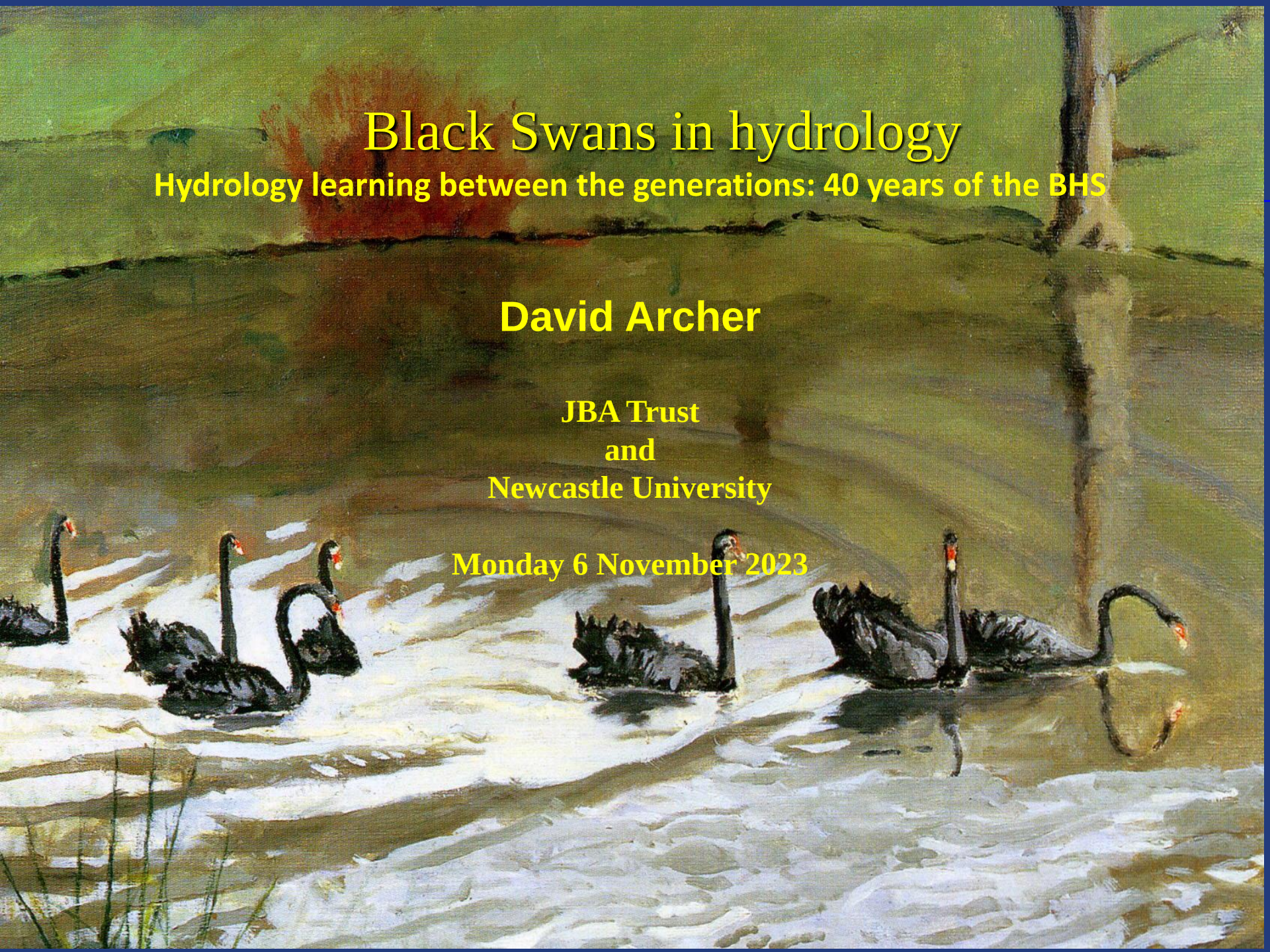


Black Swans in hydrology

Hydrology learning between the generations: 40 years of the BHS

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What is a Black swan?

Black swans are observations or events which are outside the realm of regular expectations either of previous experience or of computer capability (Talib, 2007).

Before the settlement of Australia, people in Europe were convinced all swans were white, confirmed by empirical evidence. The observation of black swans illustrates the limitation to our learning from observation. A single observation can invalidate a general statement derived from millennia of confirmatory observations of white swans.

