An Intercomparison Between NEL, NRLM, Delft Hydraulics, Alden Research Laboratories, CENAM and NIST Using a 200 mm Twin Orifice Plate Package in Water

A Report for

NMSPU
DTI
151 Buckingham Palace Road
London, SW1W 9SS

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SUMMARY

The new NEL 200 mm twin orifice plate transfer standard assembly, manufactured in stainless steel, was calibrated in water at NEL, NRLM, Delft Hydraulics, Alden Research Laboratories, CENAM, NIST and finally again at NEL.

The two orifice plate flowmeters, separated by a perforated plate flow conditioner, were identified as S1 and S2. In all the laboratories the assembly was calibrated with S1 and S2 in the upstream and downstream positions respectively and then with their positions reversed using the flange taps fitted to the flowmeters.

This report summarises the results and gives an overview of the laboratories. Comparisons of the calibrations from the different laboratories are presented.

Prepared by: Dr M J Reader-Harris

Approved by: Mr R Paton

Date: 22 December 1999
for Dr F C Kinghorn
Director

CONTENTS

1 INTRODUCTION

The project was initiated under the DTI National Measurement System Policy Unit 1996-1999 Flow Programme. An intercomparison between six laboratories was carried out in water, using a new 200 mm twin orifice plate assembly consisting of two orifice plate flowmeters separated by a perforated plate flow conditioner. This assembly had been manufactured in stainless steel at NEL.

This package was calibrated at NEL in May 1996, at NRLM in Japan in August/September 1996, at Delft Hydraulics in the Netherlands in December 1997, at Alden Research Laboratories in the United States in September/October 1998, at CENAM in Mexico in December 1998, at NIST in the United States in March 1999 and finally again at NEL in March 1999.

This report summarises the results and gives an overview of the laboratories and test methods. The salient intercomparison graphs are included. The full list of tables of results and associated figures is included. The tables and figures referenced have not been included in this report but are available in Microsoft EXCEL format in NEL Report No 305/99, entitled ‘Intercomparison work for the 1996-99 Flow Programme’. This is available from NEL as a CD ROM. It includes not only this report but also the reports of other intercomparisons carried out within the 1996-1999 Flow Programme.

2 OBJECTIVES

The objective of this project is to ensure the continuing accuracy of the participating flow calibration laboratories and thereby to ensure that data from one country are acceptable to other countries. To achieve this objective it is necessary to have fairly regular intercomparison checks between the laboratories, using a flowmetering assembly with repeatable characteristics. These dynamic checks supplement the static traceability chain for an individual laboratory, and identify the systematic differences between laboratories

3 THE LABORATORIES

3.1 NEL

The National Engineering Laboratory (NEL) is an industrial research organisation concerned with many areas of mechanical engineering research. Within NEL the Flow Centre is the holder of the UK National Standards for Flow Measurement. Facilities exist for calibration and research involving water, oil, gas and multiphase flow measurement devices. All the facilities are fully traceable to Primary National Standards and most are accredited by the United Kingdom Accreditation Service (UKAS).

This package was calibrated in the 10-inch test line of the large water flow facility with an additional 43.5*D* and 13*D* of 200 mm NB pipework upstream and downstream of the assembly respectively. Meters are calibrated using a flying start and finish technique against gravimetric standards. Three weigh tanks are available of 1 tonne, 5 tonnes and 50 tonnes. The 5 tonne tank was used for this exercise.

The large water test facility is accredited by UKAS with a best measurement capability uncertainty of 0.1 per cent of flowrate. Water/air/mercury manometers were used to measure differential pressure.

3.2 NRLM

NRLM is the National Standards Laboratory for Japan. NRLM estimates that the uncertainty of flowrate is about 0.1 per cent of the indicated value and that the uncertainty of the differential pressure is about 0.2 per cent of span.

3.2 Delft Hydraulics

Delft Hydraulics is the de facto Dutch national standard for water flowrate measurement at the flowrates for this intercomparison. Delft Hydraulics has a calibration rig uncertainty in flowrate of 0.05 per cent. This is taken to be the uncertainty in flowrate.

3.3 Alden Research Laboratories

Alden Research Laboratories in Massachusetts, USA, have two facilities, the Hooper Low Reynolds Number Facility and the Allen High Reynolds Number Facility. Both facilities used a diverter and gravimetric system. In the Hooper facility a 50,000 lb weigh tank was used, whereas in the Allen Facility a 10,000 lb weigh tank was used. In the Hooper facility the water temperature was approximately 12°C, whereas in the Allen Facility it was approximately 40°C. In the Hooper Facility a Mitsubishi type perforated plate flow straightener was installed immediately upstream of the assembly. In the Allen Facility 13*D* of 8-inch NB pipe was included upstream of the assembly. In the Hooper Facility the uncertainty in discharge coefficient was in the range 0.1 to 0.14 per cent; in the Allen Facility it was in the range 0.12 to 0.32 per cent.

3.4 CENAM

The liquid flow facility at the Centro Nacional de Metrología constitutes Mexico's primary standard for liquid flow measurements. The system is based on the static weighing principle with weighbridges of 1.5 tonne and 10 tonne. Their claimed expanded uncertainty for flowrate is in the range 0.008 to 0.06 per cent. As regards differential pressure their expanded uncertainty is 65 Pa and 87 Pa at maximum for S1 and S2 respectively. These maximum values would give rise to a contribution to the uncertainty in the discharge coefficient in the range 0.04 to 0.30 per cent and 0.05 to 0.41 per cent for S1 and S2 respectively.

3.5 NIST

The National Institute of Standards and Technology (NIST) is the national standards institute for the United States of America. The NIST Water Flow Measurement Standards use static gravimetric techniques for which the Expanded Uncertainty on the determination of volumetric flow rate is quoted to be ± 0.12%. This Expanded Uncertainty is the result of multiplying a coverage factor of 2 times the Combined Uncertainty which is the root-sum square of the A and B Type Uncertainties for the measurement. This A Type Uncertainty is obtained using statistical techniques, and the B Type is obtained using techniques other than statistical. The gravimetric system used at NIST for these measurements has a capacity to weigh 23,000 kg. This facility included upstream pipework and flow conditioning elements that have produced both mean and turbulent velocity profiles (axial and transverse) that closely approximate the distributions for fully developed, equilibrated pipe flow. These distributions were measured at the location of the inlet to the 200mm tandem orifice meter assembly with laser Doppler velocimetry (LDV) along horizontal and vertical diameters. These measurements were done in advance of the orifice testing, but during the orifice testing, these LDV distributions were monitored in real-time using a non-intrusive, 8-path, in-line ultrasonic meter that also has the diagnostic capabilities to quantify and assure that profile skew and swirl remained at the negligible levels indicated by the LDV results.

