12d Model

Civil and Surveying Software

Drainage Analysis Module

Ku & Kw Calculation

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This document describes the procedures for calculating Ku and Kw coefficients, as implemented in the *Drainage Analysis* module of *12d Model* .

For stormwater pits, maintenance holes and culvert inlets:
Ku coefficients apply to pressure head (Hp) losses.

For stormwater pits and maintenance holes:
Kw coefficients apply to water surface elevation (WSE) losses.

Introduction

For the design of piped stormwater systems, the loss (or gain) in pressure head (ΔHp) *through a pit* [1], is typically assumed proportional to the velocity head at the entrance of the downstream pipe. Likewise proportional, but sometimes of different magnitude, is the corresponding change in effective water surface elevation (ΔWSE) *between the pit and the downstream pipe*. However simple this may seem, the two coefficients of proportionality (denoted by Ku for pressure head changes, and Kw for WSE changes) are generally dependent on so many different factors, that their adequate estimation still relies largely on the results of empirical study. Perhaps the most thorough sources emanating from such study, are the so called "Missouri Charts" (Sangster *et al*, 1958) and "Hare Charts" (Hare, 1981). The *Australian Rainfall and Runoff* (ARR, 1987), suggests the use of these sets of charts, in preference to any other method.

As originally published, the charts are highly complex, varied in presentation, and somewhat open to interpretation – reflective of the chaotic nature of flow through pits. A good deal of judgement is required in selecting the appropriate chart to use for a particular pit configuration, and in most cases, iterative calculations are required. For large stormwater networks, this typically leads to a huge time-cost for the designers, or alternatively, to an overly-conservative design approach. To overcome such problems, several semi-analytical methods have been proposed, with an aim to replace the dependence on charts. These range from the relatively simple methods suggested by Argue (1986), Hare *et al* (1990)[2], and Mills *et al* (1998), to the more accurate methods (which are arguably as complex as using the charts manually) suggested by Parsell (1992), and Stein *et al* (1999). A summary paper (O'Loughlin *et al*, 2002) reviewed the latter four of these methods, and concluded that none matched acceptably well, across the full range of pit configurations covered by the charts, and that more work was required to develop a practical method suitable for implementation with a computer.

12d Model adopts a method that is purely numerical, rather than semi-analytical. It is based on the fact that the majority of the chart data (i.e. the charts for pits with no more than a single upstream pipe) offer a range suitable for consideration in a continuous sense. This fact has allowed the chart data to be re-arranged and combined into a single database of Ku and Kw values – one that both spreads evenly across the full range of the charts used, and is convenient for computation. The resultant database is used to calculate values which match the charts *perfectly*, for those pits which coincide with one of the discrete chart configurations; otherwise, values are calculated which indicate a *linear transition* between particular charts. The Ku and Kw calculations are *all* based on a robust, programmed sequence of one-dimensional and/or three-dimensional interpolations within the database.

The method may be thought of as a particular, holistic way of interpreting the chart data. It has been developed with an aim to minimise user input, and increase the overall efficiency of the design process. Individual charts *do not* need to be nominated at each pit, and horizontal and vertical misalignment of pipes (a key factor affecting Ku and Kw) is considered with minimal interaction. The method is most reliable for pits with either no upstream pipe, or one upstream pipe. For pits with two or more upstream pipes (for which very few discrete charts exist) a single equivalent upstream pipe is determined, yielding results which compare adequately with the limited chart data available.

For culvert inlets, *12d Model* adopts a different method, based on data published by the *U.S. Federal Highway Administration* (HDS5, 2005), to calculate Ku values for culverts flowing under inlet or outlet control. This method is detailed on page 19, and covers a wide range of different culvert configurations.

[1] The term "pit" is extended in meaning here, to include *maintenance holes* (where no grate inlet flow from above is possible).

[2] Sometimes referred to as the "Hare Equations". These equations differ from the "Hare Charts", in that they offer only an approximation to the *preferred configuration* charts (see configurations: G1, T1, T2, T4, T8, T10).

Ku & Kw Calculations in 12d Model

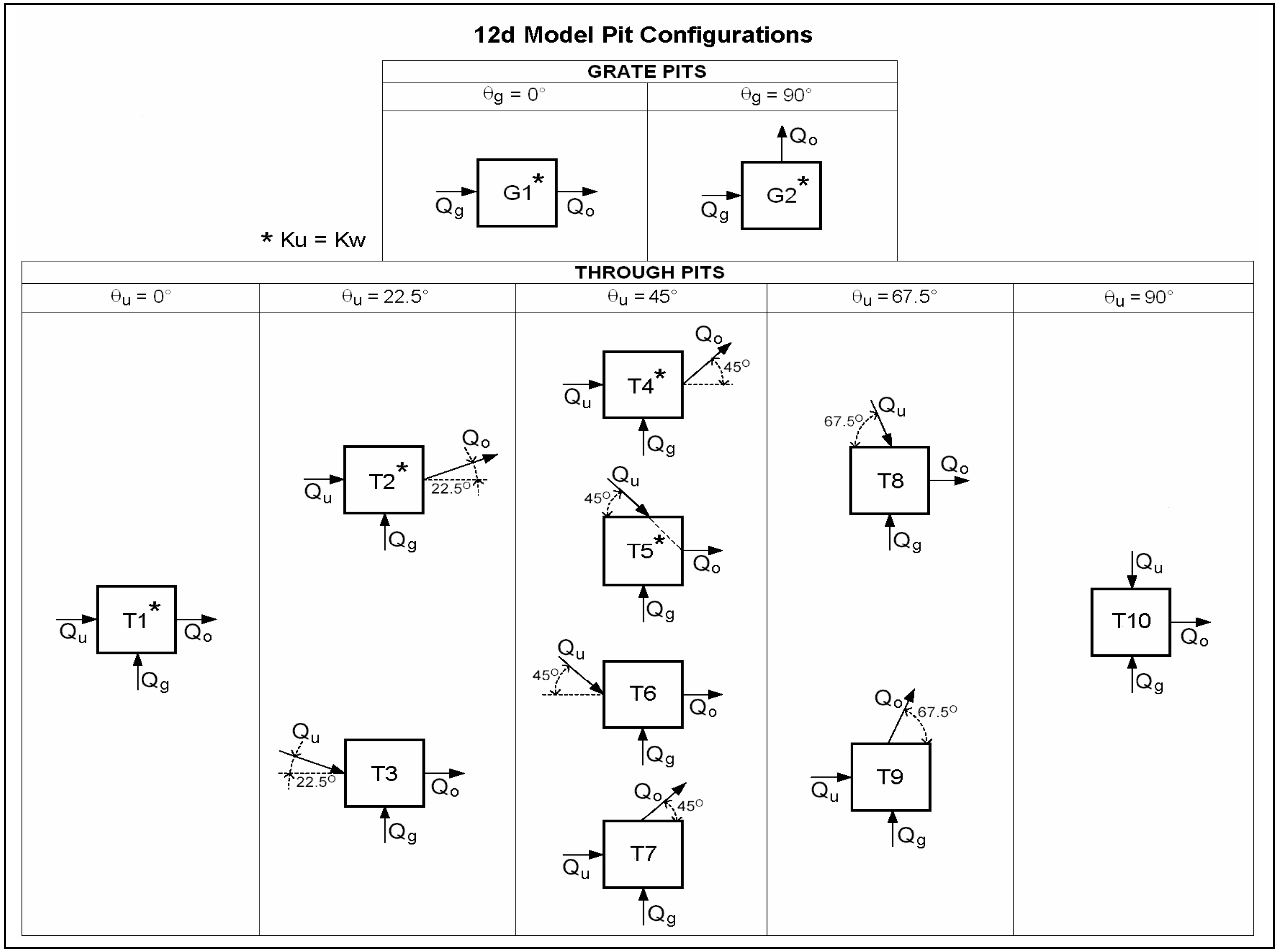


Chart Source 1: QUDM (1994).
Chart Source 2: ACTDS (2003).

In both source documents:
Chart for Grate Pits from Sangster *et al* (1958).
Charts for Through Pits from Hare (1981).

12d Pit Config	**G1**	**G2**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
QUDM Ku Chart #	32	32	33	34	35	37	37	38	40	42	44	46
QUDM Kw Chart #	32	32	33	34	36	37	37	39	41	43	45	47
ACTDS Ku Chart #	1	1	2	13	14	10	9	16	18	20	22	7
ACTDS Kw Chart #	1	1	2	13	15	10	9	17	19	21	23	8
ACTDS Pit Type #	1	2	3	11	12	8	7	13	14	15	16	6

12d Controls	**12d Settings**	**Remarks**
Ku method	Direct	Ku & Kw specified directly by user.
	Ku,Kw via Charts	Ku & Kw via chart interpolation.
	Ku,Kw>0 via Charts	Prevents -ve Ku or Kw from charts.
	33 culvert methods	See *Culvert Inlets* on page 19.
Ku config	Preferred	Gives lowest Ku & Kw (on average).
	Good	:
	Fair	:
	Poor	Gives highest Ku & Kw (on average).

Independent Chart Variables :

θg = *angle between grate flow line and d/s pipe*
θu = *angle between equivalent u/s pipe and d/s pipe*
Qg/Qo = *equivalent grate flow ratio*
Du/Do = *equivalent pipe diameter ratio*
S/Do = *submergence ratio*

Procedural Steps :

1A) Grate Pit chart is used for pits where Qg/Qo = 1.0.
- G1 used where θg <= 15°; G2 used where θg > 15°.

1B) Through Pit charts are used for pits where 0.0 <= Qg/Qo <= 0.5.
- Interpolation within a Through Pit chart is based on Qg/Qo and Du/Do.
- Interpolation between Through Pit charts is based on θu and *Ku config* : Preferred, Good, Fair, Poor.

	0°	22.5°	45°	67.5°	90°
Preferred	**T1**	**T2**	**T4**	**T8**	**T10**
Good	**T1**	**T2**	**T5**	**T8**	**T10**
Fair	**T1**	**T3**	**T6**	**T9**	**T10**
Poor	**T1**	**T3**	**T7**	**T9**	**T10**

1C) For pits where 0.5 < Qg/Qo < 1.0, a further (linear) interpolation based on Qg/Qo is made, between the interpolated data from steps 1A and 1B.

2) Step 1A, 1B or 1C produces a Ku and a Kw curve (both versus S/Do). Actual S/Do values are calculated to intersect the Kw curve, and thus find the applicable S/Do for the final Kw & Ku values.

How does 12d Model determine the Ku & Kw chart inputs: Qg/Qo, Du/Do, θg, θu?

