Hurst: an Influential Figure in Water History, Management Practices and Research Orientations in Egypt

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Hurst in Egypt

- In 1906, Hurst went to Egypt for a short stay that was to last 62 years, of which the most fruitful, to the scientific community and not only Egypt, were after he turned 65.
- His first duties included transmitting standard time from the Observatory to the Citadel of Cairo, where a gun was to be fired at midday. He also was in charge of the standardisation of the magnetic instruments at Helwan Observatory and the "Magnetic Survey of Egypt and the Sudan".

Source: StatProb website

Hurst in Egypt

- Fascinated with the Nile, he traveled extensively by river and on land, first on foot with porters, then using a bicycle, later by car, and later still by plane.
- The low Aswan Dam had been built in 1902-1903, but he later realized how important it was to Egypt that provision should be made not only for the dry years but for a series of dry years, initiating the High Dam and Reservoir at Aswan.

Source: StatProb website

Some early and unknown works (1/2)

- Standardisation of the Magnetic Instruments at Helwan Observatory, by H.E. **Hurst** - Survey Department paper No'.8, 1908.
- Discussion of the Observation on Atmospheric Electricity at Helwan Observatory from March 1906 to February 1908 by H.E. **Hurst**, Survey Department paper No. 10, 1909.
- Effect of Water on the Cultivation of Cotton: Experiments made during 1911, by H.T. Ferrar and H.E. **Hurst**, Survey Department paper No.24, 1912.
- The Magnetic Survey of Egypt and the Sudan by H.E. **Hurst**, Survey Department paper No.33, 1916.
- Correction to the "Magnetic Survey of Egypt and the Sudan" – by H.E. **Hurst**, Survey Department paper No. 33, 1924.

Some early and unknown works (2/2)

- Short Report on Nile Gauge Readings Discharge, by H.E. **Hurst**, 1920.
- The Measurement of the Discharge of the Nile through the Sluices of the Aswan Dam, by Sir M. MacDonald and H.E. **Hurst**, Minutes of Proceedings of the Institution of Civil Engineers Paper No. 4450, 1921.
- The Rains of the Nile Basin and the Nile Flood of 1913, by H.E. **Hurst**, 1923.
- The Lake Plateau Basin of the Nile, Part I, Hydrology, Meteorology and Topography of the Lake Plateau, 1925 and Part II, 1927
- The Measurement of the Discharge of the Nile through the Sluices of the Aswan Dam, by H. E. **Hurst** and D.A.F. Watt, 1928.
- Further Experiments on the Discharge of Models of Sluices, by H. E. **Hurst**, 1930.
- Report on the Measurement of Quantity of Dust in the Atmosphere of Cotton Ginneries, by H.E. **Hurst** and P.A. Curry, 1939.
- The Elements of Computation, by H.E. **Hurst**, 1941.

Papers and Books (1/2)

- **Hurst**, H.E. and D.A.F. Watt, 1921. The Similarity of Motion of Water through sluices and through scale models by, Proceedings of the Institution of Civil Engineers Paper No.4450.
- **Hurst**, H.E. and D.A.F. Watt, 1924. The Measurement of the Discharge of the Nile through the sluices of the Aswan Dam by, Proceedings of the Institution of Civil Engineers Paper No. 4475,.
- **Hurst**, H.E. A Short Account of the Nile and its Basin, by, Presented to the International Geography Cairo, 1925.
- **Hurst**, H.E. Suspension of Sand in Water, Proceedings of the Royal Society A. Vol. 124, 1929.
- **Hurst**, H.E. The Nile Flood, Nature, Vol. 142, No. 3608, pp. 1106-1107, 1938.
- **Hurst**, H.E., Black, R.P. and Simaika, Y.M. A Long-Term Plan for the Nile Basin, Nature, Vol. 160, No. 4070, pp. 611-612, 1947.

Papers and Books (2/2)

- **Hurst,** H.E. Long-Term Storage Capacity of Reservoirs, Proceedings American Society of Civil Engineers Vol. 76, 1950.
- **Hurst,** H.E. and S. Leliavsky, 1950. Flow-Net Construction simplified by using the principle of the Magnetic Field, Civil Engineering, American Society of civil engineers.
- **Hurst**, H.E. 1955. Methods of using long-term storage in reservoirs. *Proceedings of the Institution of Civil Engineers*, part 1, 519-577.
- **Hurst,** H. E. (1952, 1957 2nd enlarged Ed.) The Nile. Constable, London.
- **Hurst**, H.E., Black, R.P. and Simaika, Y.M. 1965. *Long-term Storage, an Experimental Study*. Constable, London.

Nile Basin "Encyclopedia" (1/3)

- The Nile Basin, Vol. I, General Description of the Basin, Meteorology, Topography of the White Nile Basin, by H.E. Hurst, and P. Philips 1931.
- The Nile Basin, Vol. II, Measured Discharges of the Nile and Tributaries, by H.E. Hurst, and P. Philips 1932, and supplements 1-15 (1932-date).
- The Nile Basin, Vol. III, Ten-day Mean and Monthly Mean Gauge Readings of the Nile and its Tributaries, by H.E. Hurst and P. Philips 1933, and supplements 1-15 (1933-date)
- The Nile Basin, Vol. IV, Ten-day Mean and Monthly Mean Discharges of the Nile and its Tributaries, by H.E. Hurst, and P. Philips 1933, and supplements 1-15 (1933-date)

Nile Basin “Encyclopedia” (2/3)

- The Nile Basin, Vol. V, Hydrology of the Lake Plateau and Bahr el Gebel, by H.E. Hurst and P. Philips, 1938.
- The Nile Basin, Vol. VI, Monthly and Annual Rainfall Totals and Number of Rainy Days at Stations in and near the Basin for the Period ending 1937 by H.E. Hurst and R.P. Black, 1943, and supplements 1-13 (1943 to date).
- A Short Account of the Nile Basin by H.E. Hurst, 1944.
- The Nile Basin, Vol. VII, The Future Conservation of the Nile by H.E. Hurst and R.P. Black and Y.M. Simaika, 1946, Reprinted 1951.

Nile Basin "Encyclopedia" (3/3)

- The Nile Basin Supplement to Vol. VII The Capacity needed in Reservoirs for Long- Term Storage by H.E. Hurst (for official use).
- The Nile Basin, Vol. VIII, The Hydrology of the Sobat and White Nile and Topography of the Blue Nile and Atbara by H.E. Hurst, 1950.
- The Nile Basin, Vol. IX, The Hydrology of the Blue Nile and Atbara and of the Main Nile to Aswan, with some Reference to Projects, by Hurst, H. E., Black, R. P. & Simaika, Y. M., 1959.
- The Nile Basin, Vol. X, The Major Nile Projects, by Hurst, H. E., Black, R. P. & Simaika, Y. M. , 1966.
- The Nile Basin, Vol. XI The Hydrology of the Sadd El Aali, and Other Topics, by Hurst, H. E., Black, R. P. & Simaika, Y. M., 1978.
- The Nile Basin, Vol. XII & Vol. XIII (In Press, written by Hurst followers in the Ministry of Water Resources and Irrigation, Egypt)

Nile Basin “Encyclopedia” (maintained?)

ARAB REPUBLIC OF EGYPT
Ministry of Water Resources and Irrigation
Nile Water Sector
Nile Control Department

