FACETS OF UNCERTAINTY
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International Union of Geodesy and Geophysics
5th EGU LEONARDO CONFERENCE • HYDROFRACTALS '13 • STATISTICAL HYDROLOGY—STAHY '13

Round Table: The legacy of Harold Edwin Hurst in hydrological stochastics

Hurst, Climate Variability and Sustainable Nile Water Management

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The Nile, Long-term Climate Variability, and the Legacy of Hurst

My Personal Indebtedness to Harold Edwin Hurst

Sustainable Nile Water Management

The Nile River Basin

From Loucks
and van Beek (2006)

Heights of Ancient Nile Floods

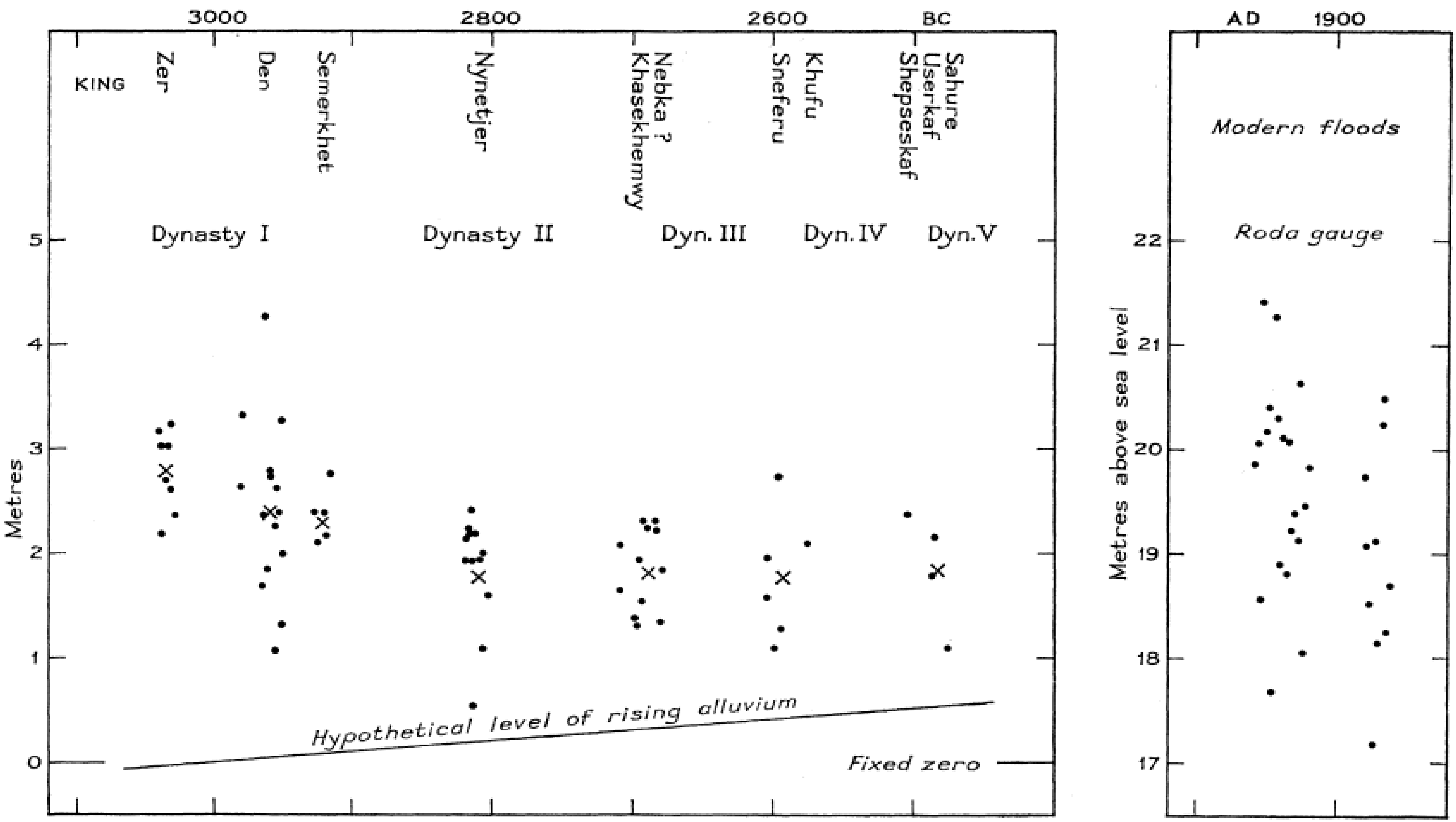


Fig. 1. Height of ancient Nile floods in metres above arbitrary zero (left): black dots = individual floods, X = averages; and (right) height of modern floods measured at Roda, in metres above sea level

(Bell,1970)

The Role of the Pharaoh

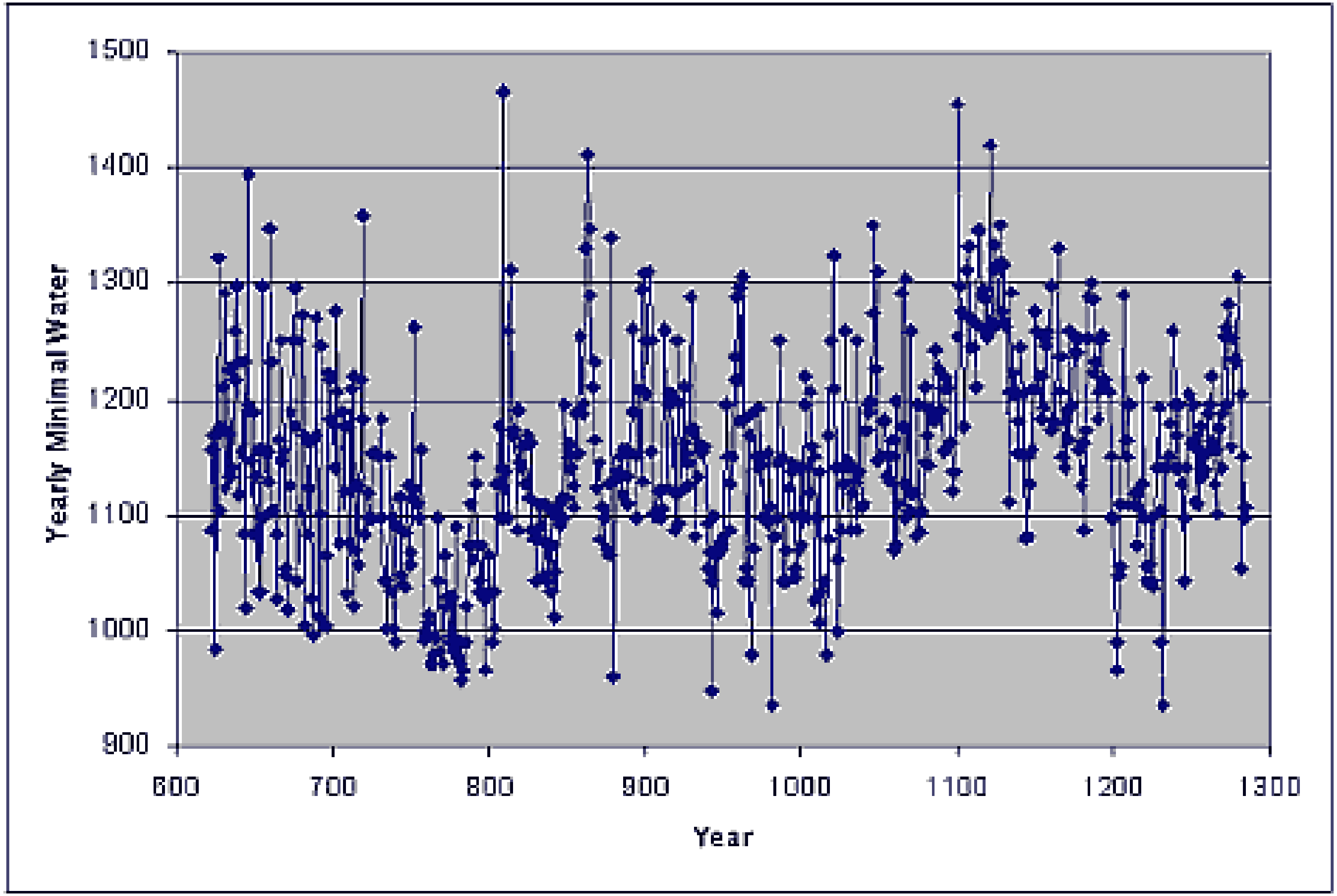
"I was the one who made barley, the beloved of the Grain-god. The Nile honoured me on every broad expanse. No one thirsted therein......everything which I had commanded was in its proper place"

(Wilson,1955)