Example with grate flow and 3 u/s pipes:

Qg/Qo *equivalent grate flow ratio* (Steps: 1A, 1B, 1C)

	From Rational Method	Rescaled to Conserve Mass	
	Qrat	**Qeq**	
Qg	53.0	48.8	
Qu1	246.0	226.7	
Qu2	151.0	139.2	
Qu3	98.0	90.3	
Qu	495.0	456.2	
Qg + Qu	548.0	505.0	
Qo	505.0	505.0	**Qg/Qo =** 48.8/505.0 = **0.097**

Qg/Qo = (Qg)eq / Qo
0.0 <= Qg/Qo <=1.0

Du/Do *equivalent pipe diameter ratio* (Steps: 1B, 1C)

Pipe Diameters		**Pipe Areas**		
Du1	375	**Au1**	0.110	
Du2	300	**Au2**	0.071	
Du3	225	**Au3**	0.040	
		Au	0.221	
Do	600	**Ao**	0.283	**Du/Do =** SQR(.221/.283) = **0.884**

Du/Do = SQR(Au/Ao)
0.6 <= Du/Do <= 1.0

θg *angle between grate flow line and d/s pipe* (Steps: 1A, 1C)

Angle between setout string and d/s pipe	**θg =**	**32.0**

0° <= θg <= 90°

θu *angle between equivalent u/s pipe and d/s pipe* (Steps: 1B, 1C)

	Horiz θ	**Drop**	**VAF***	**θ**	
Qu1->Qo	0	20	1.547	0	**θu =** (0.0) 226.7/456.2 +
Qu2->Qo	90	40	1.867	90	(90.0) 139.2/456.2 +
Qu3->Qo	30	590	0.044	54.7	(54.7) 90.3/456.2 = **38.3**

θu = θ1.Qu1/Qu
+ θ2.Qu2/Qu
+ θ3.Qu3/Qu
0° <= θu <= 90°

*VAF = Vertical Alignment Factor = (Do - Drop) / Du
For VAF < +0.25 (i.e. excessive vertical misalignment),
θ is increased linearly to compensate, viz:
+0.25 > VAF > -0.25
Horiz θ < θ < 90°

Grate Pits (i.e. grate flow only)

Example of Kw calculation (Ku = Kw) :

INPUT

θg	32.0
Do	0.300
Vo	0.920
ILo	27.224
HGLo	27.900

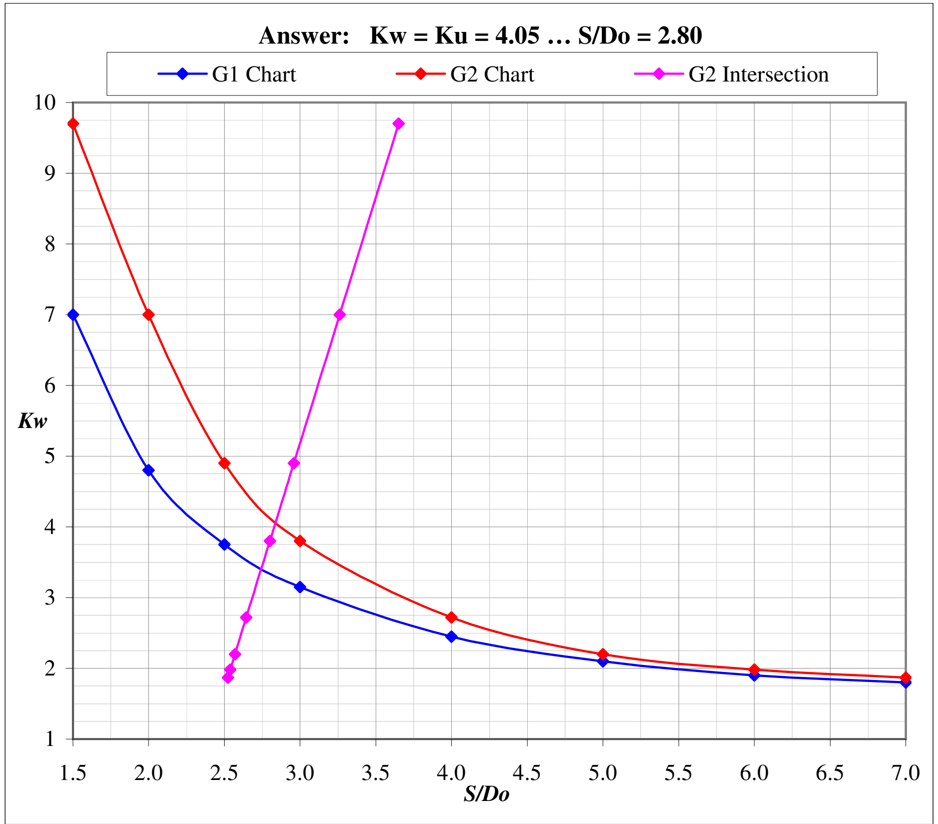
Chart :	**G1**	**G2**
θg	0°	90°
S/Do	**Kw**	**Kw**
1.5	7.00	9.70
2.0	4.80	7.00
2.5	3.75	4.90
3.0	3.15	3.80
4.0	2.45	2.72
5.0	2.10	2.20
6.0	1.90	1.98
7.0	1.80	1.87

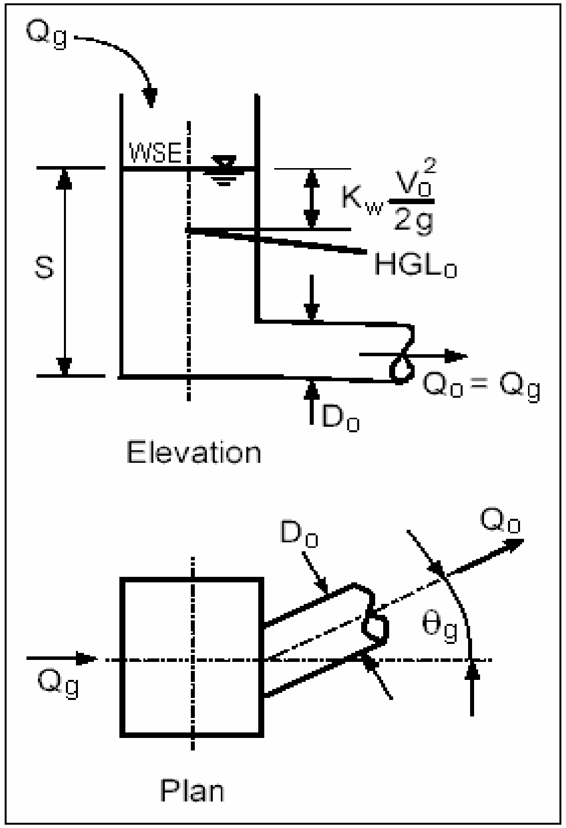
(G2)
(>15°)

$Kw.Vo^2/2g$	**WSE**	**S**	**S/Do**	**Error**
0.419	28.319	1.095	3.650	-2.150
0.302	28.202	0.978	3.261	-1.261
0.212	28.112	0.888	2.959	-0.459
0.164	28.064	0.840	2.800	0.200
0.117	28.017	0.793	2.645	1.355
0.095	27.995	0.771	2.570	2.430
0.086	27.986	0.762	2.538	3.462
0.081	27.981	0.757	2.523	4.477

G1 used where θg <= 15°
G2 used where θg > 15°
(as per Chart 32 of QUDM, 1994)

$-\Delta WSE = WSE - HGLo = Kw.Vo^2/2g$





Through Pits (i.e. through flow and grate flow)

Example of Ku & Kw calculation :

INPUT	
θu	38.3
Qg/Qo	0.097
Du/Do	0.884
Ku config	Poor
Do	0.600
Vo	2.340
ILo	28.277
HGLo	29.100

Chart :	T3	T3	T3	T3	T7	T7	T7	T7
θu	22.5	22.5	22.5	22.5	45.0	45.0	45.0	45.0
Qg/Qo	0.0	0.0	0.5	0.5	0.0	0.0	0.5	0.5
Du/Do	0.8	0.9	0.8	0.9	0.8	0.9	0.8	0.9

3-d interpolation factors

a	0.702	1 - a	0.298
b	0.246	1 - b	0.754
c	0.840	1 - c	0.160

a = (θu - 22.5) / (45.0 - 22.5)
* b = (N - 0.0) / (0.5 - 0.0)
c = (Du/Do - 0.8) / (0.9 - 0.8)

S/Do	Kw1	Kw2	Kw3	Kw4	Kw5	Kw6	Kw7	Kw8	Kw	Kw.Vo²/2g	WSE	S	S/Do	Error
1.5	1.84	1.98	2.30	2.35	3.24	3.01	2.86	2.90	2.72	0.761	29.861	1.584	2.640	-1.140
2.0	1.57	1.69	2.00	2.05	2.81	2.65	2.55	2.53	2.38	0.665	29.765	1.488	2.479	-0.479
2.5	1.33	1.43	1.79	1.83	2.62	2.48	2.21	2.19	2.15	0.602	29.702	1.425	2.375	0.125
3.0	1.25	1.32	1.61	1.63	2.58	2.41	2.08	2.05	2.06	0.575	29.675	1.398	2.330	0.670
4.0	1.16	1.22	1.52	1.50	2.53	2.36	1.91	1.87	1.97	0.550	29.650	1.373	2.289	1.711

S/Do	Ku1	Ku2	Ku3	Ku4	Ku5	Ku6	Ku7	Ku8	Ku
1.5	1.60	1.71	1.79	1.79	2.40	2.40	2.55	2.59	2.23
2.0	1.44	1.53	1.69	1.72	2.20	2.21	2.23	2.29	2.03
2.5	1.25	1.32	1.66	1.61	2.13	2.18	2.13	2.09	1.92
3.0	1.09	1.12	1.57	1.54	2.07	2.09	1.99	1.97	1.81
4.0	0.96	1.00	1.50	1.44	1.97	2.00	1.82	1.81	1.70

