

Contributing Paper

A Review of the Role of Dams and Flood Management

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Prepared for Thematic Review IV.4:
Assessment of Flood Control and Management Options

For further information see <http://www.dams.org/>

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World Commission on Dams

A Review of the Role of Dams in Flood Management

March 2000

Halcrow Water

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World Commission on Dams

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Contents Amendment Record

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1

Introduction

The World Commission on Dams (WCD) was established in May 1998, to undertake a global review of the development effectiveness of large dams, and to prepare guidelines for decision-making on future projects involving them. As part of this work, WCD is undertaking a thematic review on Assessment of Flood Control and Management Options.

This document is a contribution to the flood control thematic review, and addresses the role of dams in flood control. It has been prepared by Halcrow Water in accordance with Terms of Reference provided by WCD in February 2000.

The Terms of Reference are included at Appendix A. Essentially they require presentation of:

- a world-wide historical perspective of the role and operational experience of dams designed partially or exclusively for flood management, by reference to specific examples;
- lessons arising for the planning, design and operation of dams for flood management;
- policy criteria and guidelines for consideration in the planning process for such projects in the future, including their relationship with an overall flood management strategy.

The work has been undertaken by means of a wide-ranging literature review. It is thus constrained by the availability of published information on operational experience of individual dams.

The main body of this document comprises an overview of the use of dams for flood control, followed by 15 case studies of specific schemes which each address the dams setting and purpose(s), principles of operation, hydrological effects and flood control benefits and negative consequences. These case studies are followed by a summary of key findings.

Separate chapters follow on lessons arising and on policy criteria and guidelines.

2 Overview of the Use of Dams for Flood Control

2.1

Principles

In principle, dams are hydraulic barriers, which impound river flows to form reservoirs of water. The reservoirs can be drawn upon when such flows would otherwise be low, and are replenished by higher flows off the catchment upstream. Dams may be formed by earth or rockfill embankments, on various types of concrete structure. They normally include:

- a valved bottom outlet, to enable controlled lowering/emptying of the reservoir for maintenance or repairs;
- reservoir draw-off works, to release compensation water to the river downstream and to allow water to be taken from the reservoir for some specific purpose(s) such as water supply, hydropower generation, irrigation or regulation of river flows to support abstractions further downstream;
- a spillway (overflow) to allow safe passage of floodwater when the reservoir is full.

The effect of a dam on a flood from the catchment upstream depends on a number of factors:

- the available storage in the reservoir at the time of the flood;
- the nature of the flood;
- spillway configuration;
- the areal extent of the reservoir.

For the purposes of this discussion, a flood is defined as an event during which inflow to the reservoir significantly exceeds the draw from it for its intended purpose (eg irrigation supply).

If the reservoir is drawn down when the flood occurs, and the available storage below spillway level can accommodate its full volume, no spill will occur. In these circumstances, the flood upstream of the dam will have no effect on river flows

downstream. Floods which enter a full reservoir (or continue after the reservoir is replenished to spill level) “overflow” the dam via the spillway.

In the case of ungated spillways, the reservoir will surcharge, increasing the head and consequently the discharge over the spillway crest until equilibrium is reached with the flood inflow. Generally this equilibrium is likely to be achieved when the inflow flood has passed its peak and is receding, as shown on Figure 1(a). The peak outflow will thus be less than peak inflow. The quantum of this attenuation effect depends upon the relationship between flood volume and reservoir surface area, these being the drivers for flood rise in the reservoir.

In the case of gated spillways, gates are opened progressively to release water in response to flood rise. Generally the rate of opening is set to mimic the rising limits of the inflow hydrograph (see Figure 1b). Flood rise can be controlled within very close limits, so the attenuation effect on larger floods can be negligible if the reservoir is already full at their onset. A governing principle in the design and operation of gated spillways is that they should not lead to an increase in flood flow magnitude downstream of the dam.

Other types of spillway such as syphons are relatively rare and have not been identified in connection with the flood control dam case studies.