The Dark Ages of Ancient History

- In the 7th and 8th Dynasties of the Old Kingdom (2150 -2134 B.C.), no less that 18 kings and one queen ascended the throne (Hassan 2011)
- Initial breakdown of the Old Kingdom caused by a sudden, unanticipated and catastrophic reduction in the Nile floods over two or three decades
- Associated with abrupt, short-lived cold climate epoch that led to less rainfall and a reduction of water flow from Tibet to Italy

Time-series record of the Nile River – Roda gauge minimum water levels from 662-1284 AD



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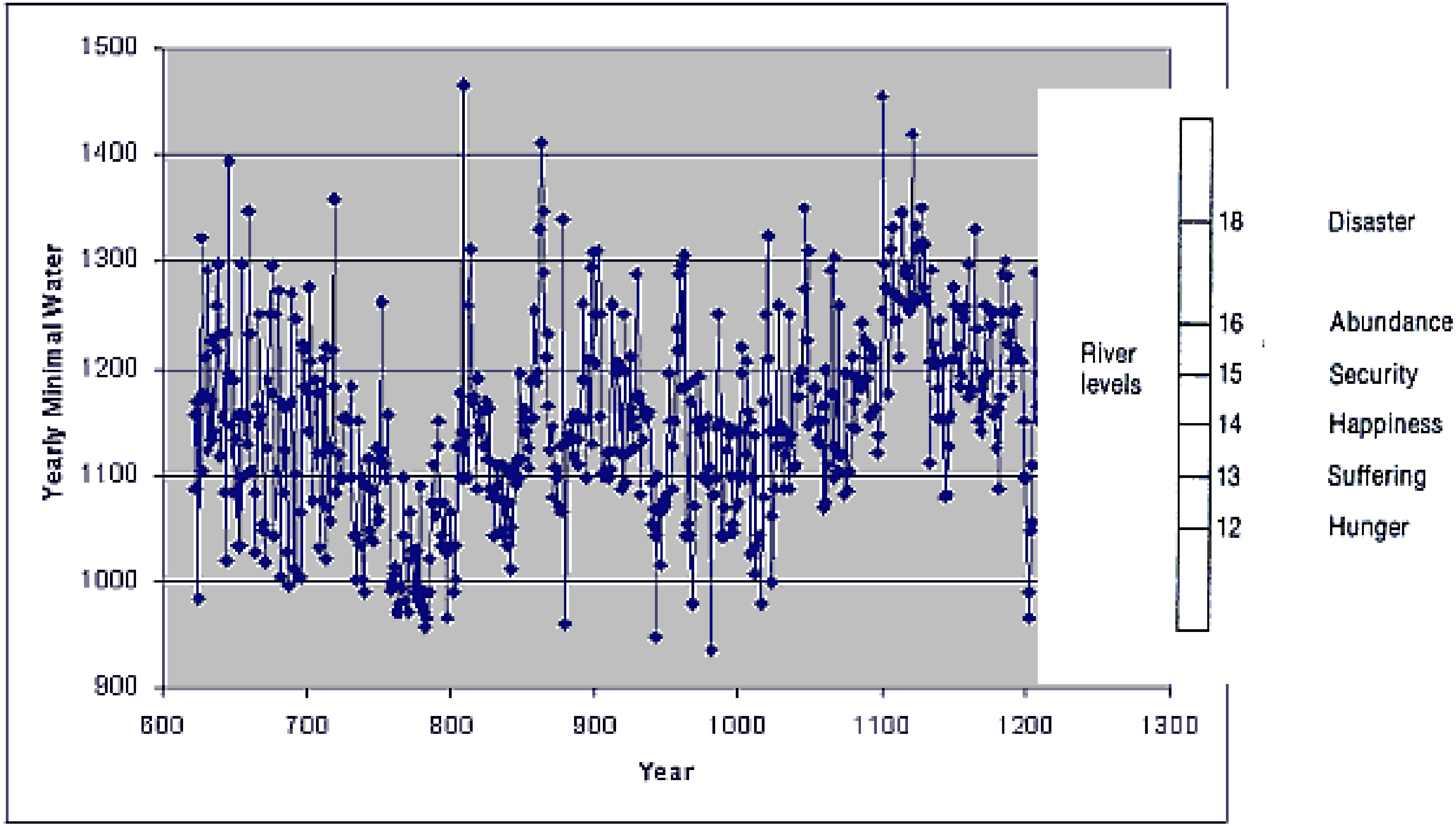
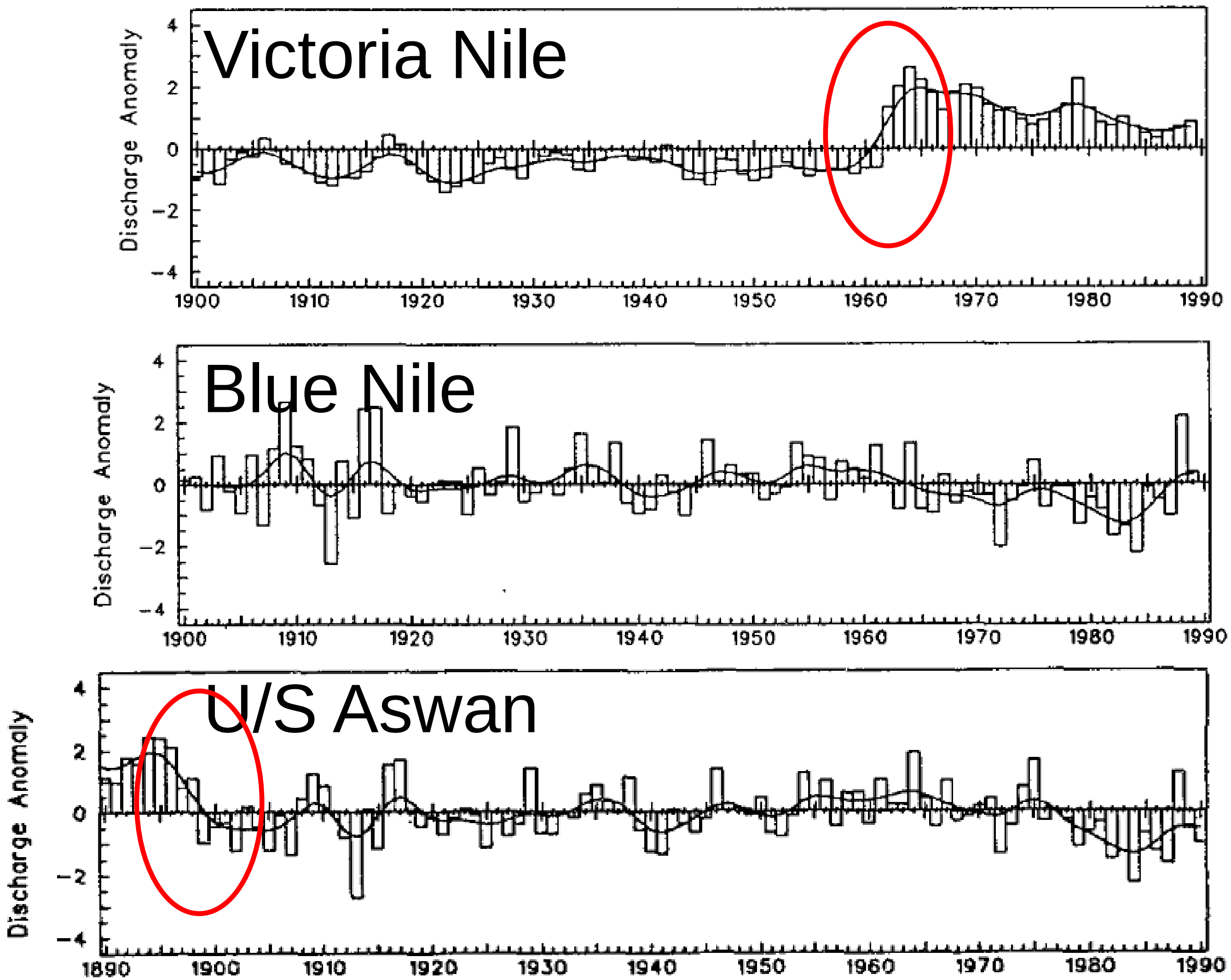


Modern Nile Instrumental Records



Conway, D., and M. Hulme. (1993) Climatic change 25.2: 127-151.