4 THE TRANSFER STANDARD

In each laboratory the 200 mm assembly was installed as shown in Figure 1 (first installation), with additional 200 mm NB pipework upstream and downstream of the assembly respectively, and the flowmeters calibrated simultaneously. The flowmeters were then interchanged as shown in the second installation of Figure 1 and again calibrated simultaneously. In all cases, the orifice plates remained attached to their respective adjacent pipes so that the results would not be affected by separating and reconnecting flanges close to them. The tappings on the orifice plates were connected via ‘triple-tee’ piezometer rings.

Dimensions of the orifice plates:

Orifice Plate	S1	S2
Throat diameter (*d*) mm	102.72	102.71
Pipe diameter (*D*) mm	205.94	206.25

A mean value of 206.09 mm for the pipe diameter was used in the calculations for both orifice plates. Both orifice plates were fitted with corner, flange, and D and D/2 tappings. Only the flange tappings (4 tappings in each tapping plane) were used in the present tests.

5 THE DATA

All the sets of data from the calibrations and the associated figures are listed in this report. All the tables of data and figures are available in NEL Report No 305/99 issued as a CD-ROM. Only the graphs pertinent to the conclusions are included here.

All the data from the different laboratories are given in Tables 1 – 19 of Report No 305/99. Each set of data has been fitted using an equation of the form

$$C = A + B\left(\frac{10^6}{Re_D}\right)^{0.5} .$$

Each set of data together with a fitted line has been plotted in Figures 2 – 25 of Report No. 305/99. So that the data can be compared the line fits of all the data are plotted in Figures 26 – 29.

Because of the range of line temperature of the data, the data have also been corrected to 20ºC on the basis that

$$d_{act} = d_{ref}[1 + 0.0000167(T_{act} - 20)],$$

where d_{act} and d_{ref} are the orifice diameters at the actual line temperature, T_{act}, and 20°C respectively. The corrected data are shown in Figures 30 - 33. The Alden data had already been corrected for temperature and so no further correction has been made.

6 CONCLUSIONS

With S1 upstream (Figure 30) the total spread of the data is 0.37 to 0.49 per cent. With S2 downstream (Figure 31) the total spread of the data is 0.26 to 0.33 per cent. With S2 upstream (Figure 32) there appears to be an error in the Allen data; excluding them the total spread is 0.28 to 0.29 per cent. With S1 downstream (Figure 33) the total spread of the data is 0.33 to 0.40 per cent. Generally the laboratories agree within approximately ± 0.2 per cent.

The spread of the downstream data is generally slightly smaller than the spread of the upstream data. The spread obtained with S2 is smaller than that obtained with S1. The two orifice meters were inspected on their return and no defects in either were seen. The pipework has been discoloured between leaving NEL and its return here. To inspect the meters thoroughly would require them to be dismantled, and this dismantling has not been done for the reasons given in Section 2.

Comparison of the upstream and the downstream data shows that the effect of the Spearman flow conditioner 15.7*D* upstream of an orifice plate of diameter ratio 0.5 is a shift in discharge coefficient of approximately -0.15 per cent.

When the upstream data are compared with the Reader-Harris/Gallagher Equation in ISO 5167-1:1991/Amd. 1:1998 the Equation lies above the mean of the data by 0.04 to 0.00 per cent for S1 and by 0.15 to 0.12 per cent for S2. This is well within the expected uncertainty of the Equation.

ACKNOWLEDGEMENTS

The participation of NRLM, Delft Hydraulics, Alden Research Laboratories, CENAM and NIST and the hard work of their staff are gratefully acknowledged.

LIST OF TABLES PROVIDED IN NEL REPORT No 305/99, ENTITLED "INTERCOMPARISON WORK FOR 1996-99 FLOW PROGRAMME"

