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Institut de recherche pour le développement

Volta-HYCOS PROJECT

TRAINING SESSION ON RATING CURVES :

Case study

Accra, 23rd – 27th April 2007

CASE STUDY

RATING CURVE OF THE SENEGAL RIVER AT GOUINA – UPSTREAM STATION

The rating curve of the Senegal River at Gouina-upstream station is of a single value stage/discharge relationship type, steady and without any anomaly. The station is located upstream of a fall of about 10 meters, and therefore has a very efficient downstream control section.

Numerous flow measurements have been carried out for mean water levels, for which the water surface slope has been measured. The rating curve is well defined for mean water levels, but the extension from a flow of 2 500 $m^3.s^{-1}$ to 7 000 $m^3.s^{-1}$ is quite difficult.

I LOCATION OF THE STATION

Gouina station is located in the upper part of the Senegal River basin at about 50 km from Kayes city, an important regional capital in the Republic of Mali.

The coordinates of the station are: 14°00N & 11°06W

II CHARACTERISTICS OF THE STATION

See figures A2.1, A2.2 & A2.3

2.1 The first staff gauge was installed in 1925 by UHEA Company in charge of the hydro-power dam project at the level of Gouina falls (height about 10 meters). The catchment area is of 128 600 km².

2.2 Six different sections for the staff gauges have been used from 1925 to 1979 to monitor the water levels of the river.

The cross section of the upstream station, for which the rating curve is studied in this example, is of a quite complex shape (see fig. A2.3) with a double central canal, a maximum depth of more than 20 meters for high water levels and a channel width of about 300 meters. The river bed is rocky and perfectly steady.

2.3 The cross section levelling carried out by the UHEA Company was in 4th June 1951 and allowed the definition, with a good accuracy, of the relationships W(h) (Wetted Area) and R(h) (Hydraulique radius), h being the water level at the upstream water level recorder. Table A2.1 shows the list of the 27 levelling points and all the geometric parameters of the cross section.

Figure A2.6 shows the shape of the W(h) & R(h) curves. To facilitate the extension calculations these two curves are given by the formula below:

- Wetted area : W = 0.000259 h2 + 2.2993 h + 1261
    - for 0 < h < 692 (max water level)

The error in W is less than 0.1% for the whole range

- Hydraulic radius : R = 0.007982 h + 5.42 for 0 < h < 550
  R = -0.0000207 h2 + 0.008577 h + 9.81 for 550 < h < 700

The error in R is less than 0.3% for both equations.

Remark: We have drawn on figures A2.4 & A2.5 the variations in wetted area and in hydraulic radius with the water level for the whole section. As the W curve is very regular, it is very different for the R curve.

2.4 The gauging section for the mean and high water levels is located 1 040 m upstream and at about 3 km upstream of the falls. The cross section profile is more regular and the section is wider at the gauging section(see fig. A2. 3).

III HYDROMETRIC EQUIPMENT

3.1 Four staff gauges have been installed at Gouina station, on the left bank of the river between 1925 and 1929. These staff gauges rank from upstream to downstream are:

- Staff gauge N°1 installed in 1925 just upstream of the falls and made of a leaning rail graduated from 0 to 5 meters;
- Staff gauge N°2 equipped the first reach at the foot of the falls. It is a vertical rail of 8 meters, fixed on a concrete pile against the rocky bank of the river;
- Staff gauge N°3 is located at the beginning of the second reach downstream the falls it is also a vertical rail of 8 meters;
- Staff gauge N°3 equipped the third reach. It is located 900 meters downstream the previous one in the area planed by UHEA for the tail water of the hydropower plan of Gouina. It is a vertical rail of 9 meters.

3.2 UHEA has completed this equipment with two water level recorders in 1950:

- The first installation is called Gouina-upstream (Bär trade mark, mensual type) and is located 2 km upstream of the falls. Its gauge Zero level is at an altitude of 63.35 meters MEFS (Mission d'Etudes du Fleuve Senegal);

- The other installation is called Gouina-downstream (same trade mark) and is located on the right bank at about 400 meters downstream of the staff gauge N°4. Its gauge Zero level is at an altitude of 48.09 meters MEFS.

3.3 From 1953 the MAS (Mission d'Aménagement du Senegal) neglected the four staff gauges of UHEA but monitored the two water level recorders and added to them auxiliary staff gauges.

3.4 This historical summary of the Gouina station historical gives an idea of the work that has been done to ensure a homogeneous water level time series: with six different sections the problem must be complex.

IV WATER LEVEL SERIES

4.1 The four old staff gauges have been monitored from 1925 to 1950: the staff gauge N°1 from 1929 to 1942, and the three others from 1936 to 1942.

The correspondence graphs, built in plotting the water levels at the staff gauges N°1, N°2, N°4, against the water levels at the staff gauge N°3, show a high scattering of the results which gave evidence of the wrong readings. As the readings have also a lot of gaps it has not be possible to use them. So, despite the very nice and useful installations from a building point of view as two staff gauges are always in a very good condition today, the readings between 1925 and 1950 are useless.

This situation is due to the lack of staff gauges maintenance which were either badly graduated or unreadable and to the fact that the gauge readers were inefficient. Nevertheless, we have kept the maximum water levels data observed during this period. For Gouina-upstream the maximum observed water level between 1929 and 1942 was 600 cm (it occurred in 1935).

4.2 From June 1950 to October 1952, UHEA took advantage of the whole set of staff gauges of the 1st, 2nd and 3rd reaches and of both the upstream and downstream water level recorders. The only missing information was the record of the peak flood in 1950.

4.3 From 1953 to 1956 the staff gauges at Gouina station were no more observed and the monitoring of the water levels is hazardous. Despite this situation, we have corrected the records and filled the gaps for the missing or bad data.

4.4 Data are then completed from 1953 to 1955. For 1954 two months of data are missing (September and October). Since 1956 we have completed and accurate readings for the 2nd reach staff gauges, installed by the M.A.S. After two years of good monitoring (1956 & 1957), the water level recorders were no more monitored.

4.5 During the period for which records are available in the ORSTOM files, i.e. from June1st 1955 to December 31st 1979, the maximum water levels recorded at Gouina-upstream are:

- 692 cm on the 24/08/1958 for the maximum (978 cm at the 2nd reach staff gauge)
- 626 cm on the 04/06/1964
- 613 cm on the 23/08/1964
- The minimum water level of 25 cm occurred in 1976 (no date).

V GAUGING & CALIBRATION

5.1 Sixty one flow measurements have been carried out by UHEA for water levels recorded at the upstream water level recorder ranging from 0.68 m to 4.21 m (discharge from 6.5 $m^3.s^{-1}$ to 2 300 $m^3. s^{-1}$).
Table A2.2 shows chronological series of the flow measurements and table A2.3 the ranking list of these gaugings.

For the gauging in mean and high water levels, the water surface profiles were levelled each time with respect to the benchmark N°11 (alt. 70.84 m MEFS); So, are known the difference in level between the gauging point and the recorder sections (distance 1 040 m). For the low water levels, gaugings were carried out at Dipari village (6 km upstream of Galougo). A control measurement has been carried out at this section by ORSTOM in 1965.

5.2 The 61 gaugings carried out by UHEA ware undertaken between October 1950 and June 1952. The ORSTOM gauging carried out in February 1965 is of a high importance as it is the single one during the period of records. It is a chance that the calibration is steady and that the upstream and downstream staff gauges relationship is well known.

On the other hand, the two gauging carried out on 3rd & 4th of October 1951 are not usable due to cable breaking over the cross section. Despite this, the two gauging are very important as the water surface slope was measured.

The results of the discharge measurements are very good and gave an excellent rating curve between the stage 0.65 and 4.20 m (6 to 2 300 $m^3.s^{-1}$). The curve is very regular (Fig. A2. 7), the gaugings are enough and the good distribution of the gaugings enables to avoid any uncertainity in the drawing, except for discharges less than 100 $m^3.s^{-1}$. In view of the large cross section at Gouina-upstream, it is observed that the station is not very sensitive.

The single value stage/discharge relationship type at this station is confirmed by the graph as it was expected due to the location upstream of the falls.

