

Manual for the Delft Nile Sampler (DNS) at Utrecht

Author: **Maarten G. Kleinhans**, Dept. Physical Geography, Fac. Geosciences, Institute for Marine and Atmospheric Research (IMAU), Utrecht University, The Netherlands, m.kleinhans@geo.uu.nl, t+31 30 2532405, f+31 30 2531145, www.geog.uu.nl/fg/mkleinhans and www.coastalresearch.nl

Version: June 2, 2005

Introduction

This document contains a practical manual for measuring bedload transport with the Delft Nile Sampler manufactured by the Laboratory for Physical Geography of the University of Utrecht. Leo van Rijn designed the instrument (Van Rijn and Gaweesh, 1992). For general information and calibration reference is made to papers and reports. The practical information is based on the experience of the author in measurements in flumes and in the rivers Waal, Pannerdensch Kanaal, Merwede (all in the Netherlands), Mississippi and in the North Sea at a water depth of 13 and 18 m. The conditions range from large transport rates in suspension-dominated flow to very near the beginning of motion, from 0.1-0.5 m water depth in the flumes to 5-25 m water depth in the field conditions, and from fine sand to coarse gravel.

First the various parts of the sampler are described. Then the philosophy behind the design is described, which is necessary to apply the instrument appropriately. Next, the calibration data of Gaweesh and Van Rijn (1994) is summarised. Finally, as a desert, a short history of bedload samplers is given.

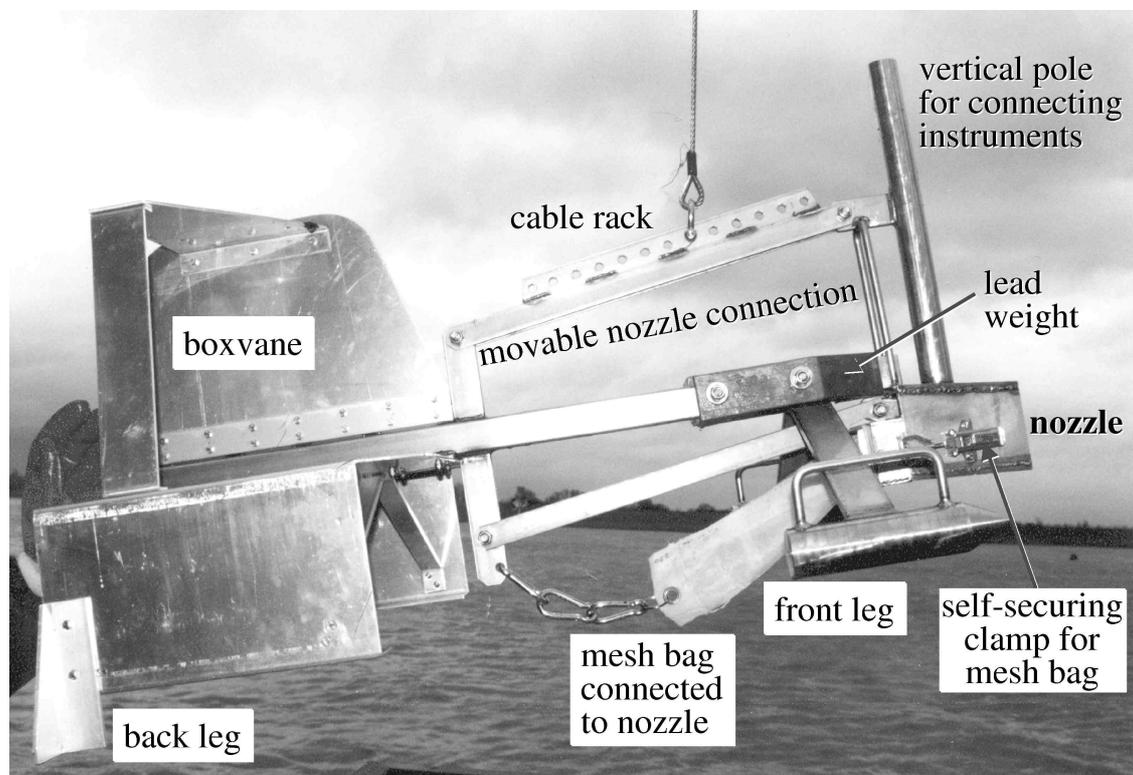


Figure 1. The Delft Nile Sampler. The flow would be from right to left. Photo courtesy: Roy Frings.

