|  |
| --- |
| **Registration form (basic details)** |

**1a. Details of applicant**

Title: dr. ir.

First name: Rolf

Initials: R W

Prefix:

Surname: Hut

Male/female: male

Address for correspondence (for the entire period of the Veni round):

Faculteit civiele techniek en geowetenschappen, kamer 4.72

Stevinweg 1

2628 CN

Delft

Preference for correspondence in English: no

Telephone: +31 6 14196541

Cell phone: +31 6 14196541

Email: [r.w.hut@tudelft.nl](mailto:r.w.hut@tudelft.nl)

Website (optional): [www.rolfhut.nl](http://www.rolfhut.nl)

Use of extension clause (see Notes): no

(if ‘yes’, give reasons and calculation)

**1b. Title of research proposal**

Sensing the earth using consumer electronics: Soil moisture with Bluetooth and RFID

**1c.** **Scientific summary of research proposal** (Max. 300 words, 297 used)

Soil moisture, the water in the top layer of the earth, makes up less than 0.1% of the water on earth, but knowing it accurately is essential in many fields of science. Rain on wet soils cause floods, rain on dry soils irrigate the plants that feed us. Too much soil moisture destabilizes hills causing landslides, while not enough soil moisture destroys harvests causing famine.

Current state of the art in soil moisture sensing includes either expensive local measurements at the centimeter scale, or satellite observations with pixels of tens of kilometers. Soil moisture can vary by significant amounts at field scale, yet few fields are equipped with sensors due to the high cost involved.

In this research, a novel type of soil moisture sensing system will be developed that uses the economies of scale of consumer electronics, combined with state of the art signal analyses and tomography, to determine the soil moisture distribution of entire fields at a fraction of the cost of the current state of the art.

An already tested prototype showed that signal strength of Bluetooth Low Energy and RFID beacons buried in the soil, as recorded with a mobile phone above the soil, decreases with the amount of moisture between the beacon and the phone. The aim of this research is to take this prototype and make it into a tried and tested method that can be deployed in any field, giving precision farmers the tools to know soil moisture at individual plants.

This novel method is ideally suited as input for tomography that allows to calculate the entire spatial distribution of soil moisture on a field. By comparing this with satellite images, better up- and downscaling statistical laws can be derived, improving the worldwide value of satellite based soil moisture measurements.

**1d. Keywords** (Max. five keywords)

**1e. Current institution of employment**

Delft University of Technology

**1f. Prospective host institution** (If known)

Delft University of Technology

**1g. NWO Division** (Choose one)

|  |  |
| --- | --- |
| Interdivisional\* |  |
| ALW |  |
| CW |  |
| EW |  |
| GW |  |
| MaGW |  |
| ZonMw |  |
| N |  |
| STW | x |

**\* Explanation of the interdivisional character of the proposal** (only to be filled out if you have chosen to submit your application as interdivisional, 50-100 words):

**1h. Main field of research (see notes)**

If applicable: other fields of research, in order of relevance

|  |  |
| --- | --- |
| **Code** | **Main field of research** |
| 15.60.00 | Hydrosphere sciences |

# 1i. Public summary of your research proposal

# (In Dutch and in English, max. 50 words each, see notes).

**begraven OV-chipkaart helpt overstromingen voorspellen**

Dr. ir. R.W. (Rolf) Hut (m), TU Delft, Civiele Techniek en Geowetenschappen.

Met ingegraven Bluetooth en RFID (dezelfde techniek als in de OV-chipkaart) meten we hoe nat grond is, door te kijken naar hoe slecht de RFID te lezen is. Deze meting is nodig om optimaal planten water te geven, maar ook voor het beter voorspellen van het weer en zelfs overstromingen.

**Buried Oyster Card helps predicting floods**

Dr. ir. R.W. (Rolf) Hut (m), Delft University of Technology, Civil Engineering an Geosciences.

By burying Bluetooth and RFID beacons (same technology as used in the Oyster Card) we measure soil-wetness, by checking how hard it is to still read the RFID. Knowing the soil-wetness helps in optimal irrigation of crops, but also in better weather predictions, and even better floods predictions.

|  |
| --- |
| **Research proposal** |

**2a1 and 2a2. Description of the proposed research**

Less than 0.0002% of the water on earth is soil moisture: the water in the top most soil layer of the earth [1]. Yet it plays a pivotal role in the behavior of the water cycle. Wet soils route rainfall overland to rivers, potentially causing floods. Dry soils absorb rainfall, routing it to groundwater storage, or feeding it to the plants that feed the world.

Accurate knowledge of the distribution of soil moisture, is essential in a wide array of applications and fields of science, including

* Precision farming (in the same field individual plants can have too much or too little water)
* Weather forecasting (the air over dryer soil heats up faster)
* Flood and drought forecasting (rain on saturated soil causes downstream flooding)

Unfortunately, soil moisture is notoriously hard to measure, mainly because it can vary greatly within a single field. The shadow of a tree, the presence of plants, the type of soil, human influences such as roads and drains all influence soil moisture at very local (meter) scales [2]. Satellites are able to observe soil moistures, however the scale is in the range of 10-kilometer pixels at best [3]. Furthermore, the relation between local soil moisture and soil moisture as seen by satellites is not straightforward. Much research has been done on this relation, but it remains, ultimately, an open problem [4].

To have access to soil moisture information at field scale, one would have to measure every individual field. This is unfeasible given the price of current state of the art soil moisture sensors. Alternatively, one has to know how the statistical rules to downscale global satellite observations of soil moisture to the field scale. The state of the art to determine these statistical rules are expensive measurement campaigns where selected fields are equipped with a very large amount of classical point scale soil moisture sensors The number of such experiments is limited due to, in part, the cost of the physical installation. Furthermore, the ability to derive the complex statistical relations that describe the observed variability at the field scale is limited due to the point-scale nature of measurements. [5, 6].