The mean deviation between the measured discharges and the calculated one is of 3.3% for the 60 gaugings carried out by UHEA & IRD and 2.3 % for the gauging out of the stage 1.50 m. This shows the excellent quality of the gauging carried out by UHEA.

If the water level range were just a little bit more than the maximum gauging the extension of the rating curve of Gouina upstream would be easy, but the curve has to be extrapolated to the level 6.92 m (i.e. an additional 2.70 m).

VI RATING CURVE EXTENSION

6.1 Remark

A gauging carried out by a Russian team in 1965 doesn't appear in the list, as it was known only after this study. So, the value was not used in establishing the rating curve but for validation.

Taking into account the three usual methods for rating curve extension, it will be useful to check the limits of use for each one and to make his own judgment if the constraints are respected or not.

6.2 Logarithmic method

Constraint 1 (Single value stage/discharge relationship of exponential type), 3 (Regular shape cross section), and 4 (downstream hydraulic control) are well respected. On the other hand, the second constraint (numerous gauging up to a sufficient water level) is not well respected, despite the fact that the plotting of the gauging shows a good alignment of the points (Fig. A2.8) and allows an attractive but daring extension. The discharge for the maximum water level (692 cm) can be read directly on the graph: 9400$m^3.s^1$.

6.3 Steven's method

The use constraints are the same as for the previous method and, as for this one the gauging are not enough to well define the curve of discharges. Figure A2.9 shows this deficiency better than in the figure A2.8, maybe due to logarithmic coordinates? The extension of the discharge curve may or may not give good results :

- The extension has to be made according to the line (1), fitted with the gauging points between 1 000 & 2 300 $m^3.s^1$, the result for the maximum discharge is 6 150 $m^3.s^1$ for the stage 692cm;
- The Stevens method doesn't allow the extension following the curve (2) which brings to the result of the log. Method;

- We will justify below the extension following the curve (3), drawing which cannot be “guessed” a priori.

6.4 Slope - Area method

Even if the wetted area is fully defined till the maximum level, the extension of the relationship U(h) (U = mean velocity) is not possible (see fig; A2.10). So, it is necessary to use the Strickler’s formula, accordingly we known the value of the surface water slope for all complete gauging and also for the two incomplete one carried out for stages 489 & 557 cm.
The two parameters that we have to calculate are the roughness coefficient (K) and the water surface slope. Figure A2.11 shows the distribution of the K coefficient for all the gauging. We have retained the value of K + 19 which correspond to the two maximum gauging stages. It will be possible also to select the value K = 1_ which correspond to the median value, but it seems that K is not yet stabilized for the stage 420 cm.

On figure A2. 12 the relationship J(h) is represented, the two values of the water surface slope measured for the stages 489 & 557 are of a high interest to guide the extension of the curve to the stage 692 cm. The extension is made quasi-linear as we don’t have any more information.

The extension consists in the estimation of the K value and the drawing of the J(h) curve to the 692 range.

With K = 19 and the value of the surface water slope read on the figure A2. 12, we have to calculate the discharges for the maximum stages by using the Strickler formula:

H cm	S m2	R m	J cm/km	KJ 1/2	U m/s	Q calculated m3/s	Q tabulated m3/s	Deviation %
489	2447	9.32	30.19	0.330	1.662	3580	3510	+ 2.0
557	2622	9.87	43.27	0.395	1.819	4770	4770	0
613	2591	10.27	56.00	0.450	2.124	5880	5850	+ 0.6
626	2802	10.34	58.00	0.458	2.172	6085	6100	- 0.2
692	2976	10.61	73.50	0.515	2.487	7400	7400	0

The rating curve is shown on figure A2. 14.

<u>Remark:</u> The shape of the U(h) & $KJ^{1/2}$ curves (fig. A2.10 & A2.13) are a little bit strange, in fact, this is regular as the K value is not yet stabilized and the value of J increased more slowly.

VII CONCLUSION

The case study of the rating curve calibration for the Gouina upstream station on the Senegal River shows that it is very important to check the three methods for the extension of the rating curve, the difference in the results obtain by the logarithmic and Stevens methods should alert the operator. The water surface slope variation study in respect with the elevation of the water level is the single method to solve correctly this problem.

This also shows the importance of carrying out levelling on each station as well as cross section and longitudinal profiles.

Table A2.1: CROSS SECTION PROFILE AT THE GOUINA UPSTREAM WLR LEVELLING

Point (m)	Distance (cm)	Height (cm)	Point (m)	Distance (cm)	Height (cm)
1	0.0	693	14	105.9	-1276
2	5.2	659	15	113.9	-1516
3	12.9	373	16	127.4	-1186
4	19.2	174	17	138.9	-656
5	26.5	3	18	157.4	-646
6	29.4	-30	19	170.4	-886
7	32.4	-53	20	197.3	-186
8	38.4	-196	21	217.9	-166
9	50.4	-296	22	230.9	-186
10	70.4	-336	23	245.9	-206
11	80.6	-676	24	258.1	114
12	89.4	-786	25	264.1	510
13	90.4	-966	26	268.3	619
			27	273.8	690

CHARACTERISTICS OF THE CROSS SECTION PROFILE

Stage CM	Wetted Area M²	Wetted perimeter M	Width M	Hydraulic radius M	Mean depth Mm
0	1261.09	232.51	226.99	5.42	5.56
25	1318.12	234.73	229.15	5.62	5.75
50	1375.66	236.81	231.17	5.81	5.95
75	1433.7	238.99	233.19	6.00	6.15
100	1492.25	240.97	235.21	6.19	6.34
125	1551.29	242.82	236.98	6.39	6.55
150	1610.72	244.37	238.42	6.59	6.76
175	1670.50	245.91	239.86	6.79	6.97
200	1730.62	247.19	241.03	7.00	7.18
225	1791.02	248.48	242.20	7.21	7.40
250	1851.71	249.76	243.37	7.41	7.61
275	1912.70	251.05	244.54	7.62	7.82
300	1973.98	252.33	245.71	7.82	8.03
325	2035.55	253.61	246.88	8.03	8.25
350	2097.42	254.90	248.05	8.23	8.46
375	2159.58	256.17	249.21	8.43	8.67
400	2222.01	257.34	250.26	8.63	8.88
425	2284.71	258.52	251.31	8.84	9.09
450	2347.67	259.69	252.36	9.04	9.30
475	2410.89	260.86	253.42	9.24	9.51
500	2474.38	262.03	254.47	9.44	9.72
525	2538.15	263.53	255.87	9.63	9.92
550	2602.32	265.24	257.21	9.81	10.11
575	2666.90	266.96	259.14	9.99	10.29
600	2731.89	268.67	260.78	10.17	10.48
625	2797.30	270.61	262.65	10.34	10.65
650	2863.29	273.28	265.26	10.48	10.79
675	2930.21	277.95	269.89	10.54	10.86
700	2998.21	281.88	273.80	10.64	10.95

SENEGAL RIVER. GOUINA HYDROMETRIC STATION.