Parts of the DNS

The DNS (Fig. 1) basically consists of the **nozzle** that catches the sediment, a **box vane** to orient the sampler towards the flow and a **frame** that connects these parts. The boxvane is more stable in the current than a normal (inverted 'T') vane. It is possible to mount small pressure sensors or electronics boxes in the vane without disrupting its function. There are **two hind legs** on the box vane, which prevent that the vane rests on a stone or shell rather than on the sand. More importantly, the sharp legs dig into the sand which fixes the sampler to its position and thus prevents dredging of sediment because the nozzle is scraping over the sediment bed. The frame has holes for **lead weights** which are necessary to get the sampler down to the bed. The larger the depth and/or flow velocity, the more weight should be put on the DNS. Depending on the number of weights and the added instruments, the total weight of the DNS is 40-200 kg. There are a number of holes for the cable to the winch in the **cable rack**, which allows balancing of the sampler with different weights and instruments connected to it. The two **forelegs** are streamlined and for the Utrecht version of the DNS also has holes for extra lead weights. The nozzle is the most important part of the sampler and has the same dimensions within machine accuracy as the prototype DNS. The nozzle is connected to the **mesh bag** with **self-securing clamps**. The nozzle front is about 0.1x0.1 m, but the upper half of the nozzle does not feed the sediment into the mesh bag but back into the flow. The sediment entering the lower half of the nozzle, which has a width of 0.096 m and a height of 0.050 m, is caught in the mesh bag. The mesh bag has a mesh size of 150 or 250 μm , optionally with a patch of 500 μm on the top of the bag to prevent the blocking effect by wash load and organic material. The 150 μm mesh bag is most appropriate for fine sandbed rivers and the Dutch coastal waters, and the 250 μm is more appropriate for coarse-bedded rivers.

How the sampler works

First, a number of general problems with basket-type samplers like the Helley Smith are discussed, and then how this was solved by Leo van Rijn in the design of the DNS. This insight is necessary to appreciate the practical handling of the sampler in the field. All improvements were tested in various field and laboratory experiments.

The main problem of the Helley Smith is that the sampler disturbs the flow and generates near-bed turbulence. As a consequence, scour holes develop under the nozzle and under the frame to which the nozzle is connected. The effect is that part of the sediment passes by the nozzle and/or the nozzle digs into the bed.

The nozzle of the DNS is completely free from connections to the frame except at the nozzle top where it does not affect the near-bed flow. In addition, the nozzle is the most upstream part of the sampler, so that legs and other constructions do not affect the near-bed flow too much. The nozzle has a slightly downstream upsloping floor so that the nozzle entrance rests on the sand but the floor of the nozzle barely does, so a small shell or stone under the nozzle will not lift it above the sediment. The nozzle is also sharpened at the front so that it does not cause much turbulence which could lead to scour. Most importantly, the nozzle is connected to the frame in a movable way. When the sampler is suspended from the winch cable, the nozzle is lifted above the bottom level of the box vane and the forelegs. So, when the sampler lands on the bed, it first lands the box vane (assuming that the suspended sampler is slightly out of equilibrium with the box vane at a lower level than the forelegs), then the forelegs, and finally, when the cable is further released, it lands the nozzle. In this way any sediment that is suspended in the landing is not sampled, and any initial movements made by the sampler over the bed before the hind legs dig into the bed do not cause dredging by the nozzle scraping over the bed.