NEW NEL 200 mm TWIN ORIFICE PLATE TRANSFER STANDARD ASSEMBLY

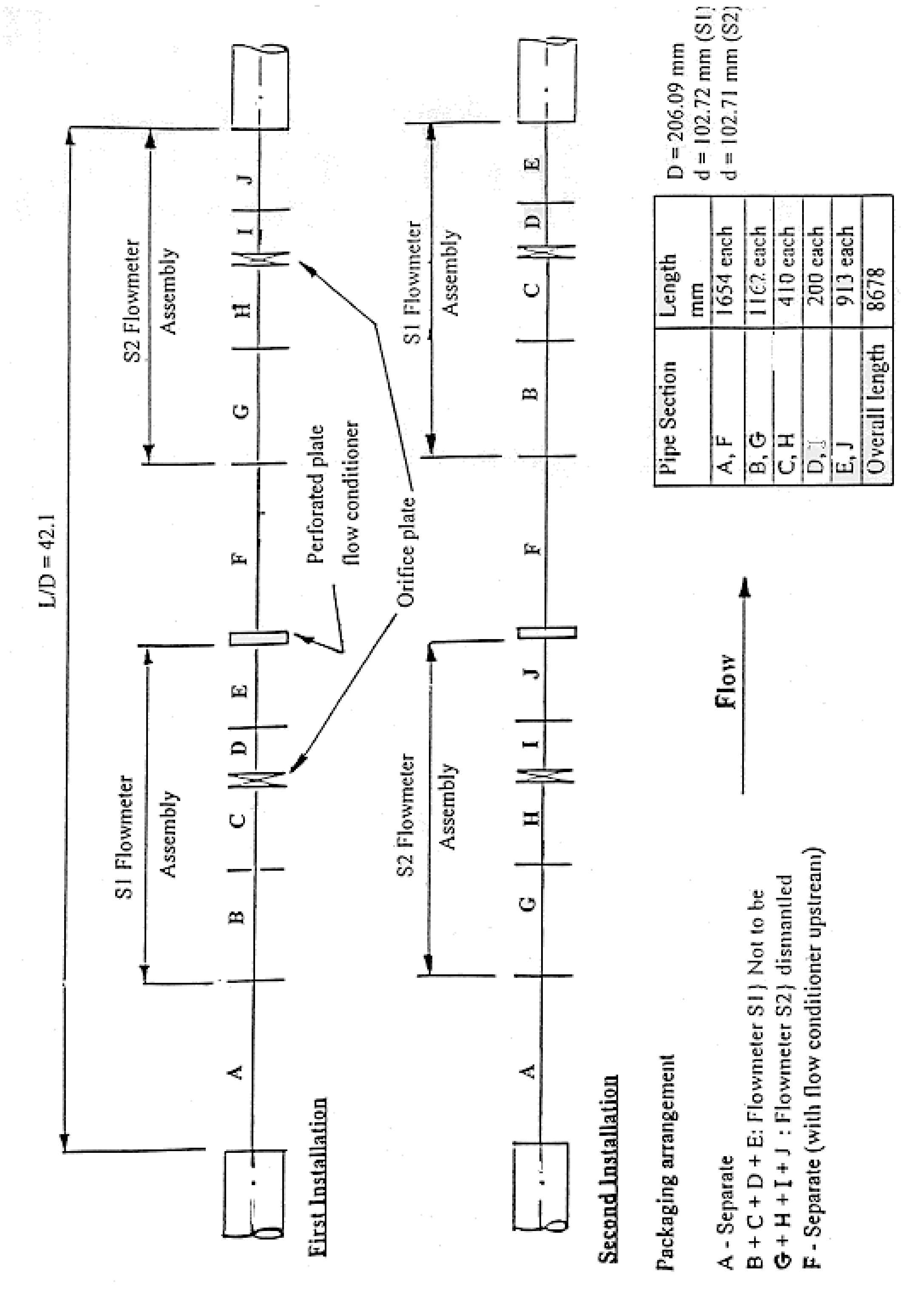
LIST OF FIGURES PROVIDED IN NEL REPORT No 305/99, ENTITLED "INTERCOMPARISON WORK FOR 1996-99 FLOW PROGRAMME"

NEW NEL 200 mm TWIN ORIFICE PLATE TRANSFER STANDARD ASSEMBLY

Figure No	Lab / Facility	Date	Test No	Flowmeter	Position
2	NEL	May-96 Mar-99	3075 3269	S1	Upstream
3	NEL	May-96 Mar-99	3075 3269	S2	Downstream
4	NEL	May-96 Mar-99	3076 3270	S2	Upstream
5	NEL	May-96 Mar-99	3076 3270	S1	Downstream
6	CENAM	Dec-98	1 3	S1	Upstream
7	CENAM	Dec-98	1 3	S2	Downstream
8	CENAM	Dec-98	2	S2	Upstream
9	CENAM	Dec-98	2	S1	Downstream
10	DELFT	Dec-97	1 2	S1	Upstream
11	DELFT	Dec-97	1 2	S2	Downstream
12	DELFT	Dec-97	3 4	S2	Upstream
13	DELFT	Dec-97	3 4	S1	Downstream
14	NIST	Mar-99	1	S1	Upstream
15	NIST	Mar-99	1	S2	Downstream
16	NIST	Mar-99	2	S2	Upstream
17	NIST	Mar-99	2	S1	Downstream
18	ALDEN (Hooper Low ReD) (Allen High ReD)	 Oct-98 Sep-98	 1 1	S1	Upstream
19	ALDEN (Hooper Low ReD) (Allen High ReD)	 Oct-98 Sep-98	 1 1	S2	Downstream

SUMMARY OF FIGURES (Contd)

Figure No	Lab / Facility	Date	Test No	Flowmeter	Position
20	ALDEN			S2	Upstream
	(Hooper Low ReD)	Oct-98	2		
	(Allen High ReD)	Sep-98	2		
21	ALDEN			S1	Downstream
	(Hooper Low ReD)	Oct-98	2		
	(Allen High ReD)	Sep-98	2		
22	NRLM	Sep-96	2	S1	Upstream
23	NRLM	Sep-96	2	S2	Downstream
24	NRLM	Aug-96	1	S2	Upstream
25	NRLM	Aug-96	1	S1	Downstream
26	Comparison of Cals.			S1	Upstream
27	Comparison of Cals.			S2	Downstream
28	Comparison of Cals.			S2	Upstream
29	Comparison of Cals.			S1	Downstream
30	Comparison of Cals.		(Corr.)	S1	Upstream
31	Comparison of Cals.		(Corr.)	S2	Downstream
32	Comparison of Cals.		(Corr.)	S2	Upstream
33	Comparison of Cals.		(Corr.)	S1	Downstream


L/D = 42.1
S1 Flowmeter Assembly
S2 Flowmeter Assembly
A
B
C
D
E
F
G
H
I
J
Perforated plate flow conditioner
Orifice plate
First Installation
Second Installation
Flow
D = 206.09 mm
d = 102.72 mm (S1)
d = 102.71 mm (S2)
Pipe Section | Length mm
A, F | 1654 each
B, G | 1162 each
C, H | 410 each
D, I | 200 each
E, J | 913 each
Overall length | 8678
Packaging arrangement
A - Separate
B + C + D + E: Flowmeter S1 } Not to be
G + H + I + J : Flowmeter S2 } dismantled
F - Separate (with flow conditioner upstream)