In general Black Swan events have, rarity, extreme impact, and retrospective (though not prospective) predictability.

Examples of black global swans

- In 1970 who would have predicted the impact of personal computers?
- In 1980 who would have predicted the impact of the Internet?
- In 1990 who would have predicted the bombing and political impact of the bombing of the Twin Towers in New York?
- In 2000 who would have predicted the financial crash of 2008?
- In 2010 who would have predicted Brexit?
- IN 2020 who would have predicted the impact of AI?
- What next?

- The best laid schemes o' Mice an' Men, Gang aft agley: R. Burns

Hydrological Black Swans

- I will present three hydrological Black Swans which I encountered in 50 years of research and practice and note the response to them.

1. Observation of a very rapid rate of peak runoff in the snowmelt flood of March 1963 on the River Wansbeck at Morpeth, implying a rate of melt several times the rate of point melt recommended to apply to PMF events.
2. Observation of decreasing summer temperatures in the Upper River Indus from the Karakoram Mountains and implications for river flow (declining) and glacier behaviour (static), subsequently referred to as the Karakoram Anomaly.
3. Observation of very rapid (near instantaneous) rates of rise in upland rivers in Britain (walls of water).

Flood Studies Report 1975

- **Met Office study (Jackson, 1977)**
  - Concerned with estimating point snowmelt of given return period and maximum rates
  - Used duration of thaw of measured water equivalent – 11 years at 9 stations
  - Determined snowmelt rates as function of temperature
  - Extreme snowmelt estimated from relationship with maximum observed temperature of 100 yr RP with snow on the ground
  - Concluded that 42 mm/day (1.75 mm/hour) was a realistic design maximum
  - This value was adopted by ICE (1978)(Floods and Reservoir Safety) for spillway design and appraisal for Probable Maximum winter Floods

Flood Studies Report 1975

- **Newcastle University study**
  - Concerned with snowmelt runoff and assessment of melt runoff factor (in mm/^{o}C/h)
  - Suggested a value for a small catchment of 0.63 mm/^{o}C/h. With a maximum temperature of 8^{o}C this gives a peak rate of runoff of 5 mm/h
  - Initial snow depth, density and water equivalent unknown and contribution from concurrent rainfall uncertain.
- **Further study in Northeast**
  - Archer (1981) described several events in a single year 1979 with peak runoff rates >1.75 mm/h (max 4.5 mm/h)

The Morpeth snowmelt flood of 1963
(the largest flood in 100 years with 600 properties flooded)



Peak flow = 340 m^3/sec
Catchment area = 287.3 km^2
Peak runoff rate = = 4.26 mm/hour
(Rainfall during flood <5mm)



FSR (1975) and subsequently ICE (1978) adopted the Met Office estimate of 42 mm/day (1.75 mm/h) as a suitably rare occurrence to be added to maximum winter rainfall

Comment

- The input from melt (or the equivalent rainfall) must be greater than the peak rate of runoff (4.26 mm/h). But by how much?
- The rainfall flood of September 2008 was considered of similar magnitude to the March 1963 flood, with persistent rainfall over 24 hours but peak catchment hourly rainfall of ~8 mm/h, suggesting a similar catchment snowmelt input in 1963.