The original Helley Smith is a pressure-difference sampler. This means that the nozzle expands, which leads to flow acceleration. This is intended to counteract the pressure generated by the

mesh bag. Depending on the nozzle shape, mesh size and filling of the bag the flow accelerates or decelerates in the nozzle and extra or less sediment is sucked into the sampler.

The DNS barely is a pressure-difference sampler, as the nozzle is barely diverging. The hydraulic coefficient of the DNS was computed from the velocity measured 2 m upstream of the sampler and in the entrance of the nozzle with a small (0.02 m) propellor in the laboratory (Van Rijn and Gaweesh, 1992). The hydraulic coefficient is near unity for 0.5-0.8 m/s (test range) but decreases slightly when the mesh bag fills with sediment. For a filling percentage of 50% the decrease still is only a few percent. This is partly due to the mesh bag which (optionally) has a patch of 500 μm on its top, which allows the flow out of the bag while dragging the sediment far into the bag.

In all cases where the sampler is deployed from a ship, it is very important that the ship is well fixed onto its position. Any movement of the ship will cause extra drag on the cable, which may lift the nozzle from the bed, or, worse, drag the sampler over the bed. Such drift will cause dredging of bed material into the nozzle.

Despite the intricate design of the Nile sampler it is still possible that the instrument does not function well, for example in very fast flows over very soft sediments. In that case the risk of dredging samples is much larger. A small camera with a lamp could be mounted on the sampler to monitor the behaviour of the sediment near the nozzle and of the nozzle during landing and lifting. This is only possible, however, when the concentration of fines is not so large that the camera is blinded.

Assembling the sampler

First, the sampler is assembled as follows:

- a. The mesh bag is connected to the nozzle with the self-securing clamps. To release the bag, the red buttons on the clamps are pulled towards the box vane and the clamps pulled outwards. In cold weather strong water-tight (rubberish) gloves are useful to protect your hands against sharp parts.
- b. Lead blocks are connected to the frame. The number depends on the conditions, but it is advised to put on at least four blocks. First, two blocks with the rounded tops forward in the most forward position on both sides of the frame (towards the nozzle). Next, two other blocks to the back of the former two, with the rounded parts backwards (towards the box vane). Next, one or two pairs of blocks on top of (not below) the first and second pair. If more lead is needed, these can be attached to the forelegs. The latter may affect the flow just upstream of the nozzle.
- c. Extra instruments are connected to the frame (preferably with clamps on the long vertical pole on top of the nozzle). This could be propellor type or electromagnetic current sensors and a pressure sensor, and possibly suction tubes or OBS instruments for suspended sediment sampling or measurements. Also a small video camera could be mounted but in turbid water the distance between camera and nozzle becomes so small that the calibration is affected dramatically (Delft Hydraulics, 1996). All cables and hoses are connected to the moving part of the sampler with tie-wraps. Care must be taken that the nozzle can move freely in the frame (enough cable between the instruments and the cable rack). I advise against too many cables and hoses to the surface because the drag on a thick umbilical cord over the whole water depth will lift the sampler nozzle from the bed. If electrical cables must be used then an integrated cable is preferred.
- d. Finally, the steel cable (or nylon rope) is connected to the sampler in such a way that the balance is slightly tipped to the box vane. So, when the tripod is suspended from the cable, the box vane hangs in a lower position (say, 0.1 m below the forelegs). In this way, the box vane catches the first of the flow and the sampler will orient to the flow very fast without spinning and messing up cables etc.

At the same time, the ship must be made ready for sampling. The best way is to have a spud pole (a long metal pole through the ship which is pushed into the river or seabed), because then the ship is best fixed in its place. Alternatively, three- or four-point anchoring can be used with heavy anchors so that the cables can really be pulled tight. A one-point anchoring will almost certainly lead to drift of the ship, especially in reversing currents, which will lead to dredging of bed sediment. Dynamic positioning of the ship can only be used in deep water (say, water depth divided by depth of ship is at least a factor of 3-4), because otherwise the rotor-generated turbulence may affect the sediment transport.

