	7.8	11.3	12.5	15.5	16.9
Total research staff	**10.1**	**11.5**	**12.6**	**15.3**	**19.0**	**19.7**	**25.6**	**27.2**

Table B: Main Categories of Research Output

Research Unit 1: Geology	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**total**
Refereed articles	N/A	12	12	17	22	30	19	25	137
Conference papers	N/A	13	7	17	9	7	13	9	75
Books	N/A	1			1	1			3
Book chapters	N/A	6	1	5	1	1		1	15
PhD theses	N/A	1	3	2	1	3	2	3	15
Invited talks	N/A	6	2	5	6	3	5	1	28
Editorships	N/A	2	1	3	4	4	5	4	23
Total academic publications	**N/A**	**41**	**26**	**49**	**44**	**49**	**44**	**43**	**296**
Professional publications	N/A	7	4	9	11	9	2	4	46
Media appearance/outreach	N/A	7	8	19	23	4	4	7	72
Total publications	**N/A**	**55**	**38**	**77**	**78**	**62**	**50**	**54**	**414**
Research Unit 2: Geophysics									
Refereed articles	N/A	30	18	41	37	50	39	46	261
Conference papers	N/A	53	66	60	37	35	48	48	347
Books	N/A						1		1
Book chapters	N/A	3		5	4				12
PhD theses	N/A		3	3	6	9	4	5	30
Invited talks	N/A	5	2	1	3	7	12	9	39
Editorships	N/A	12	10	11	9	7	7	7	63
Total academic publications	**N/A**	**103**	**99**	**121**	**96**	**108**	**111**	**115**	**761**
Professional publications	N/A	8	3	3	9	3	2	5	33
Media appearance/outreach	N/A					1	5	3	9
Total publications	**N/A**	**111**	**102**	**124**	**105**	**112**	**118**	**123**	**795**
Research Unit 3: Geodesy									
Refereed articles	37	48	34	34	51	35	46	55	340
Conference papers	66	95	74	43	21	55	36	26	416
Books						1			1
Book chapters	1	4	6	11		2		4	28
PhD theses	1	3	3	3	3	2	4	4	23
(Invited) talks	9	5	4	7	9	11	13	16	74
Editorships	7	8	11	10	10	13	12	13	84
Total academic publications	**121**	**163**	**132**	**108**	**94**	**119**	**111**	**118**	**966**
Professional publications	3	10	11	9	2	1			36
Media appearance/outreach	1		1	12	3	2	4	11	34
Total publications	**125**	**173**	**144**	**129**	**99**	**122**	**115**	**129**	**1,036**

Research Unit 4: Geo-Engineering									
Refereed articles	N/A	6	15	15	23	19	22	35	135
Conference papers	N/A	65	52	70	34	52	43	27	343
Books	N/A				1	2	2		5
Book chapters	N/A	15	2			2	4	2	25
PhD theses	N/A	1	3	3	2		5		14
Invited talks	N/A						1	2	3
Editorships	N/A	3		3		1	4	7	18
Total academic publications	**N/A**	**90**	**72**	**91**	**60**	**76**	**81**	**73**	**543**
Professional publications	N/A	10	18	8	9	23	4	4	76
Media appearance/outreach	N/A	8	3	1			7	9	28
Total publications	**N/A**	**108**	**93**	**100**	**69**	**99**	**92**	**86**	**647**
Research Unit 5: Geo-Resources									
Refereed articles	N/A	15	19	17	18	24	18	27	138
Conference papers	N/A	21	26	21	18	23	28	37	174
Books	N/A						1	1	2
Book chapters	N/A		2					1	3
PhD theses	N/A	2	4	5	2	4	1	4	22
Invited talks	N/A	7	6	17	7	5	12	17	
Editorships	N/A	1	2	2	2	3	2	2	14
Total academic publications	**N/A**	**46**	**59**	**62**	**47**	**59**	**62**	**89**	**424**
Professional publications	N/A	4	3	2		1	3	2	15
Media appearance/outreach	N/A		1	1		8	2	10	22
Total publications	**N/A**	**50**	**63**	**65**	**47**	**68**	**67**	**101**	**461**
Research Unit 6:Atmosphere									
Refereed articles	6	16	12	11	12	18	16	23	114
Conference papers	6	16	25	23	18	26	7	34	155
Books	1								1
Book chapters		2		2					4
PhD theses		1	1	2		1	1	3	9
Invited talks			1			6	10	6	23
Editorships			2						2
Total academic publications	**13**	**35**	**41**	**38**	**30**	**51**	**34**	**66**	**308**
Professional publications				1				1	2
Media appearance/outreach						1	6	5	12
Total publications	**13**	**35**	**41**	**39**	**30**	**52**	**40**	**72**	**322**