Annual Nile Flows at Aswan (1871-1975)

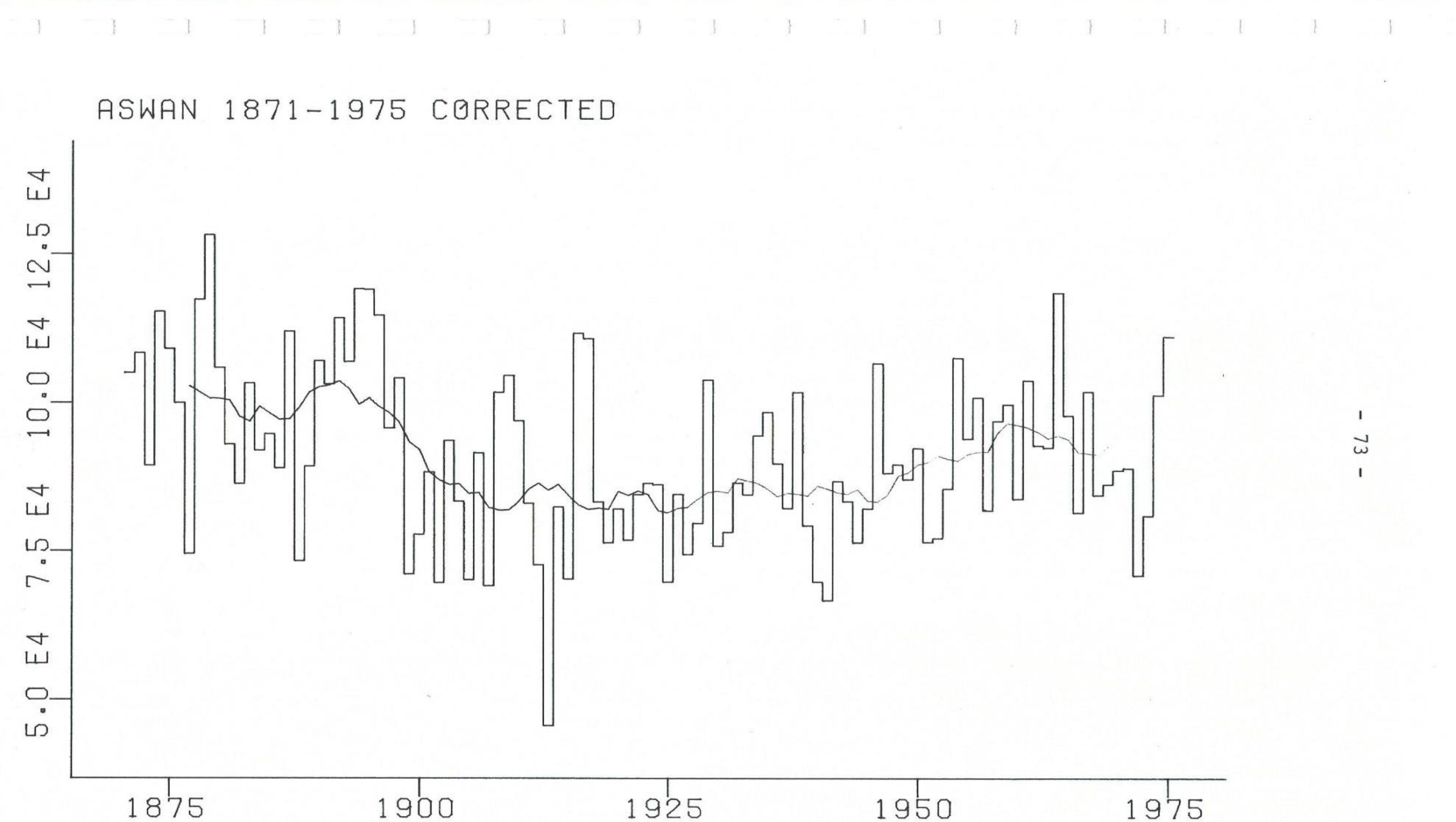


FIGURE 4.4 Annual natural flows at Aswan after applying 8% correction to the pre-1902 flows, with 13 year centred moving average

Cumulative Departures from the Mean for Tropical Annual Rainfall Records and Annual Flows at Aswan – from pre-1900

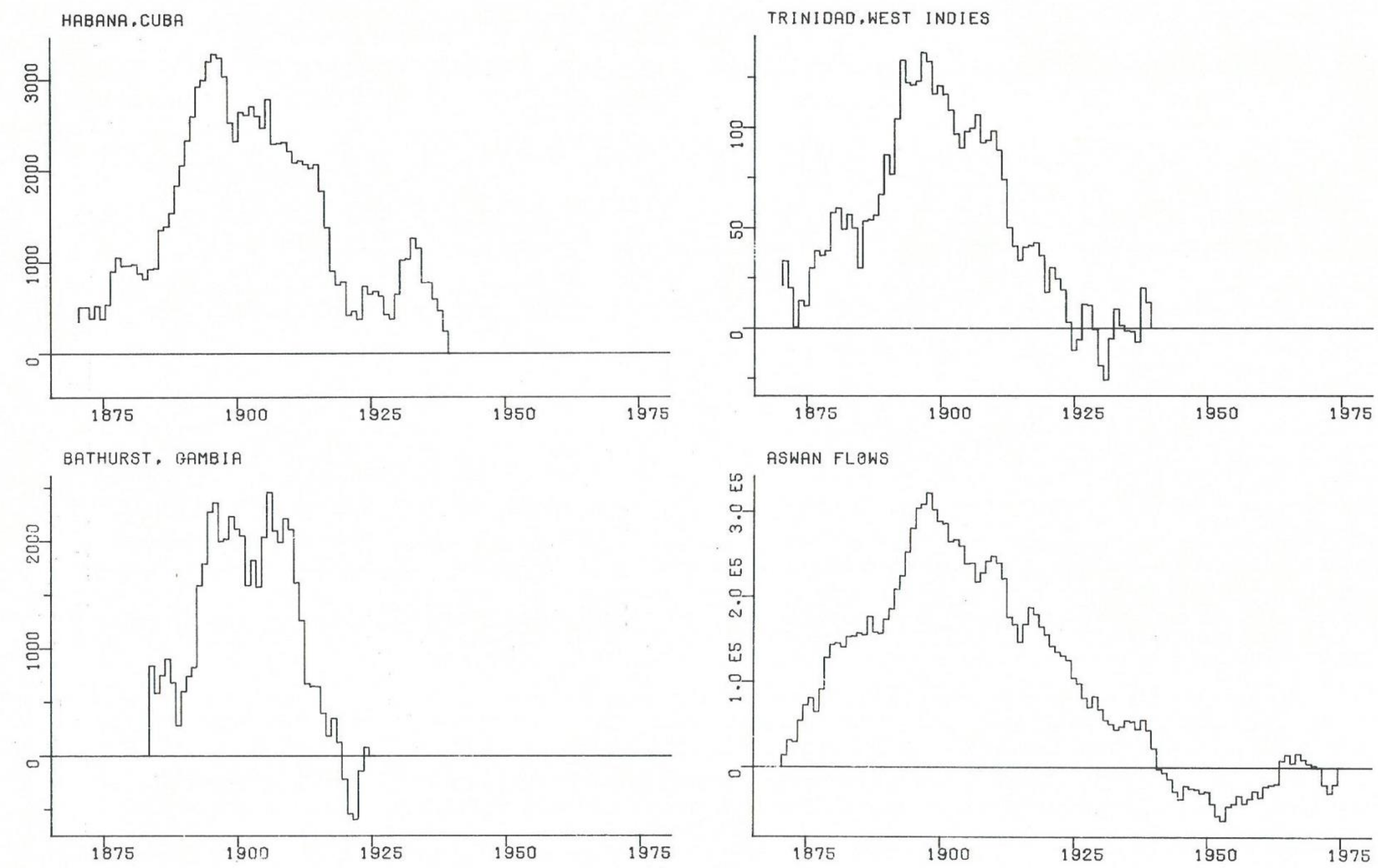


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FIGURE 4.6 Cumulative departure from mean for annual rainfall at several tropical sites and for the annual flows at Aswan.

Changes in Nile Flows

- Decrease in (Blue) Nile flows around 1900 attributed to widespread sudden decrease in tropical rainfall/partial failure of the Monsoon (Kraus, 1954)
- Rise in Lake Victoria levels attributed to increase in rainfall: water balance can be closed by appropriate weighting of rainfall observations around the Lake to account for higher rainfall over the Lake (Sutcliffe and Parks (1999))

Changes in Nile Flows

- These ‘CHANGES’ should be treated as nonstationarities IF AND ONLY IF the causal mechanisms can be identified and quantified as deterministic functions THAT CAN BE PREDICTED
- Otherwise, encapsulate this variability in a STATIONARY stochastic model as Hurst so brilliantly did (based on shifting means) in his 1957 Nature paper, and base design on the resulting uncertainty (recent exemplar is Athens water supply case study: Koutsoyannis (2011).
- PLEASE do not use IID as the Null Hypothesis when testing for ‘nonstationarity’