General 3-d interpolation equation

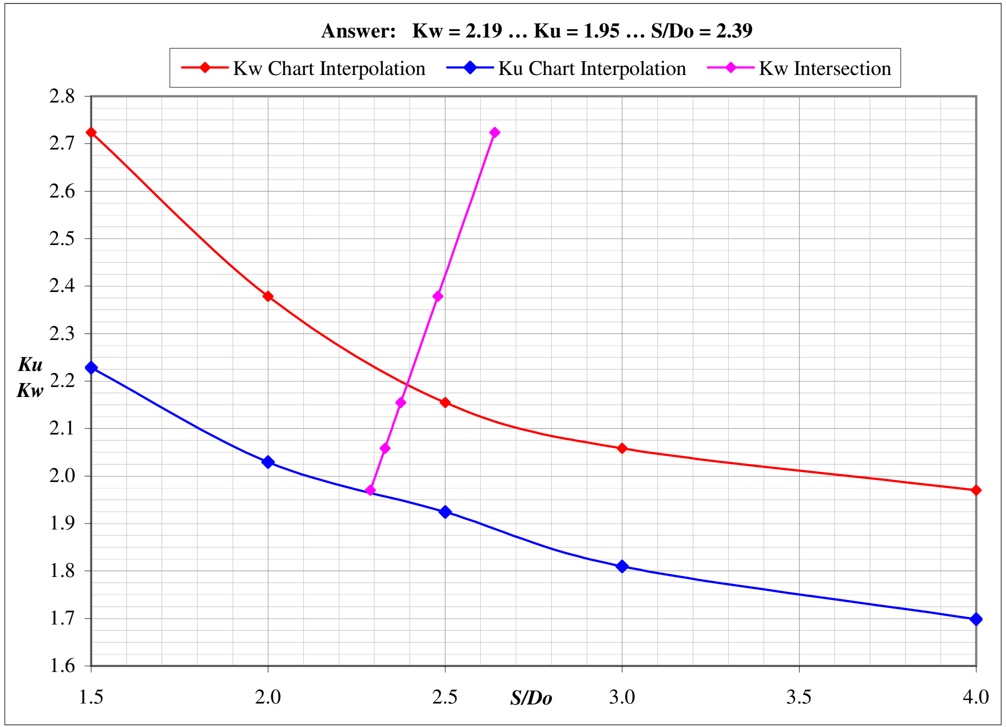
K =	(1-a) (1-b) (1-c)	K1	+	(1-a) (1-b) c	K2
+	(1-a) b (1-c)	K3	+	(1-a) b c	K4
+	a (1-b) (1-c)	K5	+	a (1-b) c	K6
+	a b (1-c)	K7	+	a b c	K8

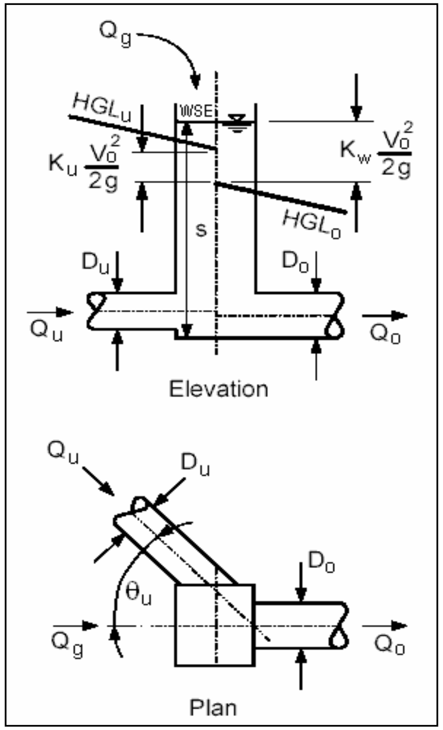
* Non-linear interpolation, as per QUDM (1994).