When there are dunes or other large bedforms, the samples must be spread over the length of the dunes. This can be done either by letting the dunes migrate under the sampler, or by moving the ship. Using very long anchoring cables allow some manoeuvrability. See Gaweesh and Van Rijn (1994) and Kleinhans and Ten Brinke (2001) for sampling strategies. The presence of bedforms may imply large transport rates, in which case fast sampling and many samples are needed to cover the natural variation. With some knowledge of the bedform dynamics at the sampling site it is possible to plan the sampling rate and order in such a way that samples are collected over the length of the bedforms and over the full width of interest while the change in velocity and/or water depth is negligible (but see Kleinhans and Ten Brinke (2001) for a correction method in gradually changing flow, or use harmonic analysis when tides are dominant).

How to work with the sampler

Now, the order of actions when sampling is described. After clamping the mesh bag to the nozzle, the sampler can be lowered into the flow. Five to ten try-outs are needed before the samples can be trusted. If the sampler is simply lowered into the water straight onto the bed, a number of things may go wrong. It takes a little bit of time for the sampler to orient towards the flow. If the sampler is lowered too fast (especially in slow flow!), then the large box vane causes the sampler to tilt nose-downwards, which may cause dredging of sediment rather than sampling the bedload. In fast flows when the transport rate is large, the sampling time is short and therefore the timing of landing and lifting must be measured accurately. During the first try-outs one must get a feeling for the time it takes to lower the sampler to the bed and for the right sampling time. Finally, if the sampler hits the bed too fast then it will grab bed material and suspend it despite its design to prevent this.

1. When the sampler is submerged just below the water surface, wait some seconds until it has aligned to the flow. There is a very small probability that the mesh bag will fold double and block the flow. Usually it also emerges like that after a measurement so the problem is obvious. To prevent this one could connect the downstream end of the bag with an elastic rope to the sampler, but this costs extra time.
2. When lowering the sampler to the bed, look carefully while it is still near the surface whether the sampler is not lowered too fast with its nose downwards. Alternatively, when the winch operator has got a feeling for the cable length or time needed to lower the sampler to the bed, the first part of the descent can be done fast, and then the last (small) part slow and carefully.
3. When the cable is no longer tense from the weight of the sampler, it has landed. In strong flows this may be a problem. While the sampler is still on deck, adjust the winch until the cable is tense, the nozzle is just lifted from the floor but the forelegs are still standing on the floor (this is also a safe way to transport the sampler). Then try out how tense the cable feels when the nozzle is pulled further from the floor. At least the cable should be much less under tension than this when the sampler is on the river or seabed. If there are wind waves or waves from passing ships, this is especially important, because the added drag by the movements of the ship may lift the sampler and drop it back on the bed (which is not good).
4. Time with stopwatch or watch, start instruments, etc. Write down when ships pass by or when large wind waves come by. Notify the winch operator in time and count down three

seconds for lifting up. The sampling duration should be so small that at most only one out of ten samples fills the bag more than 40-50%. This may mean that the sampling time is only half a minute. When there are bedforms, most samples will be small and few will be large, but samples with volumes of up to 8-10 times the average are still correct and very important for the average transport rate (Hamamori, 1962). These samples are probably collected near the bedform top or just downstream of the bedform slipface. The sample size distribution may be very skewed due to superimposed variations (small dunes or bedload variations on top of large dunes). Alternatively, when the transport rate is very small and sampling durations of up to 30 minutes are necessary, the statistical distribution will be symmetrical about the mean except for samples where dredging took place. For these long sampling durations the risk of dredging is larger (one movement is enough...). For small sampling durations many samples are necessary for some accuracy, whereas for larger sampling durations less samples are needed (but note the scatter in Kleinhans and Grasmeijer (2005) for 40 minute sampling of extremely small transport rates).