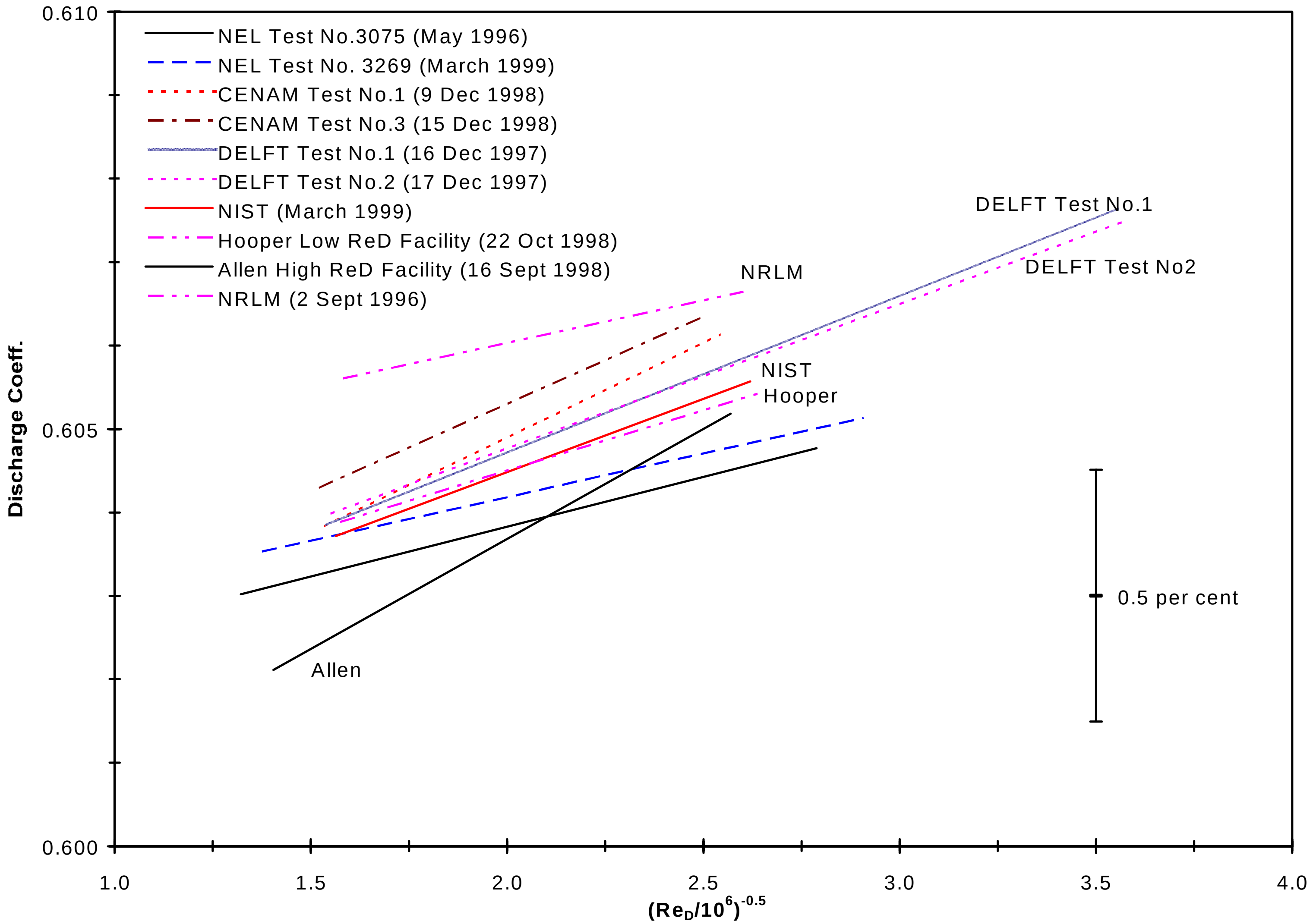


Figure 26 - Comparison of Calibrations with S1 Upstream

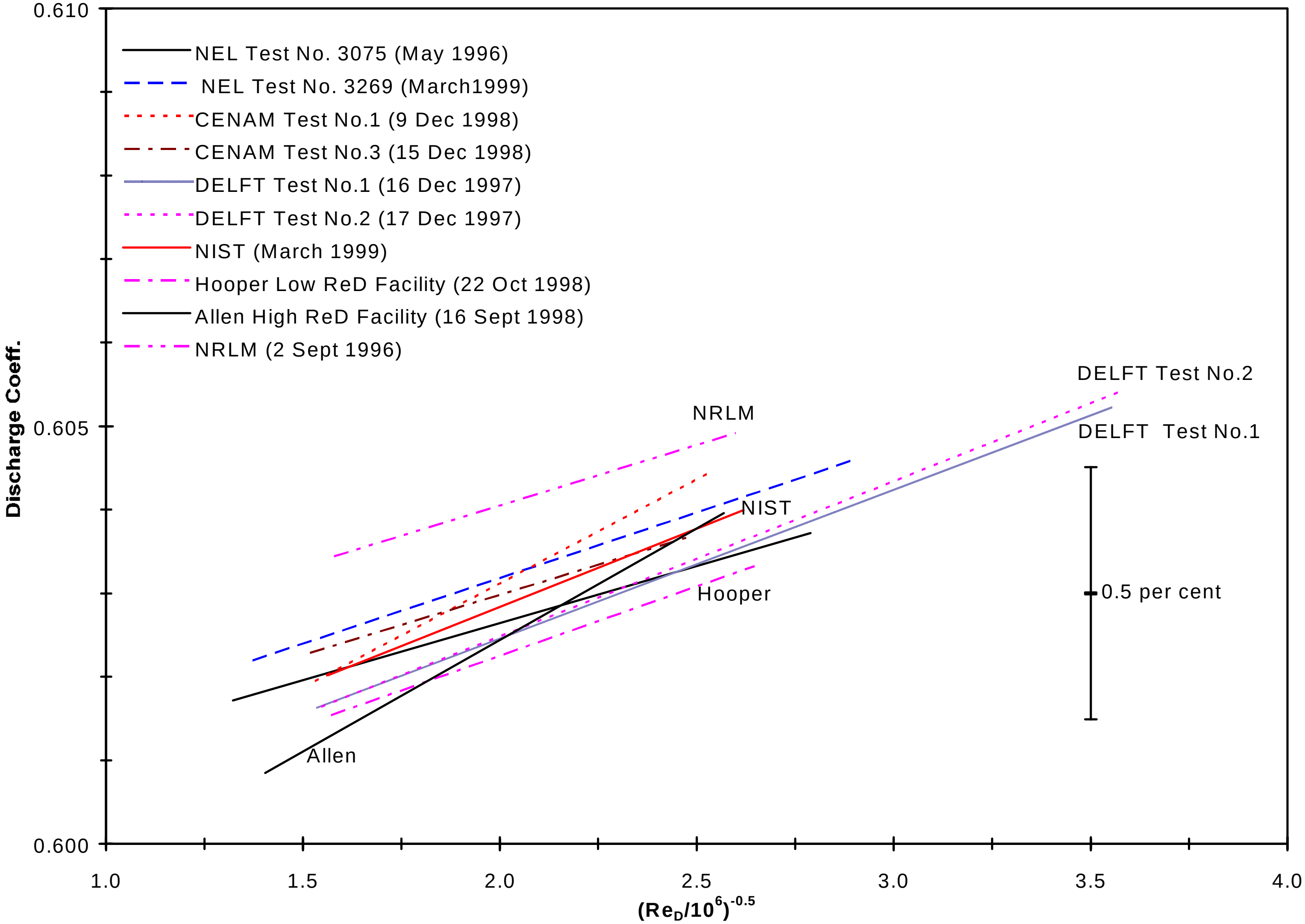


Figure 27 - Comparison of