$N = 0.66\ (2.Qg/Qo - [Qg/Qo]^2)$

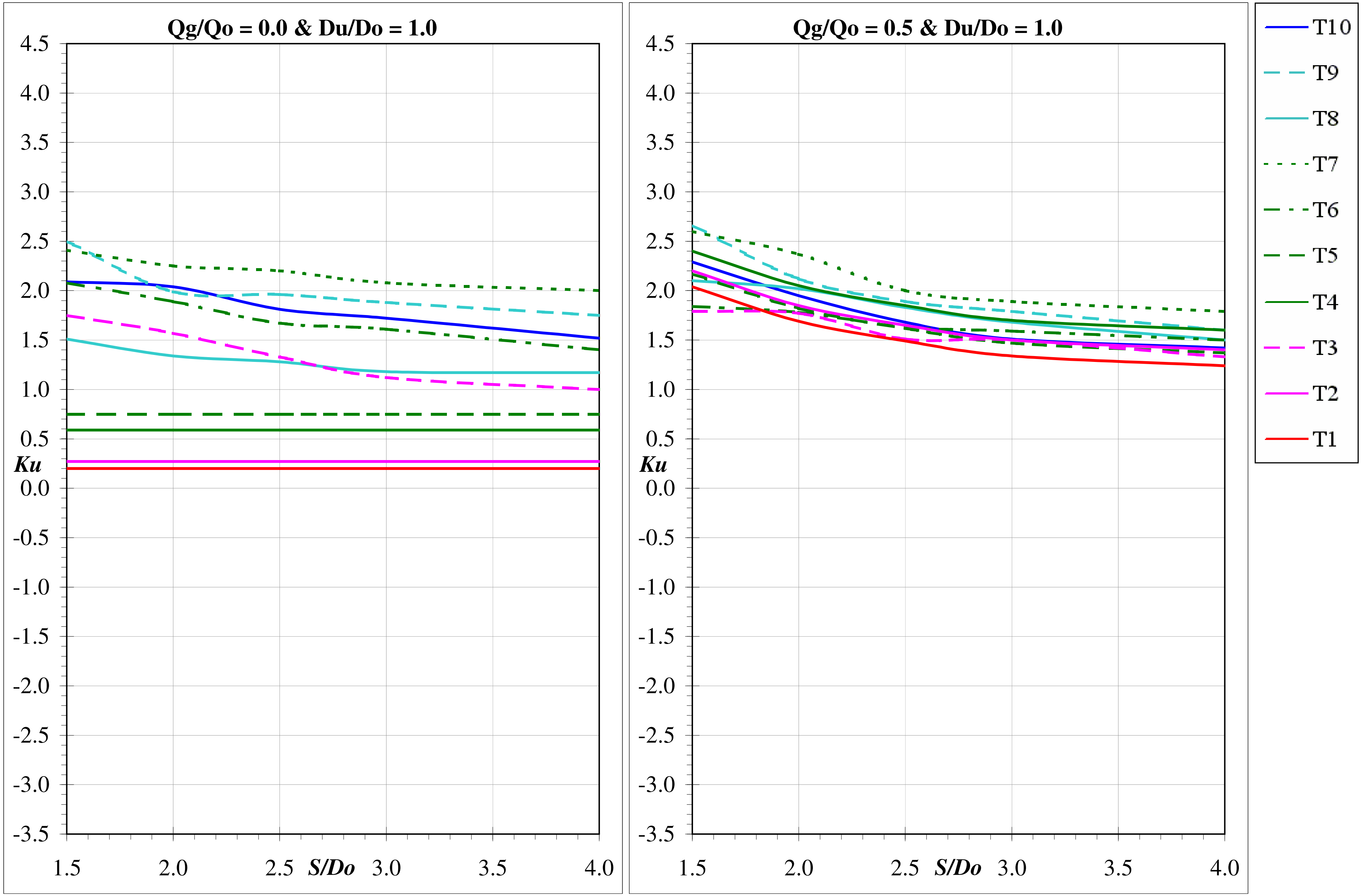
$-\Delta WSE = WSE - HGLo = Kw.Vo^2/2g$

$-\Delta Hp = HGLu - HGLo = Ku.Vo^2/2g$

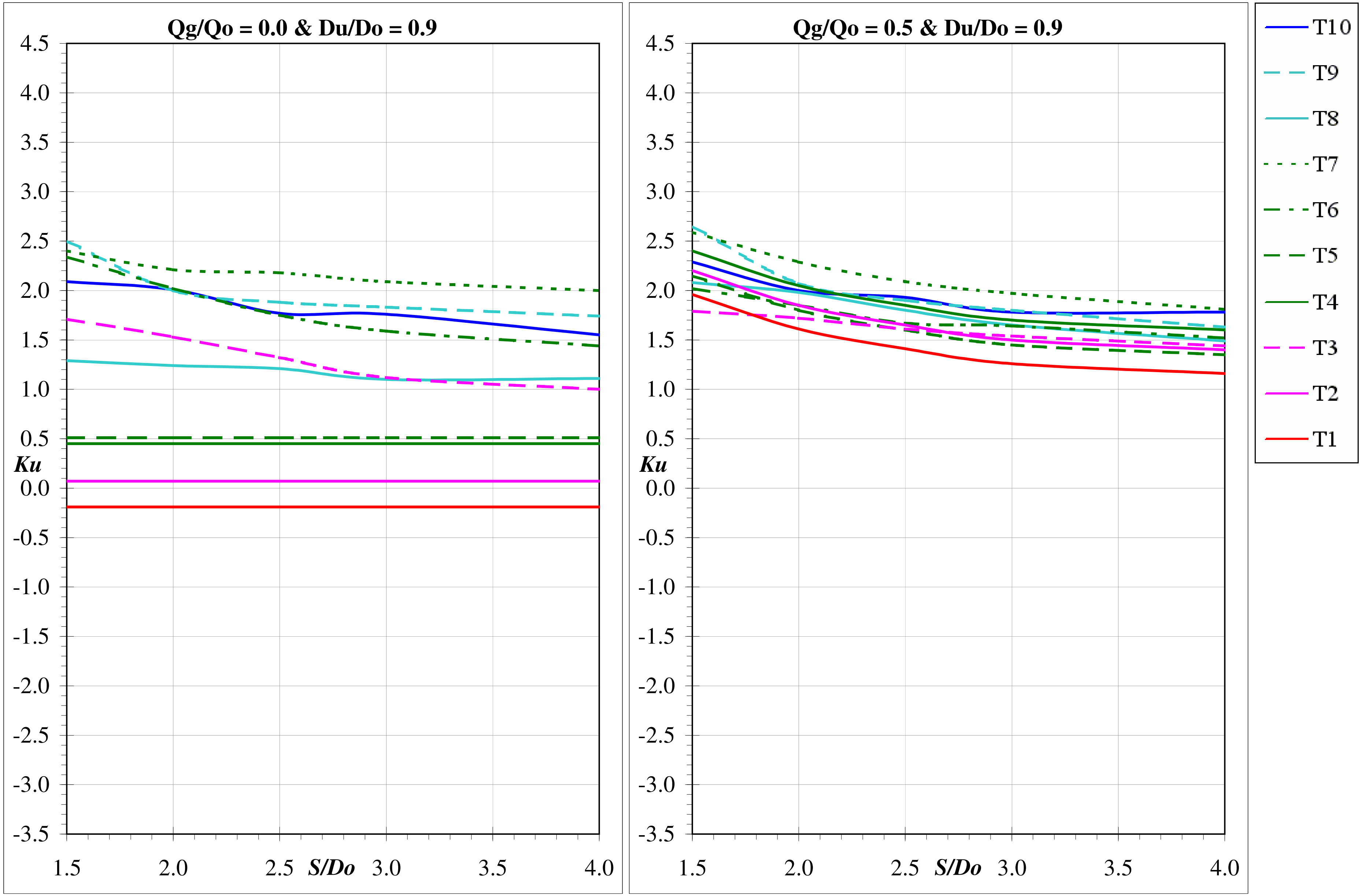




Ku Charts for Through Pits



Ku Charts for Through Pits