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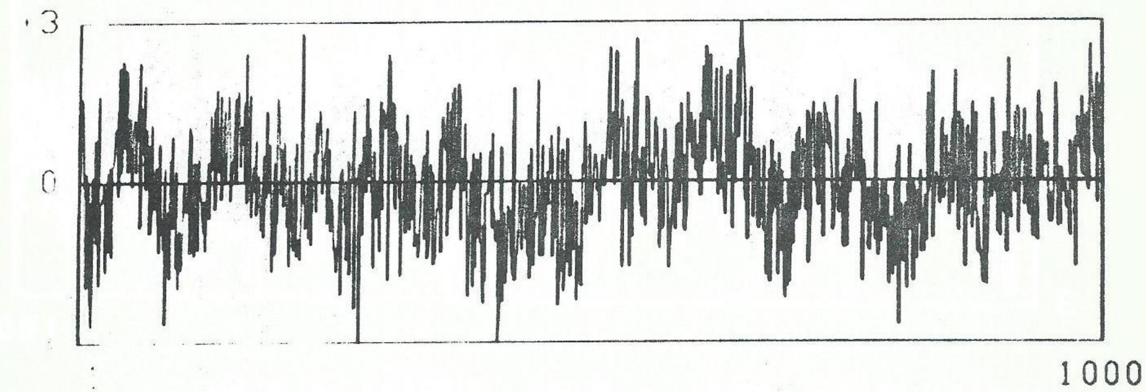
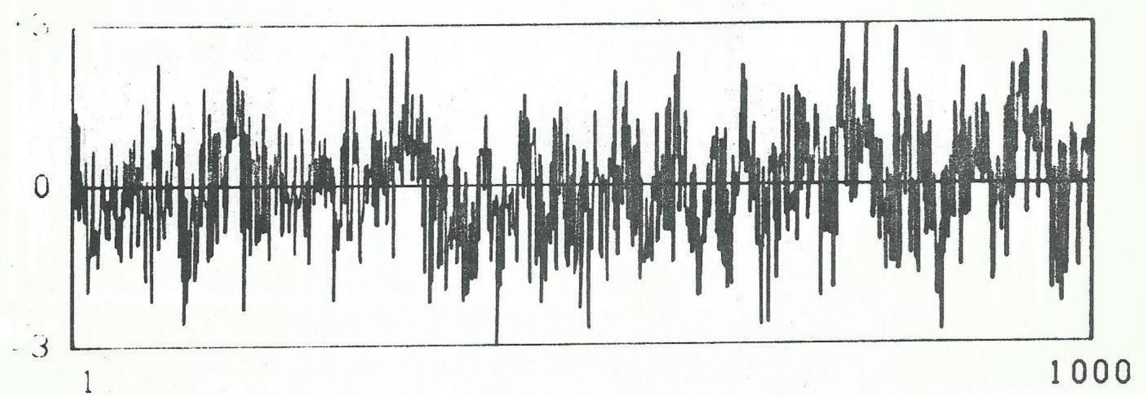
Sustainable Nile Water Management

ARMA (1,1) Modelling of Hurst Phenomenon (O'Connell,1971)

$X_t = \varphi X_{t-1} + \varepsilon_t - \theta\varepsilon_{t-1}$ $\varphi = 0.94; \theta = 0.78$

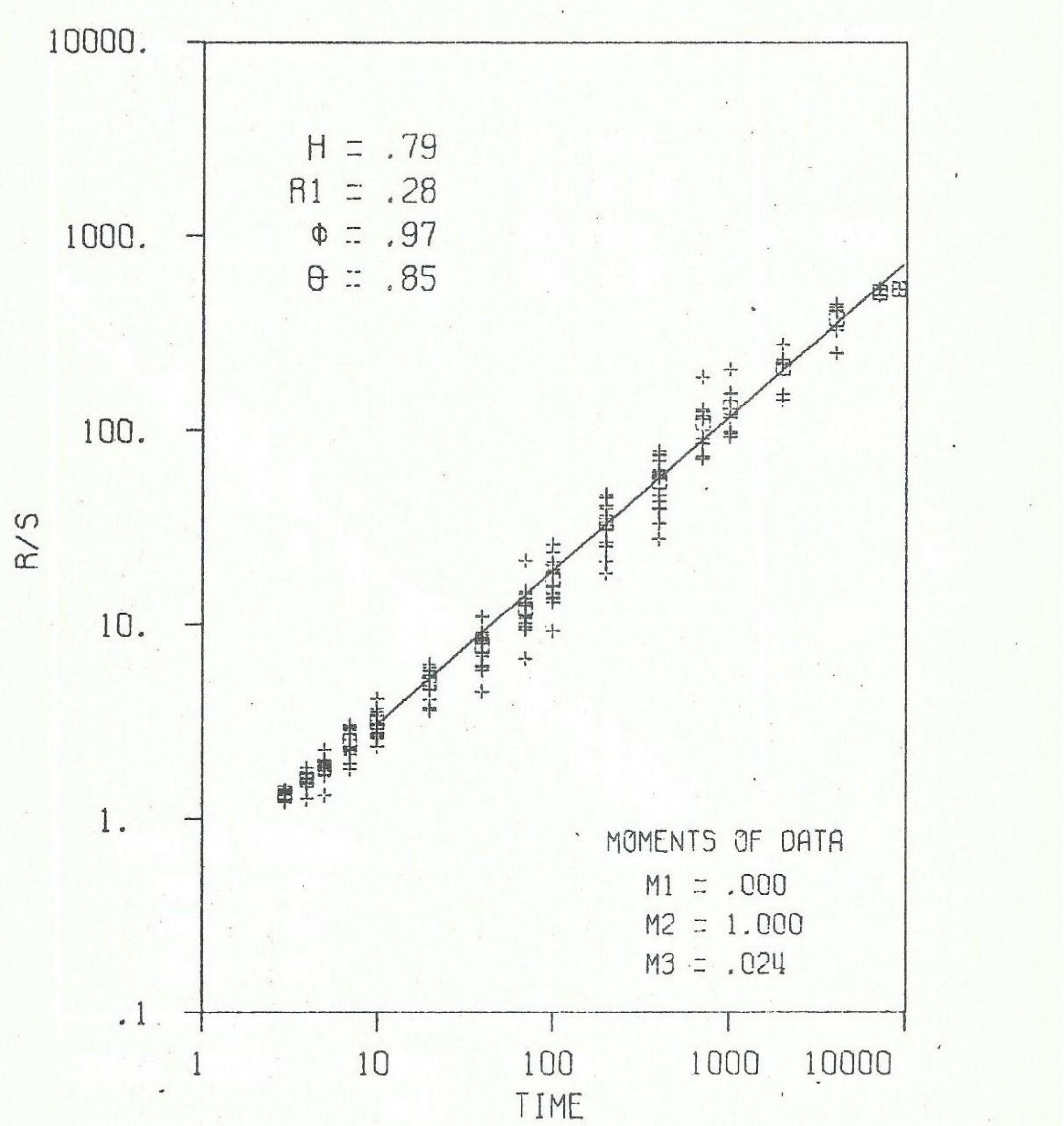


ARIMA(1,0,1) PHI1 = 0.94 THETA1 = 0.78



ARIMA(1,0,1) PHI1 = 0.94 THETA1 = 0.76

ARMA (1,1) Pox Diagram: φ =0.97 θ = 0.85 H = 0.79



ARMA (1,1) Small Sample Properties of K and ρ_1

$\varphi = 0.92$							
		$\tilde{E}[K]_n$			$\tilde{E}[\hat{\rho}_1]_n$		
θ	ρ_1 \ n	25	50	100	25	50	100
0.88	0.049	0.657	0.664	0.654	0.001	0.012	0.028
0.84	0.114	0.687	0.680	0.686	0.005	0.046	0.079
0.80	0.189	0.686	0.705	0.709	0.072	0.093	0.123
0.76	0.269	0.699	0.735	0.745	0.082	0.160	0.208
0.72	0.349	0.725	0.751	0.756	0.116	0.199	0.240
0.68	0.426	0.740	0.782	0.783	0.169	0.269	0.332
0.64	0.496	0.772	0.783	0.800	0.218	0.309	0.390
0.60	0.560	0.773	0.796	0.803	0.273	0.364	0.437
0.56	0.616	0.774	0.820	0.825	0.285	0.432	0.516
0.52	0.665	0.794	0.825	0.828	0.335	0.467	0.532

Table (3.3) Values of $\tilde{E}[K]_n$ and $\tilde{E}[\hat{\rho}_1]_n$ for selected values of φ and θ

1979-80: Operation of High Aswan Dam (with E Todini)

- Development of synthetic flow generator that reproduced long-term variability/persistence in HAD inflows
- Development of monthly simulation model for Lake Nasser
- Risk-based evaluation of SDP-derived operating policies and trade-offs between multiple purposes using synthetic inflows

2010-2012: Nile Basin Decision Support System (DSS)

- Undertaken by Nile Basin Initiative
- Framework for sharing knowledge, understanding river system behaviour, designing and evaluating alternative development scenarios, investment projects, and management strategies.
- Software development by DHI
- Phase 1 Pilot Applications:
    - Preparation of Quality Assured Data Sets
    - Develop Baseline Model of Nile Basin
    - Develop and Evaluate Scenarios for 3 Pilot Applications