Paper No. 52A

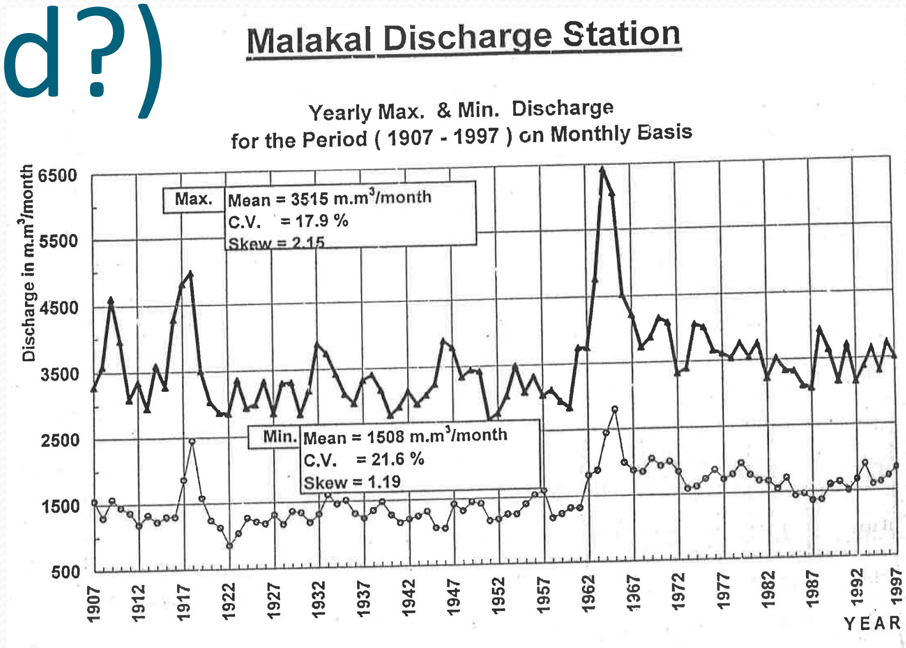
THE NILE BASIN

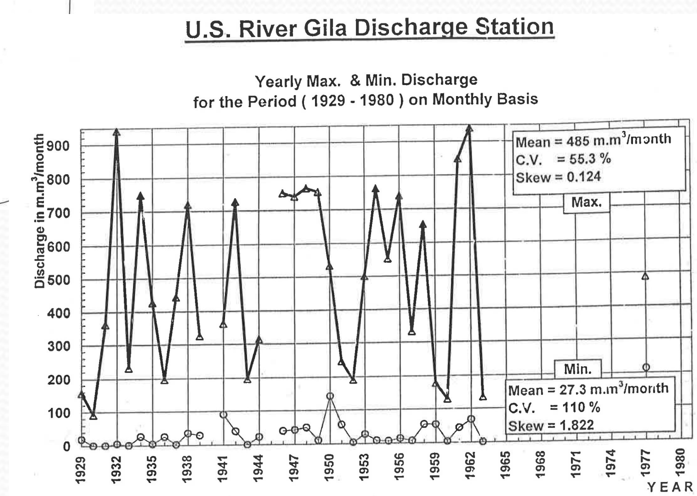
Fourteenth Supplement to Volume IV (Part II)

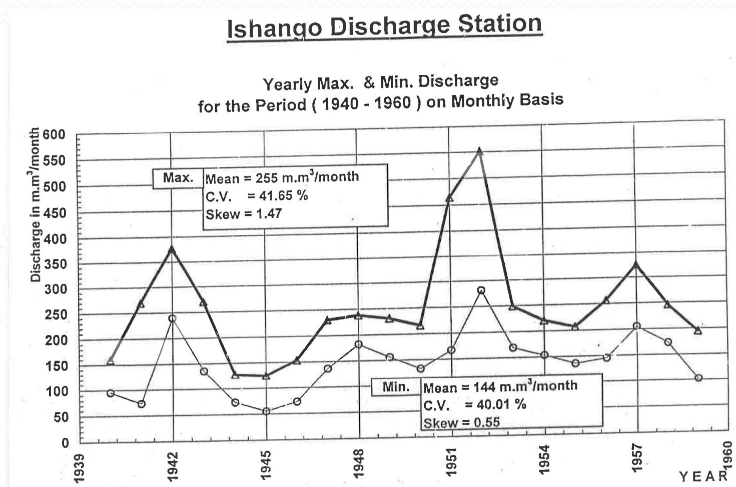
Statistical Parameters for Some Selected Discharge Stations Along the River Nile and its Tributaries

By
Nile Control Staff

Cairo
2000







Extracts from some Hurst Books

- There is no mention of the agreements which must be made, or of the compensation which might be necessary, in order that works may be built in countries outside Egypt. It is assumed that such agreements can be negotiated in a manner satisfactory to all parties. By the publication of this book, it is hoped that future negotiations will be assisted, since those interested can get some idea of the way in which projects for the full utilisation of the Nile water must proceed.

Hurst, 1947, addressing a critic of the Vol VII, The Future Conservation of the Nile.

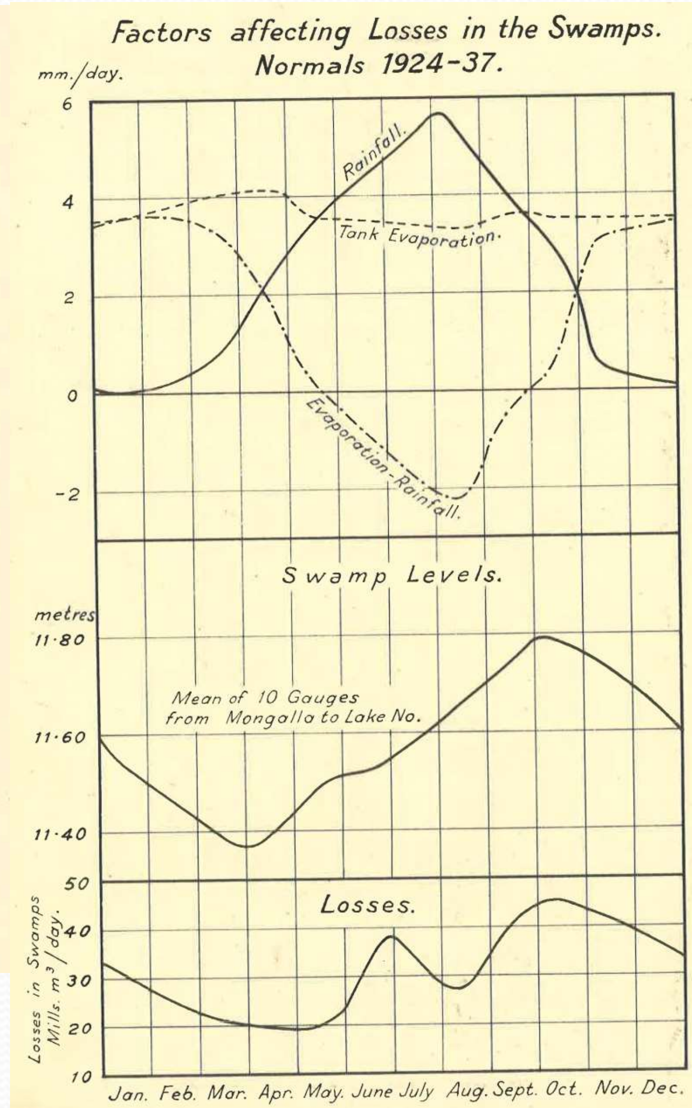
Extracts from some Hurst Books

In some of the following investigations periods have been chosen when the change of river level is small and presumably that of the Swamp also, so that the effect of this source of error is minimised.

From the above description the uncertainties about the quantities which enter into the problem can be seen.

Before examining the question in detail it is of interest to look at the normal variation of some of the factors concerned which are plotted in Plate 41a. The rainfall and the swamp gauges are each the mean from 10 stations for the month against which they are plotted. The evaporation is that from the papyrus tank. The losses have been taken for the purpose of this diagram as the difference between Mongalla discharge and the discharge at the tail of the swamps three months later, and these have been plotted so as to correspond with dates in the middle of the swamp; thus Mongalla January minus Swamps April is plotted against the end of February and beginning of March.

It will be seen that the loss plotted in this way follows roughly the gauges and is least when the level is lowest. Actually the variation of the loss is mainly due to the variation of the discharge at Mongalla which is much greater than that of the discharge at the tail of the swamps. The peak in May is only shown to a small extent by the gauges. For $4\frac{1}{2}$ months the rainfall is greater than the tank evaporation and during this time the losses are increasing to their maximum, part of which increase goes to raise the general level of the swamp and another part to the wetting of ground over which the water spreads.



The Nile Basin, Vol. V, Hydrology of the Lake Plateau and Bahr el Gebel, by H.E. Hurst and P. Philips, 1938.

Long Term Storage on the Nile according to Hurst

- In 1946, the future conservation of the Nile consisted of long-term reservoirs in Lakes Victoria and Albert , a regulator below Lake Kyoga to avoid the delay in the passage of water below the Upper Victoria Nile, the Jonglei diversion canal to reduce the losses in the Bahr ElJebel Basin, an over-year storage reservoir in Lake Tana, and another reservoir at the 4th Cataract on the Main Nile near Merowe for annual storage and regulation of the discharge coming from the Upper Nile reservoirs (Hurst, Black, and Simaika, Y.M., 1946).
- By 1950, of all the above-mentioned works, only the Owen Falls Dam had been built . The benefit of this storage work to either Egypt or the Sudan is limited . In 1952, Hurst and his co-workers suggested a combination of the Upper Nile projects and a High Dam to be built at Aswan for the “full” utilization of the Nile water.

What if Hurst did not discover his exponent value of 0.72?