Table C: Funding

	2007		2008		2009		2010		2011		2012		2013		2014	
Research Unit 1: Geology																
Funding:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Direct funding	N/A	N/A	806	38	704	40	791	37	629	34	311	20	416	30	645	41
National government funding	N/A	N/A	549	26	800	45	487	23	332	18	360	23	347	25	293	19
Industrial/EU funding	N/A	N/A	759	36	264	15	856	40	892	48	922	58	638	46	628	40
Total funding	**N/A**	**N/A**	**2,114**	**100**	**1,768**	**100**	**2,134**	**100**	**1,853**	**100**	**1,593**	**100**	**1,401**	**100**	**1,566**	**100**
Expenditure:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Personnel costs	N/A	N/A	1,083	53	1,244	58	1,715	86	1,772	81	1,382	72	1,278	84	1,482	84
Other costs	N/A	N/A	972	47	901	42	287	14	429	19	540	28	237	16	282	16
Total expenditure	**N/A**	**N/A**	**2,055**	**100**	**2,145**	**100**	**2,002**	**100**	**2,201**	**100**	**1,922**	**100**	**1,515**	**100**	**1,764**	**100**
Research Unit 2: Geophysics																
Funding:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Direct funding	N/A	N/A	480	13	654	22	716	21	837	22	479	17	483	19	810	28
National government funding	N/A	N/A	1,276	35	813	27	718	21	967	26	992	35	508	20	358	12
Industrial/EU funding	N/A	N/A	1,922	52	1,517	51	1,954	58	1,945	52	1,400	49	1,606	62	1,736	60
Total funding	**N/A**	**N/A**	**3,678**	**100**	**2,984**	**100**	**3,388**	**100**	**3,749**	**100**	**2,871**	**100**	**2,597**	**100**	**2,904**	**100**
Expenditure::	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Personnel costs	N/A	N/A	2,204	61	2,108	75	2,433	74	2,209	73	1,915	76	2,144	79	2,076	75
Other costs	N/A	N/A	1,400	39	695	25	872	26	833	27	597	24	559	21	709	25
Total expenditure	**N/A**	**N/A**	**3,604**	**100**	**2,803**	**100**	**3,305**	**100**	**3,042**	**100**	**2,512**	**100**	**2,703**	**100**	**2,785**	**100**