5. Lift the sampler as fast as possible to prevent dredging, to save time and minimise the amount of suspended sediment caught in the sampler. If possible, the long arm of the crane is best moved in the flow direction so that the sampler is lifted in a more vertical direction to prevent dredging, and the long arm should then move as far upstream as possible when deploying the sampler.
6. Put the sampler on deck, change the mesh bag and deploy again. Meanwhile, empty the mesh bag into a bucket using water. The sand can then be collected into a graduated cylinder for submerged volume determination (shake a little and take care the sediment surface in the cylinder is horizontal) and then into a sampling bag or large bucket for combined samples for grain size analysis. Even if the weights of the samples will be determined in the lab it is still advised to measure the volume, because the pore space of the sediment is very constant between the measurements so the submerged volume is a very good approximation of the sediment weight which makes loss of samples or sample numbers written or stuck on the bags not a catastrophe. The pore space can be determined afterwards in the lab.

During the measurements (at least after the first experiences and try-outs) the zero-catch must be determined. This is the amount of sampled sediment due to the bumpy landing or the suspension of bed material during the landing, or the collection of suspended sediment in the descent and rise. This is done by lowering the sampler to the bed and immediately lifting it up again, and repeating this 5-10 times before collecting the sampled sediment. The sediment volume or weight caught in the zero sampling divided by the number of zero-samples is the zero-sampling correction which must be subtracted from all samples. When the transport rate is large, then it must be estimated how long (in seconds) the sampler stands on the bed, and after calculating the bedload transport rate the volume transported in that time should be subtracted from the zero sampling volume. It is likely that the zero-sampling volume is negligible if the sampling is done careful.

Calibration of the DNS

The calibration coefficient α is herein defined as true divided by measured bedload transport, and hence is the factor with which the measured transport must be multiplied to obtain the true (estimated) transport. To obtain the transport rate, the sampled volume must be corrected for pore space and the sampler width:

$$q_{truebedload} = \alpha \frac{(1 - p_{porespace})(V_{sample} - V_{zerosample})}{w_{samplerwidth=0.098m} t_{samplingtime}}$$

wherein $q_{truebedload}$ =estimate of the corrected bedload transport rate in m^3/s ; i.e. cubic meters per meter width per second, α =calibration factor, $p_{porespace}$ =pore space fraction, commonly 0.35-0.4,

V_{sample} =average sampled volume of bedload in m^3 , $V_{\text{zerosample}}$ =zerosampling volume of bedload in m^3 (divided by the number of zero samples), $w_{\text{samplerwidth}}$ =inner width of the sampler nozzle, and $t_{\text{samplingtime}}$ =sampling time of the bedload sample in seconds. If the dry weight of the samples is measured rather than the volume including pores, then the correction for pore space should not be done and the $q_{\text{truebedload}}$ is in kg/ms ; i.e. in kilogrammes per second per meter width.

There are various methods for calibrating bedload samplers (Kleinhans, 2001). The best known calibration is an extensive field calibration by Emmett (1980) of a hand-held '3 inch' Helley Smith (HS) in East Fork River, USA, (width 14.6 m, depth 0.5-1.2 m, poorly sorted gravel). The true transport and its composition were estimated with a conveyor belt which collects all the sediment passing the sampling cross-section of the river. Emmett found that the smallest size fractions were oversampled and the largest were undersampled. Hubbell (1987) calibrated the Helley Smith with the probability matching method, which compares true and sampled transport on the basis of their probabilities. Thomas & Lewis (1993) used a non-standard regression model (with parameters estimated by maximum likelihood) and found calibration coefficients about equal to unity for all sizes, although the variances of the coefficients were very large.