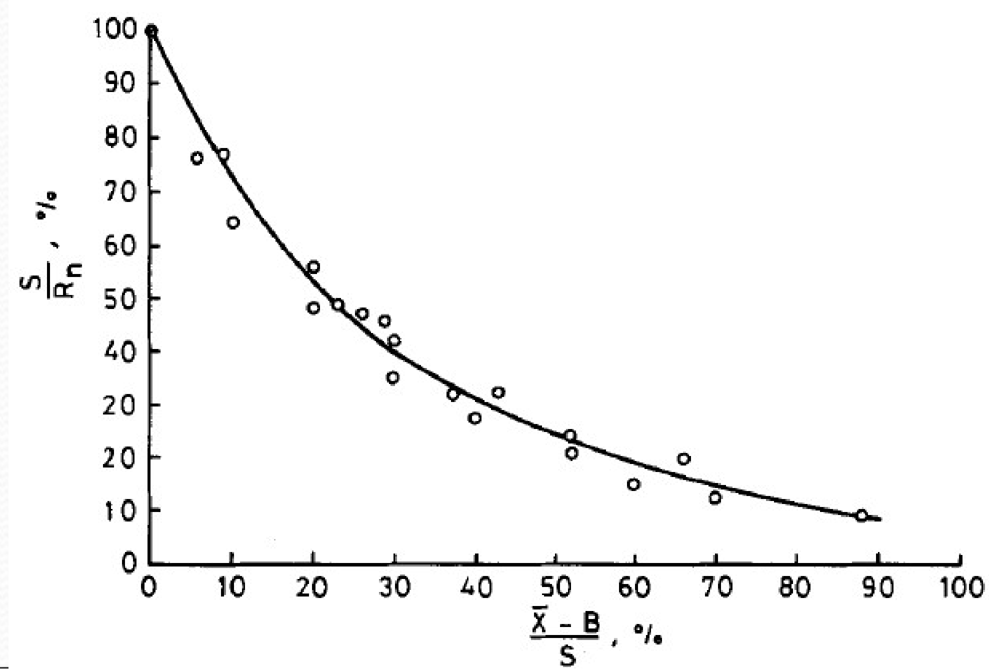
$$\frac{R_n}{s} = \left(\frac{n}{2}\right)^h$$

- If n=100, s=18 BCM, h=0.72, R would be 300 BCM (km^3).
- Applying the two equations from the "second" set , assuming a guaranteed draft (B) of 84 BCM for a mean of 92 BCM, gives S (HAD reservoir capacity) of 89.68 and 94.63, rounded to 90 BCM.
- If h would have been 0.5, S of HAD could be around 40.

$$\log_{10}\left(\frac{S}{R_n}\right) = -0.08 - 1.00\left(\frac{\bar{X}-B}{s}\right)$$

$$\log_{10}\left(\frac{S}{R}\right) = -0.11 - 0.88\left(\frac{\bar{X}-B}{s}\right)$$

$$\frac{S}{R_n} = 0.91 - 0.89\left(\frac{\bar{X}-B}{s}\right)^{\frac{1}{2}}$$



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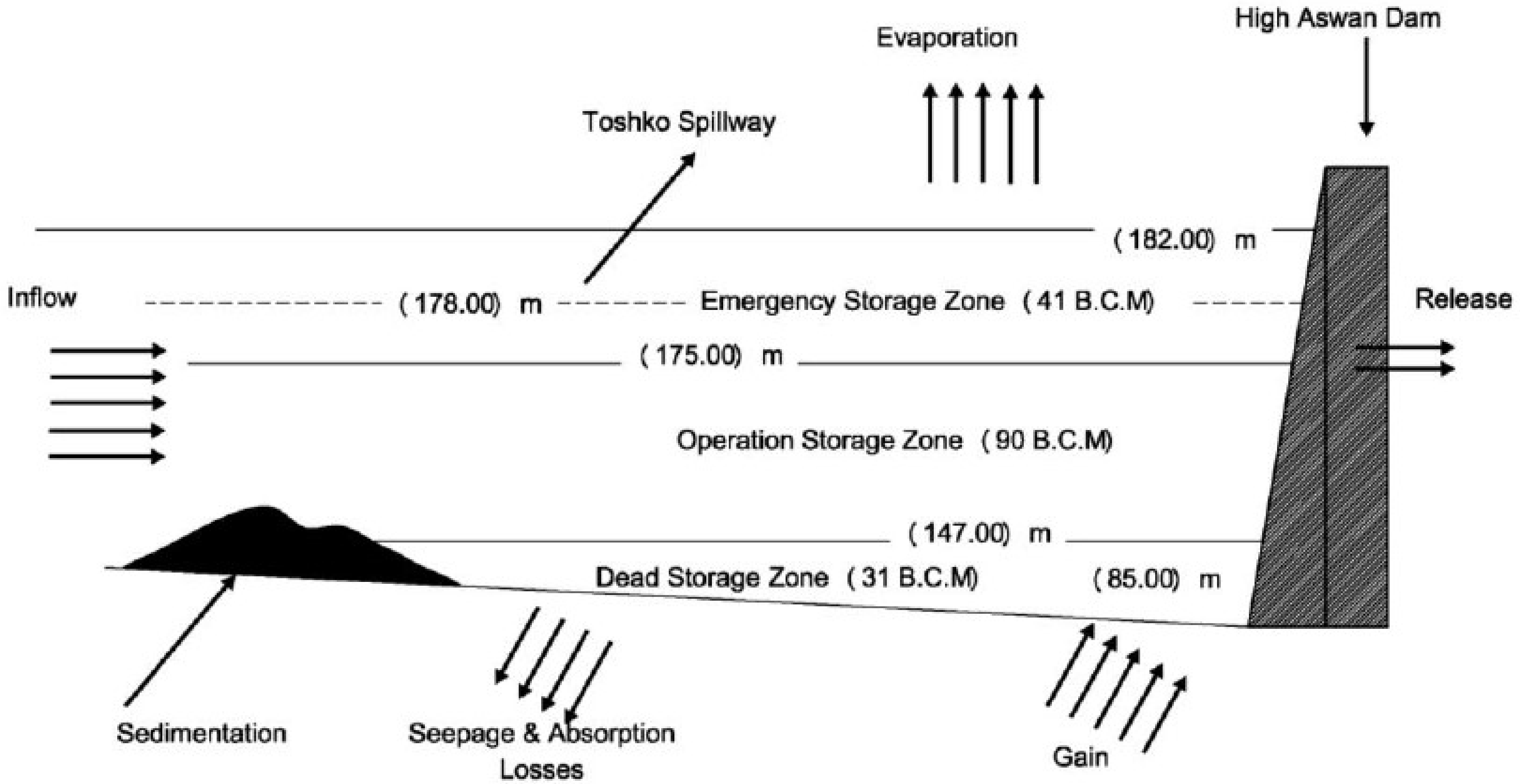
Schematic of Reservoir Simulation Zones



Reservoir Performance Indicators (1/2)

- **Temporal Reliability**

$R_t = \frac{Ns}{Nm}$ $0 < R_t < 1$

Where *N*s is the number of years that the target draft can be met and *Nm* is the total number of years in the simulation.

- **Maximum Deficit in the Reservoir Yield**

maxdef = max (target draft-actual release in a year) BCM

Target Draft of Egypt = 55.5 BCM

Reservoir Performance Indicators (2/2)

- **Recurrence Times of Operating the Toshka (Lateral) Spillway**

$$T_T = \frac{NT}{Nm}$$

where N_T is the number of years in which the Lake level exceeded the spillway level and *Nm* is the total number of years.