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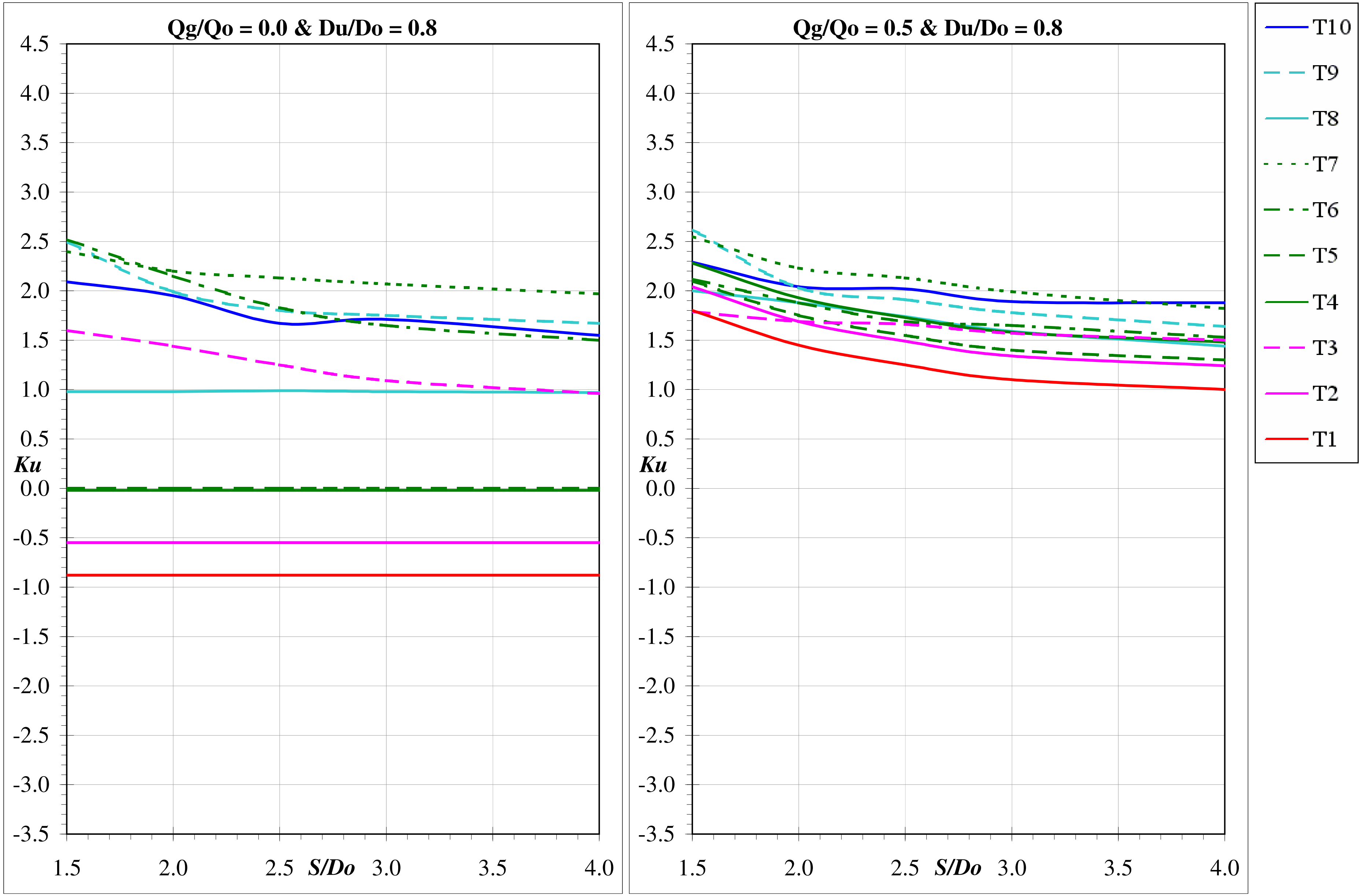

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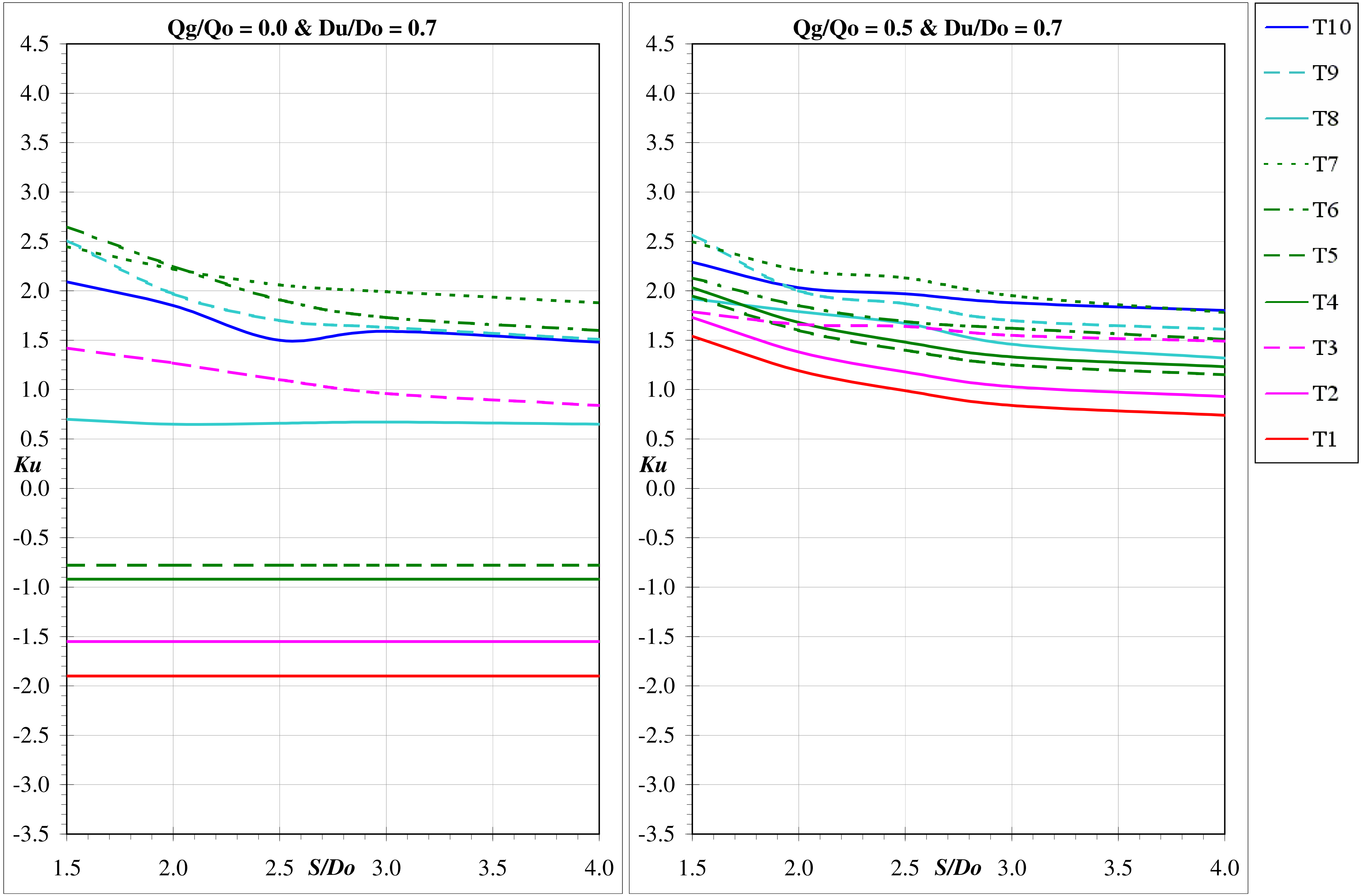
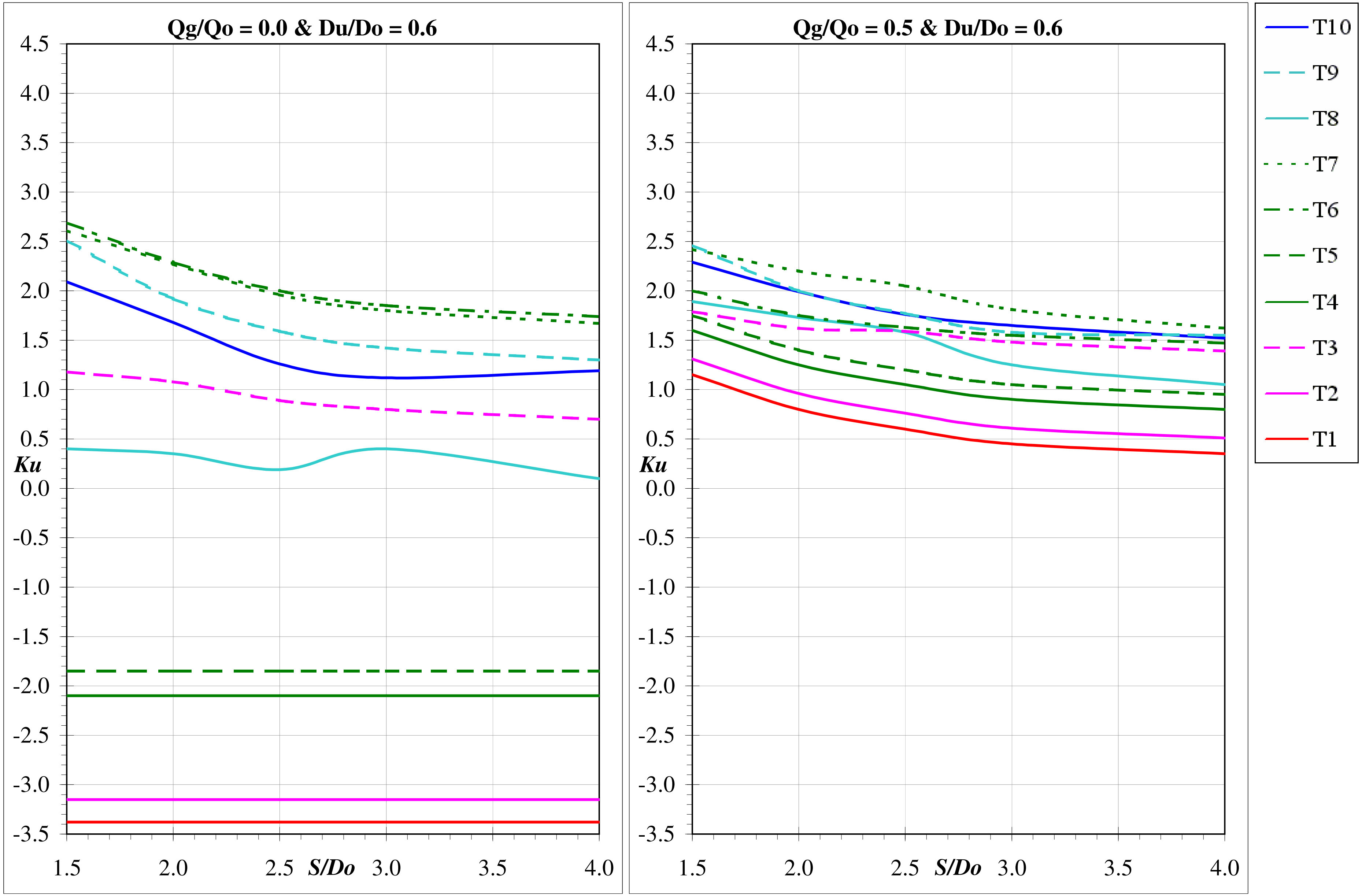
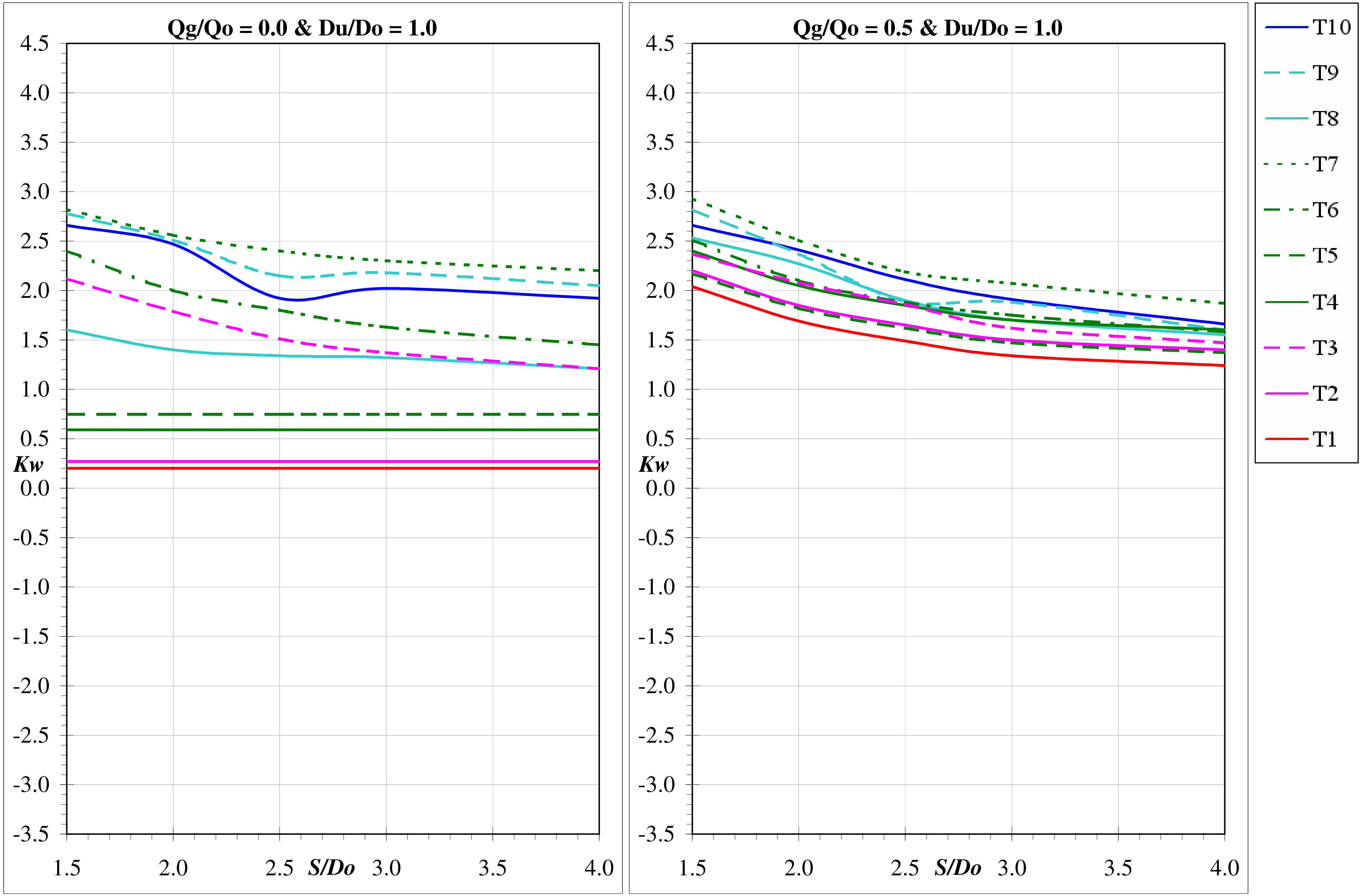