Calibrations with S2 Downstream

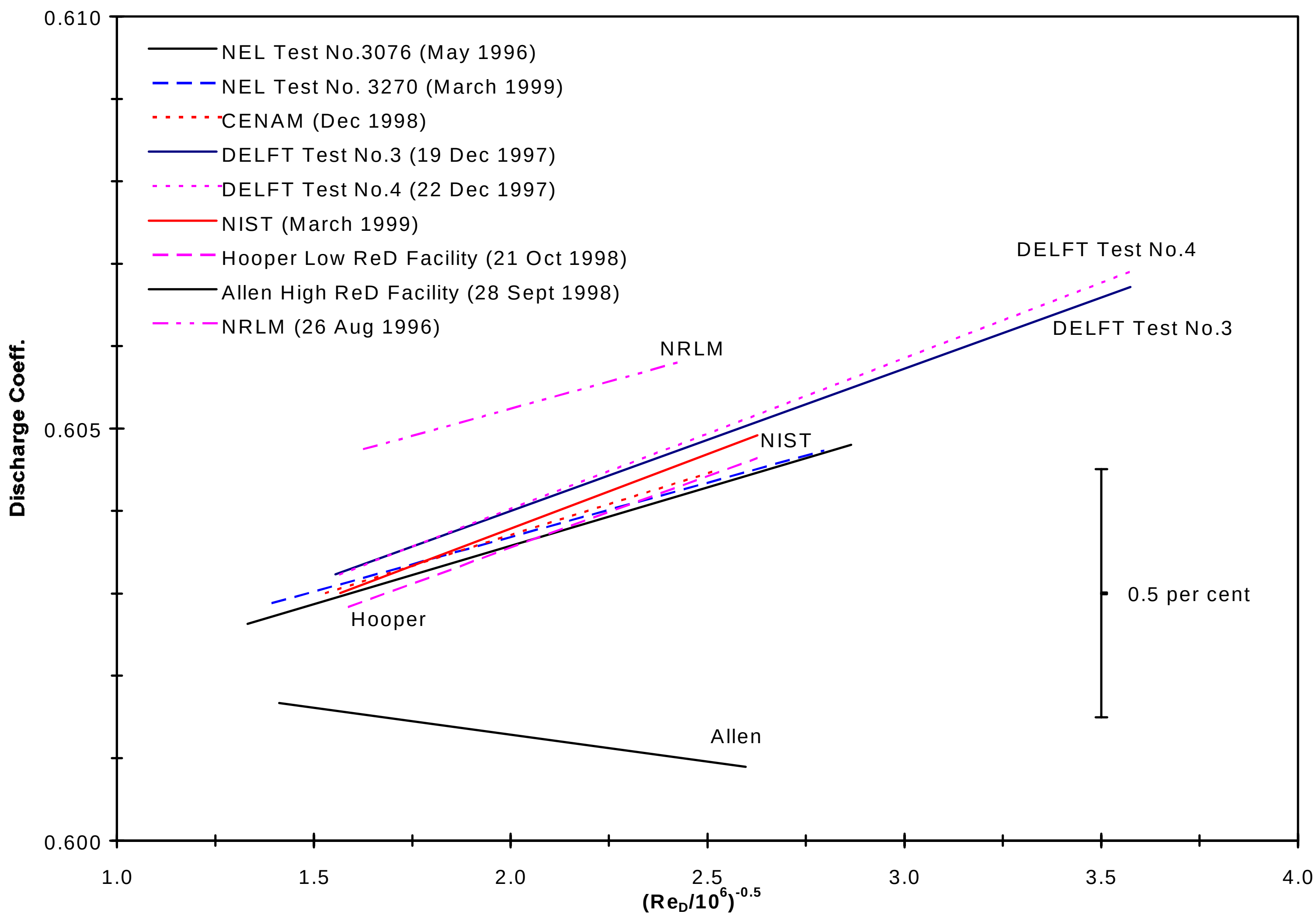


Figure 28 - Comparison of Calibrations with S2 Upstream

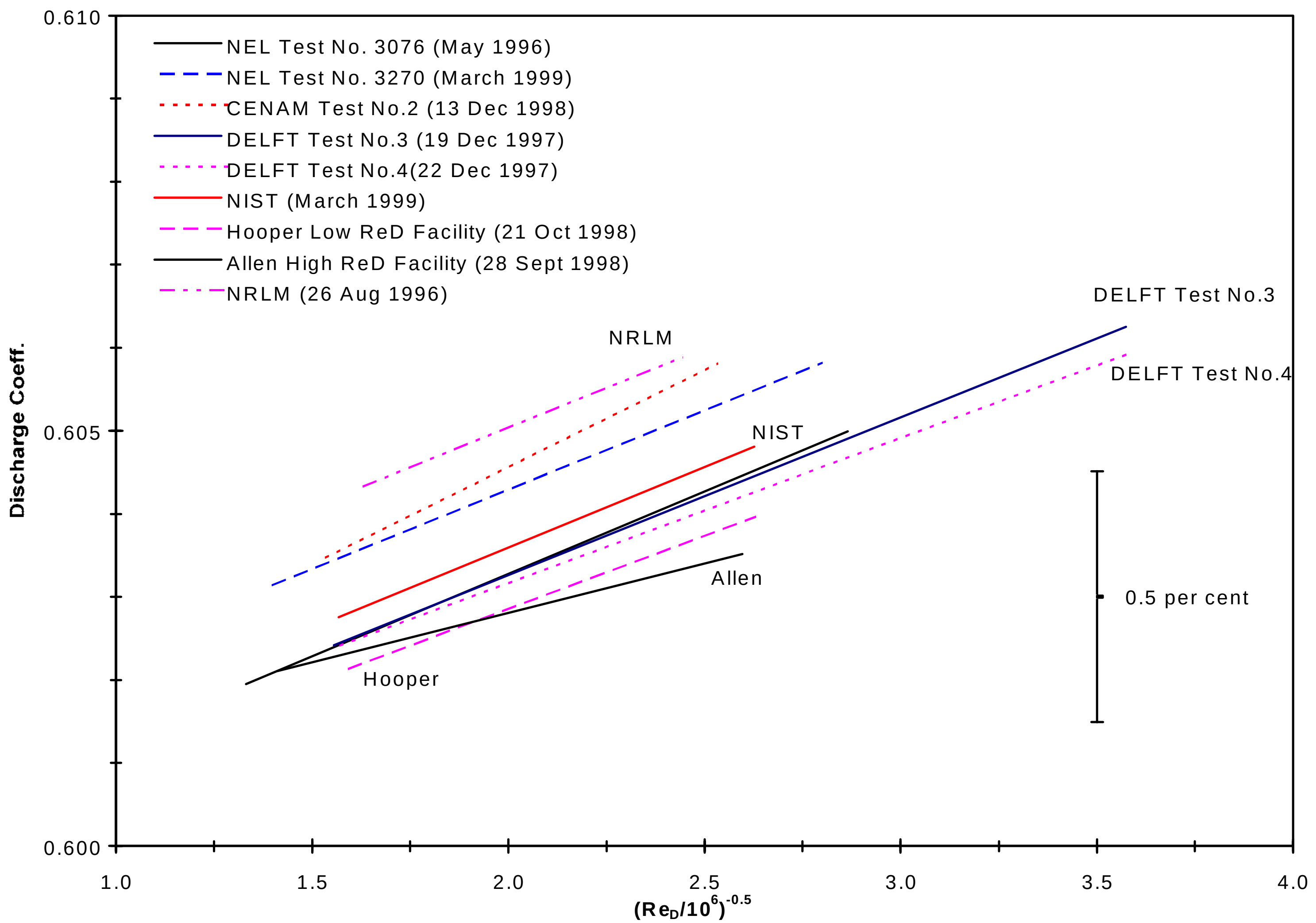