Baseline Model

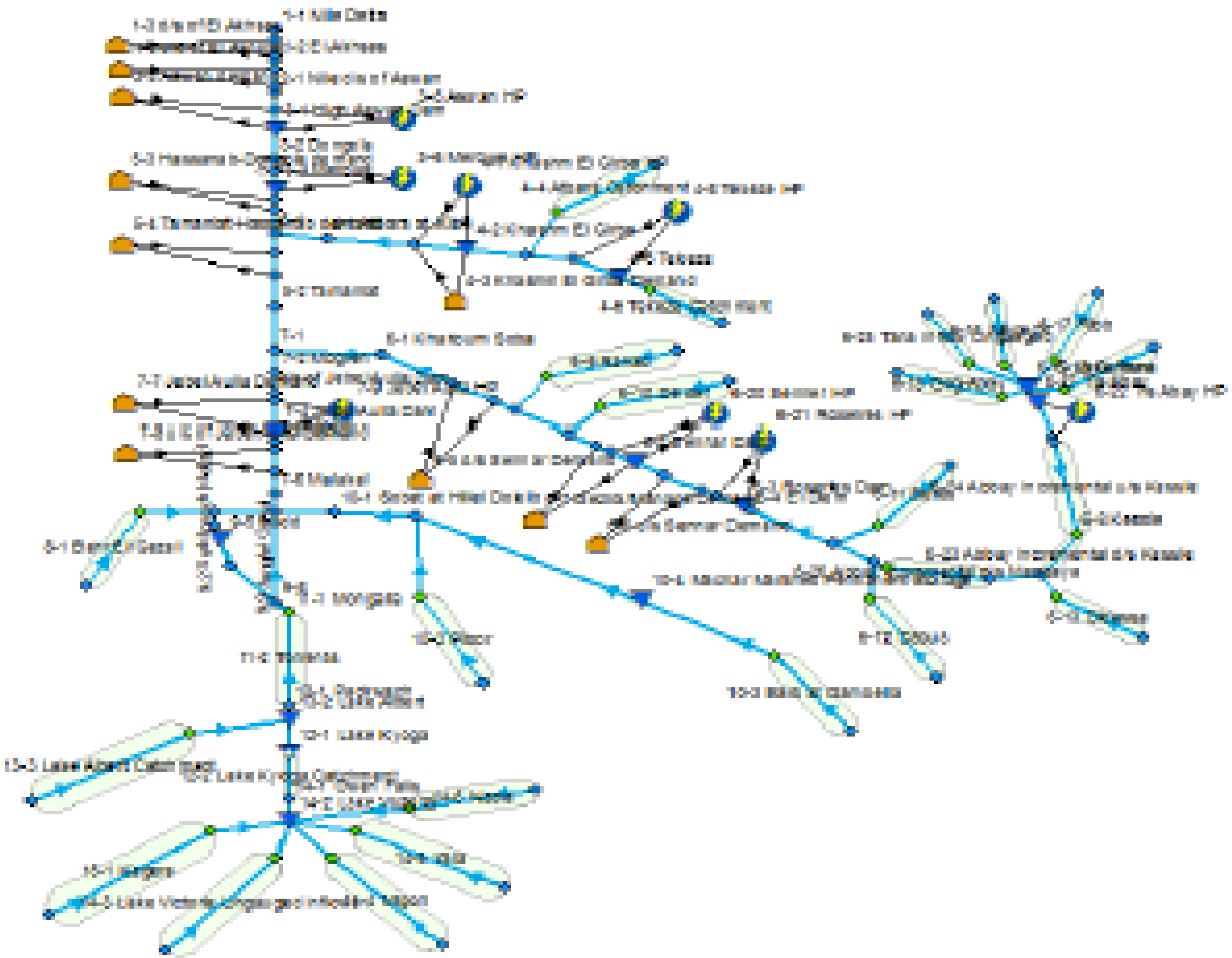
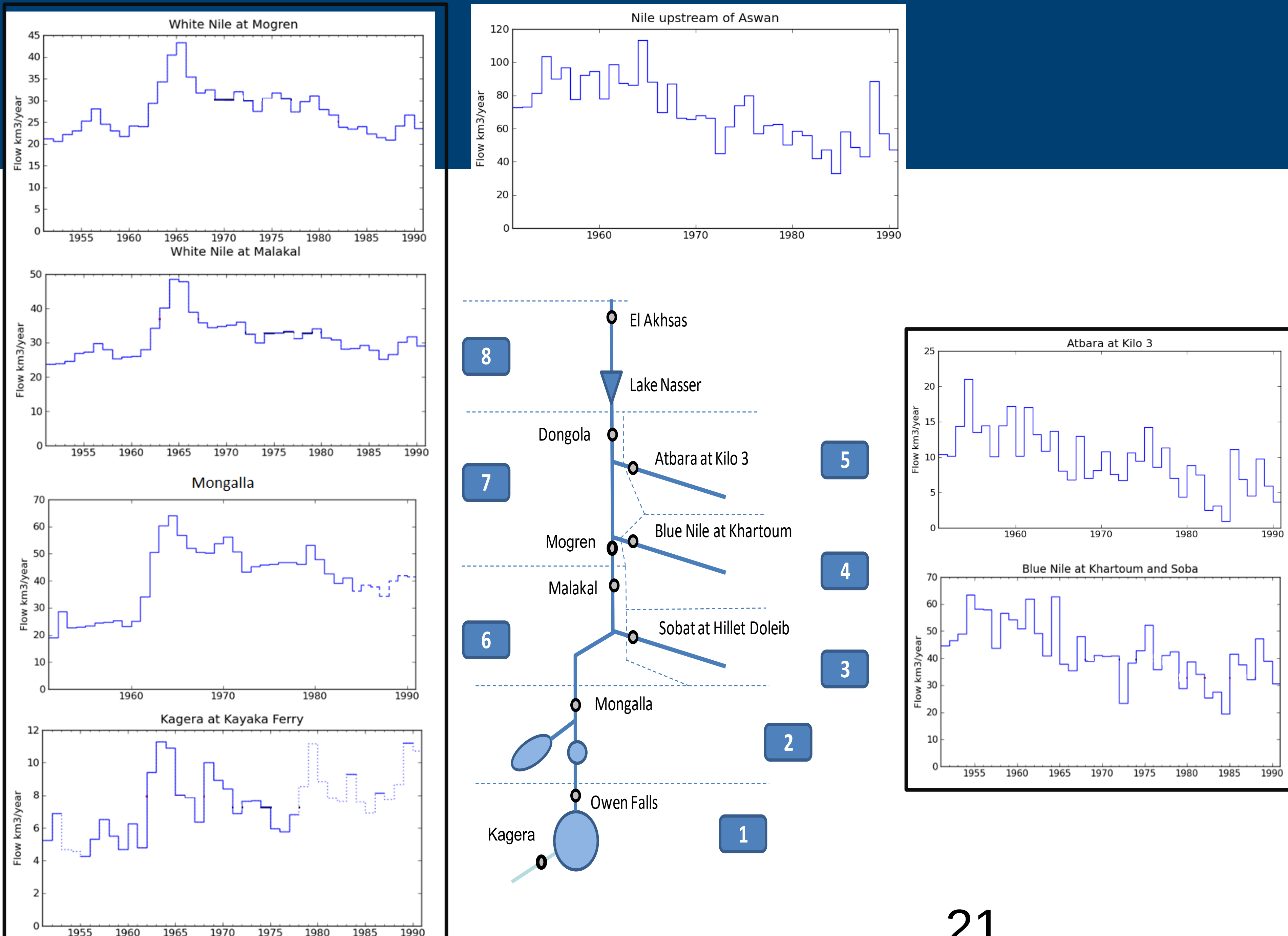


Figure 2 Nile Baseline Model MIKEBASIN schematic, showing the 83 building blocks


White Nile at Mogren
Flow km3/year
White Nile at Malakal
Flow km3/year
Mongalla
Flow km3/year
Kagera at Kayaka Ferry
Flow km3/year
Nile upstream of Aswan
Flow km3/year
El Akhsas
Lake Nasser
Dongola
Atbara at Kilo 3
Blue Nile at Khartoum
Mogren
Malakal
Sobat at Hillet Doleib
Mongalla
Owen Falls
Kagera
8
7
6
5
4
3
2
1
Atbara at Kilo 3
Flow km3/year
Blue Nile at Khartoum and Soba
Flow km3/year

Victoria Nile: Observed and Simulated Monthly Flows (1950-1990)