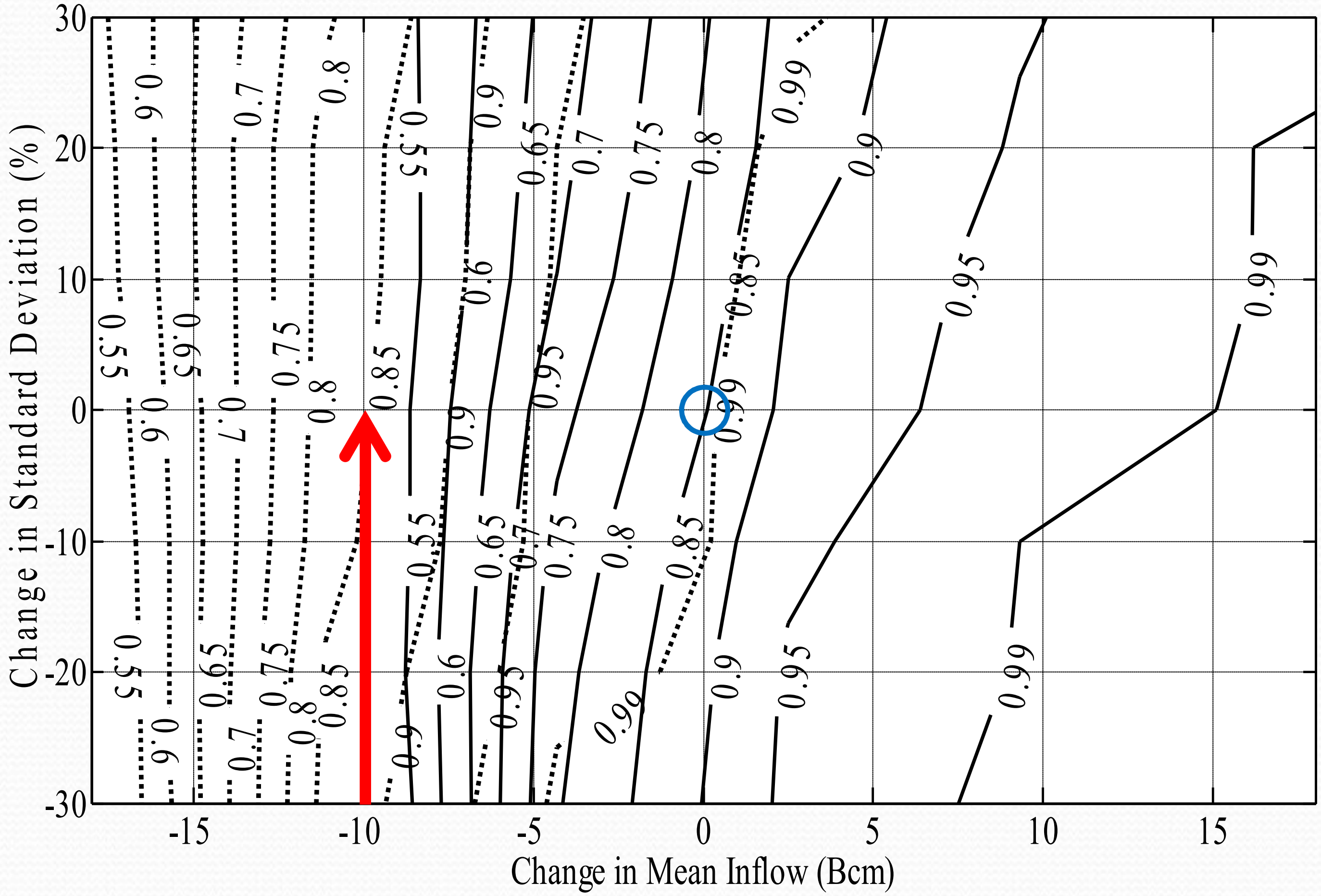
- **Toshka Spillway Spillage**

average annual water volume spilled through the Toshka spillway

$$Q = \left(\sum_{i=1}^{365} 20.382 * (H_i - T)^{1.5}\right))$$

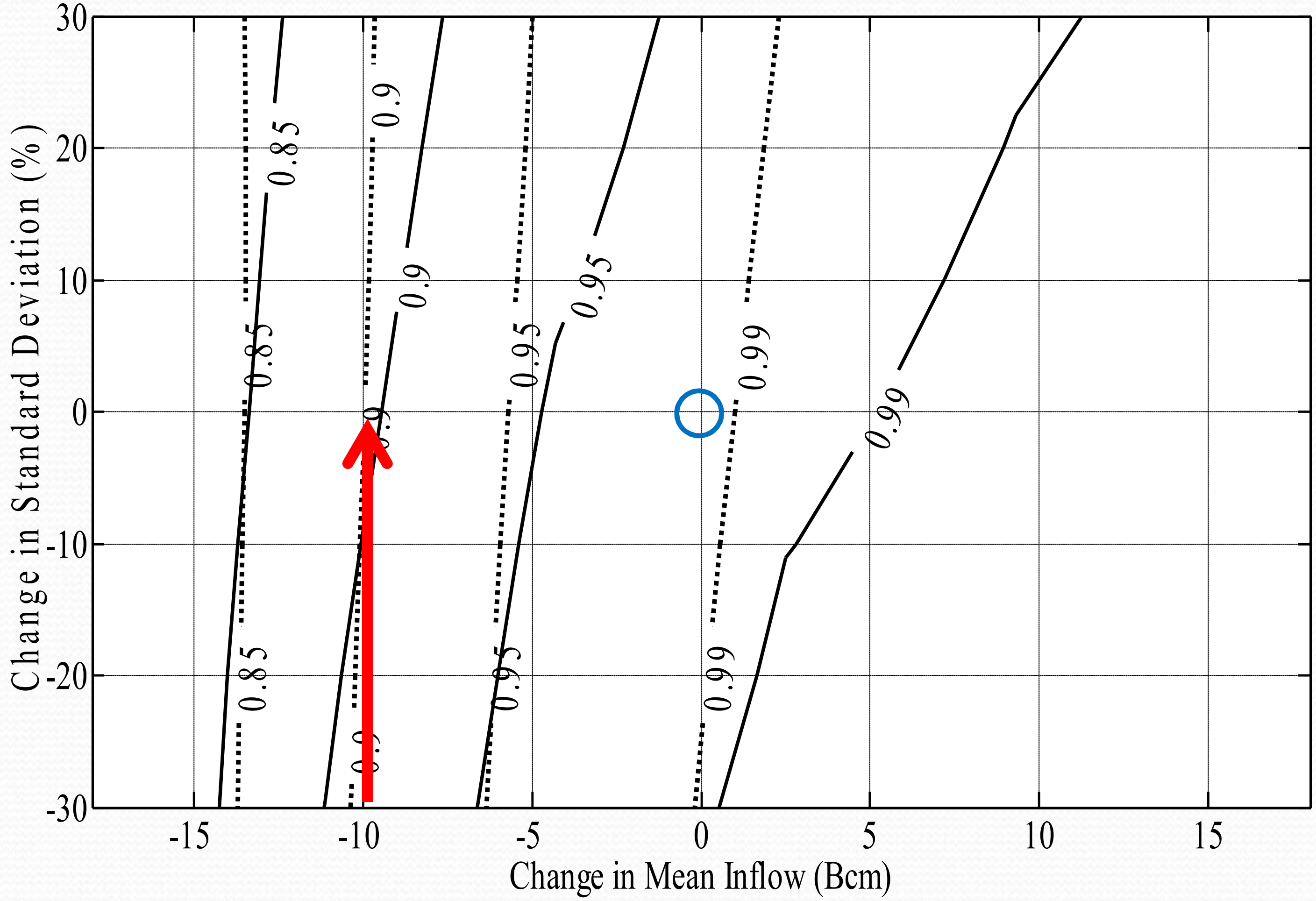
Where *Hi* is the HAD reservoir level in day i, *T* is the Toshka spillway level.

Contour plot of the temporal reliability (for S = 50 BCM)



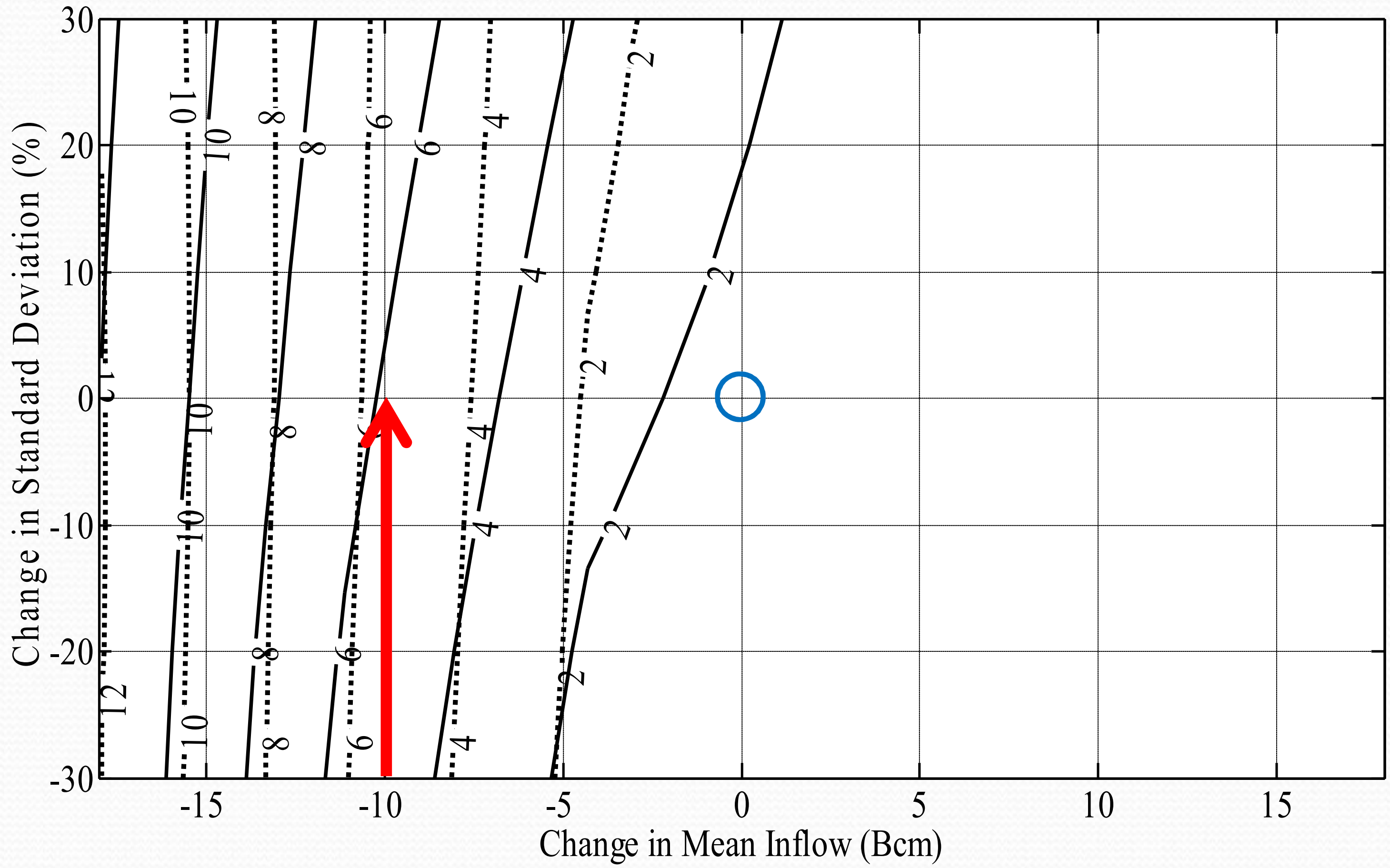
Temporal Reliability drops from 0.99 to 0.85 at actual conditions and from 0.85 to less than 0.55 if the Inflow decreases by 10 BCM