It can be seen that a reservoir’s flood attenuation capacity is greater if it is drawn down at onset. This is easier to arrange if the only purpose of the dam is to attenuate floods. If the dam is also intended to serve other purposes which depend upon an abundant supply of water being stored behind it at certain times of year, conflicts of interest can arise regarding level management in the reservoir. These may lead to compromise by which a reduced flood attenuation performance is accepted.

Because reservoirs still the water flowing into them, water-borne sediment from the catchment upstream drops out and settles on the reservoir bed; this effect is more marked towards the upstream end, where most flow energy is dissipated. In the more critical cases of a flood entering an already-full reservoir, such sedimentation is relevant to flood attenuation only insofar as it reduces the reservoir surface area at spill level. In the case of a drawn-down reservoir, sedimentation will reduce the storage available to absorb floods before spilling.

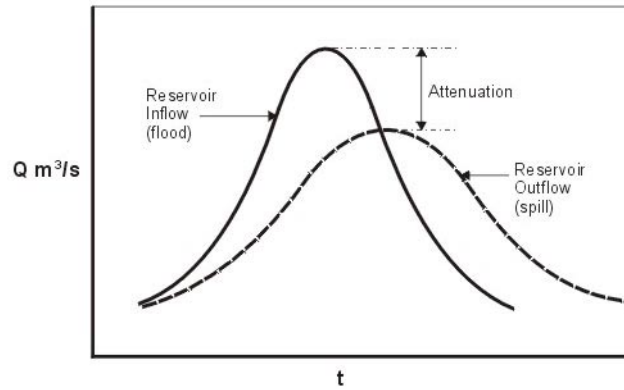


Figure 1a *Flood attenuation with free overfall spillway reservoir full at flood onset*

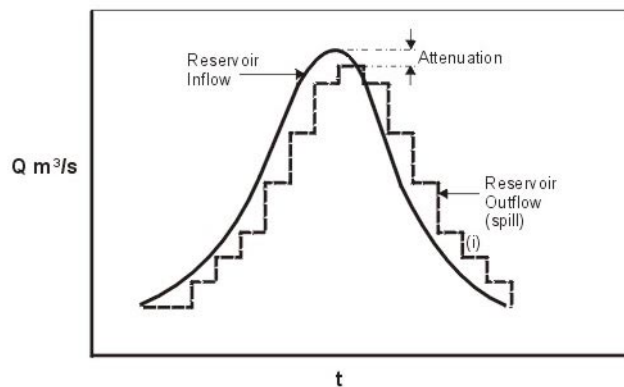


Figure 1b *Gated spillway: More attenuation can be achieved if gates opened ahead of inflow hydrograph rise, or if reservoir is drawn down at flood onset so that some of flood volume can be stored*

It should also be borne in mind that spillwater has a negligible sediment load (and other quality differences compared with influent water). Floods discharged downstream of a dam are thus more erosive than would have been the case before it was built.

In summary, the effect of a dam and reservoir on a river's flood hydrology is a function of dam design and reservoir characteristics as well as of the nature of influent floods from the catchment upstream. It is very much an event and site-specific phenomenon.

2.2

Context

Flood control is but one of a range of purposes for which a dam may be built. The important point to note here is that whereas other purposes generate revenue (through water sales for supply or irrigation, or electricity sales in the case of hydropower schemes), flood control does not. Rather, it reduces expenditure on other forms of flood mitigation and reparation of flood damage. The economics thus hinge upon expenditure avoided at some future date, rather than revenue generated. As flooding is always unpredictable, and severe flooding infrequent, the benefit stream accruing from the flood protection function is much less certain than for other functions for dams. This means that dams intended solely for flood protection are likely to be more difficult to justify economically, unless the assets protected are of particularly high value.

Just as dams perform other functions besides flood control, there are means other than dams for reducing the risk of flood damage. Upstream washlands, development control, warning systems and other non-structural approaches are also all valid techniques. Ideally, the flood mitigation strategy adopted in a particular catchment should be an optimal integration of the most appropriate techniques to afford the required standard of protection, taking into account the hydrological, land use, settlement and environmental characteristics of the valley.