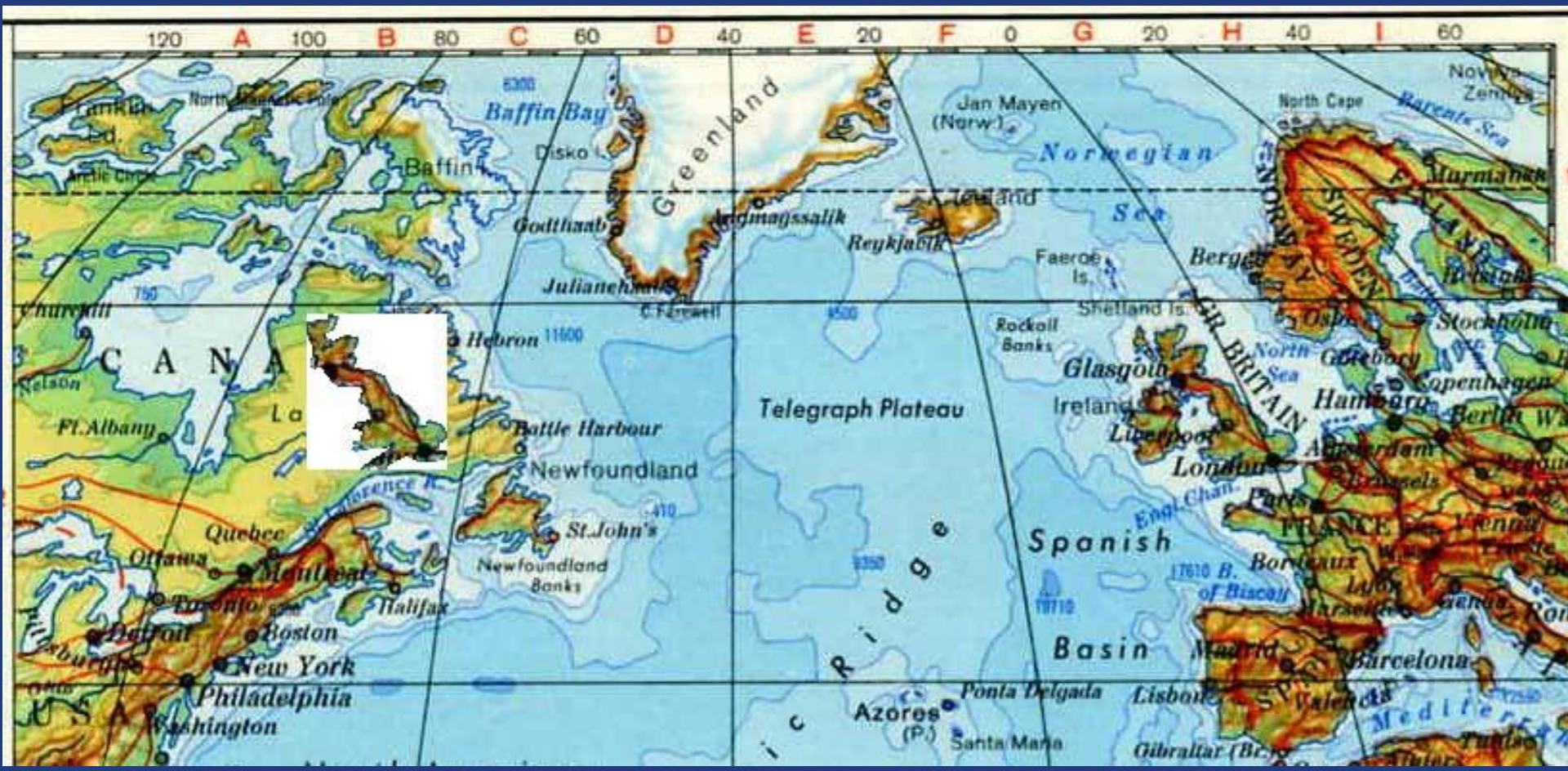
- Why is melt runoff rate so much greater than the observed point melt rate?
- Input rates to the catchment seem higher than can reasonably be assigned to the energy exchange
- Point melt rates may be transformed by storage in the snow pack to give a yield at the base of shorter duration and higher intensity – but still puzzling

Snowmelt runoff rates and current flood risk

- **So What?**
- Flood risk from snowmelt runoff depends both on rates of melt and more critically on initial snowpack water equivalent.
- With climate change the risk of snowpack water equivalent as occurred in 1963 is much reduced. (Periods of accumulation are broken by periods of melt).

- **What if?……**
- Future climate change includes the potential for serious decline of the Atlantic Ocean current that brings warm water to Britain from the tropics. (It has weakened by 15% since the middle of the last century).
- Without it, even with a warming world, winters in Britain could be more than 5^{o}C colder with greater risk of higher snow accumulation and rapid transition to summer warmth.

Britain is at the same latitude as Labrador Ungava!



Central Labrador Ungava 55ºN
January mean daily temperature - (-21.5 C)
3/4 months with mean temperature below 0 F (-18 C)
Duration of snow cover – November to mid-May