The DNS has been calibrated in a flume with many different uniform sediments (Gaweesh & Van Rijn, 1994, Fig. 2). The averages of sampled and true transport were compared for the calibration. The sediments were more or less uniform and the median diameter ranged from 280 to 1070 μm (see Table 2). The average calibration coefficient is $\alpha=1.0$, which is recommended for general use. The samples of the finest material have a lower calibration coefficient (0.81), which is probably caused by suspended load transport. This is also indicated by the dependence of the calibration coefficient on the Shields parameter. There is no obvious dependence of calibration coefficient on sampling period, sampled volume and the mesh size of the sampling bag. Recent DNS measurements in the river Rhine in the Netherlands (Frings and Kleinhans, in prep.) in comparison to dune tracking bedload determination demonstrates that the DNS also has a calibration factor of 1.5-1 for poorly sorted sand-gravel mixtures.

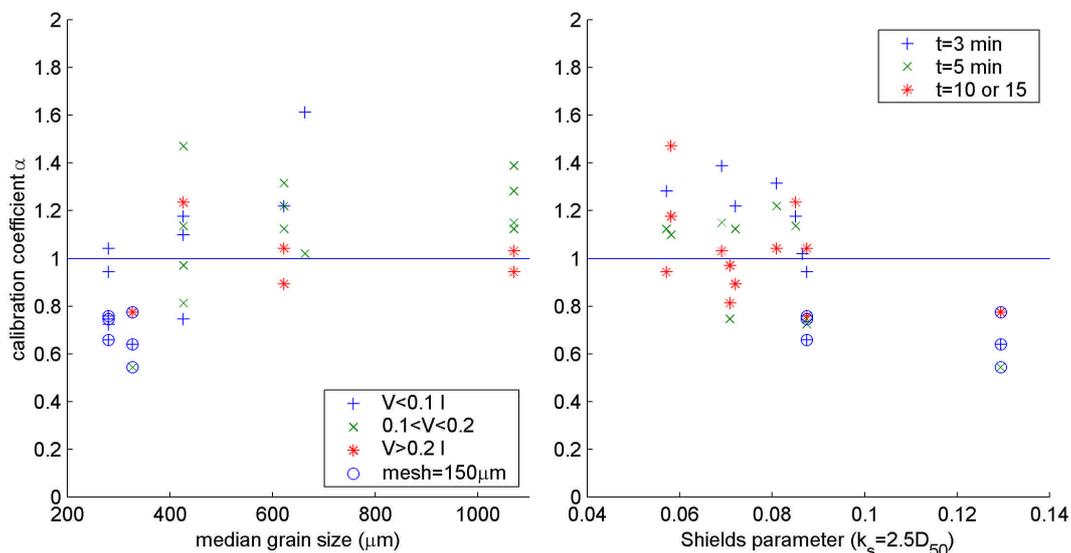


Figure 2. Calibration of the DNS based on data in Gaweesh and Van Rijn (1994). The calibration coefficient is plotted against median grain size (D_{50}) and the Shields parameter related to grain roughness ($k_s=D_{50}$), and the data are classified for sample volume V (in liters) and sampling time t (in minutes). All experiments were done with a mesh bag of 250mm except those indicated with 'mesh=150mm'. Each point represents 30-300 samples.

A short history of bedload samplers

In the thirties, several trap type bedload samplers were simultaneously developed in Europe. Most samplers were designed for shallow gravel-bed rivers where the samplers can be held by hand into the flow. Ehrenberger (1931) and Einstein (1937) (both in Hubbell 1987) reported on the calibration of an Austrian and a Swiss bedload transport sampler. In 1936 the Arnhem sampler or 'Bedload Transport Measurement device Arnhem' (BTMA) was developed in Arnhem, the Netherlands, by the Research Department of the Ministry of Transport, Public Works and Watermanagement ('Rijkswaterstaat') in cooperation with Delft Hydraulics. The development was initiated after several discussions with Prof. E. Meyer-Peter since 1932. The nozzle had a width of 8.5 cm and a height of 5 cm. The instrument was calibrated by Meyer-Peter (1937, in Havinga (1982)) in Zürich. After World War II it was redesigned and recalibrated. The improved BTMA was a pressure-difference sampler with a 'fish' (supporting structure with vanes) that released the nozzle on the bed after it had landed to prevent suspension of bed material due to the landing. The mesh size is 300 μm and the nozzle was attached to the mesh wire in a flexible way. The instrument was designed for coarse sand and fine gravel. The BTMA was lowered with its tail pointing down, aiming to prevent disturbance of the bed near the nozzle.