Fig- A2-1- LOCATION SKETCH (approximative scale: 1cm ⟶250cm)

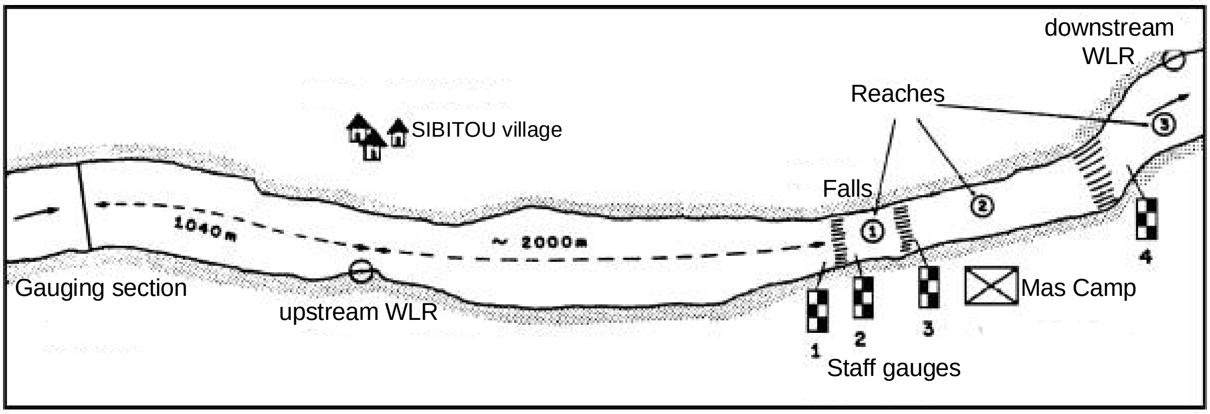


Fig- A2-2- LONGITUDINAL PROFILE (max.water level- 1942)

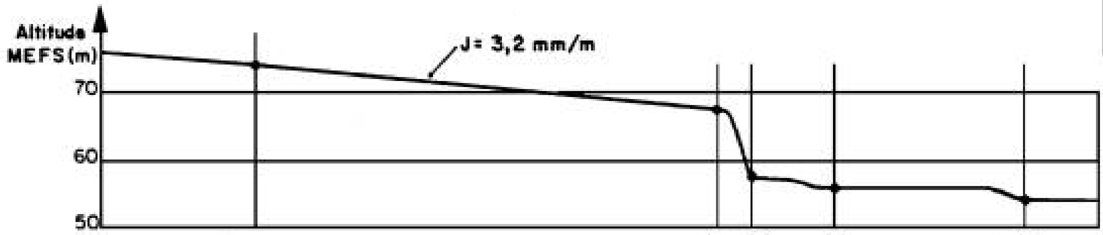


Fig-A2-3- CROSS SECTION PROFILE

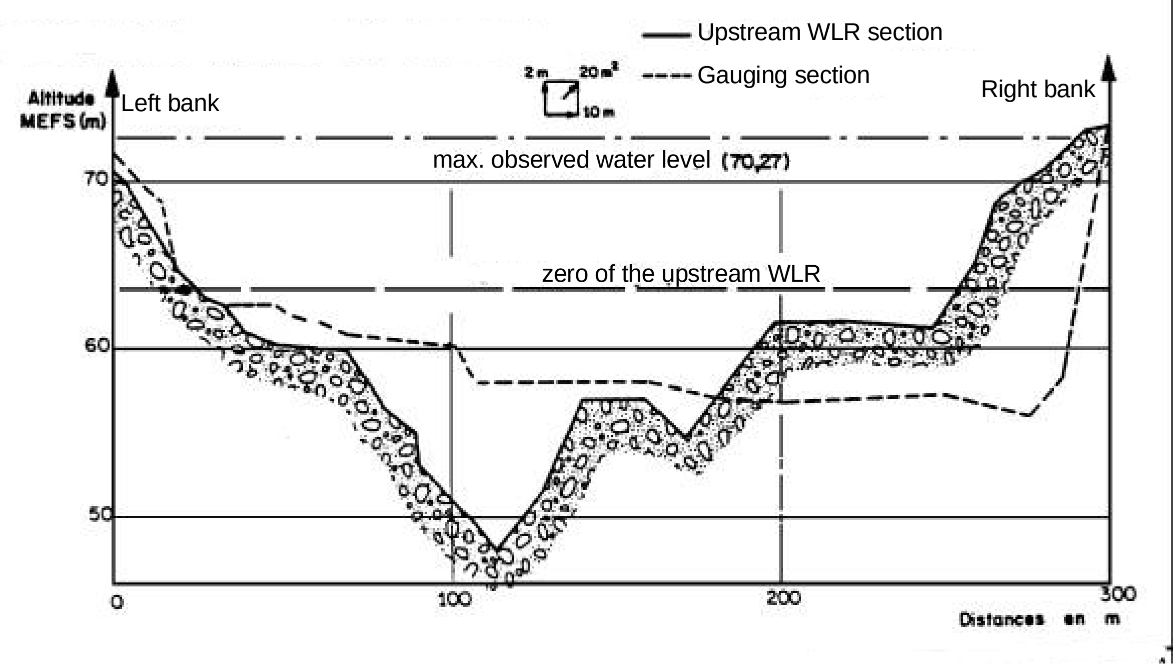


Table A2.2a: GAUGING TIME LIST

Date	Stage (cm)	Discharge m^3/s	A M²	U m/s	R m	Slope cm/km	$KJ^{1/2}$	K Strickler
30.10.50	333	1150	2055	0.560	8.08	5.87	0.139	18.16
02.11.50	314	996	2009	0.496	7.93	7.40	0.125	14.50
04.11.50	303	890	1981	0.449	7.84	4.62	0.114	16.74
06.11.50	294	828	1959	0.423	7.77	3.85	0.108	17.38
09.11.50	282	735	1930	0.381	7.67	2.40	0.098	20.00
13.11.50	264	606	1886	0.321	7.53	3.46	0.084	14.21
21.11.50	238	434	1823	0.238	7.32	2.50	0.063	12.68
05.12.50	206	308	1746	0.176	7.06	0.48	0.048	21.82
13.12.50	194	289	1717	0.168	6.97	0.02	0.046	103.00
11.01.51	163	140	1643	0.085	6.72	-	-	-
22.01.51	129	57	1562	0.036	5.88	-	-	-
23.01.51	152	108	1616	0.067	6.63	-	-	-
19.03.51	108	28	1512	0.019	5.64	-	-	-
15.07.51	252	510	1857	0.275	7.43	2.69	0.072	13.92
19.07.51	292	758	1954	0.388	7.75	4.04	0.099	15.59
22.07.51	281	631	1928	0.327	7.66	3.27	0.084	14.71
25.07.51	256	505	1867	0.271	7.46	2.31	0.071	14.76
02.08.51	254	495	1862	0.266	7.45	1.83	0.070	16.31
04.08/51	319	956	2020	0.473	7.97	5.29	0.119	16.30
06.08.51	338	1185	2068	0.573	8.12	7.21	0.142	16.71
09.08.51	363	1495	2130	0.702	8.32	9.13	0.171	17.90
10.08.51	350	1265	2097	0.603	8.21	9.13	0.148	15.5
14.08.51	364	1470	2132	0.689	8.33	9.23	0.168	17.46
18.08.51	337	1195	2065	0.579	8.11	7.12	0.143	17.00
20.08.51	385	1730	2185	0.792	8.49	12.21	0.190	17.22
21.08.51	415	2160	2260	0.956	8.73	16.25	0.225	17.68
23.08.51	379	1645	2170	0.758	8.45	11.25	0.183	17.23
25.08.51	368	1495	2142	0.698	8.36	10.28	0.169	16.72
30.08.51	360	1470	2122	0.693	8.29	10.66	0.169	16.38
04.09.51	391	1865	2200	0.848	8.54	13.08	0.203	17.75
05.09.51	406	2060	2237	0.921	8.66	14.62	0.218	18.06
06.09.51	410	2130	2247	0.948	8.69	15.48	0.224	18.02
29.09.51	393	1830	2205	0.830	8.56	12.79	0.198	17.54
03.10.51	489	3700	2450	1.512	9.32	30.19	0.341	19.64
04.10.51	557	5080	2620	1.937	9.87	43.27	0.421	20.24
17.10.51	411	2130	2250	0.947	8.70	14.42	0.224	18.64
21.10.51	403	2015	2230	0.904	8.64	14.52	0.215	17.82
27.10.51	406	2075	2237	0.928	8.66	14.90	0.220	18.03
28.10.51	420	2305	2272	1.014	8.77	15.48	0.238	19.16
29.10.51	421	2280	2275	1.002	8.78	15.77	0.235	18.75
31.10.51	379	1825	2170	0.841	8.45	12.30	0.203	18.29
02.11.51	372	1610	2152	0.748	8.39	10.67	0.181	17.56
11.11.51	355	1400	2110	0.664	8.25	8.46	0.163	17.68
13.11.51	337	1210	2065	0.586	8.11	8.22	0.145	16.01
15.11.51	328	1070	2043	0.524	8.04	6.25	0.131	16.52
16.11.51	309	900	1996	0.451	7.89	4.52	0.114	16.93
23.11.51	281	671	1928	0.348	7.66	2.21	0.090	19.05
23.11.51	264	556	1886	0.295	7.53	2.79	0.077	14.54
30.11.51	254	495	1862	0.266	7.45	2.89	0.070	13.00