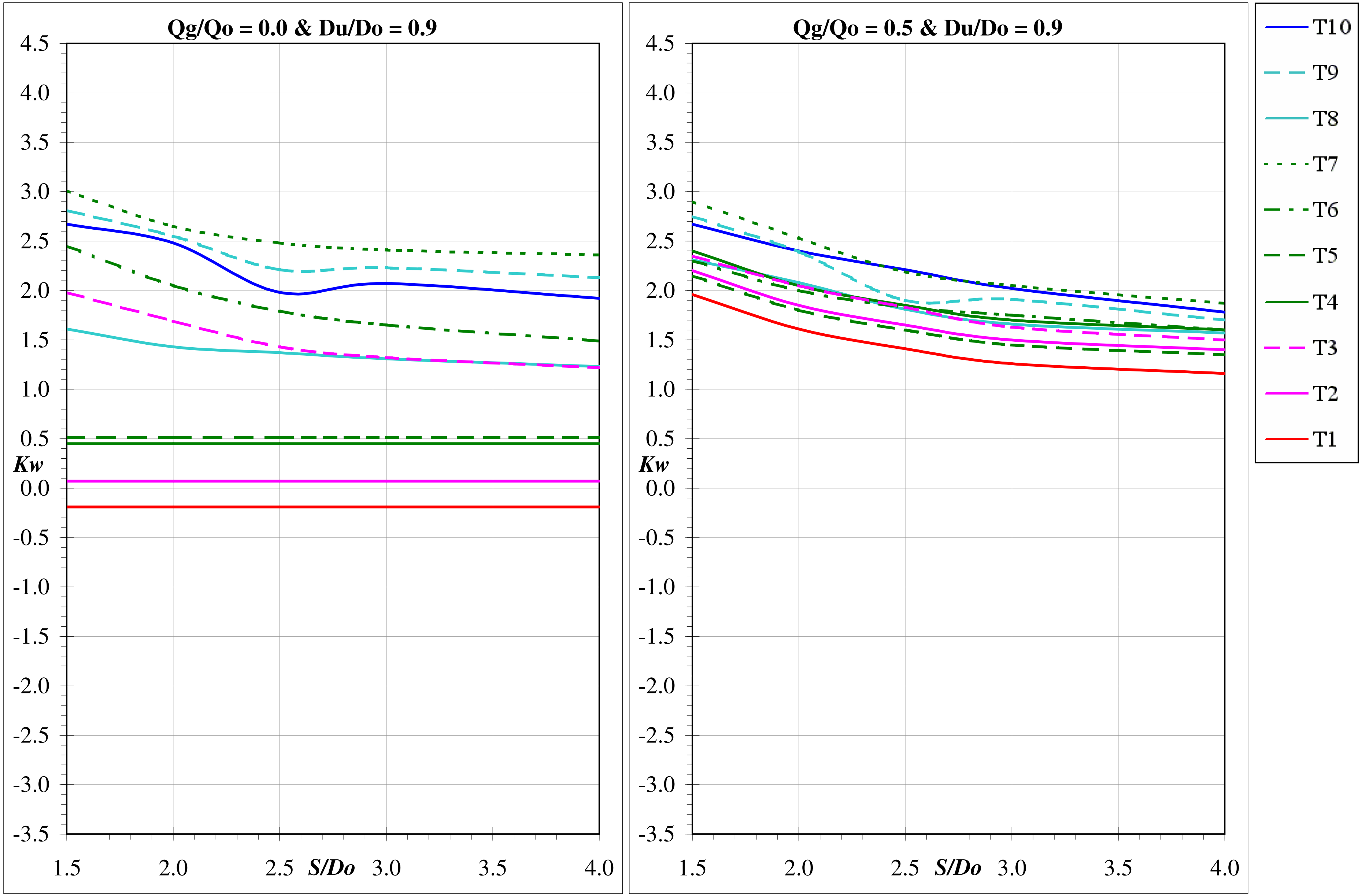
Ku Charts for Through Pits



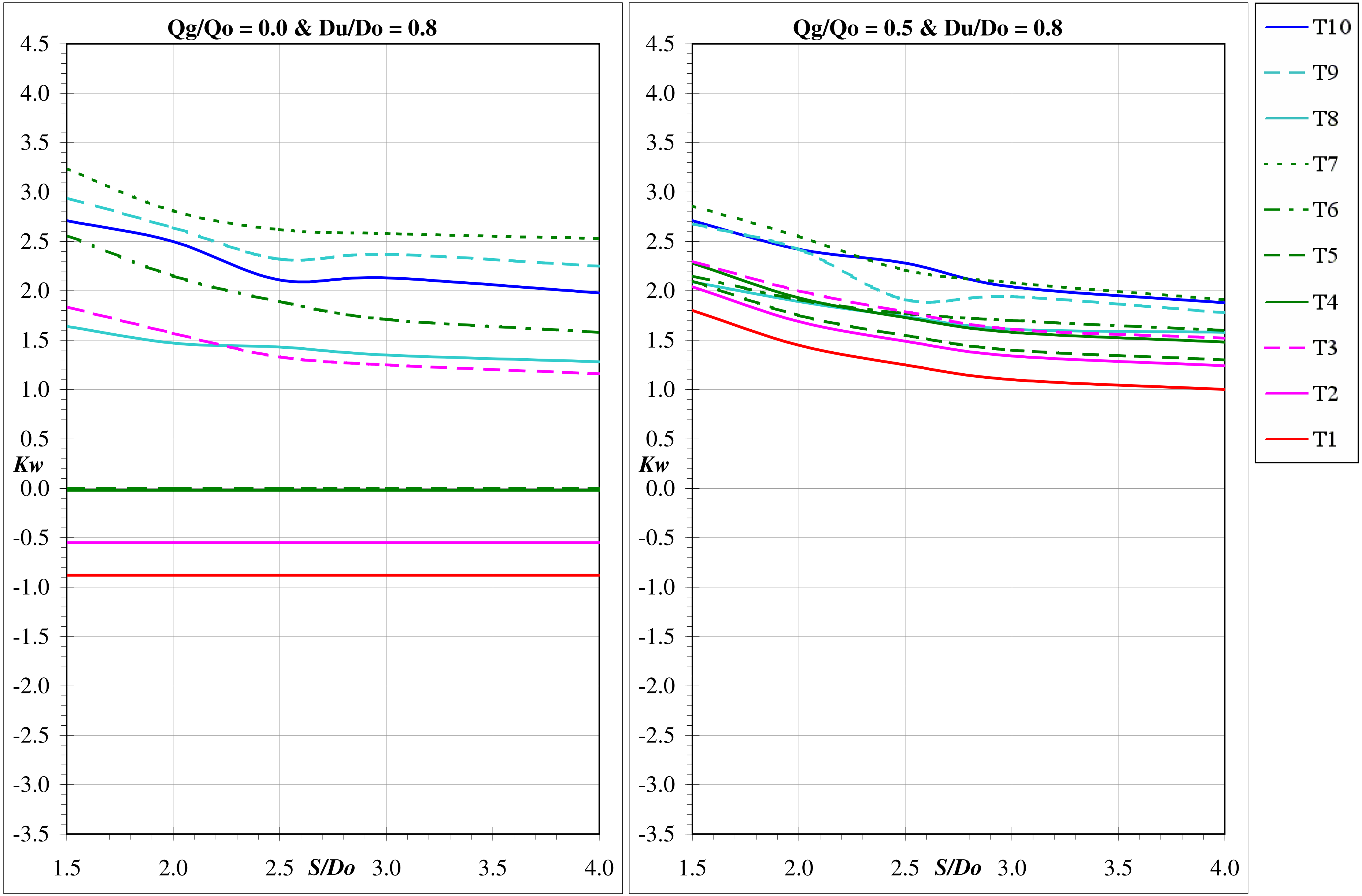
Kw Charts for Through Pits



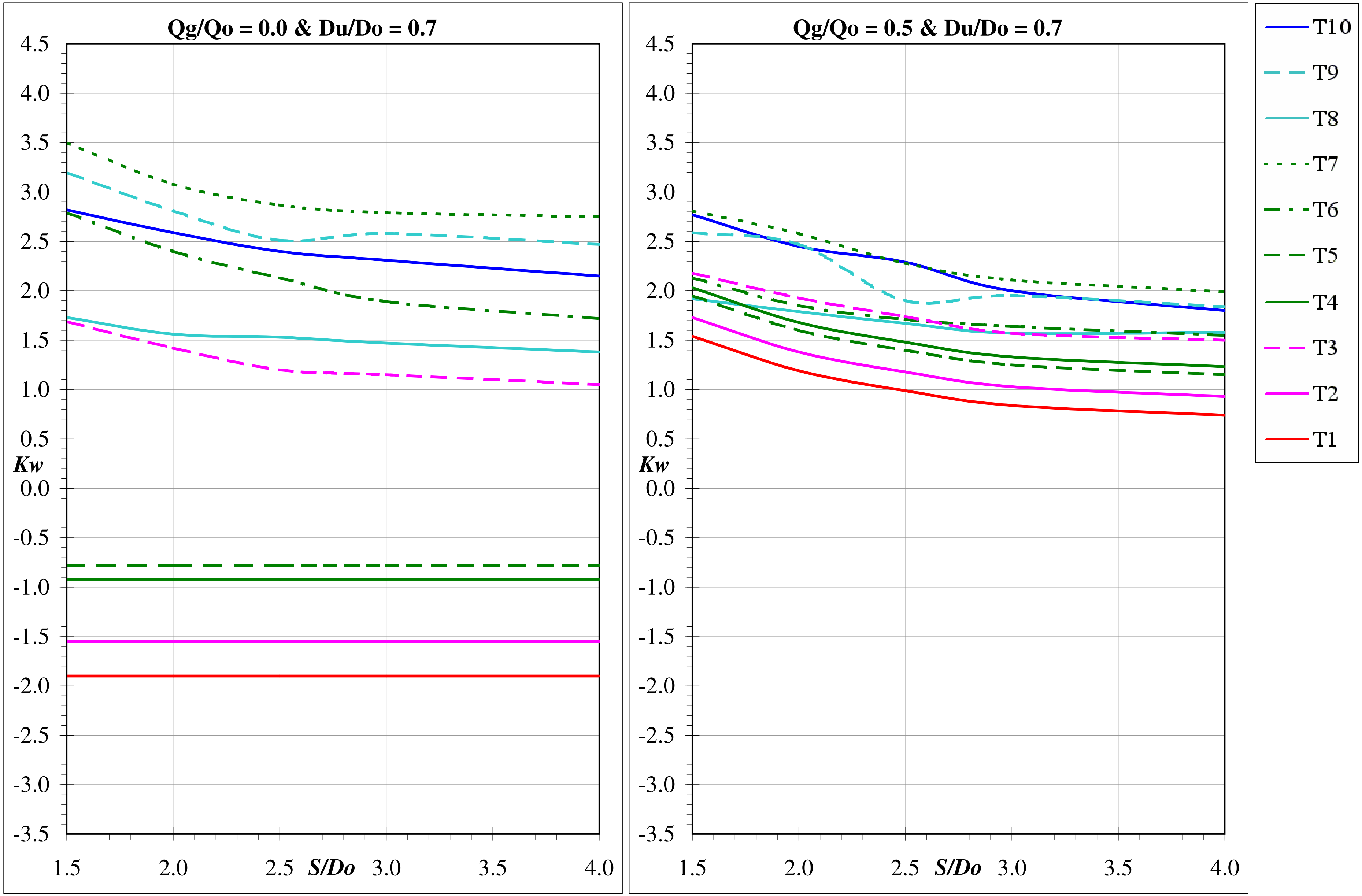
Kw Charts for Through Pits



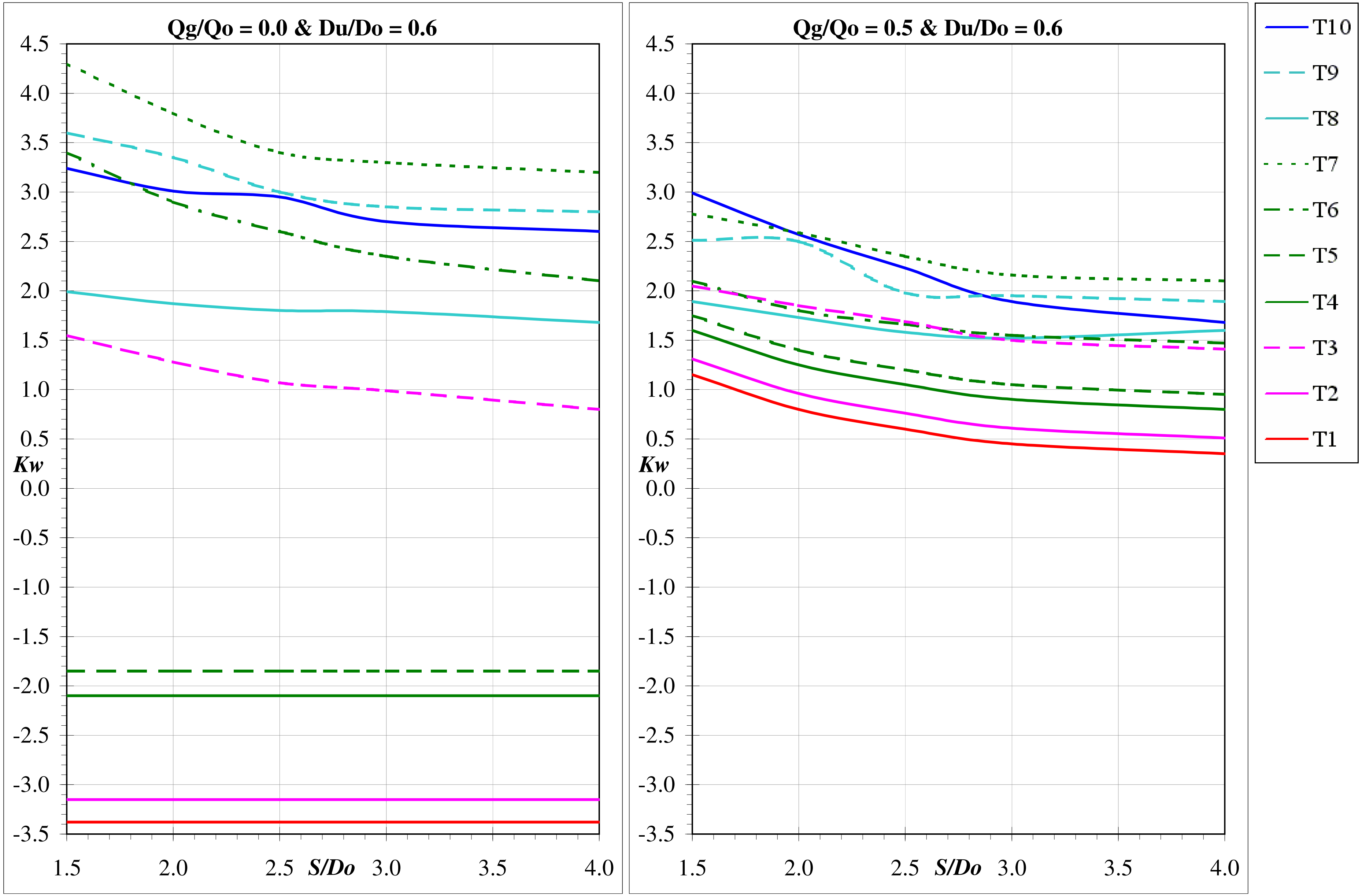
Kw Charts for Through Pits



Kw Charts for Through Pits

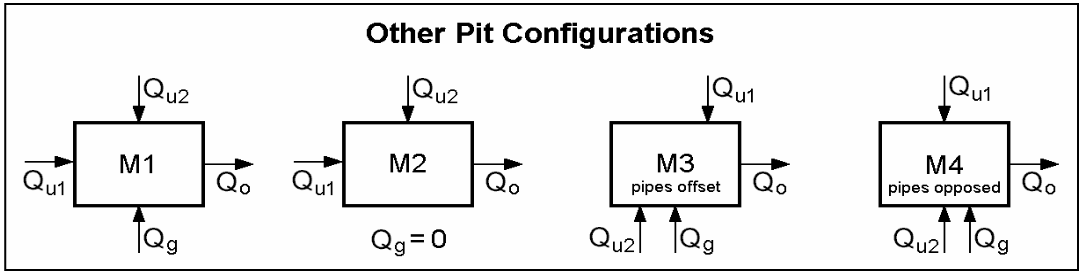


Kw Charts for Through Pits



Other Chart Data

Both source documents contain other charts not used by *12d Model*, covering the following limited set of four pit configurations, each with two upstream pipes:



Other Config	**M1**	**M2**	**M3**	**M4**
QUDM Ku Chart #	48	52, 53	49	49
QUDM Kw Chart #	48	52, 53	49	49
ACTDS Ku Chart #	3	4, 5, 6	11	12
ACTDS Kw Chart #	3	5, 6	11	12
ACTDS Pit Type #	4	5	9	10

The charts for M3, M4, and (under certain conditions) M2, suggest *slightly* independent (i.e. *slightly* different) Ku values for each of the two upstream pipes. However, the peak flows in each pipe (determined by *12d Model* via the Rational Method) do not, in general, occur at the same moment in time, and so provide little justification to account for these slight differences. As such, *12d Model* supports only a single Ku (and a single Kw) at each pit. The Rational Method is a statistical design method with much to commend it, but it is not sophisticated enough for these particular charts, which are perhaps better suited to a method based on unsteady flow simulations.