	2007		2008		2009		2010		2011		2012		2013		2014	
Research Unit 3: Geodesy																
Funding:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Direct funding	1,510	54	1,618	61	1,265	55	1,262	46	979	41	1,212	50	1,190	47	1,257	44
National government funding	370	13	319	12	319	14	259	9	228	9	213	9	237	9	649	23
Industrial/EU funding	924	33	701	27	701	31	1,225	45	1,203	50	983	41	1,099	44	956	33
Total funding	**2,804**	**100**	**2,638**	**100**	**2,285**	**100**	**2,746**	**100**	**2,410**	**100**	**2,408**	**100**	**2,526**	**100**	**2,862**	**100**
Expenditure:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Personnel costs	2,507	87	2,616	95	2,528	93	2,431	92	2,242	90	1,932	90	2,219	90	2,321	94
Other costs	383	13	152	5	200	7	212	8	246	10	211	10	260	10	151	6
Total expenditure	**2,890**	**100**	**2,768**	**100**	**2,728**	**100**	**2,643**	**100**	**2,488**	**100**	**2,143**	**100**	**2,479**	**100**	**2,472**	**100**
Research Unit 4: Geo-Engineering																
Funding:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Direct funding	N/A	N/A	983	58	828	50	911	45	607	27	527	31	464	27	886	34
National government funding	N/A	N/A	5	0	1	0	1	0	14	1	531	31	403	23	764	30
Industrial/EU funding	N/A	N/A	693	41	830	50	1,132	55	1,607	72	637	38	867	50	927	36
Total funding	**N/A**	**N/A**	**1,681**	**100**	**1,659**	**100**	**2,044**	**100**	**2,228**	**100**	**1,695**	**100**	**1,734**	**100**	**2,577**	**100**
Expenditure:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Personnel costs	N/A	N/A	1,540	70	1,620	70	1,997	81	2,263	87	1,648	78	1,728	87	2,043	80
Other costs	N/A	N/A	656	30	686	30	455	19	345	13	464	22	262	13	513	20
Total expenditure	**N/A**	**N/A**	**2,196**	**100**	**2,306**	**100**	**2,452**	**100**	**2,608**	**100**	**2,112**	**100**	**1,990**	**100**	**2,556**	**100**

	2007		2008		2009		2010		2011		2012*		2013		2014	
Research Unit 5: Geo-Resources																
Funding:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Direct funding	N/A	N/A	482	29	686	33	554	25	688	36	740	21	728	22	990	26
National government funding	N/A	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial/EU funding	N/A	N/A	1,167	71	1,368	67	1,635	75	1,248	64	2,860	79	2,596	78	2,805	74
Total funding	**N/A**	**N/A**	**1,649**	**100**	**2,054**	**100**	**2,189**	**100**	**1,936**	**100**	**3,600**	**100**	**3,324**	**100**	**3,795**	**100**
Expenditure:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Personnel costs	N/A	N/A	1,068	58	1,086	62	1,807	80	1,488	72	2,295	60	2,140	64	2,435	76
Other costs	N/A	N/A	771	42	653	38	446	20	582	28	1,511	40	1,218	36	761	24
Total expenditure	**N/A**	**N/A**	**1,839**	**100**	**1,739**	**100**	**2,253**	**100**	**2,070**	**100**	**3,806**	**100**	**3,358**	**100**	**3,196**	**100**
Research Unit 6: Atmosphere																
Funding:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Direct funding	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	821	63	924	61
National government funding	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	53	4	70	5
Industrial/EU funding	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	430	33	516	34
Total funding	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1,304**	**100**	**1,510**	**100**
Expenditure:	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**	**k€**	**%**
Personnel costs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,128	94	1,373	87
Other costs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	78	6	213	13
Total expenditure	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1,206**	**100**	**1,586**	**100**

* Note that the sudden increase in funding and expenditure of the Research Unit Geo-Resources in 2012 is due to newly established Resource Engineering group.

Table D: PhD candidates

Enrolment				**Success rates**								**Total**			
Starting year	Enrolment			Graduated after								Not yet finished		Discontinued	
				≤ 4 years		≤ 5 years		≤ 6 years		≤ 7 years					
	M	F	Total	#	%	#	%	#	%	#	%	#	%	#	%
2006	17	5	**22**	2	**9**	11	**50**	15	**68**	19	**86**	2	**9**	1	**5**
2007	14	8	**22**	1	**5**	9	**41**	14	**64**	15	**68**	3	**14**	2	**9**
2008	18	3	**21**	0	**0**	9	**43**	13	**62**	13	**62**	6	**29**	2	**10**
2009	15	4	**19**	0	**0**	5	**26**	5	**26**			13	**68**	1	**5**
2010	23	9	**32**	3	**9**	7	**22**					24	**75**	1	**3**

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