Table A2.2b: GAUGING TIME LIST

Date	Stage (cm)	Discharge m^3/s	A m2	U m/s	R m	Slope cm/km	$KJ^{1/2}$	K Strickler
03.12.51	245	458	1840	0.249	7.38	1.25	0.066	18.59
08.12.51	233	421	1811	0.232	7.28	0.96	0.062	19.93
13.12.51	221	360	1782	0.202	7.18	1.92	0.054	12.38
20.12.51	211	314	1758	0.179	7.10	-	-	-
31.12.51	195	243	1719	0.141	6.98	0.67	0.039	14.92
21.01.52	175	185	1671	0.111	-	-	-	-
19.02.52	150	105	1612	0.065	-	-	-	-
24.03.52	121	52	1543	0.034	-	-	-	-
30.04.52	89	11	1468	0.007	-	-	-	-
24.05.52	68	6.5	1419	0.005	-	-	-	-
04.06.52	85	10	1458	0.007	-	-	-	-
24.06.52	120	51	1541	0.033	-	-	-	-
17.02.65	137	63.6	1581	0.040	-	-	-	-

Table A2.3a: RANKING GAUGING LIST

Date	Water level cm	Measured discharge m^3/s	Tabulated discharge m^3/s	Deviation en %	
24.05.52	68	6.5	6.5	0	
04.06.52	85	10	10.4		- 4.0
30.04.52	89	11	12.4		-12.7
19.03.51	108	28	28.3		- 0.9
24.06.52	120	51	44.1	+13.5	
24.03.52	121	52	45.6	+12.3	
22.02.51	129	57	58.7		- 3.0
17.02.65	137	63.6	74.2		-16.7
19.02.52	150	105	405	0	
23.01.51	152	108	110		- 2.2
11.01.51	163	140	143		- 1.9
21.01.52	175	185	183	+0.9	
13.12.50	194	209	252	+12.8	
31.12.51	195	243	256		- 5.2
05.12.50	206	308	299	+3.0	
20.12.51	211	314	319		- 1.6
13.12.51	221	360	361		- 0.4
08.12.51	233	421	415	+1.5	
21.12.50	238	424	438		- 0.8
03.12.51	245	458	471		- 2.8
15.07.51	252	510	506	+0.9	
02.08.51	254	495	516		- 4.3
30.12.51	254	495	516		- 4.3
27.05.51	256	505	527		- 4.5
13.11.50	264	606	574	+5.2	
27.11.51	264	556	574		- 3.3
22.07.51	281	631	687		- .8
23.11.51	281	671	687		- 2.3
09.11.50	282	735	694	+5.6	
19.07.51	292	758	769		- 1.4
06.11.50	294	828	785	+5.2	
04.11.50	303	890	859	+3.5	
18.11.51	309	900	911		- 1.2
02.11.50	314	996	956	+4.1	
04.08.51	319	956	1002		- 4.8
15.11.51	328	1070	1090		- 1.9
30.10.50	333	1150	1141	+0.8	
18.08.51	337	1195	1183	+1.0	
13.11.51	337	1210	1183	+2.3	
06.08.51	338	1185	1193		- 0.7
10.08.51	350	1265	1325		- 4.7
11.11.51	355	1400	1383	+1.2	
30.08.51	360	1470	1442	+1.9	
09.08.51	363	1495	1478	+1.1	
14.08.51	364	1470	1490		-1.4
25.08.51	368	1495	1540		-3.0
02.11.51	372	1610	1590	+1.2	

Table A2.3b: RANKING GAUGING LIST

Date	Water level cm	Measured discharge m^3/s	Tabulated discharge m^3/s	Deviation en %	
23.08.51	379	1645	1680		-2.2
31.10.51	379	1825	1680	+7.9	
20.08.51	385	1730	1760		-1.8
04.09.51	391	1865	1845	+1.2	
29.09.51	393	1830	1870		-2.2
21.10.51	403	2015	2015	0	
05.09.51	406	2060	2060	0	
27.10.51	406	2075	2060	+0.8	
06.09.51	410	2130	2120	+0.6	
17.10.51	411	2130	2130	0	
21.08.51	415	2160	2190		-1.5
28.10.51	420	2305	2270	+1.5	
29.10.51	421	2280	2290		-0.3
03.10.51	489	3700*			
04.10.51	557				

* Incomplete, partially calculated (cf. table A2.2)

Table A2.4: Splitting in parabola segments

MALI SÉNÉGAL SÉNÉGAL GOUINA-Upstream

ÉTAL. n° 1 : validity from 30th October 1950 to 31 December 1979

Values of limit height HP(L) and intermediates HINT (L) & limit discharges Q(L) & intermediates QINT (L)

L	HP(L) in m	Q(L) in m^3/s	HINT (L) in m	QINT (L) in m^3/s
1	0.68	6.500		
2	1.00	20.000	0.85	10.000
3	1.30	60.500	1.15	36.800
4	1.74	180.000	1.50	105.000
5	2.50	495.000	2.10	317.000
6	4.20	2320.000	3.20	1010.000
7	6.92	7400.000	5.50	4100.000

VALUES OF THE PARABOLAS COEFFICIENTS

SEGMENTS	C (1.L)	C (2.L)	C (3.L)
1	0.1439950E+03	-.3890940E+01	0.6500000E+01
2	0.1533330E+03	0.8900000E+02	0.2000000E+02
3	0.2045460E+03	0.1815910E+03	0.6050000E+02
4	0.8479510E+02	0.3500290E+03	0.1800000E+03
5	0.3378150E+03	0.4992430E+03	0.4950000E+03
6	0.5095770E+02	0.1729040E+04	0.2320000E+04

ANGLE BETWEEN THE TANGENTS AT THE LIMITS

SEGMENTS	LIMITS POINTS		ANGLES (in degrees)
	H (in m)	Q (in m3/s)	
1 - 2	1.00	20.000	0.24
2 - 3	1.30	60.500	0.09
3 - 4	1.74	180.000	-0.93
4 - 5	2.50	495.000	1.19
5 - 6	4.20	2320.000	1.38

4TH November 1986

STATION NUMÉRO: 27260115
MALI SÉNÉGAL GOUINA-Upstream

Rating curve n°1: validity from 30 October 1950 to 31 December 1979

H(m)	Q(m^3/s)	H(m)	Q(m^3/s	H(m)	Q(m^3/s)
0.60	7.733	2.80	675.000	4.90	3560.000
0.70	6.480	2.90	749.000	5.00	3740.000
0.80	8.110	3.00	829.000	5.10	3920.000
0.90	12.600	3.10	916.000	5.20	4100.000
1.00	20.000	3.20	1010.000	5.30	4280.000
1.10	30.400	3.30	1110.000	5.40	4470.000
1.20	43.900	3.40	1220.000	5.50	4650.000
1.30	60.500	3.50	1330.000	5.60	4840.000
1.40	80.700	3.60	1450.000	5.70	5030.000
1.50	105.000	3.70	1580.000	5.80	5220.000
1.60	133.000	3.80	1710.000	5.90	5410.000
1.70	166.000	3.90	1860.000	6.00	5600.000
1.80	201.000	4.00	2000.000	6.10	5790.000
1.90	238.000	4.10	2160.000	6.20	5980.000
2.00	277.000	4.20	2320.000	6.30	6180.000
2.10	317.000	4.30	2490.000	6.40	6370.000
2.20	359.000	4.40	2670.000	6.50	6570.000
2.30	403.000	4.50	2840.000	6.60	6760.000
2.40	446.000	4.60	3020.000	6.70	6960.000
2.50	495.000	4.70	3200.000	6.80	7160.000
2.60	548.000	4.80	3380.000	6.90	7360.000
2.70	608.000				