Contour plot of the volumetric reliability (for S = 50 BCM)



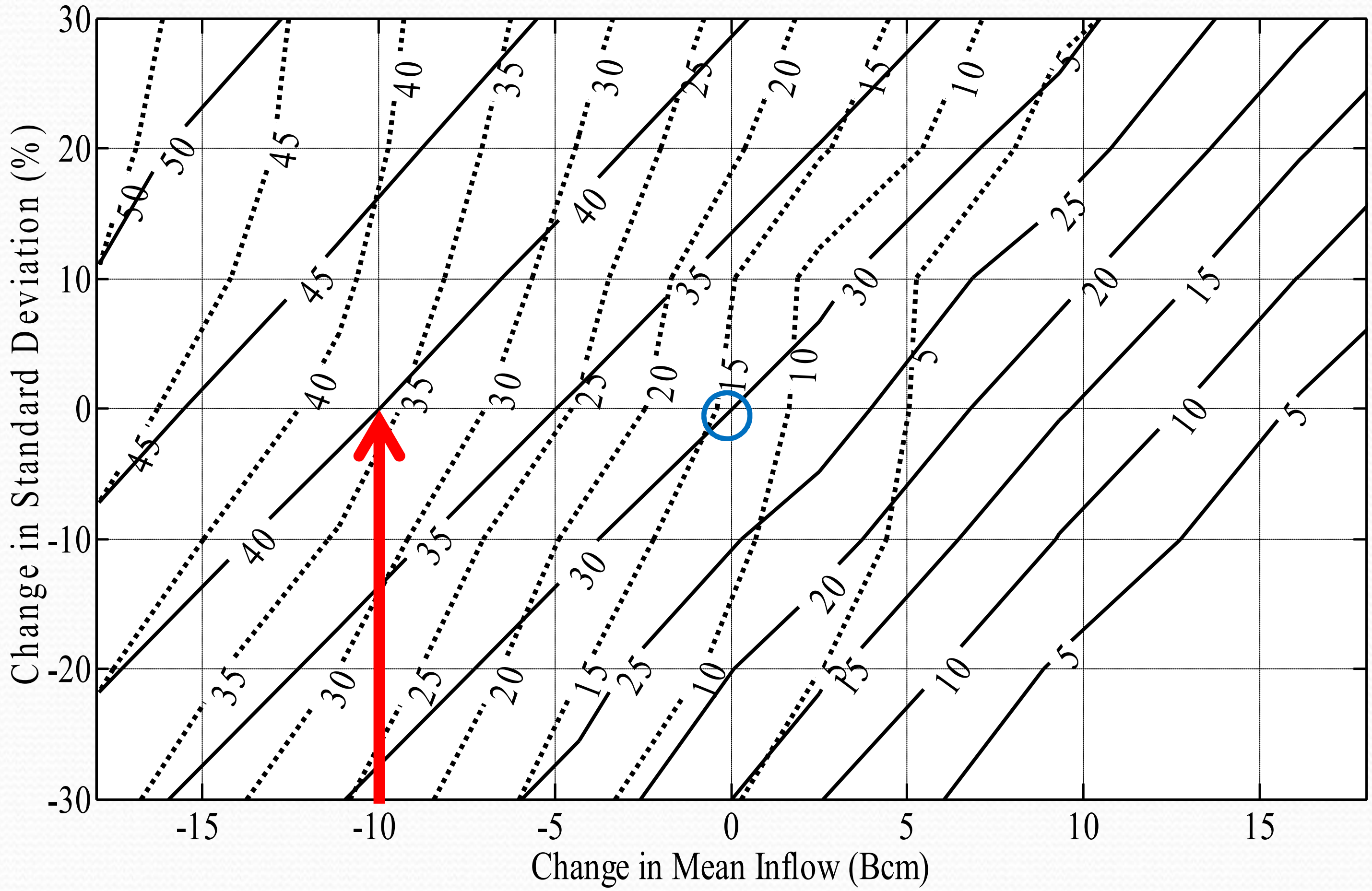
Volumetric Reliability drops from 0.98 to 0.96 at actual conditions and almost no change if the Inflow decreases by 10 BCM

Contour plot of the mean deficit in the reservoir yield (for S = 50 BCM)



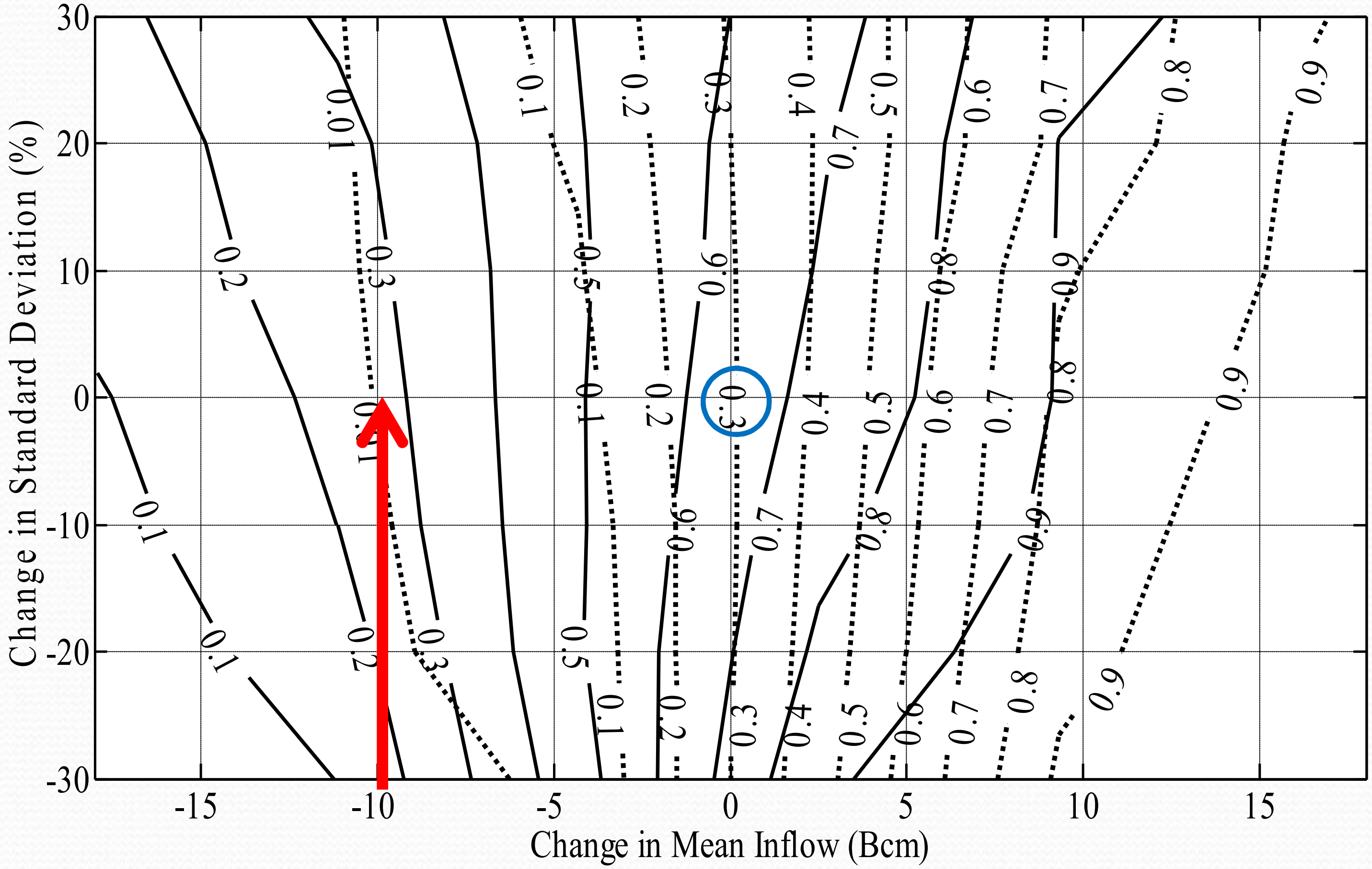
Mean deficit increases from less than 1.0 to 1.5 at actual conditions and almost no change if the Inflow decreases by 10 BCM

Contour plot of the maximum deficit in the reservoir yield (for S = 50 BCM)