In 1971, E.J. Helley and W. Smith introduced a bedload sampler that was based on the BTMA. The sampler, named after their designers, is used all over the world today. The 'Helley Smith' (HS) had a square, expanding nozzle with 7.62 cm entrance, and a nylon bag with mesh size 200 to 250 μm . The Helley Smith was calibrated in the field by Emmett (1980) for coarse sand and fine gravel. The original instrument did not have a fish nor other constructions to prevent suspension due to disturbing the bed, because it was meant to be lowered to the bed manually in clear, shallow water. Since then many variations on the Helley Smith have been constructed, and many calibration reports are available. For use in deep water the nozzle is usually fixed tightly to a fish.

In 1992, Van Rijn and Gaweesh (1992) introduced a new trap type sampler, the Delft Nile sampler (DNS) with a less expanding nozzle to obtain a hydraulic efficiency of unity. This sampler was designed for sand-bed rivers, potentially with much suspension. Sand-bed rivers commonly are much deeper so the sampler can no longer be hand-held. Moreover, sandy beds are much more prone to scour than gravel beds. The nozzle had a width of 9.6 cm and a height of 5.0 cm. In their design they rehabilitated the BTMA structure that slowly releases the nozzle to the bed only after the fish has landed, which was necessary because the DNS was lowered from a boat on large rivers. Other refinements were the suspended sediment sampler (pump system), current meters and a video camera to monitor the processes at the nozzle. The mesh nylon bag had a mesh size of 150 or 250 μm , optionally with a patch of 500 μm to prevent the blocking effect by wash load and organic material. The sampler was calibrated in flume tests with several sediment sizes.

In 1996, several of the principles mentioned above were combined in one sampler called the Helley Smith Sand (HSS) by the Institute for Inland Water Management and Waste Water Treatment (RIZA). The original dimensions of the nozzle of Helley and Smith were restored and the Helley Smith fish was made heavier and given larger vanes (but not box vanes) for use in a deep river from a boat. The BTMA structure was applied that slowly releases the nozzle to the bed only after the fish has landed, refined with a damped spring construction aiming to prevent suspension on a sand bed. Also a current meter and a video camera were installed. The Helley Smith Sand was calibrated in a flume with sediment mixtures dredged from the field location for which it is used (Delft Hydraulics, 1996, 1997). Kleinhans (2002) listed a number of design problems of the Helley Smith Sand and demonstrated (based on the forementioned flume experiments and a comparison of field measurements and dunetracking) that the calibration coefficient of the HSS is as large as 2.74, indicating much undersampling. Since then, the DNS is used in the Dutch rivers.