Hydrological Black Swans

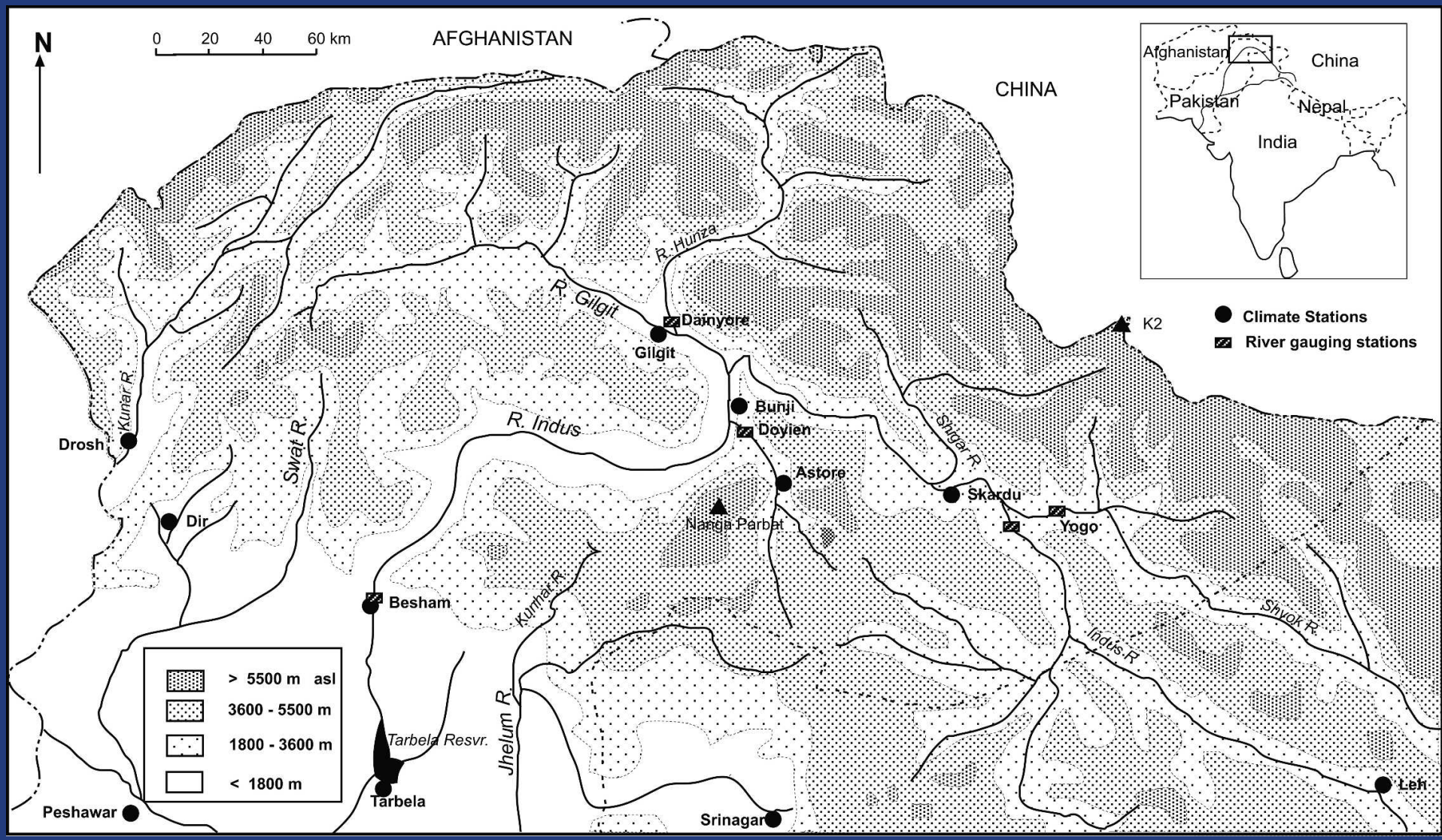
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3. Observation of very rapid (near instantaneous) rates of rise in upland rivers in Britain (walls of water).

Background

- I went as a Voluntary Service Overseas (VSO) volunteer to Pakistan in 2000 and was placed with GTZ (German Technical Development Agency) who were working for WAPDA (Water and Power Authority) and was asked to write a report on the impact of extreme floods on the development of hydropower schemes.
- I found that in order to carry out this study, a comprehensive review of the climate and hydrology of the Upper Indus was necessary (and had never been done before)
- Streamflow and climate data had been collected for several decades but its use seemed to await a suitable project.
- Through GTZ, WAPDA and the Pakistan Met Department, I acquired streamflow and climate (temperature and precipitation) data.
- I analysed climate and streamflow data and came to some surprising conclusions.
- On return to Britain I wrote these results up in a number of papers with Hayley Fowler at Newcastle University