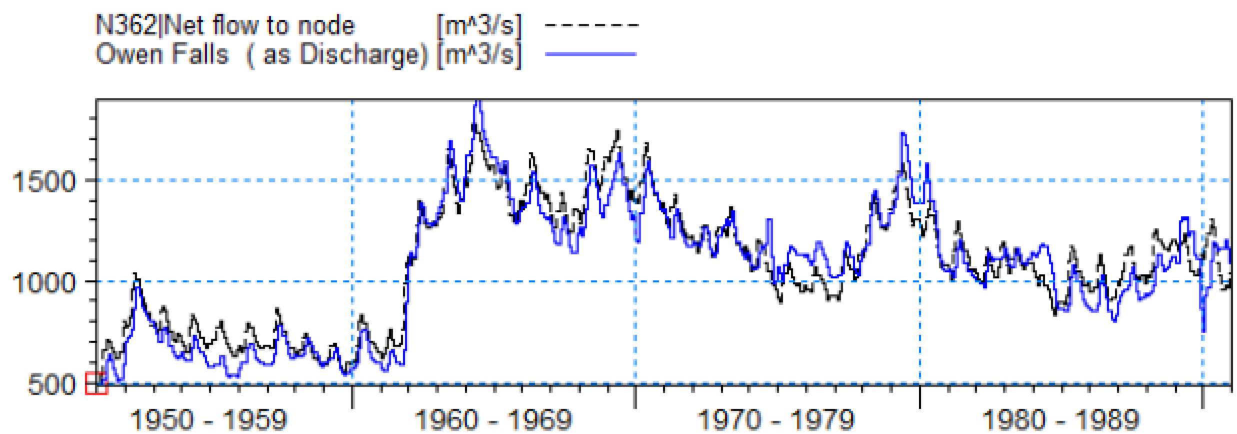


Figure 12 Observed and simulated monthly flows at Owen Falls, Lake Victoria

Baseline Model: Observed and Simulated Lake Nasser Levels

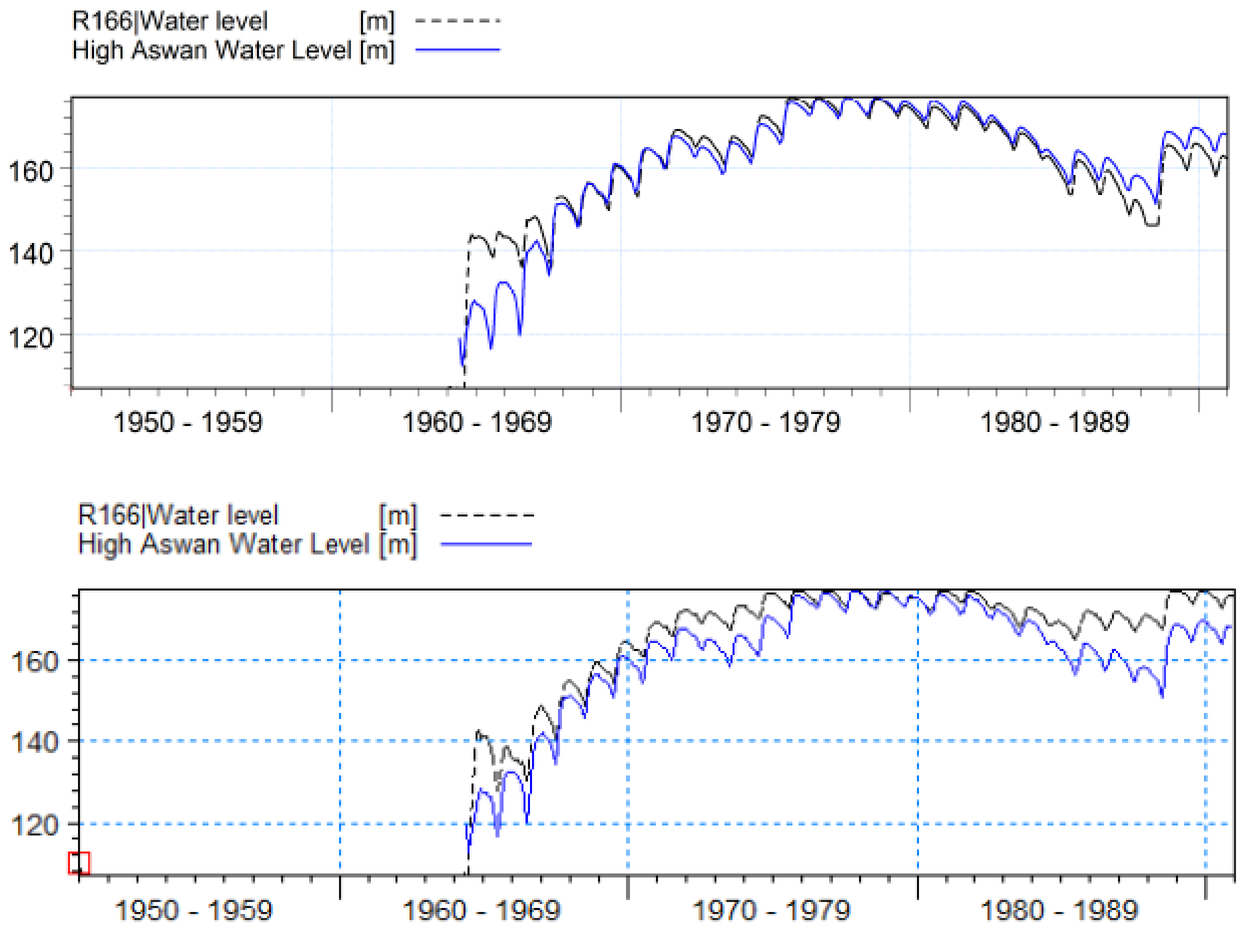
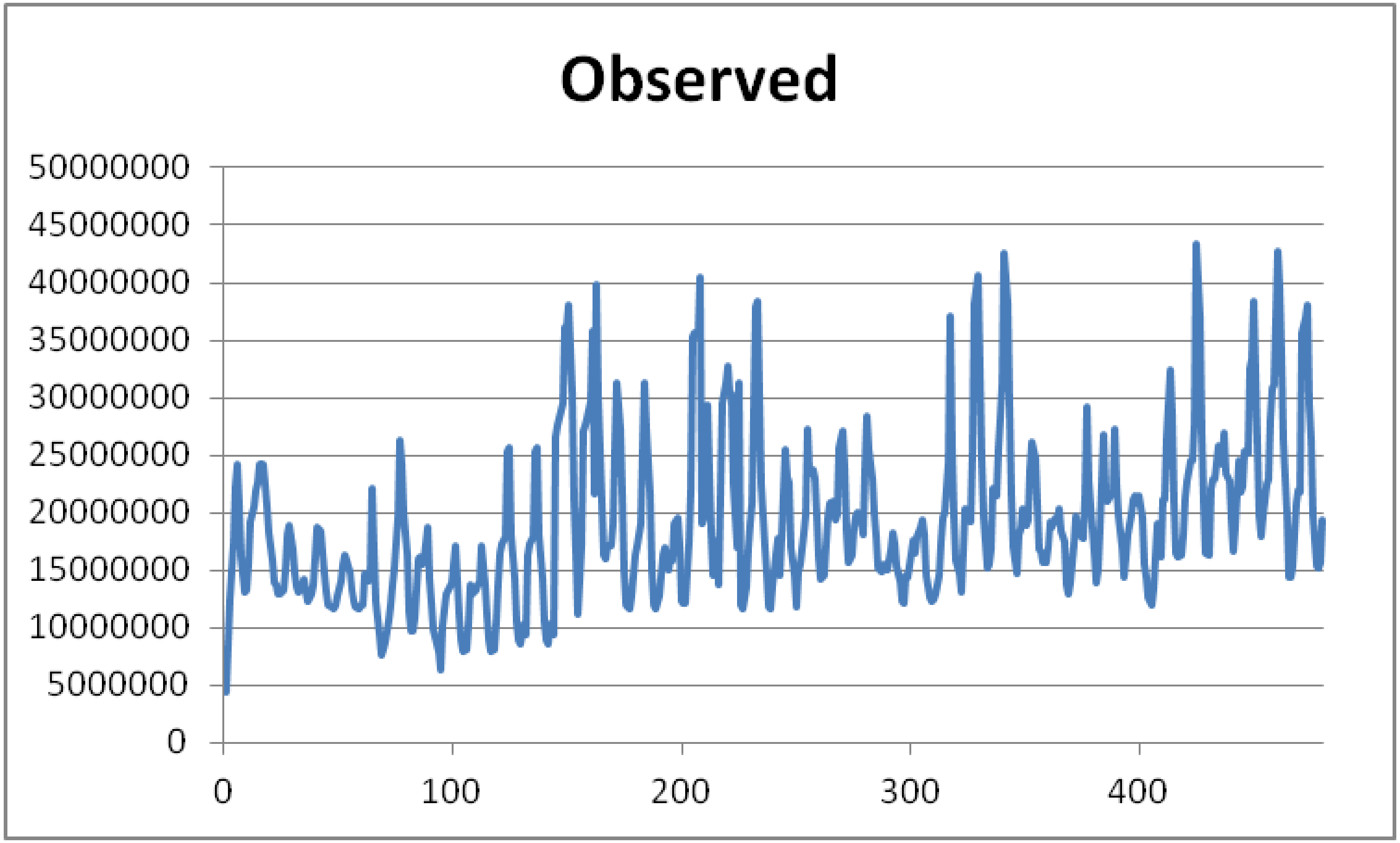
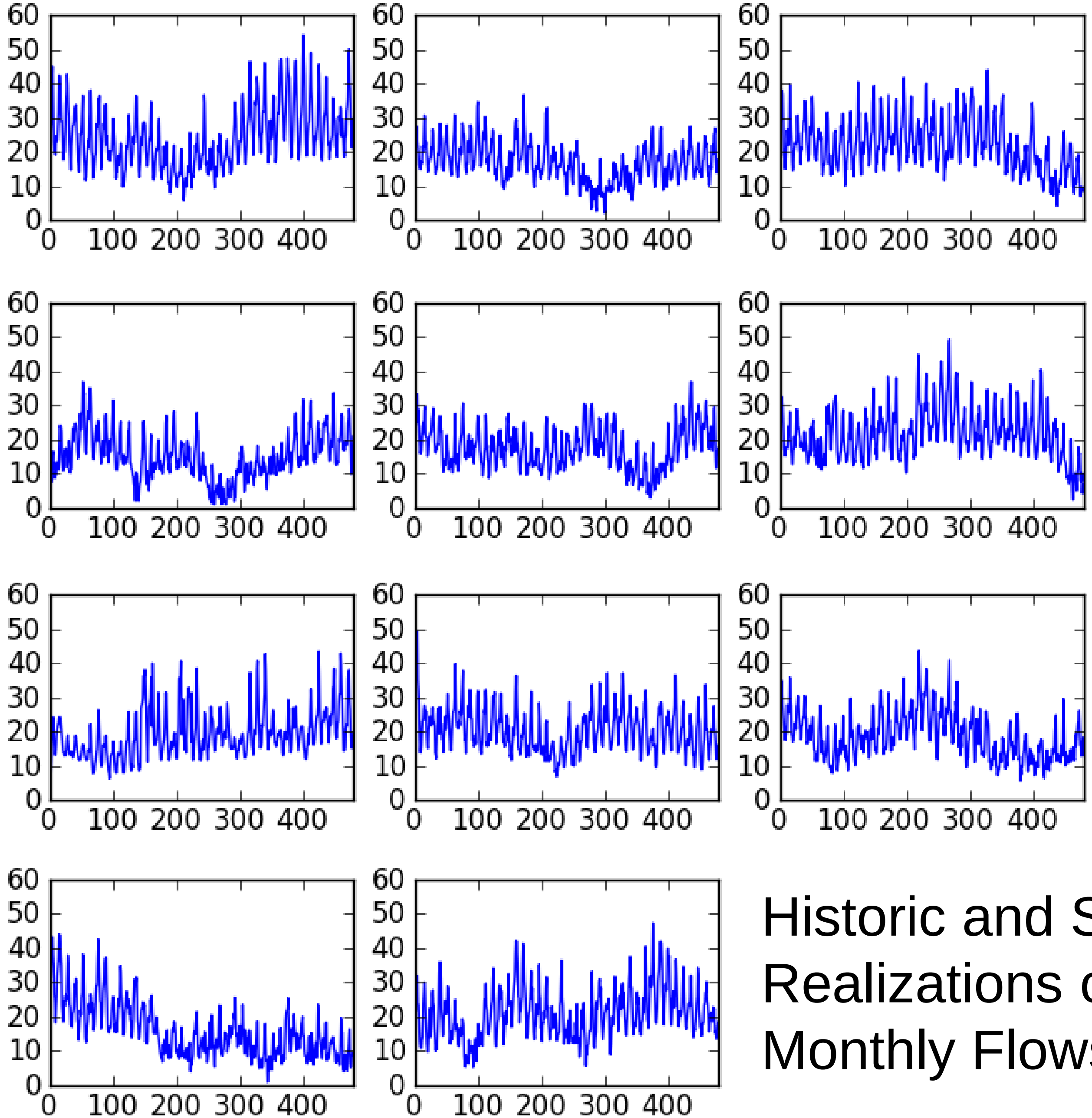