Fig-A2-4- Variation of the wetted area

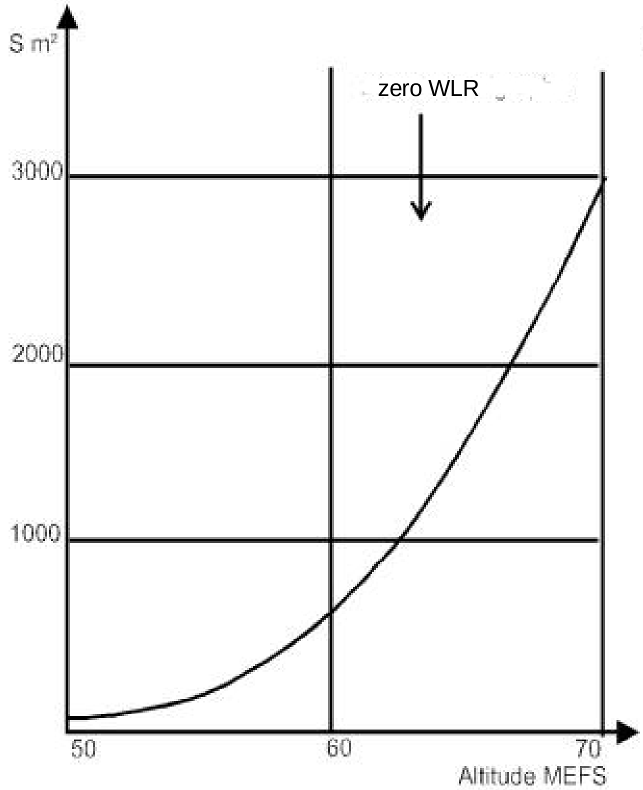


Fig-A2-5- Variation of the hydraulic radius

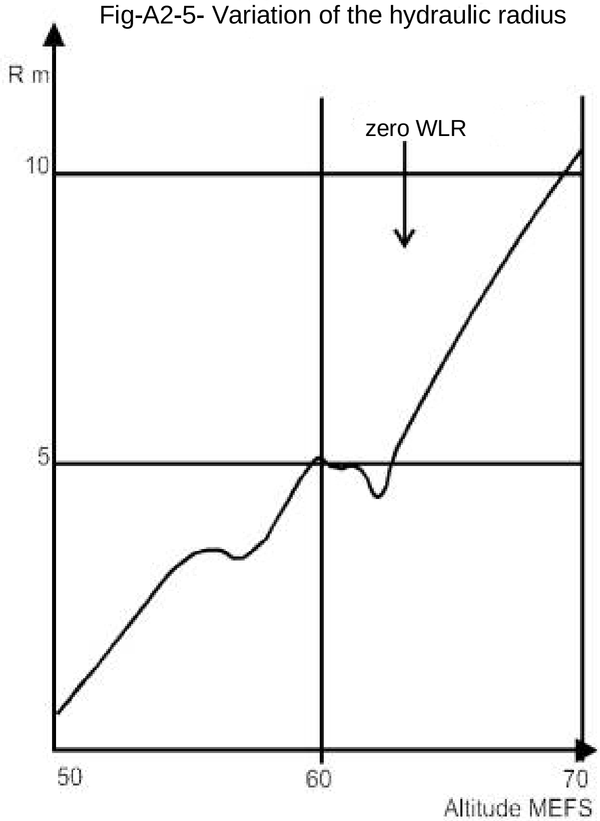


Fig-A2-6- Curves S (h) - R (h)

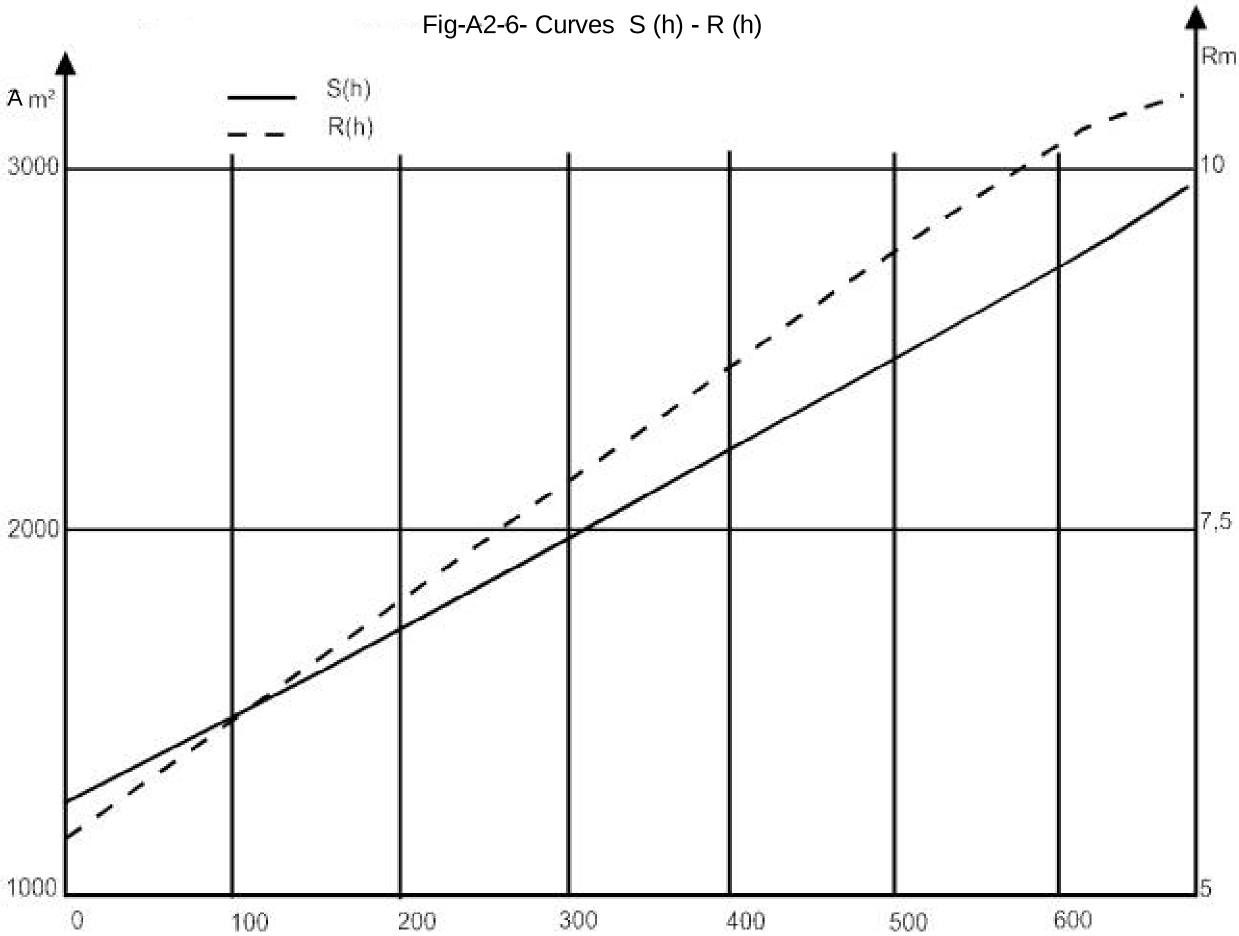
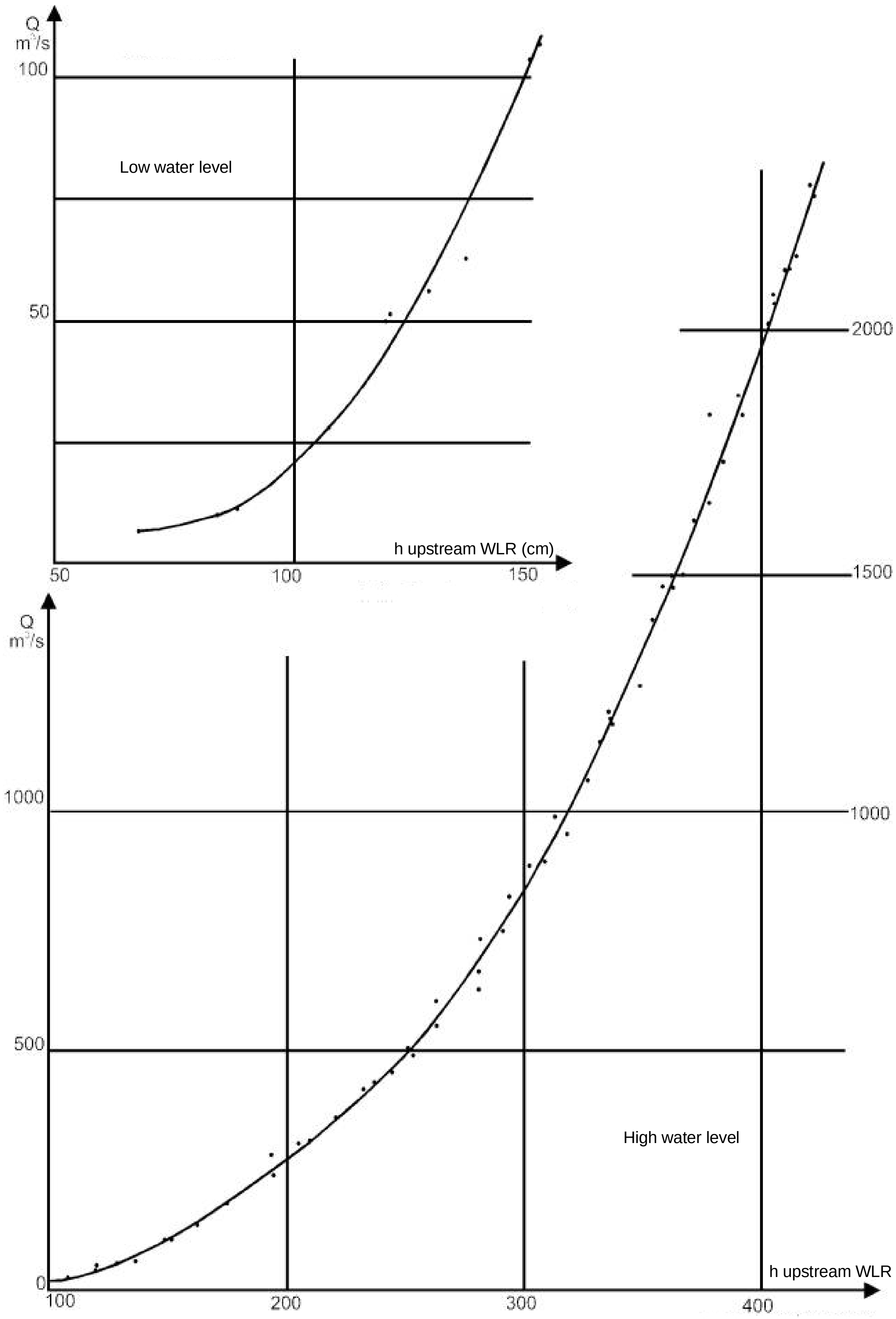