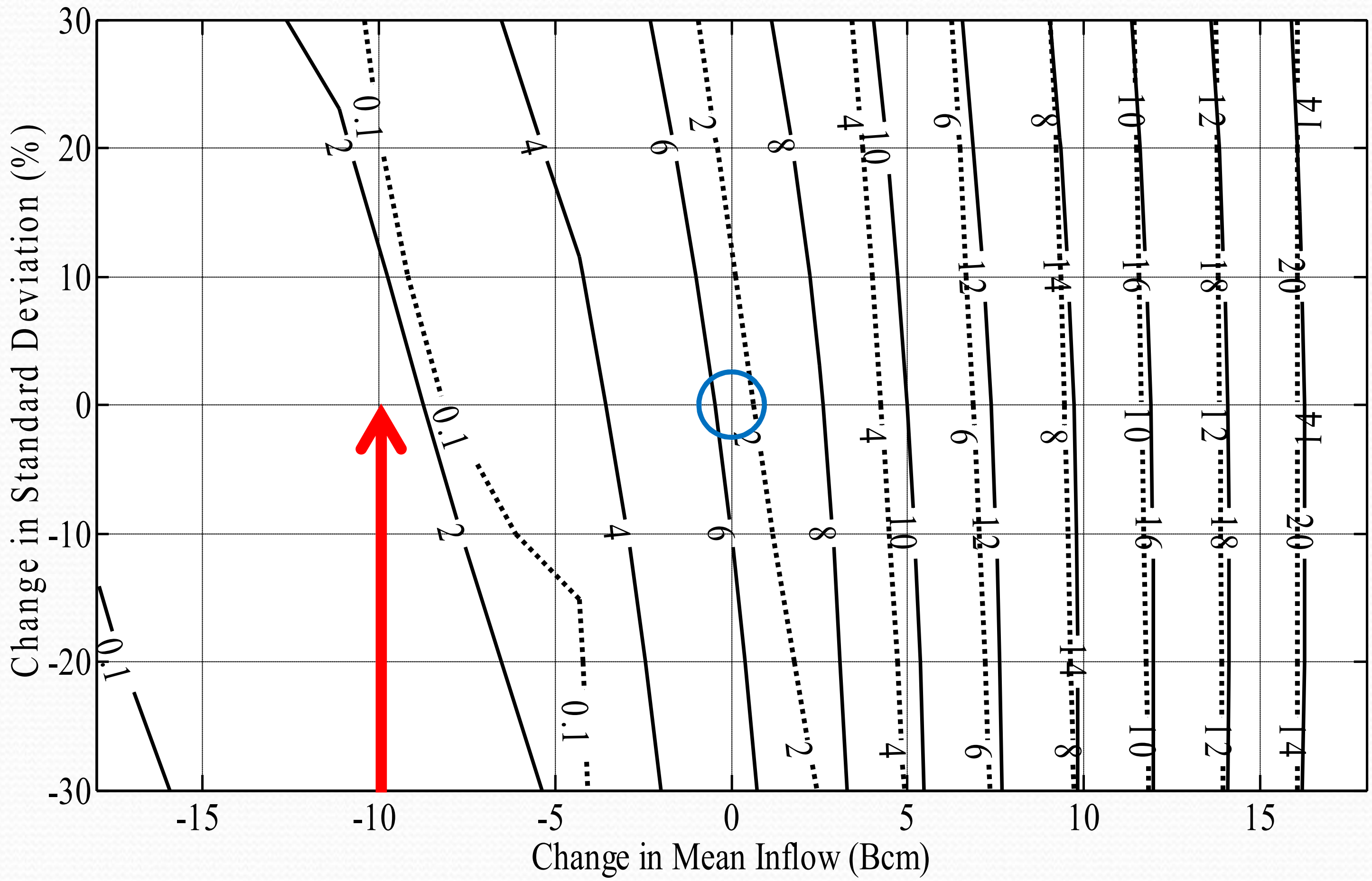
Maximum Deficit increases from 15 to 30 at actual conditions and from 35 to 40 if the Inflow decreases by 10 BCM

Contour plot of the Spilling Frequency (for S = 50 BCM)



Spilling Frequency increases from 0.3 to 0.65 at actual conditions and from 0.01 to 0.3 if the Inflow decreases by 10 BCM

Contour plot of the Spilled Volume (BCM) (for S = 50 BCM)



Average Spilled Volume increases from 2 to 6.5 BCM at actual conditions and from less than 0.1 to less than 2 BCM if the Inflow decreases by 10 BCM

If Hurst would have sized the Grand Ethiopian Renaissance Dam (GERD) …

$$\frac{R}{s} = \left(\frac{n}{2}\right)^h$$

- If n=100, s=8.56 BCM, h=0.72, R would be 143 BCM.
- Applying the two equations from the "second" set , assuming a guaranteed draft (B) of 41 BCM for a mean of 48.32 BCM gives S (GERD reservoir capacity) of 16.6 and 15.5, rounded to 16 BCM. Actually, Hurst sized a dam on Lake Tana with this size.

$$\log_{10}\left(\frac{S}{R_n}\right) = -0.08 - 1.00\left(\frac{\bar{X}-B}{s}\right)$$

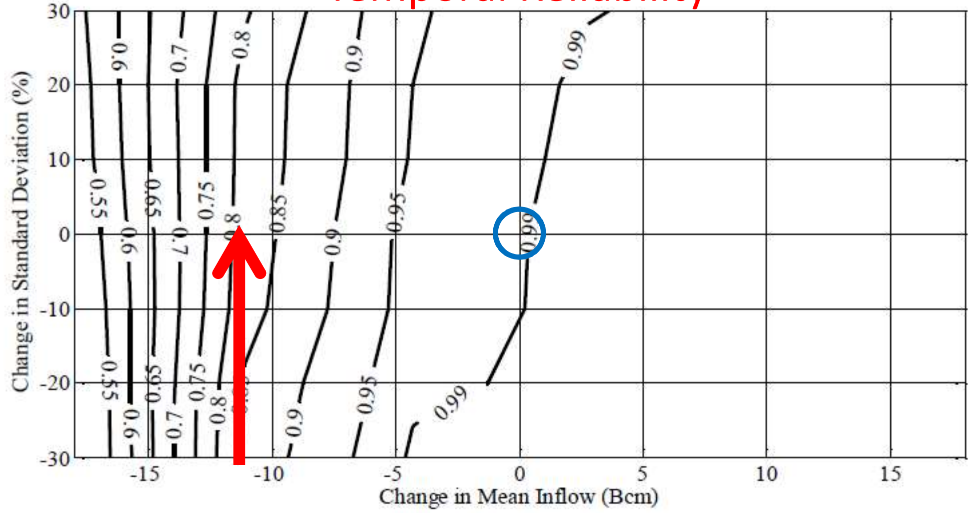
$$\log_{10}\left(\frac{S}{R_n}\right) = -0.11 - 0.88\left(\frac{\bar{X}-B}{s}\right)$$

$$\frac{S}{R_n} = 0.91 - 0.89\left(\frac{\bar{X}-B}{s}\right)^{\frac{1}{2}}$$

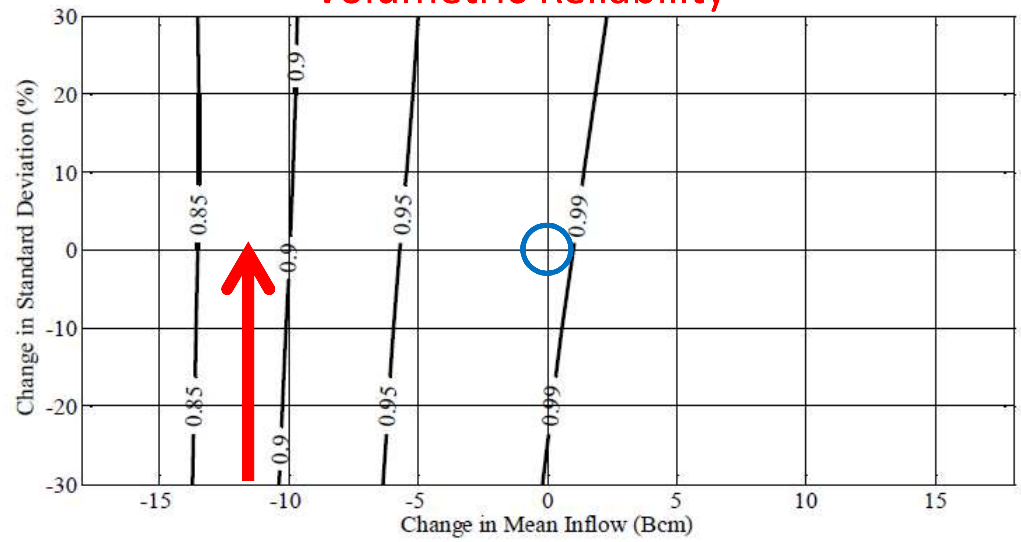
- If the guaranteed draft (B) is 44.12 BCM for a mean of 48.32 BCM (similar to 84/92 for the HAD), gives GERD capacity) rounded to 40 BCM., producing approx. 15000 GWH/year.
- This value would have been the size of all long term storage dams on the Blue Nile.
- As opposed to 74 BCM, currently underway, to maximize the hydropower feasibility of the GERD., producing slightly higher (16000 GWH/year) power production.