Figure 61 Observed and simulated levels for the High Aswan Dam (top: calibrated model section, bottom: full model simulation)

Historical Monthly Flows: Kagera at Rusumo Falls (1951-90)





Historic and Synthetic Realizations of Kagera Monthly Flows (40 years)

Physical Explanation of the Hurst Phenomenon? (Vit Klemes)

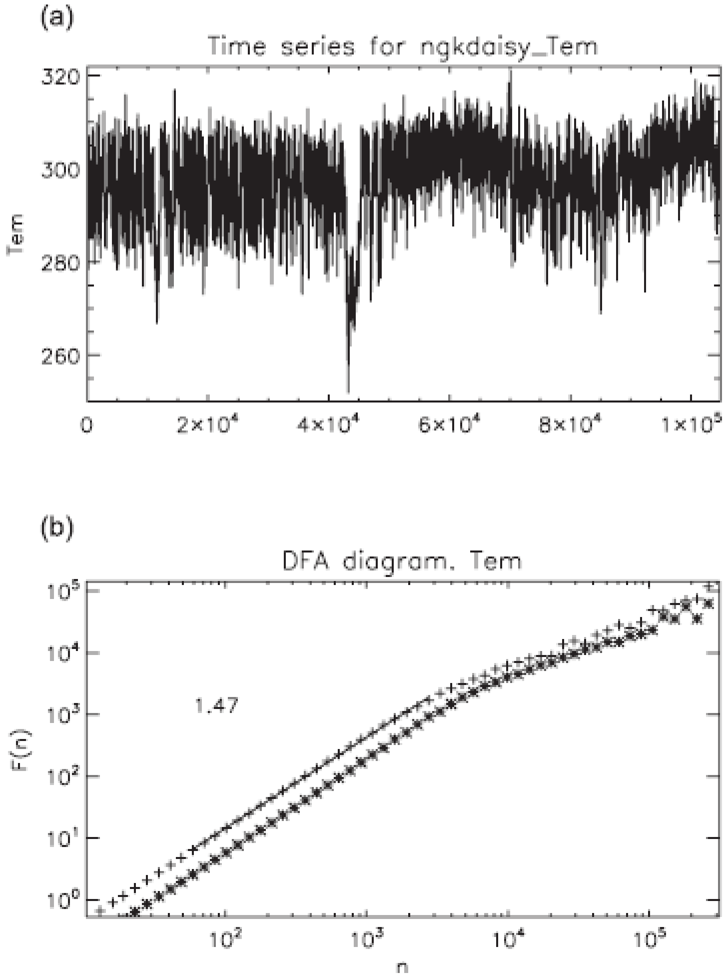


Figure 11. Similar to Figure 6 for (a) the forced NGK Daisyworld model with random noise forcing with standard deviation, $\sigma = 5.0$, and amplitude of the forcing $L_0 = 0.819$. (b) DFA diagram is more linear. The slope of the power spectral density is -2.0 (not shown).

Mesa, O. J., Gupta, V. K. and O'Connell, P. E. (2012) : **Dynamical system exploration of the Hurst phenomenon in simple climate models,** **in *Extreme Events and Natural Hazards: The Complexity Perspective*, Geophys. Monogr. Ser., vol. 196, edited by A. S. Sharma et al. 209–229, AGU, Washington, D. C., doi:10.1029/2011GM001081**

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Sustainable Nile Water Management

Pressures

- Main pressures coming from increasing population growth in all the Nile Basin countries, mainly Egypt, Ethiopia and Sudan.
- Egypt and Sudan plan expansion of irrigated land
- Ethiopia needs water for irrigation and to develop HP dams on Abbay/Blue Nile
- Subsistence agriculture in Ethiopia causing massive erosion: major sedimentation problems downstream in Sudan
- Water for ecosystem functioning….?

The Challenge

- How to deliver economic and social benefits for all (win-win) in the Nile basin

  - without compromising environmental sustainability
  - under highly variable climatic conditions, potentially exacerbated by global warming
  - under transboundary conditions where national interests have historically prevailed

Nile Basin Initiative (NBI)

NILE BASIN INITIATIVE
Initiative du Bassin du Nil

Established in 1999

“to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the common Nile Basin water resources.”