Cost of sensors is the main bottleneck in acquiring soil moisture information, both for farmers who want to accurately measure their own fields to improve their farming practices, as well as for meteorologist and water managers who want to downscale coarse satellite data to the field scale for optimal weather and flood predictions.



Figure 1: the core idea of this proposal visualised: bluetooth and RFID beacons below ground communicate with a phone. The signal strength is a measure for soil moisture.

The core idea in this Veni research is to reduce the cost of sensing soil moisture by using economies of scale achieved in consumer electronics. Radio signal strength of Bluetooth Low Energy (BLE) beacons and RFID beacons is strongly related to the amount of moisture between the sender (beacons) and receiver (usually a mobile phone). A first prototype that demonstrated the feasibility of BLE signal strength as a proxy for soil moisture has been successfully tested and demonstrated recently [7], see figure 2. RFID signal strength has also been related to soil moisture for optimized antenna configurations [8]. Here, we aim to use standard, off-the-shelf RFID-tags. In this way off-the-shelf, low cost consumer electronics, combined with the omnipresent mobile phone, are turned into soil moisture sensors that integrate over the line between beacon and phone. By burying a collection of beacons in a field, at different horizontal and vertical locations, a single phone moving around can “scan” the entire soil moisture distribution of the field, as is depicted in figure 1. This alleviates two of the problems with current state of the art campaigns:

* BLE and RFID beacons, even when combined with mobile phones, are lower cost than current generation soil moisture sensors. A beacon or tag cost as little as $5 and a single phone can log the signal strength from multiple beacons and tags within range.
* BLE and RFID beacons combined with phones as receivers integrate soil moisture over a line between the beacon and the phone. When the phone moves around, by mounting it on a drone that flies over the field, a large amount of measured lines can be stored, basically scanning the soil moisture distribution of the entire field. This method is unique in that it measures integrated soil moisture over a line between sender and receiver, where most conventional sensors measure soil moisture in a control volume (most field sensors), a complex weighted local average (cosmic ray probes)[9], or a large area average of top-layer soil moisture (satellites and radar).

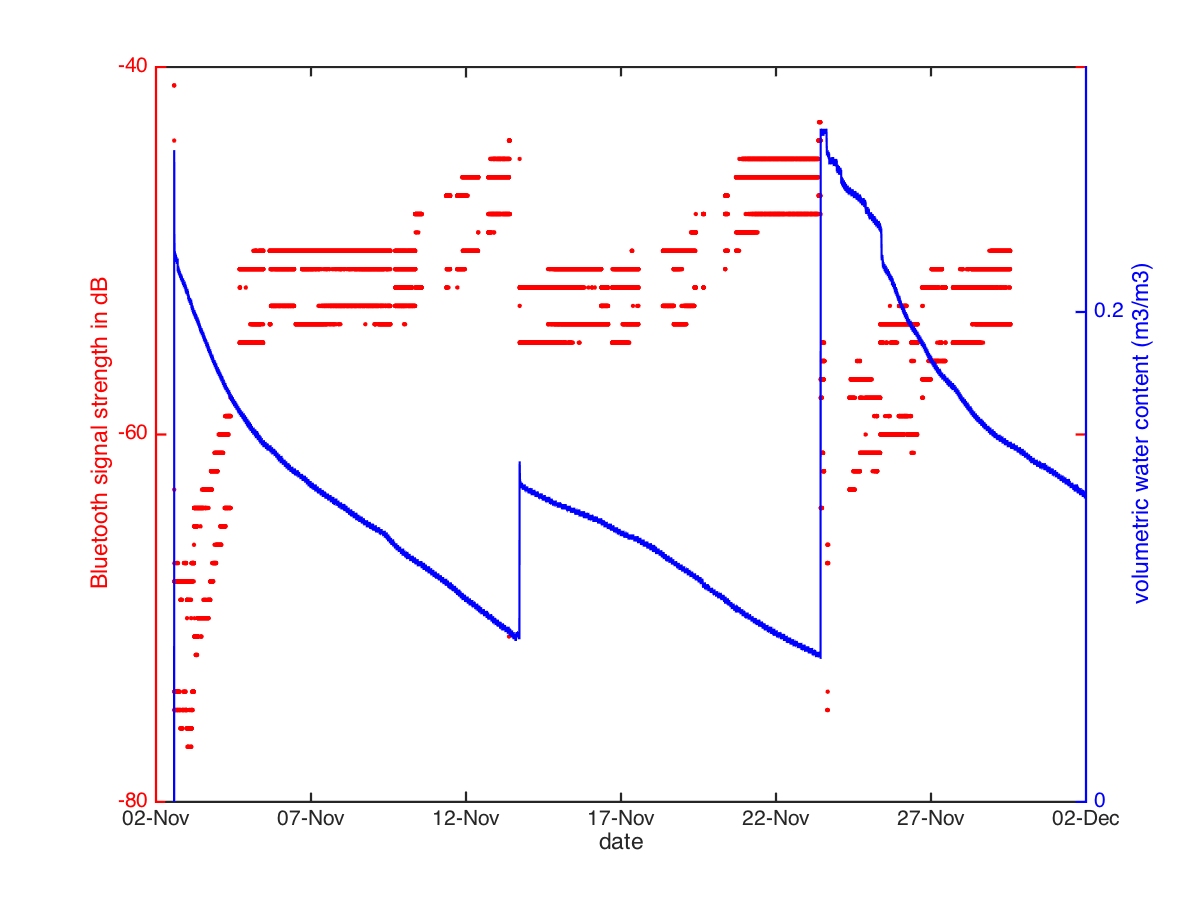


Figure 2: results of first proof of concept, showing Bluetooth signal strength increasing with decreasing soil moisture. From Hut 2015 [7].