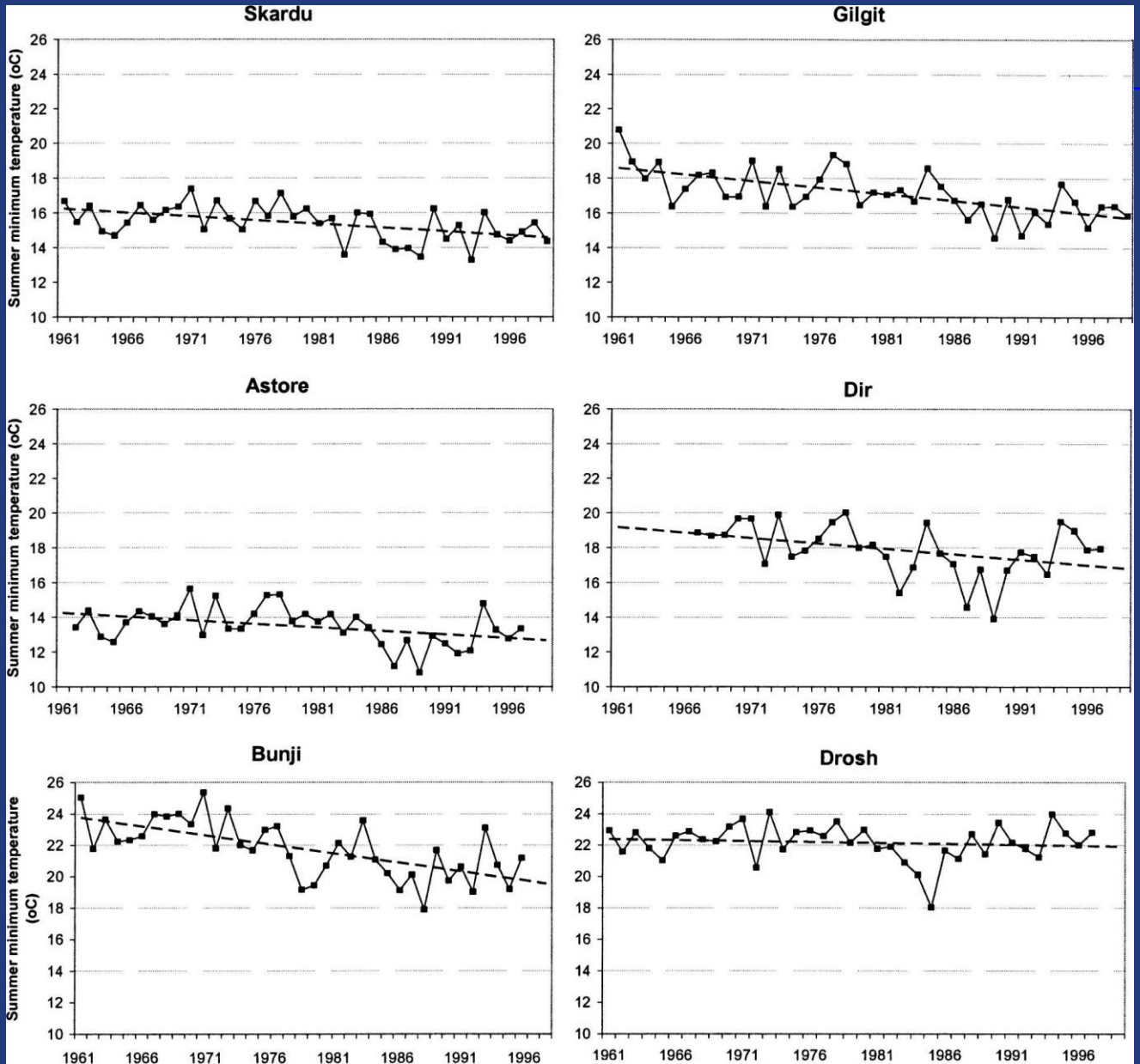
The Upper Indus Basin showing climate stations



Common patterns of climate change at Upper Indus climate stations 1960- 1999 (Fowler and Archer, J Climate 2006)