9 Countries:
Burundi, D.R.Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan,Tanzania, Uganda

Prior Agreements

Nile Water Agreement of 1929

- Egypt's natural and historical rights to waters of the Nile protected: no upstream development without agreement of Egypt

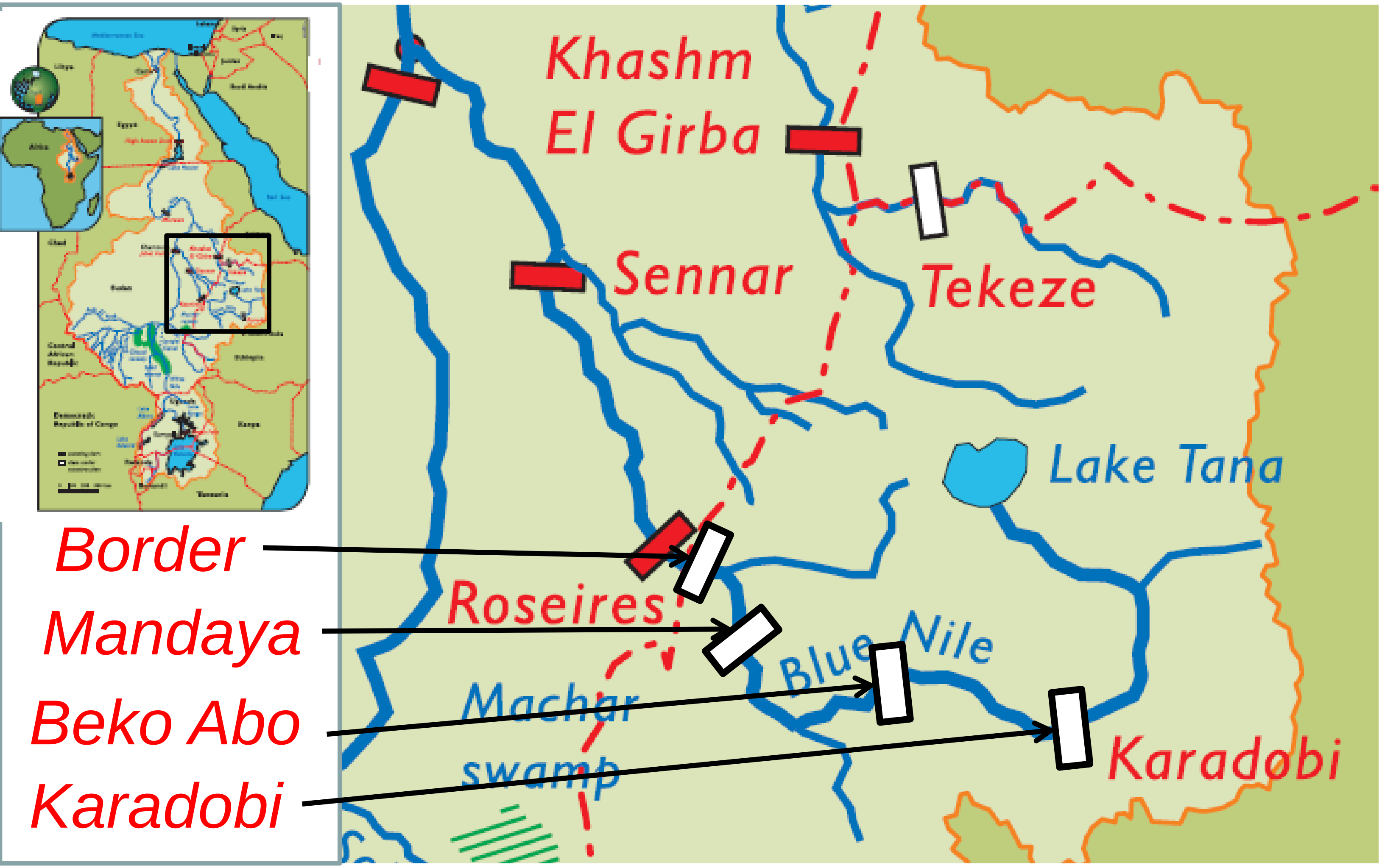
Nile Water Agreement of 1959

- Concluded by Egypt and Sudan: shared Nile water resources as
  - 55.5 km3/yr to Egypt;
  - 18.5 km3/yr to Sudan

2008: Nile Basin Initiative launched First Phase of Joint Multipurpose Programme (JMP1)

"*identify and prepare a major initial project, within a broader multipurpose programme, to demonstrate the benefits of a cooperative approach to the management and development of the Eastern Nile*"

Proposed Cascade of Hydropower Dams on Abbay/Blue Nile



Proposed multipurpose hydropower dams on Blue Nile

Site	Dam height (m)	Full supply level (m)	Gross Storage ($10^6 m^3$)	Installed Capacity (MW)	Firm Energy Output (GWh)
Karadobi	252	1153	32,500	1350	5845
Mabil	171	906	13,600	1200	5314
Mandaya	164	741	15,930	1620	7800
Border	84.5	575	11,074	1400	6200

From Eastern Nile Power Trade Study (2007)

Grand Ethiopian Renaissance Dam

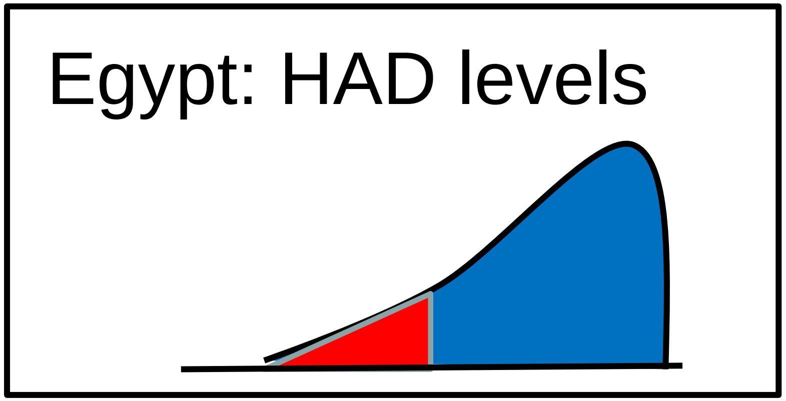
- Announced on April 2 2011 by the Ethiopian Prime Minister
- Volume of 67x10**9 M3
- 5250MW HP capacity
- Largest dam in Africa/ 10^{th} largest in the world
- Cost US$ 4-5 Billion: completion by 2015

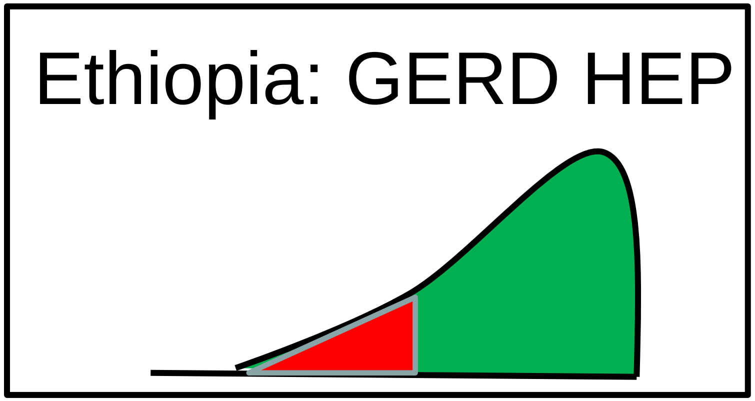
Grand Ethiopian Renaissance Dam

- Will achieve high level of regulation of Nile flood: downstream flood risk largely eliminated
- Increased low flows will enable downstream abstraction for irrigation throughout the year
- Will act as a major sediment trap, reducing sedimentation of downstream irrigation schemes and Lake Nasser
- Will impact adversely the livelihoods of some 800,000 people downstream who practice recession agriculture
- Will impact adversely downstream wetlands/ migration of people and animals/fish spawning

The Major Issue

- How will the filling and operation of GERD affect HAD storage and the security of Egypt's water resources?
- Had levels will drop during filling: need adaptive risk-based approach that balances the risk of HAD release shortfalls for Egypt with the risk of hydropower shortfalls for Ethiopia





The Major Issue

- Long-term persistence means that recovery of Lake Nasser levels could be slow
- However, IF HAD were to continue to be operated at lower levels, then:
  - Evaporation loss from Lake Nasser would be reduced;
  - Conjunctive use of Lake Nasser and GERD storage would be required to achieve required reliability of supply for Egypt in times of major drought (as in 1980s); switch GERD priority from HEP to meeting downstream supply needs

Climate Risk-based Analysis of Conjunctive HAD and GERD Operation

- Climate model outputs not useable: lack of interannual variability etc (eg Johnson et al (2011), Brown and Wilby (2012))
- Draw on legacy of HE Hurst: employ stochastic model that reproduces long-term climatic variability/persistence (eg fGn/shifting mean/ARMA(1,1)) to do risk-based analysis of impact of GERD filling and operation on reliability of HAD releases.

The Legacy of Hurst

- **To Egypt (and the Nile Countries)**: the HAD which proved robust to the major drought in the 1980s; the Nile Basin Gauging Network; Nile Basin Volumes etc
- **To Hydrological Science /Practice**: a pillar of modern Stochastic Hydrology/basis for design under high climatic uncertainty
- **To Climate/Geophysical Science**: analysis of long-term variability/memory in the climate system/paleo records
- **To Fractals** which emerged from Mandelbrot's initial focus on the Hurst Phenomenon
- **To Statistics**: properties of the Rescaled Range and statistics of long memory processes.

Thank you for your attention……

and thanks to my hero: Harold Edwin Hurst