Integrated line measurements allow the use of more advances statistical inversion techniques than point measurements do. Tomography, the inversion technique used in fields such as seismic exploration to find petrochemicals, ground penetrating radar to locate archeological sites or and medical imaging to find cancer, is ideally suited as an algorithm to determine the soil moisture field from line measurements.

BLE and RFID beacons each have their own strengths. BLE beacons can be used with mobile phones directly off-the-shelf. Some BLE beacons allow the connection of additional sensors, which could measure for example soil temperature, saturation and vapor pressure. The measurements would be send to the phone using BLE and the strength of the BLE signal that contains the measurement would be an additional measurement of soil moisture. For environmental safety, BLE beacons, which contain batteries, have to confirm to RHOS and ISO standards, which most current generation beacons luckily do.

Passive RFID beacons (also called tags) require no batteries and can be as small as a grain of rice [10]. Although range is limited compared to BLE, a large amount can be ploughed into a field at limited cost. Those small beacons are also used inside pets for tracking them and thus completely inert[11]. Finally, RFID tags can be used in different frequency bands, potentially allowing us to identify different types of water in the soil (ie. saturated vs unsaturated water content).

In this Veni-research I will expand on the success of the first prototype to develop a method to measure soil moisture of entire fields using a collection of BLE and RFID beacons and both fixed position phones as well as drone mounted phones. This method will greatly benefit precision farming.

I will adapt the mathematical formulation of tomography to fit the specifics of near surface soil moisture sensing. This allows me to invert the measurement result to determine the soil moisture distribution at the field scale. This will be used to calculate statistical laws to correctly interpret satellite based soil moisture and to be better able to use (globally available) satellite data in local scale decision making.

To achieve this ambitious goal, the research will be done in four phases: developing the sensor, field testing the sensor, tomography and finally statistically up- and down-scaling laws. These phases will be briefly explained in the research plan below:

**Research plan**

**Phase 1: sensor development**

In the first phase of this VENI-project I will develop an optimized beacon-receiver system where the receiver logs the Bluetooth and RFID signal strength (RSSI) of all beacons it can identify. This will be based as much as possible on existing technology: using off-the-shelf beacons such as the low cost Tile ($5) and using mobile phones equipped with custom made apps to record the BLE signal strength of the beacons.

The phones will be used in two ways: as fixed position receivers, that will continuously monitor signal strength integrated over the line between beacon and receiver. Secondly, we will mount a phone on a drone, so we can measure soil moisture from the buried beacons while flying over a field, generating large amounts of data necessary for tomography (phase 3).

Thorough testing in controlled settings in the lab will give detailed information on sensitivity of proposed setup to changes in soil moistures as well as other environmental variables that we can control in the lab such as soil type, temperature, relative humidity, etc.

The BLE system will be developed at Delft University of Technology, where the combination of the water laboratory and the sensor design division will provide an excellent academic facility.

The RFID system will be developed in collaboration with (and partly at) the OPENS laboratory at Oregon State University, where I have been invited to work on this technology. Oregon State University fill cover part of the costs of this trip (in kind co-funding).

**Timeperiod phase 1:** August 2016-July 2017

During phase 1 an extended visit to Oregon State University is planned to work on the RFID system.

**Output of phase 1:**

* Working prototype with calibrated soil moisture to signal strength relation for both BLE and RFID systems.
* Sensitivity analyses of possible confounding variables such as soil type (sand/clay ratio), temperature and relative humidity.
* At least one peer reviewed article in a sensor design focused journal.

**Phase 2: field work**

Multiple field locations will be selected to implement the novel BLE and RFID based method. One of these locations is the TERENO site in Germany: This site is equipped with a large number of classic (point scale) soil moisture sensors. Academic colleagues of the TERENO project have expressed their willingness to host me when this VENI is funded, emails available on request.

The beacons will be placed in two ways: one set will be placed such that they will measure very local soil moisture directly, without the need for tomography. This dataset will be used to compare the classical sensors to the new BLE-beacon-phone sensors.

The second set of beacons will be placed in such a configuration to facilitate the tomography of phase 3.

**Timeperiod phase 2:** August 2017-July 2018

During phase 2 visits for field work to the TERENO site in Germany and to Oregon State University are planned.

**Output phase 2:**

* Data set of measurement campaign, shared through open access data portal.
* At least one peer reviewed article in an experimental hydrology focused academic journal.
* A white paper describing the method and field results, aimed at farmers and others interested in using this method in their daily practice.
* Blogs, vlogs and media appearances explaining this method to the general public and potential users.

**Phase 3: tomography of field measurements to determine heterogeneous soil moisture fields**

Tomography has been used successful in many fields [12,13,14]. To use it for the data gathered in phase 2, the algorithm itself needs to be adjusted and fine tuned to the specifics of this application: BLE (2.4GHz) electromagnetic signals measured over tens of meters. The resulting adjusted tomographic algorithm will bear much resemblance to the ERT (electric resistivity tomography) [15] method often used in geosciences, with the notable differences that BLE works with electromagnetic waves, where as ERT works with direct current. This makes the BLE tomography more akin to Electrical Impedance Tomography (EIT) that is often used in medical imaging [16].

**Timeperiod phase 3:** August 2018-January 2018

**Output of phase 3:**

* A peer reviewed paper in a “methods in geosciences” journal explaining the adjusted tomography method.