Another example: Impact of Filling Stage of Renaissance Dam on HAD Performance Indicators (1/3)

Temporal Reliability



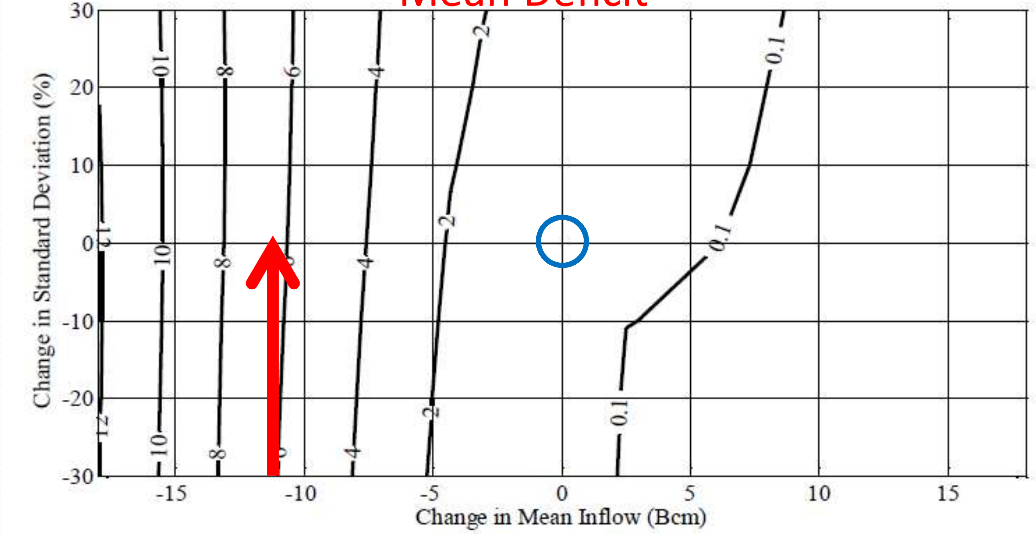
Volumetric Reliability



Temporal Reliability drops from 0.99 to 0.8 and Volumetric Reliability from about 0.98 to 0.87.

Another example:
Impact of Filling Stage of Renaissance Dam on HAD Performance Indicators (2/3)

Mean Deficit

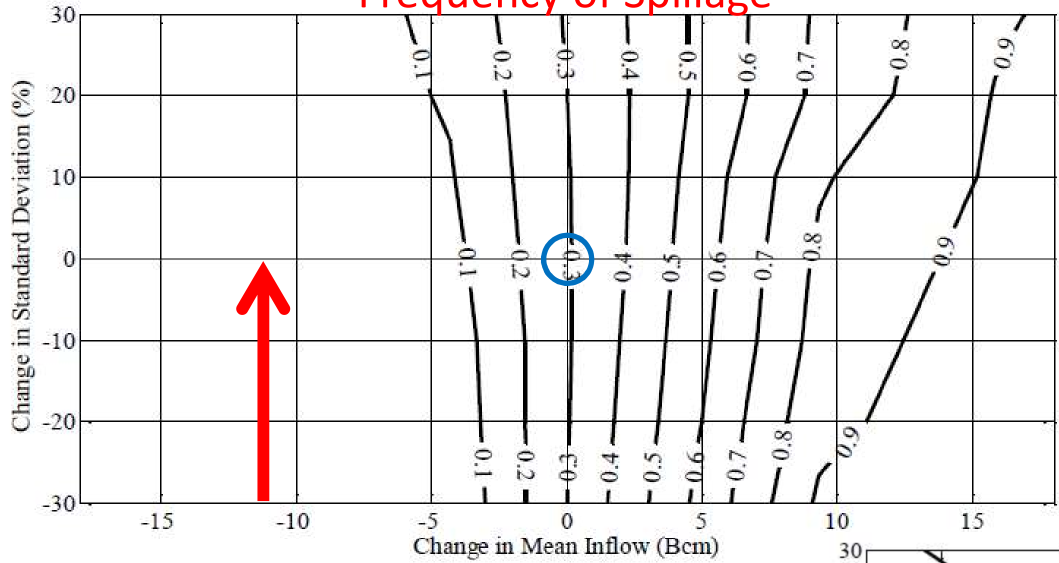


Maximum Deficit

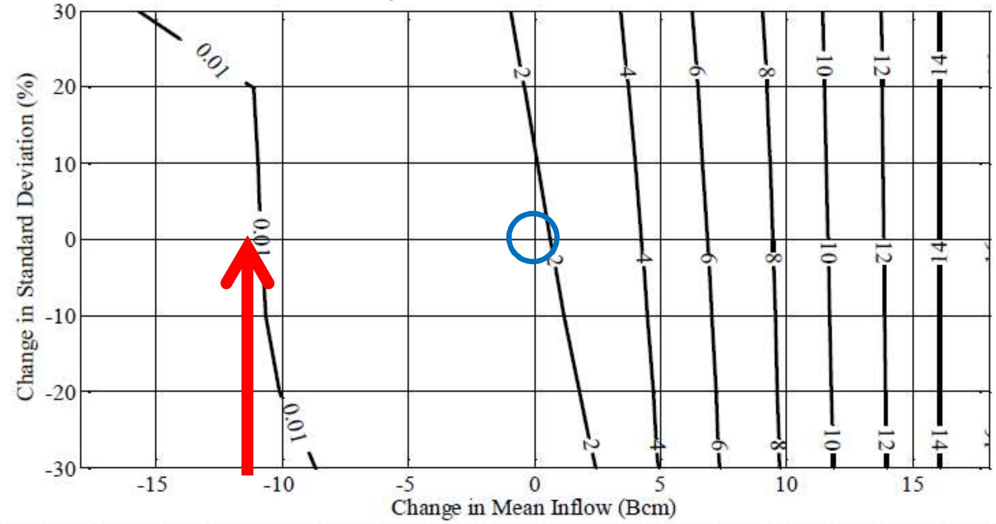
Mean Deficit increases from 1.0 to 6.3 BCM and Maximum Deficit from 15 to 38 BCM.

Another example: Impact of Filling Stage of Renaissance Dam on HAD Performance Indicators (3/3)

Frequency of Spillage



Spilled Volume (BCM)



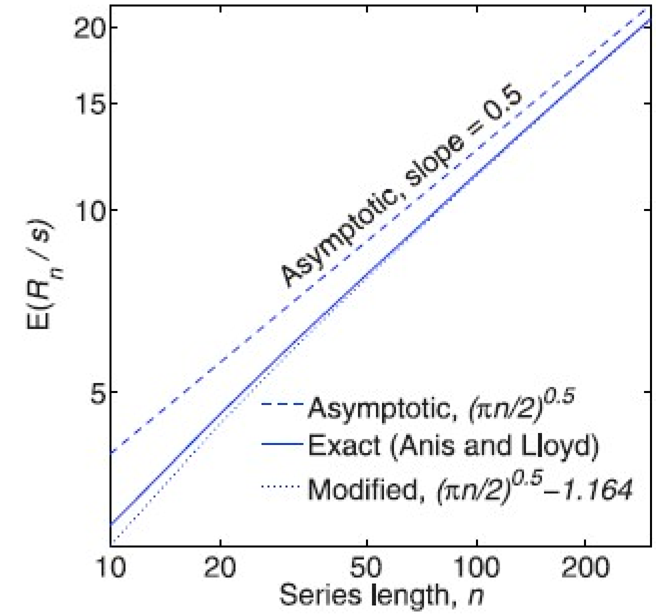
Frequency of Spillage decreases from 0.3 to almost null and Spilled Volume from less than 2 to 0.01 BCM.