2.3

Provenance

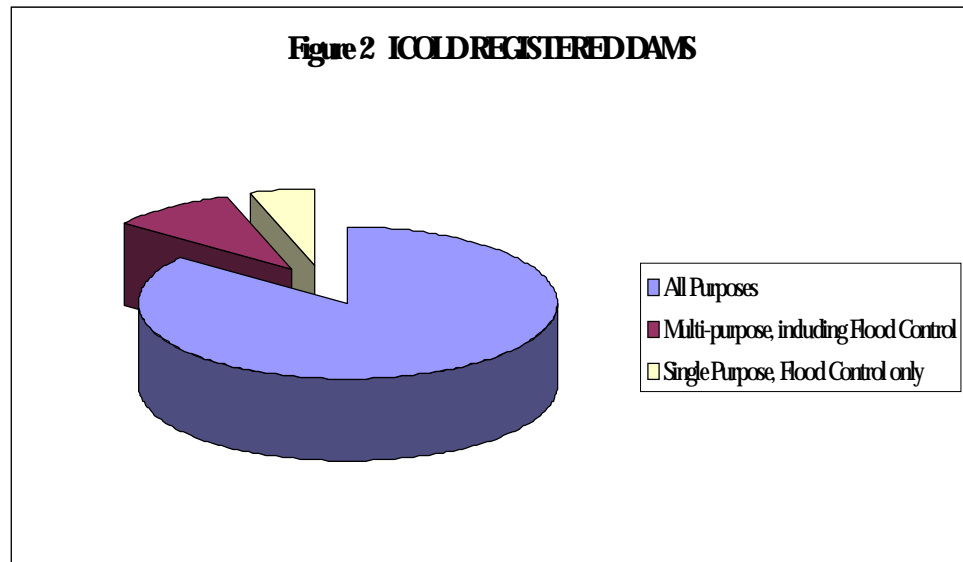
The World Register of Dams 1998, published by ICOLD, lists details of some 25400 dams that have been registered by member countries as compliant with ICOLD's criteria for large dams (they are, that the dam is greater than 15m high or that the dam is in the range 5-15m high and impounds a reservoir of more than 3 million cubic metres storage capacity).

The ICOLD register is known to be incomplete. Some countries (such as the Philippines) are not listed; others have differing criteria for large dams (Japan, for example, identifies large dams as 30m + high), and a few such as China have many more dams than are registered.

Of the 25400 dams registered by ICOLD:

- some 4400 are operated either completely or partially for flood control purposes;
- some 1500 are operated solely for flood control purposes.

The above breakdown is illustrated in Figure 2.



Countries which each have more than 10 registered dams with an exclusive or partial flood control function are listed in Table 1 and account for some 95% of the approximate 4400 total registered in these categories. In terms of global distribution:

- some 2100 (nearly half) of the registered dams with a flood control function are in the USA;
- China, Japan and Korea between them have nearly 1100 such dams;
- Europe is also well represented, with 535 such dams spread among 12 countries;
- Australia is poorly represented and there are no countries in the Indian sub-continent or in sub-Saharan Africa with more than 10 registered flood control dams;
- of the USA flood control function registered dams, nearly half are exclusively for that purpose;
- elsewhere, some 25% of registered flood control dams are exclusively for that purpose;
- conspicuous outliers for this trend are Venezuela, Turkey, China, Korea, Austria, Poland and Slovakia, where exclusively flood control dams are rare, and Brazil, Saudi Arabia, Spain and Yugoslavia where the converse applies.

In fact, none of the Indian registered dams has a flood control function. It is understood that India has not particularly favoured flood control by regulation, preferring to use levees.