**Phase 4: statistical down- and up-scaling rules based on tomography.**

The results of the tomography phase will be used to compare measured high-resolution soil moisture fields at the test sites to images recorded with satellites. From this exercise, improved statistical up- and down-scaling laws will be derived, including bounds on the uncertainty in those relations. This will build on the wealth of work already done in this field [4, 17]. With these improved laws, satellite data on soil moisture can be interpreted more accurately allowing decision makers in different fields (agriculture, flood/drought forecasting) to base their decisions on more precise information.

**Timeperiod phase 4:** February 2018-July 2019

**Output phase 4**

* A peer reviewed paper in a “remote sensing in geosciences” journal explaining the improved statistical laws to up- and down-scale soil moisture from the high resolution field scale to the satellite observed scale.

**2b. Knowledge utilisation**

Measuring soil moisture using Bluetooth and RFID signal strength has the potential to revolutionize many aspects of society and academia. Precision farmers get a complete overview of which parts of their fields are wet, which are dry and will use this information to fine tune irrigation on the individual plant level. More precise irrigation will lead to improved yields at higher water efficiencies and less water use by farmers, one of the biggest contributors to, for example, the current Californian drought.

Very detailed mapping of soil moisture field in experimental catchments will allow other scientists to answer a key open question in current hydrology: how much of the water that percolates into the earth is preferential flow (flow through fast channels within the earth) versus matrix flow (flow through the regular soil). This, in turn, will lead to better predictability of the rainfall-runoff relations (how fast does rainfall end up in a river) and thus: flood forecasts.

Finally, better understanding of soil moisture states and processes feeds back into the land-surface component of atmospheric models, improving our weather forecasts and climate scenarios.

Achieving all of this requires active outreach to different communities. Through projects such as TAHMO [18], I have access to a large network of on-the-ground practitioners and sensor design professionals. Working together with sensor design companies that already have sales networks in the agricultural sector, we will introduce the novel sensing technique to a wide audience of potential users. After successful completion of phase 2 (see above), trade shows of agricultural and meteorological sensing equipment will be joined to present our novel method. From my work in our start-up Disdrometrcis, which develops rain gauges, I have a good network within this community.

Reaching out to fellow academics in other disciplines will be done by joining them at their own conferences, presenting my work in their midst. Luckily, the geosciences have two very broad conferences each year (the EGU General Assembly and the AGU Fall Meeting), where scientists from all corners of geoscience come together. Through my current post-doc project: the eWaterCycle project [19], I have good personal network within the operational forecasting community, including an invitation to present my recent work at ECWMF (global weather forecasting agency of the EU). The results of phase 3 and 4 will be presented at these meetings to inform the broader academic community.

Finally, using a device originally intended for consumers and re-inventing it to be used as a scientific measurement device is a very attractive narrative to bring science closer to the general public. I have used this type of narrative before to explain my work on developing rain gauges. I am a columnist for a major Dutch newspaper and have appeared in multiple science based television programs. Furthermore, the BBC has covered my work on my umbrella raingauge as well as my work on modelling the escape from Alcatraz. Getting the BBC involved is always a good way to get international attention to once work. During phase 1 and 2, I will actively involve my network of journalists (both national and international) to communicate the societal importance of the work that this VENI proposal funds to a broad public.

**2c. Number of words used: section 2a** 1998\_\_\_\_\_\_\_\_\_\_ (max. 2000 words)

**Number of words used: section 2b** 529\_\_\_\_\_\_\_\_\_\_\_ (max. 750 words)

**2d. Literature references**

[1] Shiklomanov, Igor A. "World water resources." *A new appraisal and assessment for the 21st century* (1998).

[2] Mittelbach, H., Lehner, I., & Seneviratne, S. I. (2012). Comparison of four soil moisture sensor types under field conditions in Switzerland. *Journal of Hydrology*, *430-431*, 39–49. <http://doi.org/10.1016/j.jhydrol.2012.01.041>

[3] Barrett, B., Dwyer, E., & Whelan, P. (2009). Soil Moisture Retrieval from Active Spaceborne Microwave Observations: An Evaluation of Current Techniques. *Remote Sensing*, *1*(3), 210–242. <http://doi.org/10.3390/rs1030210>

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[8] Soontornpipit, Pichitpong, et al. "Optimization of a buried microstrip antenna for simultaneous communication and sensing of soil moisture." *Antennas and Propagation, IEEE Transactions on* 54.3 (2006): 797-800.

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[11] Ting, Jacky SL, et al. "A dynamic RFID-based mobile monitoring system in animal care management over a wireless network." *Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007. International Conference on*. IEEE, 2007.

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[14] Yi, Chin A., et al. "Coregistered whole body magnetic resonance imaging‐positron emission tomography (MRI‐PET) versus PET‐computed tomography plus brain MRI in staging resectable lung cancer." *Cancer* 119.10 (2013): 1784-1791.

[15] Kemna, Andreas, Bernd Kulessa, and Harry Vereecken. "Imaging and characterisation of subsurface solute transport using electrical resistivity tomography (ERT) and equivalent transport models." *Journal of Hydrology*267.3 (2002): 125-146.

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|  |
| --- |
| **Cost estimates** |

**3a. Budget**

Also check the Explanatory Notes accompanying the form.