Fig-A2-7- SENEGAL AT GOUINA - UPSTREAM - RATING CURVE



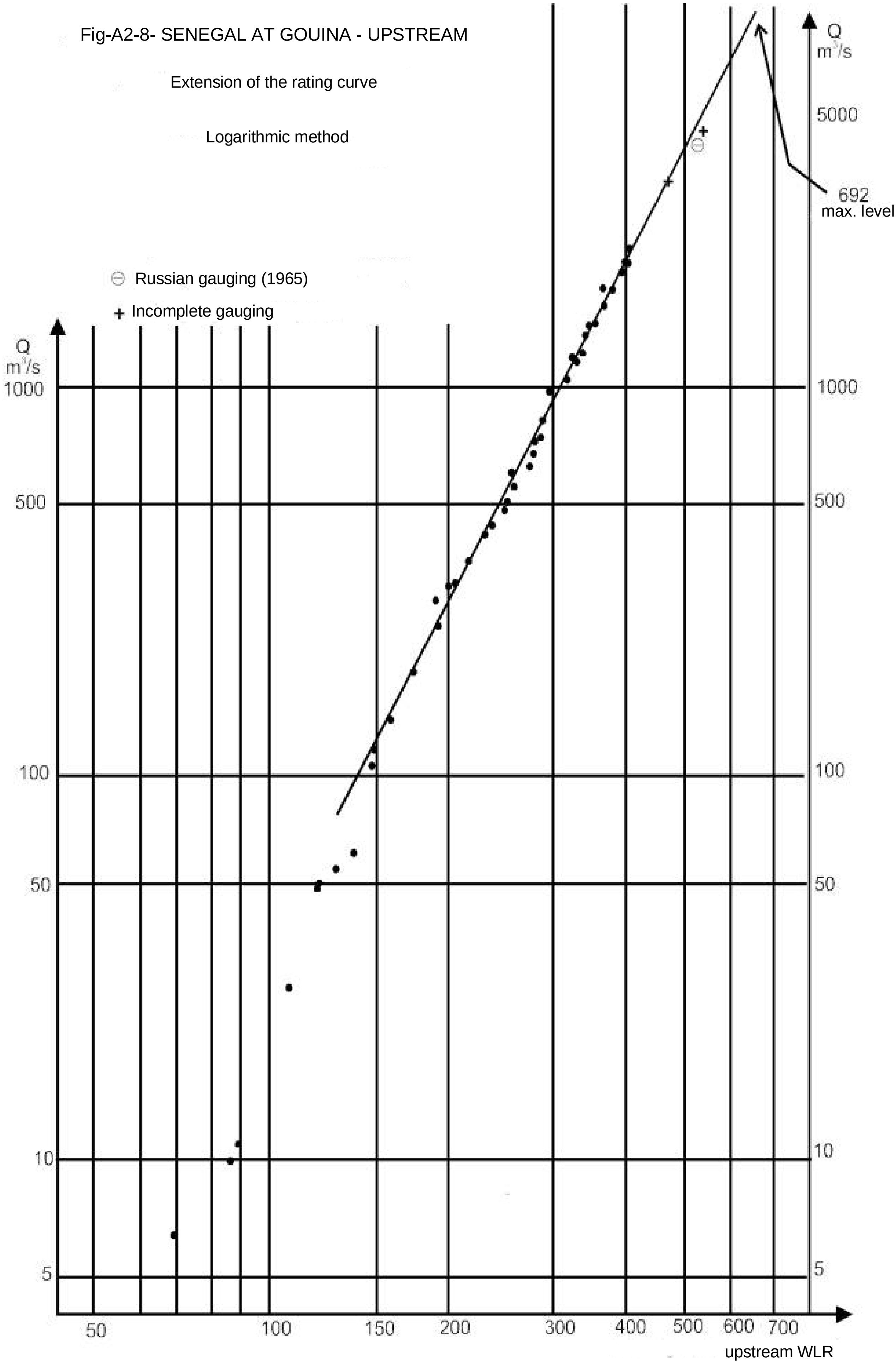


Fig-A2-8- SENEGAL AT GOUINA - UPSTREAM
Extension of the rating curve
Logarithmic method
Russian gauging (1965)
Incomplete gauging
Q
m3/s
1000
500
100
50
10
5
5000
692
max. level
50
100
150
200
300
400
500
600
700
upstream WLR