Figure 29 - Comparison of Calibrations with S1 Downstream

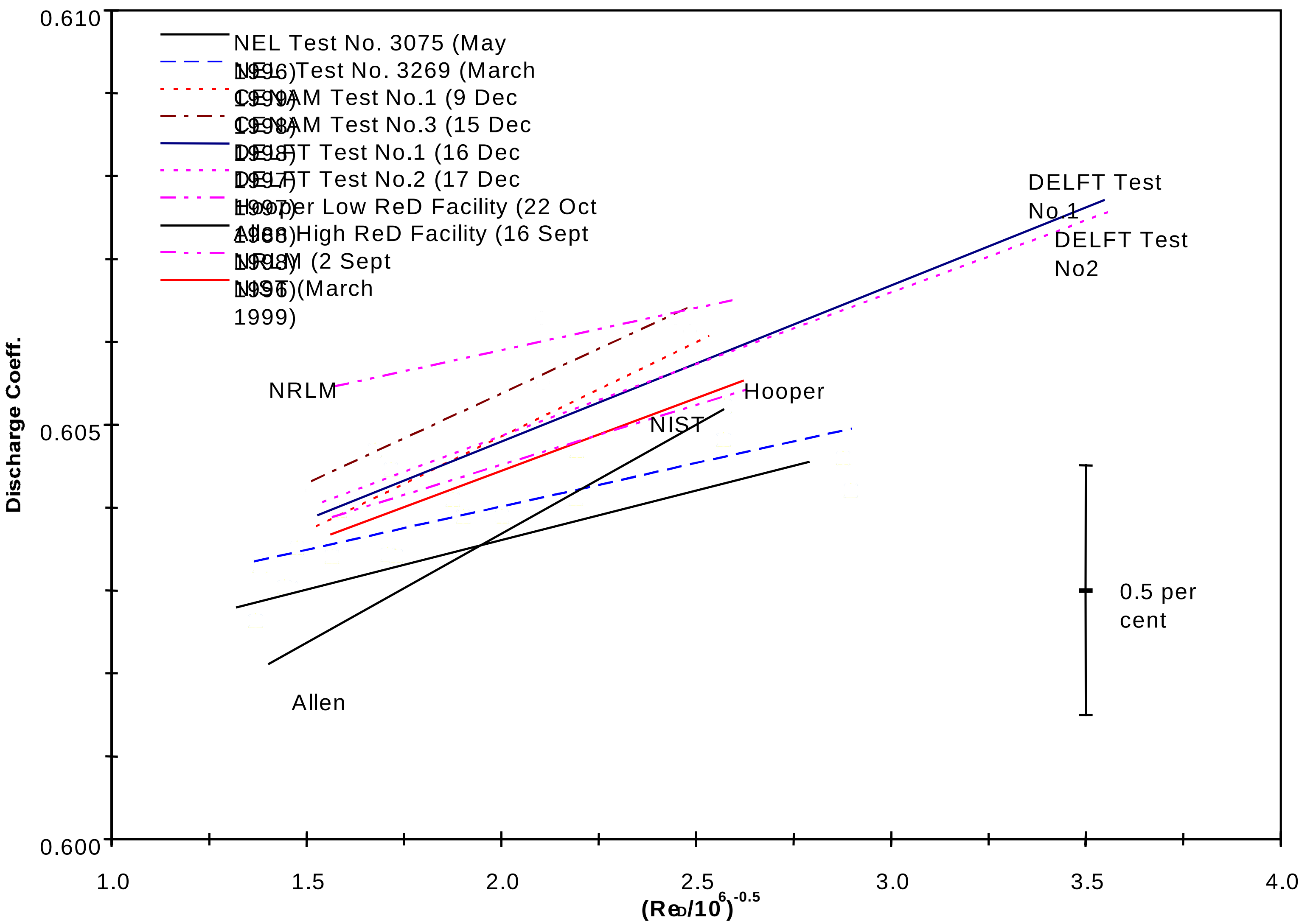


Figure 30 - Comparison of Calibrations withS1 Upstream (Corrected)