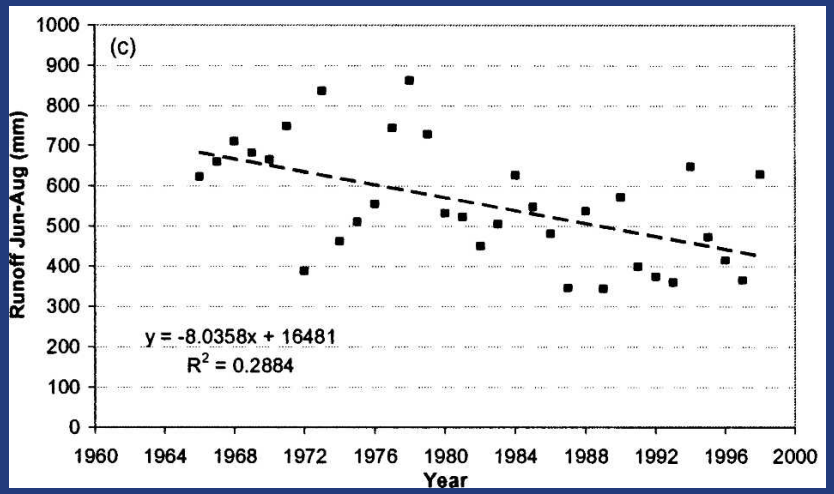
- 1) Decrease in summer mean temperature (seven of seven sites, four significant)
- 2) Decrease in summer minimum temperature (six of six sites, five significant)
- 3) Decrease in fall minimum temperature (six of six sites, four significant)
- 4) Increase in fall maximum temperature (four of sixsites, three significant)
- 5) Increase in winter mean temperature (five of seven sites, three significant)
- 6) Increase in winter maximum temperature (five of six sites, three significant)
- 7) Decrease in annual minimum temperature (six of six sites, four significant)
- 8) Increase in annual maximum temperature (four of six sites, two significant)
- 9) Increase in diurnal temperature range (DTR) at Skardu and Gilgit in all seasons

An example - Trend in summer minimum temperature



Hydrological impacts

- The hydrological and glaciological impact temperature change is highly dependent upon the season of the change. Summer cooling has a widespread impact at all elevations whereas effects of winter warming are restricted to lower elevations.
- These results are confirmed for the river Hunza where there is a significant downward trend in observed runoff for spring and summer of 46% and 35%, respectively, over the record period.



The high mountain tributaries of the Indus, Hunza and Shyok contribute more than 25% of the inflow to Tarbela Dam, which is the main controlling structure for the Indus Basin Irrigation System, one of the world's largest integrated irrigation networks.

- Temperatures recorded in valley climate stations are highly correlated with catchment runoff generated at higher elevations (River Hunza and Shyok)(Archer 2003).
- Glaciers in the Karakoram were reported as expanding and thickening (Hewitt 1998, 2005), consistent with the observed climatic changes. Karakoram glaciers offer a significant contrast with those in the eastern Himalayas

Publication response!

- The paper was first submitted for publication in J. Climate in April 2004
- After 6 months of waiting we were told the submission had been 'lost'.
- We resubmitted in 2005 but we received a rejection. We assumed this was because the reviewers could not conceive of a summer fall in temperature. (Indeed subsequently it was subsequently commandeered by some climate skeptics).
- We asked Phil Jones (UEA) for his opinion on the suitability of the paper for publication. He gave it his endorsement and we resubmitted.
- It was finally accepted and published in September 2006.
- At last count (July 2023) it had 550 citations.

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Background

- I was the flood warning duty officer at Northumbrian Water in July 1983 when I received a telephone message from a policeman to say that there was a ‘wall of water’ coming down the River Wear near Stanhope
- Though initially skeptical, I checked the flow record at Stanhope gauging station to find that the river rose 1.53 m in 15 minutes and from 0.76 m/s to 71 m/s. Anyone standing in the river would have little chance of escape.
- That incident started a 40 year interest in such events which, it seemed, hydrologists and hydraulic experts in Britain had previously ignored or erroneously attributed to failure of upstream blockages.
- In my recent chronology of flash floods in Britain, I found 289 such rapid rise events with no evidence whatever of upstream blockages.
- I have now been asked by reviewers to call these events ‘abrupt wave front floods’