The maximum amount of a Veni grant is € 250,000 spread over a period of maximum 3 years. If the proposed research is of shorter duration, the maximum amount will be reduced accordingly.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Description** | | | **Year 1** | **Year 2** | **Year 3** | **Total** |
| **Staff** |  | **FTE\*\*** | **Months** |  |  |  |  |
| WP\* | **Applicant** | 0.9 | 36 | 66.621 | 67.620 | 68.634 | 202.875 |
| NWP\* |  |  |  |  |  |  |  |
| **Total Staff** |  |  |  | **66.621** | **67.620** | **68.634** | **202.875** |
| Equipment | Lab equipment for phase 1 | | | 10.000 |  |  | 10.000 |
|  | Field equipment for phase 2 | | |  | 15.000 |  | 15.000 |
| **Total Equipment** |  | | | **10.000** | **15.000** |  | **25.000** |
| Materials | Lab materials | | | 10.000 |  |  | 10.000 |
|  | Field materials | | |  | 5.000 |  | 5.000 |
| **Total Materials** |  | | | **10.000** | **5.000** |  | **15.000** |
| Travel | Visit to Oregon State University | | | 14.000 |  |  | 14.000 |
|  | Visit to TERENO field site | | |  | 5.000 |  | 5.000 |
|  | Two conferences per year | | | 5.000 | 5.000 | 5.000 | 15.000 |
| **Total Travel** |  | | | **19.000** | **10.000** | **5.000** | **34.000** |
| Other | Printing, cost related to outreach | | | 1.000 | 1.000 | 1.000 | 3.000 |
| **Total Other** |  | | | **1.000** | **1.000** | **1.000** | **3.000** |
|  |  | | |  |  |  |  |
| **Grand total** | | | | 106.621 | 98.620 | 74.634 | **279.875** |

* Use for each staff member, type of equipment, type of investment or type of material one row. You can add rows under the (bold print) headings. You cannot add headings.
* Years are Project Years. For example: if your intended starting date is 1 October 2016, then Year 1 ranges from 1 October 2016 to 30 September 2017. Etcetera.

\* WP = Scientific Staff; NWP = Non Scientific Staff

\*\* Fill out the time you spend on your Veni (including any FTE that your university

may pay for work on your Veni). If your university pays (part of) the time you spend

on your Veni you can indicate this in 3b.

**3b. Cofinancing ‘in kind’**

|  |  |  |
| --- | --- | --- |
| **Cofinancer/party** | **Description** | **Estimated value in Euro** |
| Oregon State University | Will host and support me during a lab visit | €10.000 |
| Delft University of Technology | Delft University of Technology will pay the difference between a typical VENI applicant and my current salary level. | €20.478 |

**3c. Cofinancing ‘in cash’**

|  |  |  |
| --- | --- | --- |
| **Cofinancer/party** | **Description** | **Euro** |
| N/A |  |  |

**3d. Totals**

|  |  |
| --- | --- |
| **Grand total** | € 279.875 (=3a) |
| **Requested budget** | € 249.397 (=3a minus 3b/3c) |

**3e**. **Intended starting date**

August 1st 2016.

**3f. Have you requested any additional grants for this project either from NWO or from any other institution, and/or has the same idea been submitted elsewhere?**

No

|  |
| --- |
| **Curriculum vitae** |

# 4a. Personal details

Title(s), initial(s), first name, surname: dr. ir. Rolf Willem Hut

Date and place of birth: 28 november 1980, Amsterdam

Nationality: Dutch

## **4b. Master's (‘doctoraal’)**

University/College of Higher Education: Delft University of Technology

Date: 01/02/2005

Main subject: Applied Physics, acoustics.

# 4c. Doctorate

University/College of Higher Education:

Starting date: 01/04/2007

Date of PhD award: 01/11/2013

Supervisor (‘Promotor’): Nick van de Giesen

Title of thesis: New Observational Tools and DataSources for Hydrology

# 4d. Work experience since completing your PhD

Current and previous positions. Specify per appointment: period, number of fte, type of position and institution.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Position** | **Period (date-date)** | **Number of fte** | **Type of position** (fixed term, permanent, tenure track, other) | **Institution** |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Researcher | 01/02/2005-31/12/2005 | 1.0 | Fixed term | Delft University of Technology |
| Senior Statistical Researcher | 01/03/2006-31/12/2010 | 1.0 (01/03/2006-31/03/2007) then 0.6 (01/04/2007-31/12/2010) | Permanent | Dutch Statistics (Centraal Bureau voor de Statistiek) |
| CTO | 01/12/2011-present | 0.1 | Permanent (founder) | Disdrometrics (start-up) |
| Columnist | 26/04/2014-present | 0.1 | Free lance | De Volkskrant |
| Post Doc | 1/11/2013-present | 1.0 | Permanent | Delft University of Technology |

# Work experience in months spent since completing your PhD

Please include the calculation (see notes)

|  |  |
| --- | --- |
| **Experience** | **Number of months** |
| Research activities | 20 (27 months since PhD, minus all other activities) |
| Education | 3 (no formal assignment, but I teach a course which took about this much time) |
| Care or sick leave | 0 |
| Management tasks | 0 |
| Other, please specify | 4, I took all the leave that had build up during my PhD to write and publish a book aimed at the general public: “Rolfs Maakbare Wereld”, on tinkering solutions to everyday situations in and around the home |

# 4e. Academic staff supervised

|  |  |  |
| --- | --- | --- |
|  |  | **Please indicate your (formal) role** |
| **Master students** | 6 students | Daily supervisor |
| *Subtotal master students* | 6 students |  |
| **Other** |  |  |
| International exchange student (msc) | 1 student | Daily supervisor |
| Bsc thesis | 5 students | Daily supervisor |
| High school students (profielwerkstukken) | 4 students | External supervisor |
| *Subtotal other* | *6* |  |

# 4f. Brief summary of research over the last five years

([Rx] refers to publication number x in my publication list, provided at point 5b, below)

My research has always been about unintended uses of datasources and equipment, backed by a solid understanding of signal analyses and statistics.