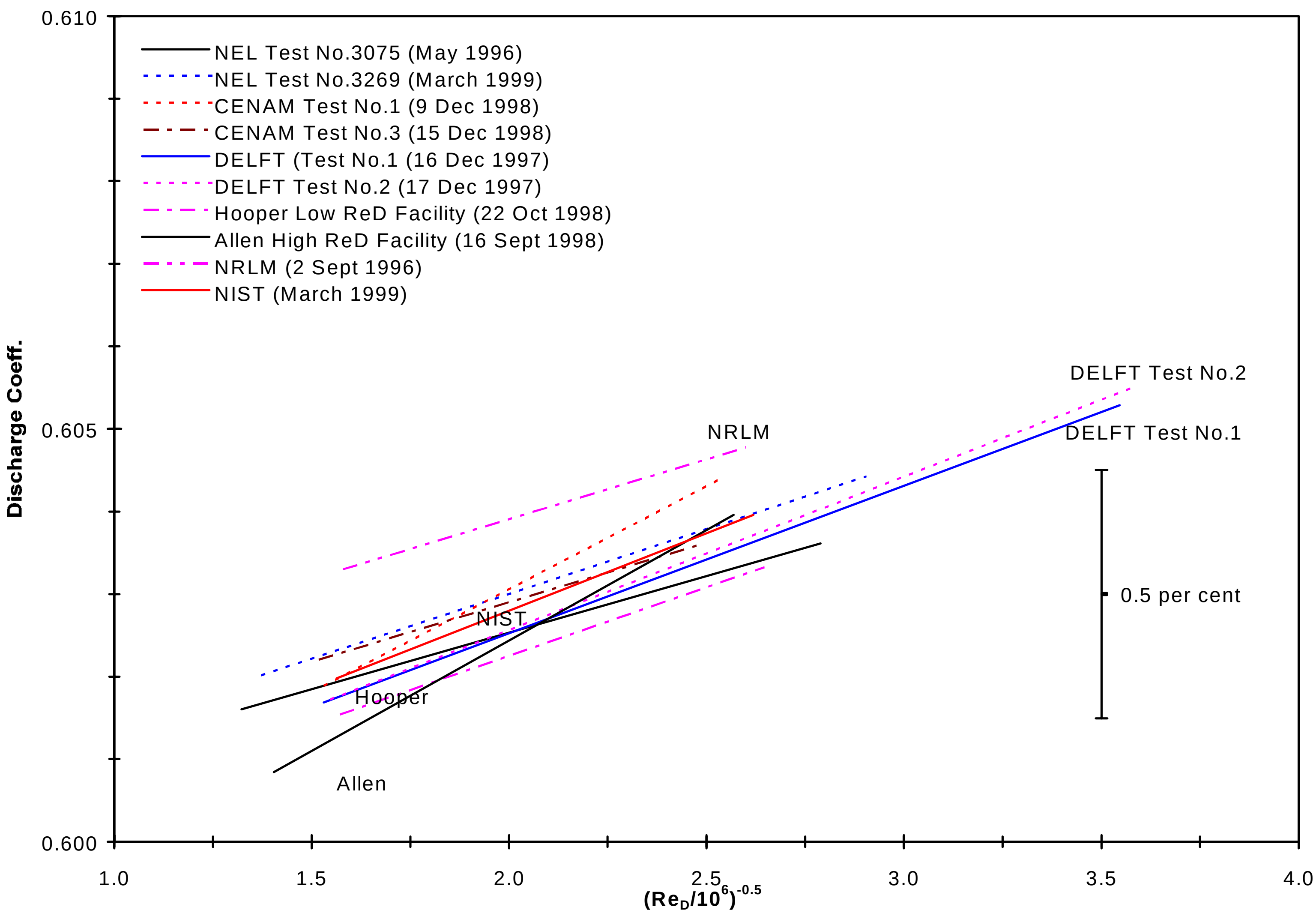


Figure 31 - Comparison of Caliibrations with S2 Downstream (Corrected)