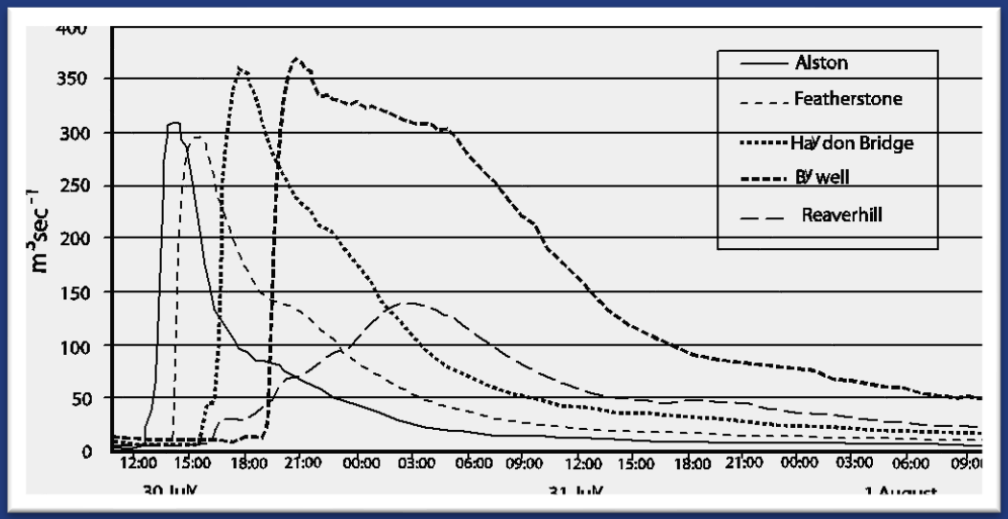
Why are abrupt wave front floods important?

- The focus of all flood risk analysis and forecasting has been on the magnitude and timing of the peak water level and flow.
- Peak water level is critical for the flooding of land and property but risk to life is more dependent on rate of rise in level and velocity.

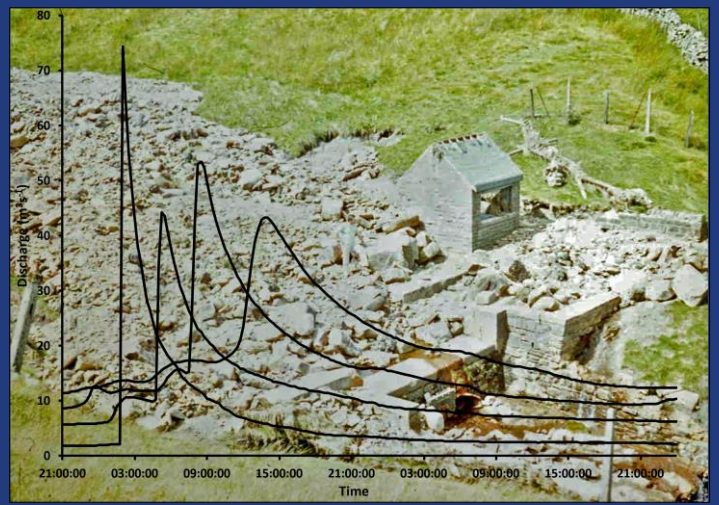
- **Examples of deaths by drowning in abrupt wave front floods:**
- 1. 22 Jul 1951 A boy was swept off steps and drowned at Bolam Bridge, Kirkby Stephen on the River Eden by a ‘wall of water’
- 2. 6 Jun 1982 A boy was drowned while swimming in the River Gelt a tributary of the Irthing/Eden by a ‘10 foot wall of water’.
- 3. Aug 1998 A couple were drowned on the River Wharfe on the second day of their honeymoon. An observer noted the river had risen by up to 5 feet instantly (Addingham GS 0.80m in 15 m)

Some problematic characteristics of abrupt wave front floods

- The wave front may steepen as it moves downstream and may incorporate the inflow from tributary streams (eg Tyne Jul 2002) 1.
- Rapid rise in level is accompanied by rapid increase in velocity. On the main River Tyne velocity of over 5 m/s has been measured.
- Especially on the source rivers the wave front carries a heavy load of sediment, often large boulders (eg. West Grain Beck, River Wear). 2.
- The wave front may also be accompanied by severe floating debris.
- The combination of the impulse of the wave front, sediment load and scour of the foundations can lead to bridge damage or destruction.



2.