Since 2010 I have been involved in the TAHMO project, which aims to install 20.000 weather stations in sub Saharan African [R3]. To achieve this goal, current generation weather sensors need to come down in price, an effort that most of my PhD work supported by researching novel measurement methods. [R28]

During my PhD I developed an acoustic rain gauge based on low cost piezo technology on which start-up Disdrometrics was based. I developed an integrating rain gauge based on a mass spring system [R6]. I used a game console, the Nintendo Wii, to measure water levels [R7] and I combined demographic data with water quality samples to determine which population group living in the Rhine basin uses which pharmaceuticals [R4].

The data unlocked by the TAHMO project will revolutionize hydrological forecasting but also confront us with new challenges, one of which I tackled in my first post-doc as part of the eWaterCycle project: devising a memory efficient variant of the Ensemble Kalman Filter (EnKF) [R1]. This will allow future global hydrological models at hyperresolution to run seamlessly on high performance computer architecture (supercomputers) [R2].

During my post doc I worked on the high resolution real time operational forecasting systems and continued my passion for designing novel sensors that feed data into these systems, closing the gap between experimental and modelling hydrologists, as is evident from my most recent papers. [R1, R2, R5, R13, R16]

(Max. 250 words, words used: 246)

# 4g. International activities (see Notes)

* During my PhD I collaborated with Oregon State University, being invited to work two weeks at their lab in Corvallis, Oregon. This collaboration lead to a joint paper on a novel rain gauge [R6].
* As part of the TAHMO project, which aims to install 20.000 weather stations in sub Saharan Africa, I spend a week in Nairobi, hosting the first “TAHMO Sensors Design Competition Finale” in which teams from all over Africa came together in Nairobi for a week of collaboration on weather station design. [R3, R20, R21]
* 3 of my Msc students and 3 of my Bsc students did (part of their) work abroad: one in the US (at the Ace Basin National Estuarine Research Reserve) and the rest in Africa [R22]. I coordinated with foreign counterparts about their work and supervision.

**4h. Other academic activities** (see Notes)

* Associate editor for “Frontiers in earth science” since 2014
* I initiated and convene the “Transformative Measurements to Understand the Geosphere: Zip-Ties, Arduinos, Novel Sensors, and Twitter” Session at the AGU Fall meeting and the “Innovative techniques and unintended use of measurement equipment” session at the EGU general assembly, both since 2010. In these sessions, geoscientists present novel sensors, or unintended uses of existing equipment or data-sources.
* A special issue in “Frontiers in earth sciences” based on the contributions to these sessions over the last six years is forthcoming.
* From January 2012 till December 2013 I was student representative of the hydrology section of the American Geophysical Union. I was the first to hold that, than new, post. In that position I initiated and motivated students to actively be part of the union and organize events for themselves, by themselves. Based on my actions, some student run activities, such as the TED-like “pop-up-session”, are now a fixed part of the AGU program.
* In 2014 I will start as member of the “Outstanding Student Presenter Award”-committee of the AGU.

**4i. Scholarships, grants and prizes**

Please list the research scholarships/grants and a link to the website for which you have successfully applied and/or prizes that you have won and indicate the amount of money involved.

\*In case of a consortium grant please specify the amount allocated for your own group or lab.

|  |  |  |  |
| --- | --- | --- | --- |
| **Scholarship/Grant/ Prize**  **Formal applicant** | **Amount** | **\*** | **Year of award** |
| Amazon Web Service Research Grants | €5.000 |  | 2015 |
| Clean Tech Business Day: Business Competition | €25.000 |  | 2014 |
| *Subtotal* | €30.000 |  |  |
| **Scholarship/Grant/Prize Formal co-applicant** |  |  |  |
| European Union’s Seventh Programme for research, technological development and demonstration. Grant agreement No 308429. | €300.000 | Start-up Disdrometrics received this grant as part of the WeSenseIt project, in which circa $6.000.000 was granted to a consortium of 12 European partners. | 2013 |
|  |  |  |  |
| *Subtotal* | €300.000 |  |  |
|  |  |  |  |
| *Total* | **€330.000** |  |  |

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| **Output** |

**5a. Output indicators**

The most important output indicator in hydrology is a person’s h-index, based on refereed articles (my h-index currently stands at 7). The most important journals in hydrology (Journal of hydrology, Water Resources Research, Hydrology and Earth System Sciences, Advances in Water Resources, Hydrological Sciences Journal) share nearly identical impact factors, making the comparison on impact factor of journals less important within this field. Furthermore, the number of articles one publishes outside of the classical hydrological journals is seen as an indicator of interdisciplinary merit.

**5b. Output**

Please number your items consecutively and also indicate the total number per category. For publications and letters: only mention those that have been published or have been accepted for publication starting with the most recent publication, do **not** list any forthcoming publications. Please mark key publications that are directly relevant to the proposed research with an S (the S stands for significant).

* **Refereed articles (12)**

**S** [R1] **Hut, R**., Amisigo, B. A., Steele-Dunne, S., & van de Giesen, N. (2015). Reduction of Used Memory Ensemble Kalman Filtering (RumEnKF): a data assimilation scheme for memory intensive, high performance computing. *Advances in Water Resources*. http://doi.org/10.1016/j.advwatres.2015.09.007

[R2] Bierkens, M. F. P., Bell, V. A., Burek, P., Chaney, N., Condon, L. E., David, C. H., et al. (including **Hut, R.**) (2015). Hyper‐resolution global hydrological modelling: what is next? *Hydrological Processes*, *29*(2), 310–320. http://doi.org/10.1002/hyp.10391

**S** [R3] van de Giesen, N., **Hut, R**., & Selker, J. (2014b). The Trans-African Hydro-Meteorological Observatory (TAHMO). *Wiley Interdisciplinary Reviews: Water*, http://doi.org/10.1002/wat2.1034