References

- Blom, A. and Kleinhans, M.G. (1999). Non-uniform sediment in morphological equilibrium situations, Data Report Sand Flume Experiments 97/98. University of Twente, Rijkswaterstaat RIZA, WL|Delft Hydraulics. Report of University of Twente, Civil Engineering and Management, Enschede, The Netherlands
- Delft Hydraulics (1996). Test and calibration measurements with an adapted Helley Smith for bedload transport measurements in sand-bed rivers. (in Dutch) Delft Hydraulics report Q2141, Delft, The Netherlands
- Delft Hydraulics (1997). Calibration and comparison Helley-Smith Sand. Delft Hydraulics report Q2345, Delft, The Netherlands
- Ehrenberger, R. (1931). Direkte Geschiebemessungen an der Donau bei Wien und deren bisherige Ergebnisse. (Direct Bedload Measurements on the Danube at Vienna and their results to date.), *Die Wasserwirtschaft*, Issue 34, 1-9
- Einstein, A.H. (1937). Die Eichung des im Rhein verwendeten Geschiebenfangers. (Calibration of the bedload sampler that was used in the Rhine.) *Schweizer, Bauzeitung*, 110(12), 29-32
- Emmett, W.W. (1980). A Field Calibration of the Sediment-Trapping Characteristics of the Helley Smith Bedload Sampler. *Geol. Surv. Prof. Pap.* 1139, U.S. Dep. of the Interior, U.S. Gov. Print. Office, Washington, USA
- Gaudet, J.M., Roy, A.G. and Best, J.L. (1994). Effect of Orientation and Size of Helley-Smith Sampler on Its Efficiency. *J. Hydr. Eng., ASCE*, Vol. 120(6) 758-766
- Gaweesh, M.T.K. and Van Rijn, L.C. (1994). Bed-Load Sampling in Sand-Bed Rivers. *J. Hydr. Eng., ASCE*, 120 (12) 1364-1384
- Hamamori, A. (1962). A theoretical investigation on the fluctuation of bed-load transport. Report R4. Hydraulics Laboratories Delft, Delft, 14 pp.
- Havinga, H. (1982). Onderzoek meetmethoden bodemtransport. Deel I: Evaluatie laboratorium ijkingen van de BTMA. (Research measurement methods for bedload transport. Part I: Evaluation of laboratory calibration of the BTMA.) Nota 82.28, Rijkswaterstaat Directie Waterhuishouding en Waterbeweging, Arnhem, The Netherlands
- Hubbell, D.W. (1987). Bed Load Sampling and Analysis. In: *Sediment Transport in Gravel-Bed Rivers*. Eds. Thorne, C.R., Bathurst, J.C. and Hey, R.D., John Wiley & Sons, Chichester, UK
- Kleinhans, M.G. (2001). Calibration of bedload measurement methods (review, in Dutch). Centre for Geo-ecological Research, report ICG01/3, Utrecht, Faculty of Geosciences, The Netherlands, 35 pages
- Kleinhans, M.G. and Ten Brinke, W.B.M. (2001). Accuracy of cross-channel sampled sediment transport in large sand-gravel-bed rivers. *J. of Hydraulic Engineering, ASCE*, 127 (4), 258-269
- Kleinhans, M.G. (2002). Extreme hysteresis of bedload and suspended load transport during a discharge wave in a sand-gravel bed river. In: Kleinhans, M.G. (2002). *Sorting out sand and gravel; sediment transport and deposition in sand-gravel bed rivers*. Netherlands Geographical Studies 293, Royal Dutch Geographical Society, Utrecht, The Netherlands, 317 pages, chapter 6, 143-174
- Kleinhans, M.G. and Grasmeijer, B.T. (2005, in press). Alongshore bed load transport on the shoreface and inner shelf. EU-Sandpit end-book, Ed. Leo van Rijn, Aqua Publications, The Netherlands, paper P.
- McLean, D.G. and Tassone, B. (1987). Discussion of Hubbell (1987), in: *Sediment Transport in Gravel-Bed Rivers*. Eds. Thorne, C.R., Bathurst, J.C. and Hey, R.D., John Wiley & Sons, Chichester, UK

Schaank, E.M.H. (1938). Toestel tot het meten van transport van vaste stoffen in de rivieren. (Device for Measuring the Transport of Solid Materials in Rivers.) Rijkswaterstaat Report 38.1, The Netherlands

Thomas, R.B. & Lewis, J. (1993) A new model for bed load sampler calibration to replace the probability-matching method. *Water Resources Research* 29(3) 583-597

Van Rijn, L.C. and Gaweesh, M.T.K. (1992). New total sediment-load sampler. *J. Hydr. Eng., ASCE*, 118 (12) 1686-1691