Using the *12d Model* method (of determining a single equivalent upstream pipe), the Ku and Kw values for M1 and M2 may be estimated adequately, if a little conservatively, with the *Ku config* set to “Fair”. For M3 and M4, adequate estimations are made regardless of the *Ku config* setting.

For other configurations of multiple upstream pipes – especially those where the jet of each upstream pipe projects wholly into the downstream pipe – *Ku config* settings of "Preferred" or "Good", may be more appropriate.

Notes :

The “Missouri Chart” used by *12d Model* for Grate Pits, possibly suggests conservatively high Kw values at low submergence ratios, compared with the evidence suggested by some other empirical and analytical studies. However, due to the typically low velocity head in the downstream pipe, a high Kw value rarely makes a significant difference in Grate Pits.

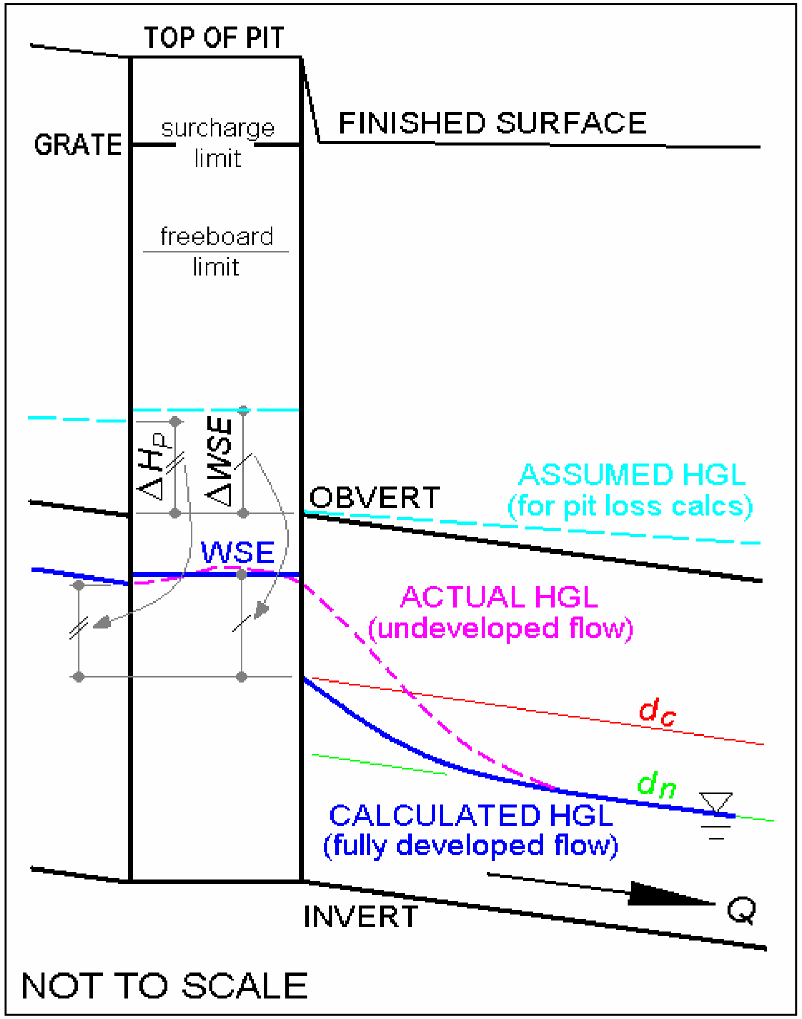
The “Hare Charts” used by *12d Model* for Through Pits, are all based on *square* pits with sides twice the diameter of the downstream pipe. Some of the comparable “Missouri Charts” consider pits with other geometries, and typically suggest lower Ku values.

If difficulties are encountered in adequately matching Ku and Kw values to a particular chart not considered by *12d Model*, simply set the *Ku method* to “Direct”, and enter the chart values manually. Alternatively, consider contacting the author (email: owen.thornton@12d.com) with information about the chart in question.

Part-full Flow and/or Extreme Submergence Ratios

Strictly speaking, the chart data are only applicable to pipes flowing full and under pressure. For pipes flowing part-full through pits, it is most common to assume reduced magnitudes of ΔHp and ΔWSE, which immediately questions the validity of the assumption that the head changes are proportional to the (higher, part-full) velocity head. Some of the current Australian design manuals provide estimation procedures for these uncertain cases, but they can often result in *increased* magnitudes of ΔHp and ΔWSE. In an attempt to provide a compromise, *12d Model* employs a procedure to ensure the magnitudes are neither increased nor reduced. At those pits where the downstream pipe flows part-full, *12d Model* determines Ku and Kw by assuming the HGL to be at the *obvert* of the pipe (with ΔHp and ΔWSE based on the *full pipe* velocity head). Once the head changes are determined in this way, they are applied from the calculated HGL in the downstream pipe, *not* the pipe obvert.

The chart data for Grate Pits give Kw values for S/Do ranging from 1.5 to 7.0, and for Through Pits give Ku and Kw values for S/Do ranging from 1.5 to 4.0. In *12d Model*, the chart data are assumed to be applicable for all S/Do values greater than or equal to 1.0, with Ku and Kw extending horizontally beyond the chart limits, when plotted against S/Do. With the "obvert assumption" outlined above for part-full flow, it is only ever a *negative* Kw value that may *potentially* cause S/Do to be calculated less than 1.0. Since this situation is far enough outside the range of the charts to be deemed "in doubt", *12d Model* handles such instances by simply (and conservatively) increasing the Ku and Kw values, so as to give S/Do equal to 1.0.



An Example of Part-full Flow

Culvert Inlets

For a pipe or box culvert, *12d Model* can calculate a Ku value to give the required loss in pressure head through the culvert entrance. The Ku value is the greater of the two values determined from consideration of the culvert under *inlet* and *outlet* control. The user need only set the *Ku method* to one of the 33 different methods applicable to culverts, as shown below.

12d Model	**HDS5**	**HDS5**	*Inlet Control Unsubmerged*			*Inlet Control Submerged*		*Inlet Control*	*Outlet Control*
Ku Method	**Chart No.**	**Chart Scale**	**Form**	**K**	**M**	**c**	**Y**	**F**	**Ke**
Ku - 101 Pipe Culvert Inlet - Concrete; Square Edge with Headwall	1	1	1	0.0098	2.000	0.03980	0.670	-0.5	0.5
Ku - 102 Pipe Culvert Inlet - Concrete; Socket End with Headwall	1	2	1	0.0018	2.000	0.02920	0.740	-0.5	0.2
Ku - 103 Pipe Culvert Inlet - Concrete; Socket End Projecting	1	3	1	0.0045	2.000	0.03170	0.690	-0.5	0.2
Ku - 104 Pipe Culvert Inlet - CMP; Headwall	2	1	1	0.0078	2.000	0.03790	0.690	-0.5	0.5
Ku - 105 Pipe Culvert Inlet - CMP; Mitred to Slope	2	2	1	0.0210	1.330	0.04630	0.750	+0.7	0.7
Ku - 106 Pipe Culvert Inlet - CMP; Projecting	2	3	1	0.0340	1.500	0.05530	0.540	-0.5	0.9
Ku - 107 Pipe Culvert Inlet - Beveled ring 45°	3	A	1	0.0018	2.500	0.03000	0.740	-0.5	0.2
Ku - 108 Pipe Culvert Inlet - Beveled ring 33.7°	3	B	1	0.0018	2.500	0.02430	0.830	-0.5	0.2
Ku - 109 Pipe Culvert Inlet - Concrete; Tapered Inlet Throat	55	1	2	0.5340	0.555	0.01960	0.900	-0.5	0.2
Ku - 110 Pipe Culvert Inlet - CMP; Tapered Inlet Throat	55	2	2	0.5190	0.640	0.02100	0.900	-0.5	0.2
Ku - 201 Box Culvert Inlet - 30° to 70° Wingwalls	8	1	1	0.0260	1.000	0.03470	0.810	-0.5	0.4
Ku - 202 Box Culvert Inlet - 90° Headwall or 15° Wingwalls	8	2	1	0.0610	0.750	0.04000	0.800	-0.5	0.5
Ku - 203 Box Culvert Inlet - 0° Wingwalls (Extension of Sides)	8	3	1	0.0610	0.750	0.04230	0.820	-0.5	0.7
Ku - 204 Box Culvert Inlet - 45° Wingwalls; d=D/24 Top Bevel	9	1	2	0.5100	0.667	0.03090	0.800	-0.5	0.2
Ku - 205 Box Culvert Inlet - 18° to 33.7° Wingwalls; d=D/12 Top Bevel	9	2	2	0.4860	0.667	0.02490	0.830	-0.5	0.2
Ku - 206 Box Culvert Inlet - 90° Headwall; 20mm Chamfers	10	1	2	0.5150	0.667	0.03750	0.790	-0.5	0.2
Ku - 207 Box Culvert Inlet - 90° Headwall; 45° Bevels	10	2	2	0.4950	0.667	0.03140	0.820	-0.5	0.2
Ku - 208 Box Culvert Inlet - 90° Headwall; 33.7° Bevels	10	3	2	0.4860	0.667	0.02520	0.865	-0.5	0.2
Ku - 209 Box Culvert Inlet - 45° Skewed Headwall; 20mm Chamfers	11	1	2	0.5450	0.667	0.04505	0.730	-0.5	0.2
Ku - 210 Box Culvert Inlet - 30° Skewed Headwall; 20mm Chamfers	11	2	2	0.5330	0.667	0.04250	0.705	-0.5	0.2
Ku - 211 Box Culvert Inlet - 15° Skewed Headwall; 20mm Chamfers	11	3	2	0.5220	0.667	0.04020	0.680	-0.5	0.2
Ku - 212 Box Culvert Inlet - 10° to 45° Skewed Headwall; 45° Bevels	11	4	2	0.4980	0.667	0.03270	0.750	-0.5	0.2
Ku - 213 Box Culvert Inlet - 45° Non-offset Wingwalls; 20mm Top Chamfer	12	1	2	0.4970	0.667	0.03390	0.803	-0.5	0.2
Ku - 214 Box Culvert Inlet - 18.4° Non-offset Wingwalls; 20mm Top Chamfer	12	2	2	0.4930	0.667	0.03610	0.806	-0.5	0.2
Ku - 215 Box Culvert Inlet - 30° Skew; 18.4° Non-offset Wingwalls; 20mm Top Chamfer	12	3	2	0.4950	0.667	0.03860	0.710	-0.5	0.2
Ku - 216 Box Culvert Inlet - 45° Offset Wingwalls; d=D/24 Top Bevel	13	1	2	0.4970	0.667	0.03020	0.835	-0.5	0.2
Ku - 217 Box Culvert Inlet - 33.7° Offset Wingwalls; d=D/12 Top Bevel	13	2	2	0.4950	0.667	0.02520	0.881	-0.5	0.2
Ku - 218 Box Culvert Inlet - 18.4° Offset Wingwalls; d=D/12 Top Bevel	13	3	2	0.4930	0.667	0.02270	0.887	-0.5	0.2
Ku - 219 Box Culvert Inlet - Tapered Inlet Throat	57	1	2	0.4750	0.667	0.01790	0.970	-0.5	0.2
Ku - 220 Box Culvert Inlet - Side Tapered Inlet Throat; Less Favourable Edges	58	1	2	0.5600	0.667	0.04460	0.850	-0.5	0.2
Ku - 221 Box Culvert Inlet - Side Tapered Inlet Throat; More Favourable Edges	58	2	2	0.5600	0.667	0.03780	0.870	-0.5	0.2
Ku - 222 Box Culvert Inlet - Slope Tapered Inlet Throat; Less Favourable Edges	59	1	2	0.5000	0.667	0.04460	0.650	-0.5	0.2
Ku - 223 Box Culvert Inlet - Slope Tapered Inlet Throat; More Favourable Edges	59	2	2	0.5000	0.667	0.03780	0.710	-0.5	0.2