Fig-A2-9- SENEGAL AT GOUINA - UPSTREAM - EXTENSION OF THE RATING CURVE. STEVENS METHOD

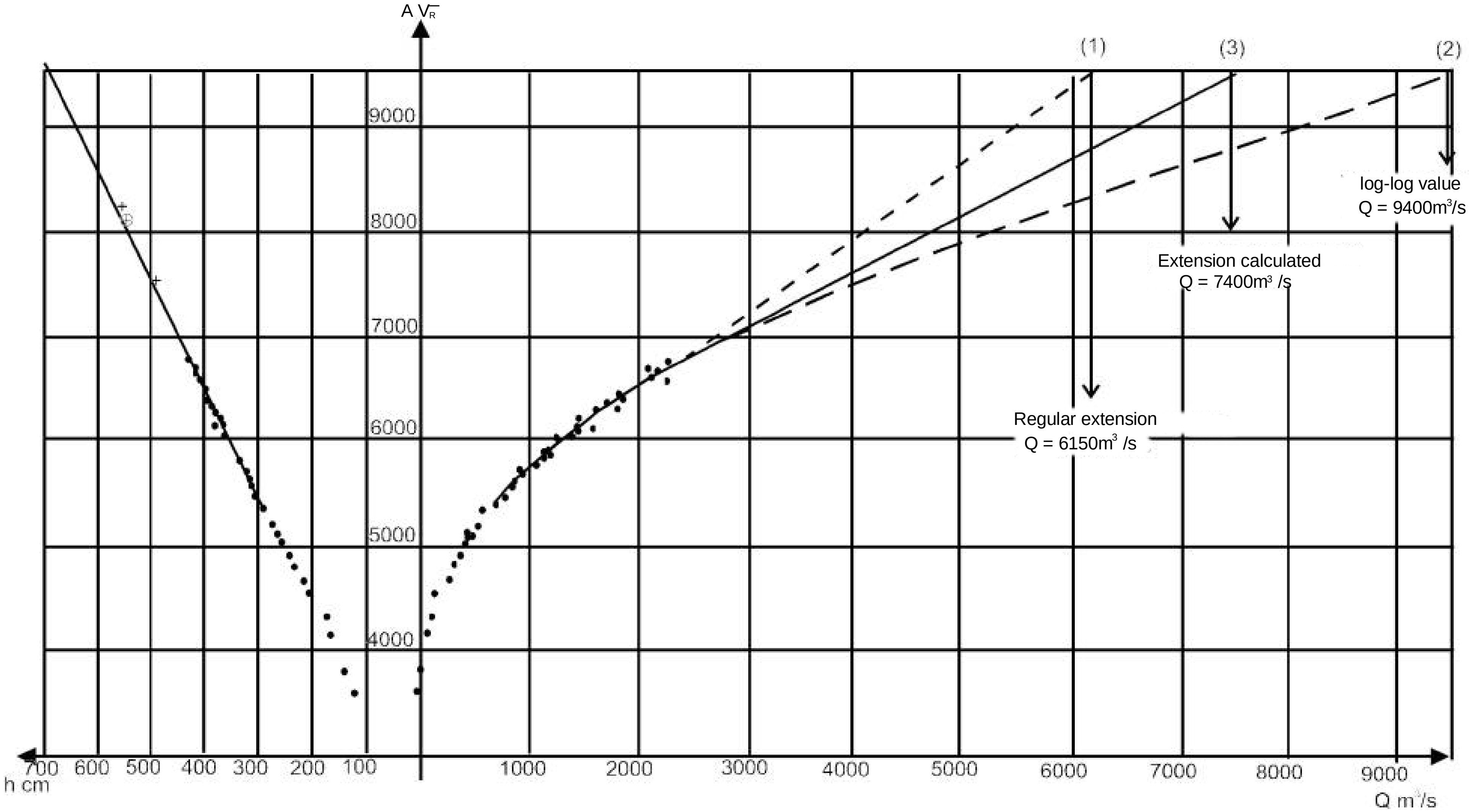


Fig-A2-10- SENEGAL AT GOUINA - UPSTREAM - CURVE U(h)