Egyptian Hydrologists Research:

Finite-Sample Behavior of the Rescaled Range for Long-Term Dependent Data, Hamed WRR 2007

- For random data, a less-biased equation for the Rescaled Range is

$$E\left(\frac{R}{s}\right) \approx \sqrt{\frac{\pi}{2}}\, n^{0.5} - 1.164$$



- Hamed (2007) obtained a different formulation for long-term dependant data

$$E\left(\frac{R}{s}\right) = a\, n^{h} + b$$

$$a = \Gamma(h)(1.5395\, h^3 - 3.4325\, h^2 + 1.5325\, h + 0.60395)$$

$$b = \Gamma(h)(10.152\, h^4 - 13.724\, h^3 + 7.9907\, h^2 - 1.8757\, h - 0.57007)$$

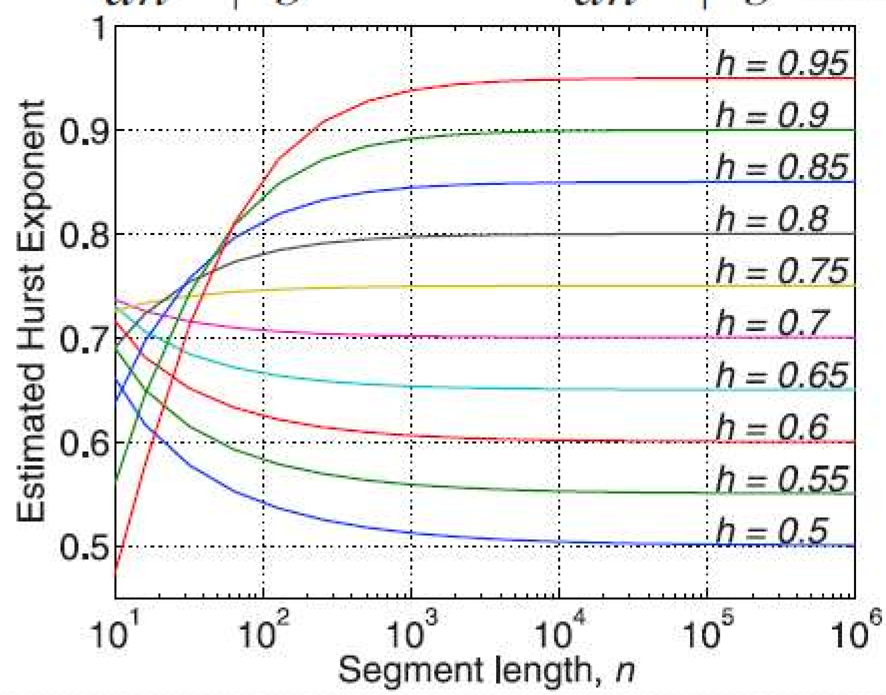
Egyptian Hydrologists Research:

Finite-Sample Behavior of the Rescaled Range for Long-Term Dependent Data, Hamed WRR 2007

- The "an^h + b" expression offers an explanation of the finite-sample behavior of Hurst exponent estimates when rescaled range analysis is used.

$$\hat{h}(n) = \frac{d\log(R/s)}{d\log(n)} = \frac{n}{R/s}\frac{d(R/s)}{d(n)} = \frac{n}{an^h + b}han^{h-1} = \frac{ahn^h}{an^h + b}$$

- Graphical representation of the equation for different values of h, shows a positive bias for h < 0.73 and negative bias for h < 0.73, almost zero bias for h=0.73.



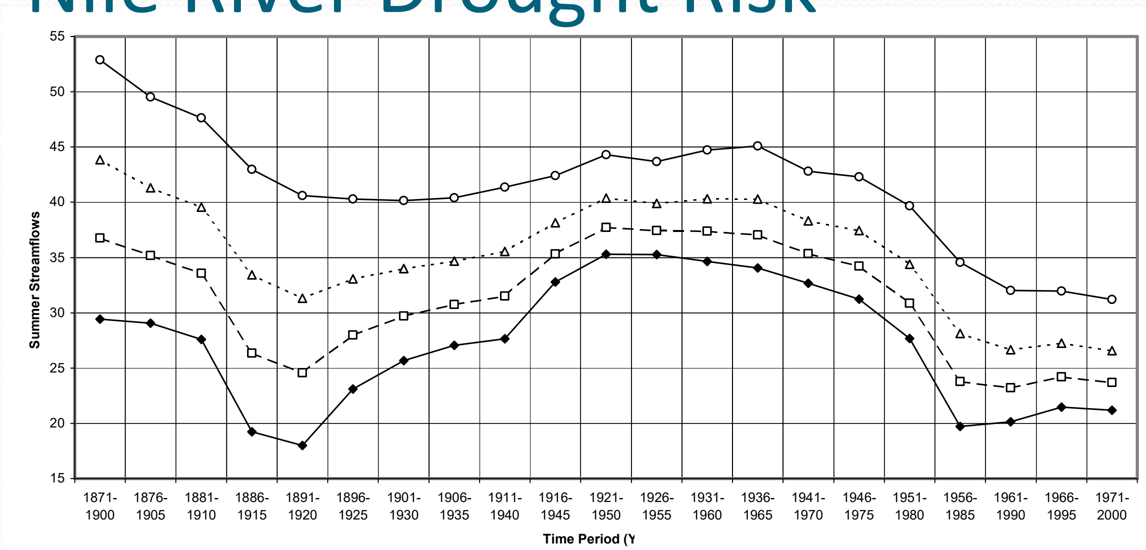
Egyptian Hydrologists Research:

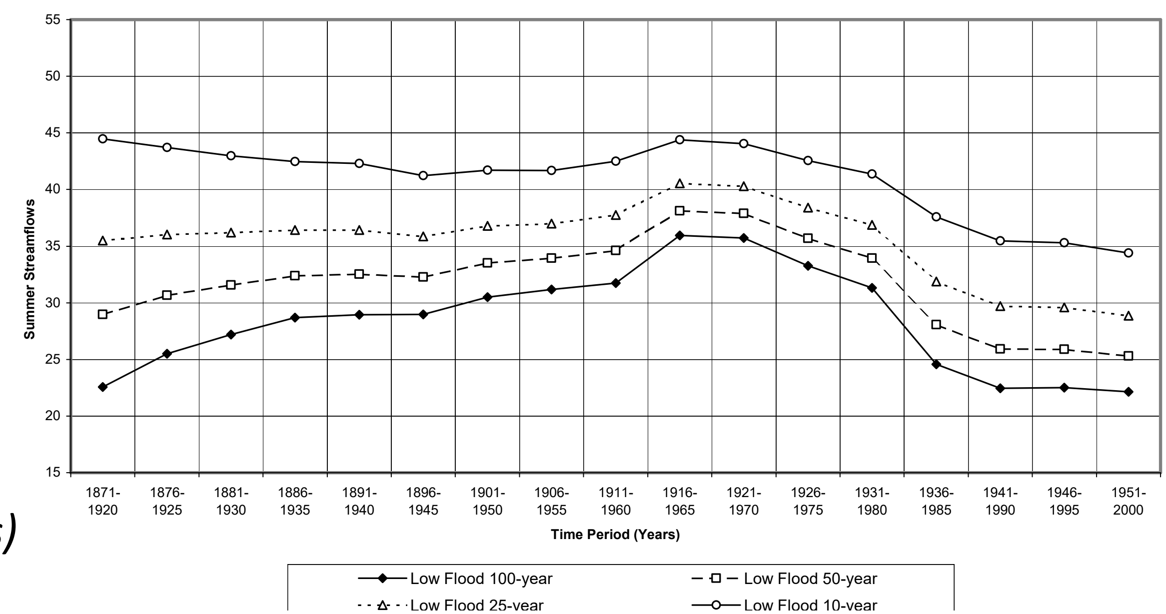
Run Tests on Annual Flow of the Nile at Aswan

Tests for special causes (runs rules)	from observation	to observation
9 observations on same side of centerline	1878	1886
	1889	1897
	1976	1984
6 observations in row increasing or decreasing	OK	OK
14 observations alternating up & down	OK	OK
2 of 3 observations in Zone A or beyond	1892	1894
	1982	1984
4 of 5 observations in Zone B or beyond	1870	1874
	1875	1879
	1887	1891
	1892	1896
	1979	1983
	1984	1988
15 observations in Zone C	OK	OK
8 observations beyond Zone C	1889	1896
	1982	1989

Awadallah (Civil Engineering and Environmental Systems, 2013, In Press)

Egyptian Hydrologists Research: Evolution of the Nile River Drought Risk





Awadallah (CEES, 2013, In Press)

Egyptian Hydrologists Research: Evolution of the Nile River Drought Risk (2/2)

- The ratio between the highest and lowest estimate of the 100-year drought exceeds 2.9
- The difference between the two estimates is much higher than the root of the average quadratic error associated the estimate of the 100-year drought based on samples of *f* years.
- A weaving pattern is present and with the same peak and trough periods, indicating that this up and down is not dependent on the moving window (*f*) value.

Awadallah (2013, In Press)

Conclusions (1/2)

- Hurst is a hydrologist with a strong practical side and a remarkable sense of observation.
- His fascination of the Nile lead to the most comprehensive account of the river; which is still maintained, at least as far as data is concerned, by the Egyptian Ministry.
- If it wasn't for the "discovery" of the Hurst exponent, Temporal Reliability of the HAD would have dropped from 0.99 to 0.85, Maximum Deficit from 15 to 30, Average Spilled Volume increased from 2 to 6.5 BCM/year.

Conclusions (2/2)

- Size of GERD is by far exceeding Hurst's initial calculations.
- Approximate impact of the filling stage of GERD is mainly on HAD temporal reliability and maximum deficit.
- Egyptian hydrologists still explore the Hurst phenomenon providing explanation related to non-stationarity of the mean and presenting less biased Hurst exponent estimators.

Thank you