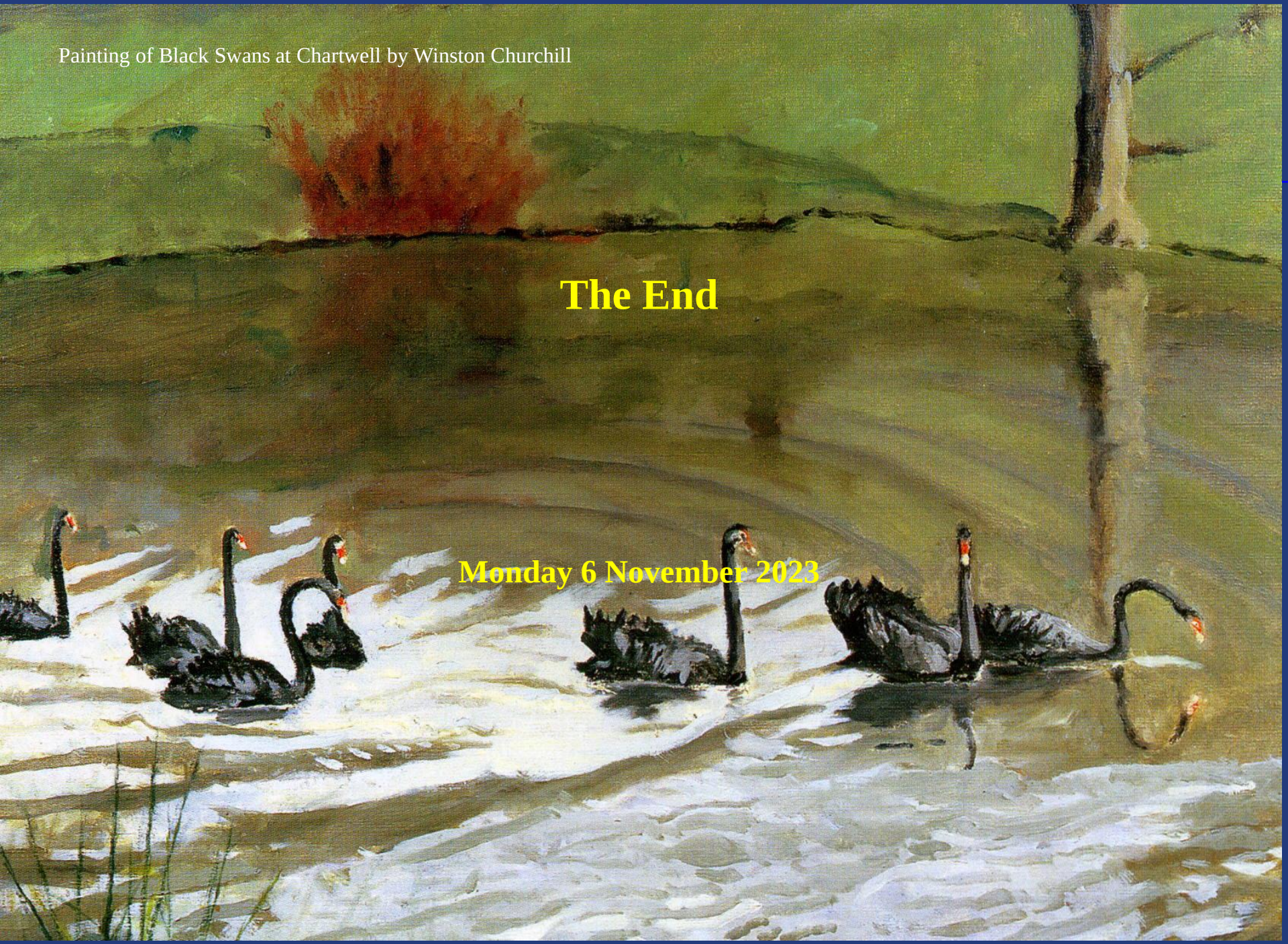


How to respond to Walls of water

- 1 . Rainfall generating such floods often cover a limited area on isolated upland catchments where ground level gauges are absent and rainfall radar uncertain at very high intensities.
- 2. An interim approach would be to identify and intercept such floods at an upstream point on the main stem and forecast their transmission downstream
- 3. Better monitoring: Currently level monitoring is at 15 minute intervals. To confirm the near-instantaneous rise reported by observers we need digital observation at 1 minute intervals on selected stations
- 4. Better modelling: Current hydrological models have not yet simulated near vertical rises (and may not be able to do so). But modelling of the rates of flood wave transmission downstream needs to be addressed.
- 5. Environment Agency needs to improve the science and practice with greater urgency.

Conclusions

- Don’t believe everything you have read or been taught even by eminent hydrologists.
- If your results don’t fit the model, don’t blame the data – but check them.
- Examine in detail the origins/ causes of the anomaly.
- Look for other examples of the phenomenon. In retrospect they may not be so unusual (cf walls of water)
- The ‘black swan’ you have encountered may be the most important discovery in your career.



Painting of Black Swans at Chartwell by Winston Churchill

The End

Monday 6 November 2023