Extension based on STRICKLER formula- with K=19

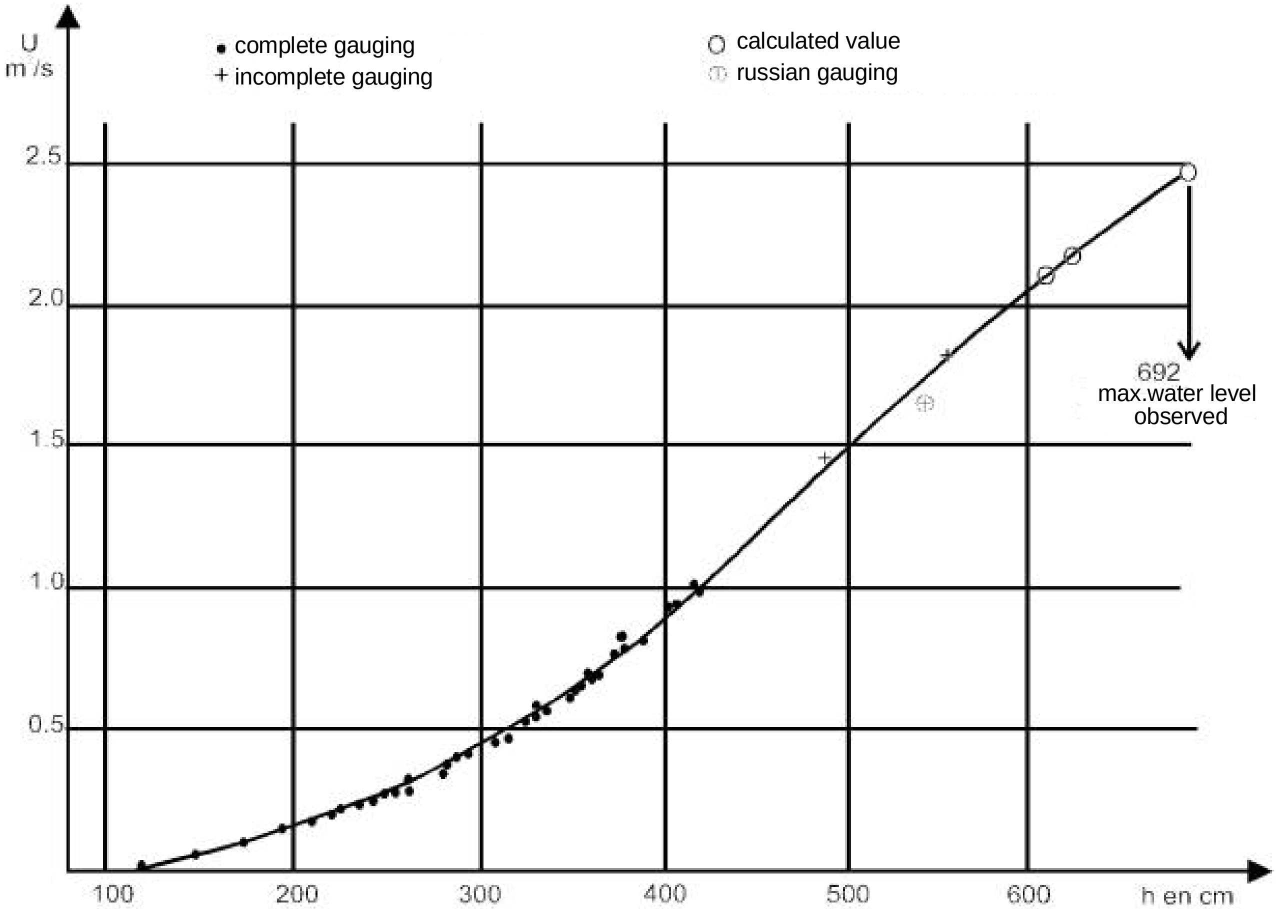


Fig-A2-11- SENEGAL AT GOUINA - UPSTREAM

Research of the STRICKLER coefficient K for high water levels

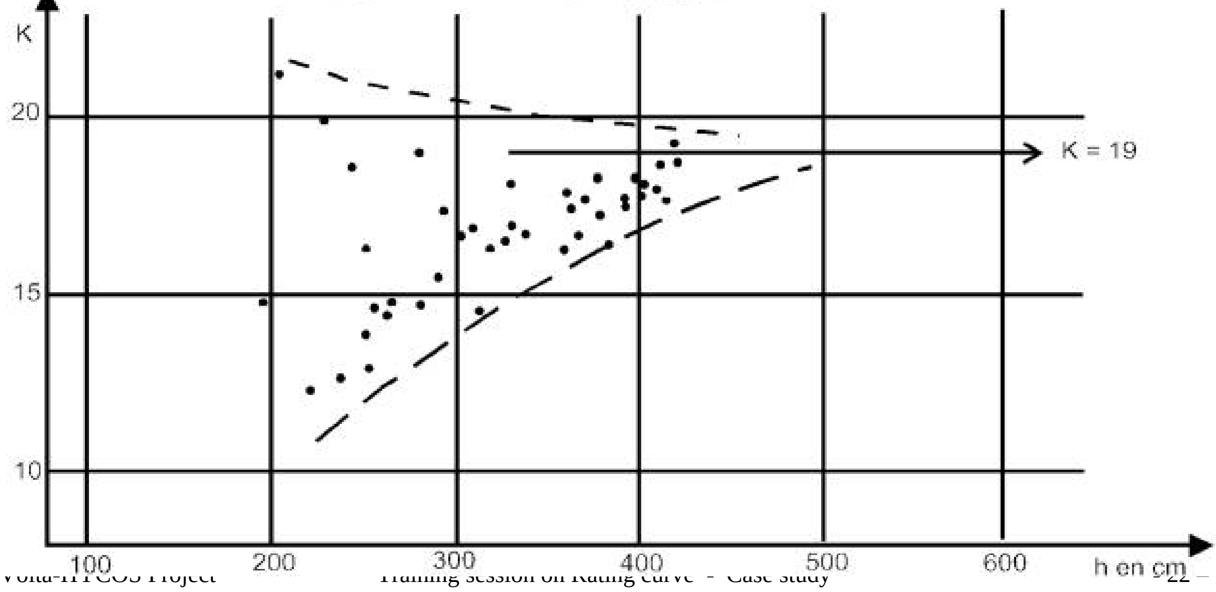


Fig-A2-12- SENEGAL AT GOUINA - UPSTREAM

Water surface slope variation

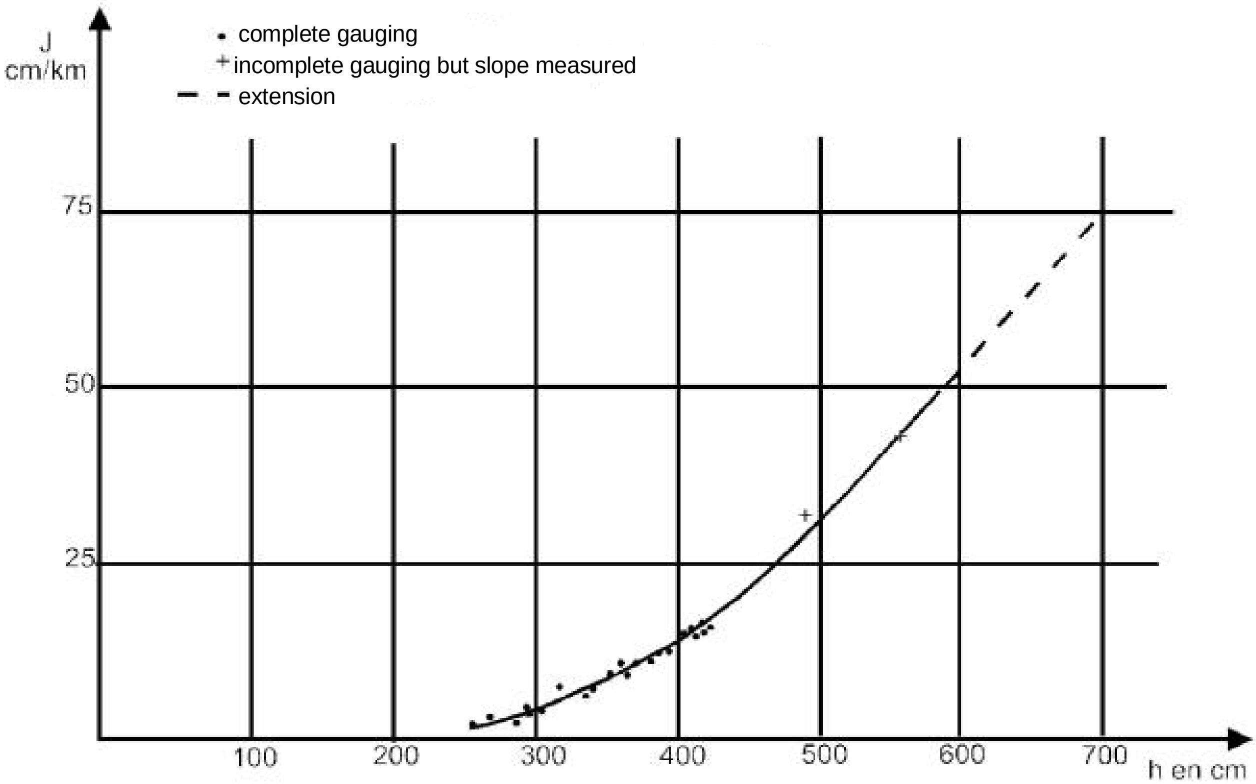


Fig-A2-13- SENEGAL AT GOUINA - UPSTREAM

Variation of the product K V‾J

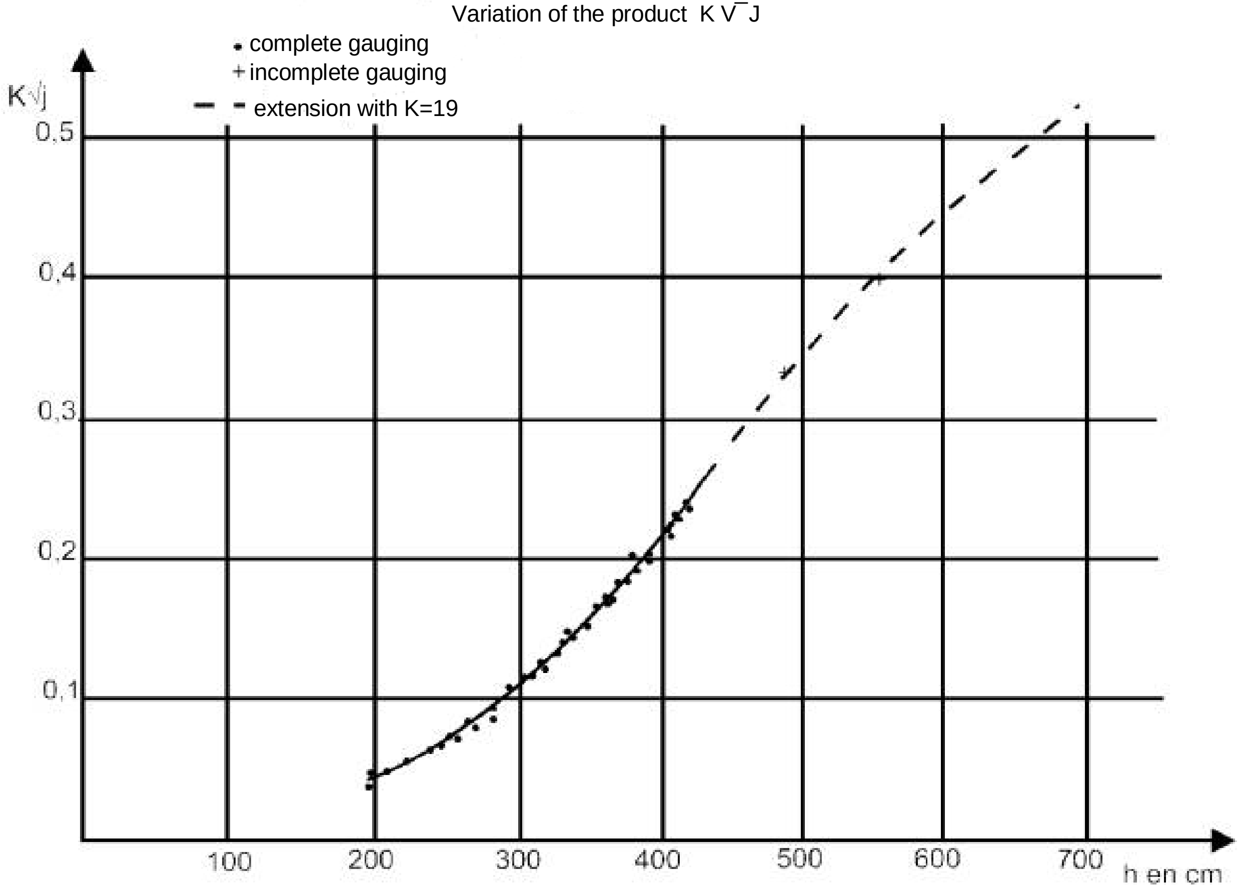


Fig-A2-14- SENEGAL AT GOUINA - UPSTREAM

(between h = 68 e h = 692cm validit from 30/10/50 to 31/12/79