[R4] **Hut, R**., van de Giesen, N., & Houtman, C. J. (2013). Medicinal footprint of the population of the Rhine basin. *Environmental Research Letters*, *8*(4), 044057. http://doi.org/10.1088/1748-9326/8/4/044057

[R5] Hrachowitz, M., Savenije, H. H. G., Blöschl, G., McDonnell, J., Sivapalan, M., Pomeroy, J. W., et al. (including **Hut, R.**) (2013). A decade of Predictions in Ungauged Basins (PUB) - a review. *Hydrological Sciences Journal*, 130522102535005. http://doi.org/10.1080/02626667.2013.803183

**S** [R6] Stewart, R. D., **Hut, R**., Rupp, D. E., Gupta, H., & Selker, J. S. (2012). A resonating rainfall and evaporation recorder. *Water Resources Research*, *48*(8), W08601–. http://doi.org/10.1029/2011WR011529

**S** [R7] **Hut, R. W**., Weijs, S. V., & Luxemburg, W. M. J. (2010). Using the Wiimote as a sensor in water research. *Water Resources Research*, *46*(12), W12601. http://doi.org/10.1029/2010WR009350

[R8] van Overloop, P., Miltenburg, I., Bombois, X., Clemmens, A., Strand, R., van de Giesen, N., & **Hut, R**. (2010). Identification of resonance waves in open water channels. *Control Engineering Practice*.

[R9] Ertsen, M., & **Hut, R.** (2009). Two waterfalls do not hear each other. Sand-storage dams, science and sustainable development in Kenya. *Physics and Chemistry of the Earth, Parts a/B/C*, *34*(1-2), 14–22.

[R10] Quilis, R., M Hoogmoed, Ertsen, M., Foppen, J., **Hut, R.,** & Vries, A. (2009). Measuring and modeling hydrological processes of sand-storage dams on different spatial scales. *Physics and Chemistry of the Earth, Parts a/B/C*, *34*(4-5), 289–298.

[R11] **Hut, R.,** Ertsen, M., Joeman, N., Vergeer, N., Winsemius, H., & Van de Giesen, N. (2008). Effects of sand storage dams on groundwater levels with examples from Kenya. *Physics and Chemistry of the Earth, Parts a/B/C*, *33*(1-2), 56–66.

[R12] **Hut, R.,** Boone, M., & Gisolf, A. (2006). Cochlear modeling as time-frequency analysis tool. *Acta Acustica United with Acustica*, *92*(4), 629–636.

* **Non-refereed articles (1)**

Articles published in journals of the European Geophysical Union go through a two tier review system. First a review by peers and the editor to judge the fitness of the work to the scope of the journal. Once through this first tier, articles are published in “open discussion review” for review by the community. The following article has cleared the first stage and is currently in open review.

**S** [R13] **Hut, R**., Tyler, S., and van Emmerik, T.: Proof of concept: temperature sensing waders for environmental sciences, Geosci. Instrum. Method. Data Syst. Discuss., 5, 427-445, doi:10.5194/gid-5-427-2015, 2015.

* **Presentations at conferences (more than 50, 13 mentioned here)**

I have presented more than 50 posters and talks at the main two conferences in the geosciences (EGU General Assembly and AGU Fall Meeting). For brevity, only those relevant to this proposal have been listed. For a full list, see my profile on Google-Scholar.

**S** [R14] **Hut, R. W.**, and Richard De Jeu. "Where did my wifi go? Measuring soil moisture using wifi signal strength." *Geophysical Research Abstracts, 17, EGU General Assembly, Vienna, Austria, 12-17 April 2015; EGU2015-8426*(2015).

**S** [R15] Van Overloop, Peter-Jules, and **R. W. Hut.** "Reading gate positions with a smartphone." *Geophysical Research Abstracts, 17, EGU General Assembly, Vienna, Austria, 12-17 April 2015; EGU2015-6967* (2015).

**S** [R16] **Hut, R. W.**, and Scott Tyler. "Stream temperature and stage monitoring using fisherman looking for fish." *Geophysical Research Abstracts, 17, EGU General Assembly, Vienna, Austria, 12-17 April 2015; EGU2015-8437*(2015).

**S** [R17] Baart, F., et al. (including **Hut, R.**) "Reconstructing the Alcatraz escape." *AGU Fall Meeting Abstracts*. Vol. 1. 2014.

**S** [R18] **Hut, Rolf**, Stijn de Jong, and Nick van de Giesen. "Using umbrellas as mobile rain gauges: prototype demonstration." *EGU General Assembly Conference Abstracts*. Vol. 16. 2014.

**S** [R19] **Hut, R.**, N. Van De Giesen, and R. Hagenaars. "Quick and low cost measurement of soil parameters using a Kinect 3D scanner." *AGU Fall Meeting Abstracts*. Vol. 1. 2013.

**S** [R20] **Hut, R.**, and N. Van De Giesen. "The TAHMO sensor design challenge: unlocking and empowering local African talent." *AGU Fall Meeting Abstracts*. Vol. 1. 2013.

**S** [R21] Van De Giesen, N., et al. (including **Hut, R.**) "Trans-African Hydro-Meteorological Observatory (TAHMO): A network to monitor weather, water, and climate in Africa." *AGU Fall Meeting Abstracts*. Vol. 1. 2013.

**S** [R22] Kooreman, Bouke, et al. (including **Hut, R.**) "Measuring vegetation water content by looking at trees blowing in the wind." *EGU General Assembly Conference Abstracts*. Vol. 15. 2013.

**S** [R23] **Hut, Rolf**, Stijn de Jong, and Nick van de Giesen. "Just in time maintenance using continuous rainfall and water level measurements on individual gullypots." *EGU General Assembly Conference Abstracts*. Vol. 15. 2013.