- HW = Headwater depth above IL [m]
- IL = Invert level at culvert entrance [m]
- HGLo = HGL level *inside* culvert entrance [m]
- U = SI units factor = 1.811
- Q = Design flow rate per culvert barrel [cumecs]
- D = Height of culvert barrel [m]
- A = Cross-sectional area of culvert barrel [m^2]
- S = Slope of culvert barrel [m/m]
- d_c = Critical flow depth in culvert [m]
- V_c = Critical flow velocity in culvert [m/s]
- V_f = Full pipe velocity in culvert = Q/A [m/s]
- g = Acceleration due to gravity [m/s/s]
- **K** = Coefficient [-]
- **M** = Coefficient [-]
- **c** = Coefficient [-]
- **Y** = Coefficient [-]
- **F** = Coefficient [-]
- **Ke** = *Energy-head* loss coefficient [-]
- Ku = *Pressure-head* change coefficient [-]

Inlet Control:

Unsubmerged Form 1: $HW/D = (d_c + V_c^2/2g) / D + \mathbf{K} [U.Q / (A\sqrt{D})]^{\mathbf{M}} + \mathbf{F}.S$ … $U.Q / (A\sqrt{D}) < 3.5$

Unsubmerged Form 2: $HW/D = \mathbf{K} [U.Q / (A\sqrt{D})]^{\mathbf{M}}$ … $U.Q / (A\sqrt{D}) < 3.5$

Submerged: $HW/D = \mathbf{c} [U.Q / (A\sqrt{D})]^2 + \mathbf{Y} + \mathbf{F}.S$ … $U.Q / (A\sqrt{D}) > 4.0$

$Ku = (HW + IL - HGLo) . 2g / V_f^2$

Outlet Control: $Ku = \mathbf{Ke} + 1.0$

Data Source: HDS5 (2005).

Notes:

1) A transition zone exists between the unsubmerged and submerged cases under inlet control. Results are obtained within this zone, via linear interpolation between the results at the limit of each case.

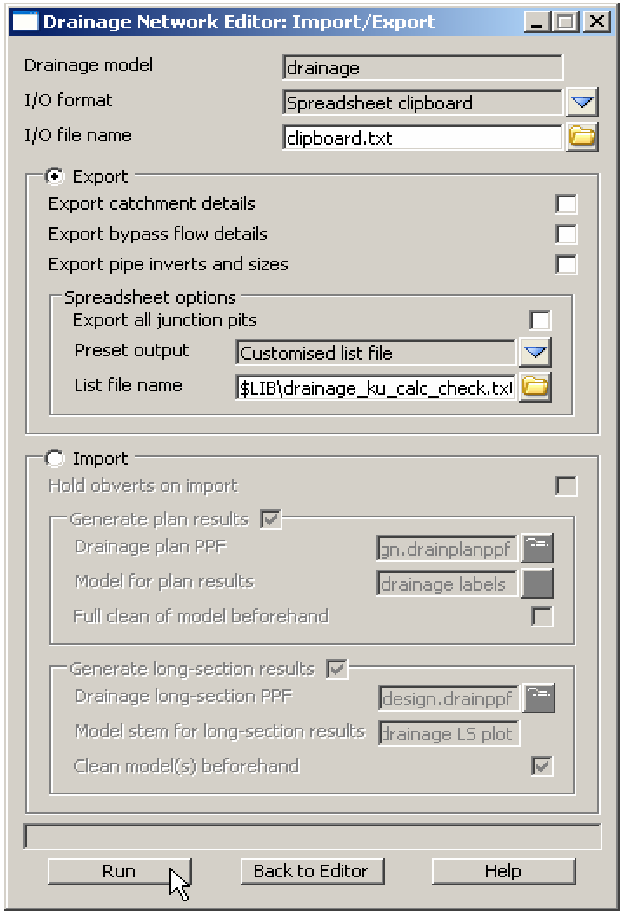
2) Technically, HW applies to the *Total Energy Line* (TEL), and not the *Hydraulic Grade Line* (HGL). However, the difference between the TEL and HGL in the upstream channel (i.e. the velocity head in the channel) is typically small, and is most commonly assumed to be negligible.

3) Culvert slope, S, is **not** squared in the these formulae ... the source document (p 192, eqn 26 & 28) refers to "*NOTE 2* ", **not** "*S to the power of* 2".

Design Checks

Spreadsheet reports may be generated quickly and easily, to allow checking and auditing of the Ku and Kw values calculated by *12d Model* .

From the *Import/Export* panel of the *Drainage Network Editor* , simply *Export* to the *Spreadsheet clipboard* , using the *Customised list file* supplied in the installed *Library* folder (as shown below), and paste the results into your spreadsheet.



Standard "Customised list file" : $LIB\drainage_ku_calc_check.txt

header

Pit	Ku	Kw	V'head	P'head Loss	WSE Loss	Ku	Ku	Qg/Qo	Grate Flow	Pipe Flow	Du/Do	S/Do	Chart(s)

header

Name				(Ku.V'head)	(Kw.V'head)	Method	Config	Ratio	Deflection	Deflection	Ratio	Ratio	Used

header

(-)	(-)	(-)	(m)	(m)	(m)	(-)	(-)	(-)	(deg)	(deg)	(-)	(-)	(-)

pit data
pit name
calculated ku
calculated kw
pipe data
calculated velocity head
pit data
calculated pit pressure head loss
calculated pit wse loss
calculated ku method
calculated ku config
calculated ku grate flow ratio
calculated ku grate flow angle
calculated ku pipe flow angle
calculated ku diameter ratio
calculated ku submergence ratio
calculated ku chart

Sample Ku & Kw Design Check Report :

Pit Name	Ku	Kw	V'head	P'head Loss (Ku.V'head)	WSE Loss (Kw.V'head)	Ku Method	Ku Config	Qg/Qo Ratio	Grate Flow Deflection	Pipe Flow Deflection	Du/Do Ratio	S/Do Ratio	Chart(s) Used
(-)	(-)	(-)	(m)	(m)	(m)	(-)	(-)	(-)	(deg)	(deg)	(-)	(-)	(-)
1.6H	1.11		0.21	0.23	0.23	Inlet Headwall							Inlet Control
2.1S	1.83		0.07	0.13	0.13	Ku,Kw via Charts	Preferred	0.50		27.7	0.72	1.56	T2/T4
2.2S	7.37		0.06	0.48	0.48	Ku,Kw via Charts		1.00	90.0			1.93	G2
3.1G	0.72		0.57	0.41	0.41	Ku,Kw via Charts	Preferred	0.08		30.2	1.00	1.88	T2/T4
3.2G	0.42		0.49	0.21	0.21	Ku,Kw via Charts	Preferred	0.14		0.0	0.89	1.91	T1
3.4M	0.82	0.83	0.36	0.29	0.30	Ku,Kw via Charts	Good	0.00		48.3	1.00	2.74	T5/T8
3.8M	0.55		0.19	0.11	0.11	Ku,Kw via Charts	Good	0.00		35.5	1.00	2.83	T2/T5
3.9S	1.07		0.17	0.18	0.18	Ku,Kw via Charts	Preferred	0.26		29.5	1.00	3.48	T2/T4
3.10G	0.34		0.50	0.17	0.17	Ku,Kw via Charts	Good	0.00		25.9	1.00	4.79	T2/T5
3.11M	1.73	1.88	0.23	0.40	0.44	Ku,Kw via Charts	Fair	0.00		48.7	1.00	2.46	T6/T9
3.12G	0.83		0.24	0.20	0.20	Ku,Kw via Charts	Good	0.23		11.3	1.00	3.88	T1/T2
3.13G	1.59	1.63	0.17	0.27	0.28	Ku,Kw via Charts	Preferred	0.53	37.0	63.5	1.00	3.95	G2/T4/T8
3.14G	5.86		0.04	0.23	0.23	Ku,Kw via Charts		1.00	0.0			1.76	G1

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*__ACTDS__ (2003) **- Errata in Appendix A**

Chart 5
a) Re the "Ku(bar) vs Dl/Do" graph: the y-axis range of Ku(bar) should be 1.3 to 2.5 (not 0.6 to1.8).

Chart 8
a) Re the "S/Do=2.5" graph: the "Qg/Qo=0.5" arrow label points to the wrong line.
b) Re the "S/Do=3.0" graph: the y-axis range of Kw should be 1.8 to 2.6 (not 2.6 to 3.4).
c) Re the "S/Do=4.0" graph: the y-axis range of Kw should be 1.6 to 2.4 (not 2.4 to 3.2).

Chart 12
a) Re the "H" graph (on left): missing "Qhv/Qo" arrow label.
b) Re the "L" graph (on right): missing "Qlv/Qo" arrow label.

Chart 16
a) Re the "S/Do=1.5" graph: the "Qg/Qo" brace labels should have 0.0 and 0.5 swapped around.
b) Re the "S/Do=2.0" graph: the "Qg/Qo" brace labels should have 0.0 and 0.5 swapped around.
c) Re the "S/Do=2.5" graph: the "Qg/Qo" brace labels should have 0.0 and 0.5 swapped around.
d) Re the "S/Do=3.0" graph: the lower arrow label should be "Qg/Qo=0.5" (not "Qg/Qo=0.0").

Chart 20
a) Re the "S/Do=3.0" graph: the y-axis range of Ku should be 0.8 to 1.8 (not 1.0 to 2.0).