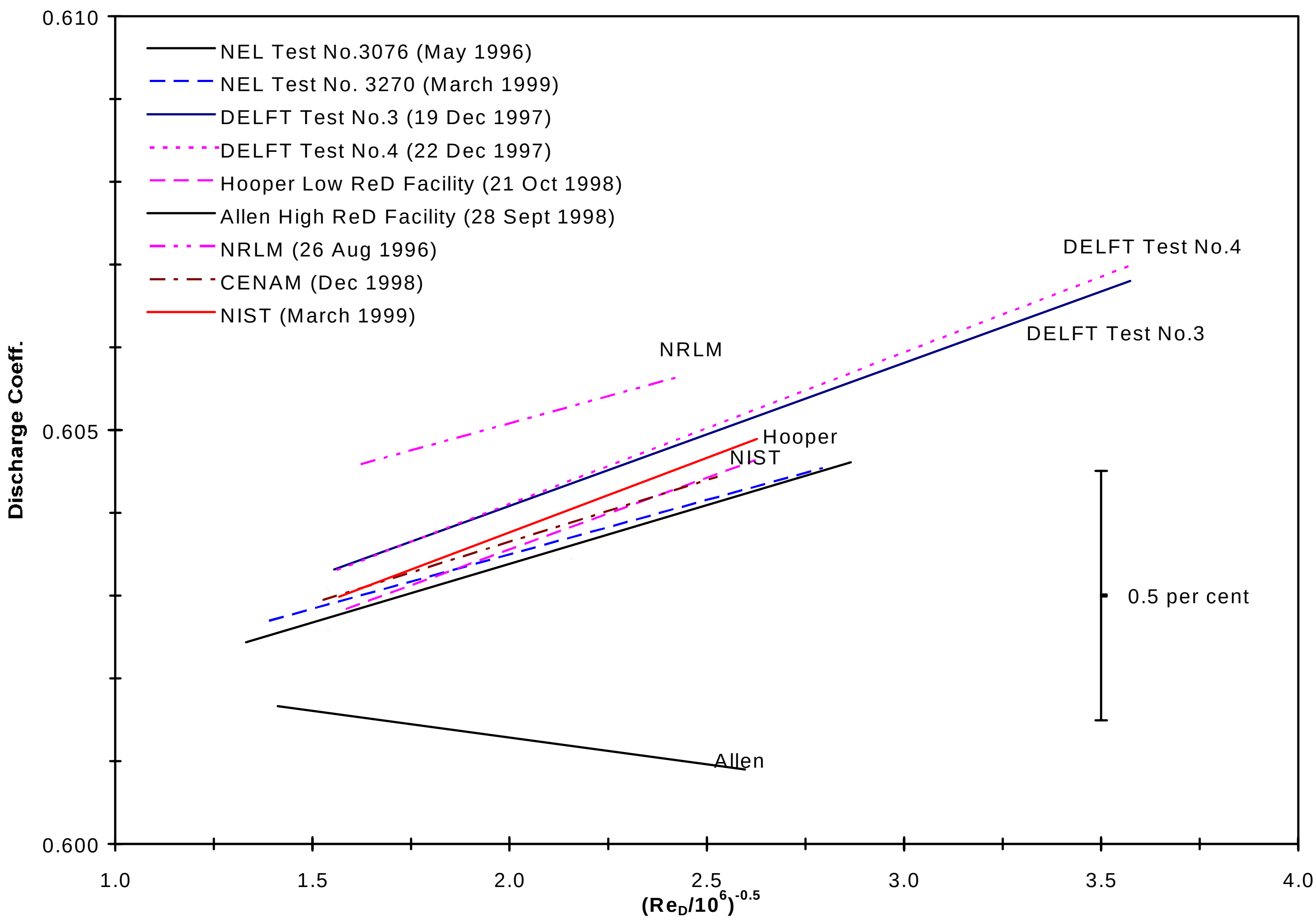


Figure 32 - Comparison of Calibrations with S2 Upstream (Corrected)

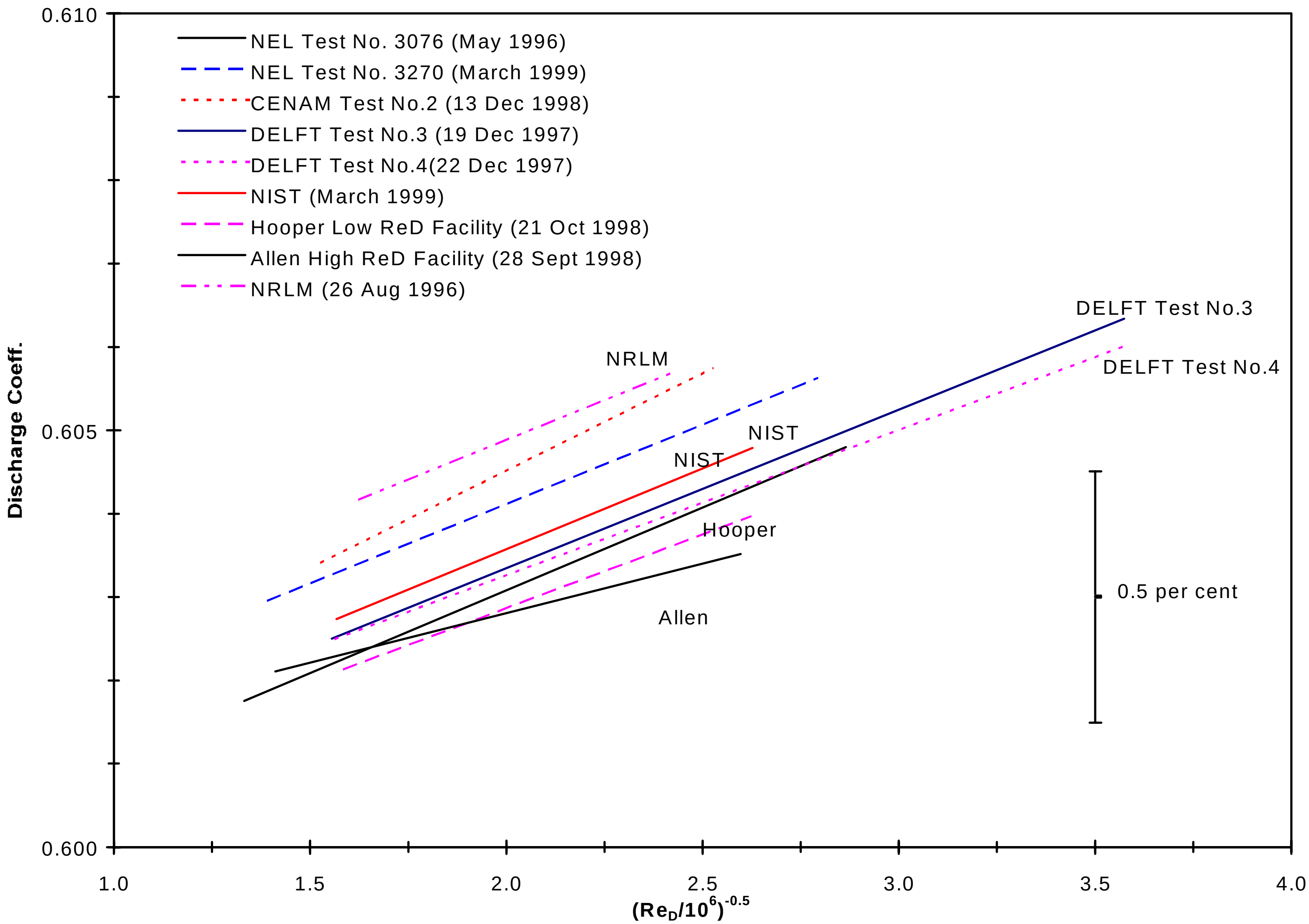


Figure 33 - Comparison of Calibrations with S1 Downstream (Corrected)