**S** [R24] van der Sterre, Boy-Santhos, **Rolf Hut**, and Nick van de Giesen. "Accurately measuring volume of soil samples using low cost Kinect 3D scanner." *EGU General Assembly Conference Abstracts*. Vol. 15. 2013.

**S** [R25] **Hut, Rolf**, et al. "Design and field test of a robust acoustic disdrometer for distributed rainfall observations." *EGU General Assembly Conference Abstracts*. Vol. 15. 2013.

**S** [R26] Stewart, R., et al. (including **Hut, R.**) "New Rainfall and Evaporation Recorder." *EGU General Assembly Conference Abstracts*. Vol. 14. 2012.

* **Book chapters (1)**

[R27] **Rolf Hut** and Michel Frijns, *Weggeven is een goed idee*, chapter in “*Nederland in ideeën*”, Maven publishing, ISBN 9789490574987 (2013, October, in Dutch)

* **Books (2)**

[R28] **Hut, R. W.** *New Observational Tools and Datasources for Hydrology*. (N. C. van de Giesen, Ed.). Delft University of Technology, Delft. (2013, October 1st). [PhD Thesis]

[R29] **Rolf Hut,** *Rolfs Maakbare Wereld*. Xander Uitgevers, Amsterdam. ISBN 9789401604123

(2015, October, in Dutch)

* **Other**

I actively involve journalists in my outreach activities. This has resulted in my work being covered widely on (international) media, such as my work on equipping an umbrella with a rain gauge [R18] being covered on the BBC (<http://rolfhut.nl/2014/05/01/umbrella-bluetooth-iphone-raingauge-on-bbc-news/>). Or my work on modelling the escape from Alcatraz [R17], which resulted in world wide media coverage, as well as a forthcoming documentary on PBS (in the US) and Discovery Channel (in Europe). See <http://rolfhut.nl/alcatrazenglish/> for details.

This active approach towards journalist has also resulted in other outreach opportunities, such as an appearance on Dutch science program “De Wereld Leert Door” and being invited as one of only a handful of not-yet-full-professors to give a public lecture at “De Universiteit van Nederland”.

**5c. Top- publications** (see Notes, **max. 5**)

**Hut, R**., Amisigo, B. A., Steele-Dunne, S., & van de Giesen, N. (2015). Reduction of Used Memory Ensemble Kalman Filtering (RumEnKF): a data assimilation scheme for memory intensive, high performance computing. *Advances in Water Resources*. http://doi.org/10.1016/j.advwatres.2015.09.007

**Hut, R**., van de Giesen, N., & Houtman, C. J. (2013). Medicinal footprint of the population of the Rhine basin. *Environmental Research Letters*, *8*(4), 044057. http://doi.org/10.1088/1748-9326/8/4/044057

Hrachowitz, M., Savenije, H. H. G., Blöschl, G., McDonnell, J., Sivapalan, M., Pomeroy, J. W., et al. (including **Hut, R.**) (2013). A decade of Predictions in Ungauged Basins (PUB) - a review. *Hydrological Sciences Journal*, 130522102535005. http://doi.org/10.1080/02626667.2013.803183

Stewart, R. D., **Hut, R**., Rupp, D. E., Gupta, H., & Selker, J. S. (2012). A resonating rainfall and evaporation recorder. *Water Resources Research*, *48*(8), W08601–. http://doi.org/10.1029/2011WR011529

**Hut, R. W**., Weijs, S. V., & Luxemburg, W. M. J. (2010). Using the Wiimote as a sensor in water research. *Water Resources Research*, *46*(12), W12601. http://doi.org/10.1029/2010WR009350

**5d. Median impact factors for your own field**

N/A.

|  |
| --- |
| **Statements by the applicant** |

**My thesis manuscript has been approved and I will send the official declaration to NWO.**

(Compulsory for Veni applicants who have not yet received their doctorates, to be sent by post and as a PDF using the electronic system.)

**Ethical aspects**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Not applicable | Not yet applied for | Applied for | Received |
| Approval from a recognised medical ethics review committee | x |  |  |  |
| Approval from an animal experiments committee | x |  |  |  |
| Permission for research with the population screening Act | x |  |  |  |

If applicable you need to send a copy of (one of) the aforementioned documents to NWO when your application has been granted and before the start of your project.

By signing this form I endorse the code of conduct for laboratory animals and the code of conduct for biosecurity/possibility for dual use of the expected results and will act accordingly if applicable.

x I have completed this form truthfully.

x By submitting this document I declare that I satisfy the nationally and internationally accepted standards for scientific conduct as stated in the *Netherlands Code of Conduct for Scientific Practice* *20121* (Association of Universities in the Netherlands)

I have submitted non-referees.2

Name: Rolf Hut

Place: Haarlem

Date: January 3rd, 2016.

1 More information: <http://www.vsnu.nl/files/documenten/Domeinen/Onderzoek/The_Netherlands_Code_of_Conduct_for_Scientific_Practice_2012.pdf>

2 It is possible to indicate non-referees (maximum of three names). The non-referees will NOT be asked to assess your application. Do not incorporate the names in the application. Please submit a separate PDF file with the names of non-referees via the electronic system at the same time as your proposal.

Please submit the application to NWO in electronic form (PDF format is required!) using the ISAAC system, which can be accessed via the NWO website (isaac.nwo.nl). The only exception to this rule concerns applications within the Medical Sciences. The Medical Sciences division uses a similar system called ProjectNet, to which access is provided via the division’s own website ([www.zonmw.nl](http://www.zonmw.nl/)). For any technical questions regarding submission, please contact the ISAAC helpdesk ([isaac.helpdesk@nwo.nl](mailto:isaac.helpdesk@nwo.nl)).