Table 1 Summary of Countries with more than 10 Dams Whose Purpose Includes Flood Control (Source: ICOLD World Register of Dams, 1998)

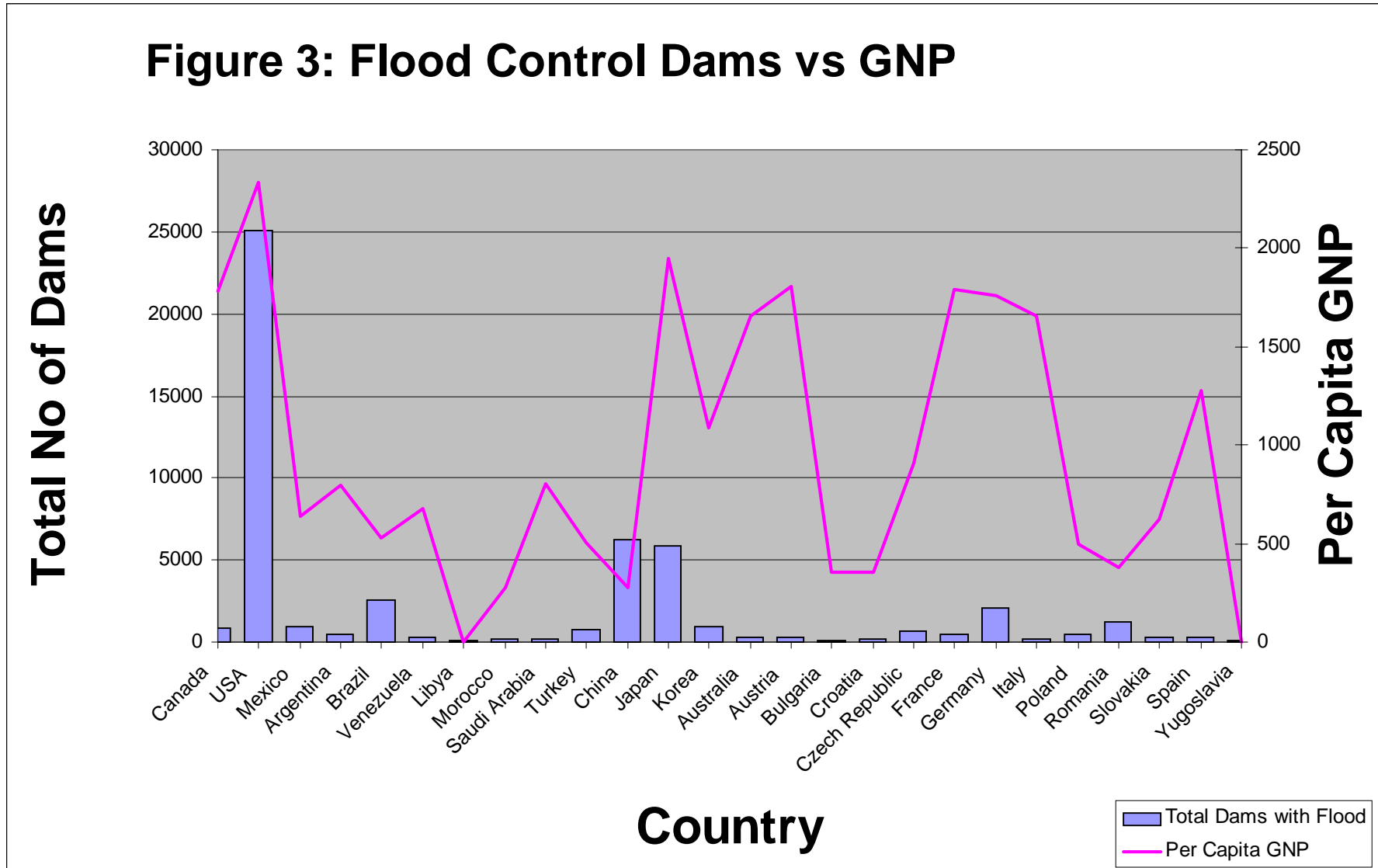
Region	Country	Single Purpose Flood Control Dams (No)	Multi-Purpose Dams incl Flood Control
America N	Canada	21	53
	USA	988	1099
America Central	Mexico	20	61
America S	Argentina	5	35
	Brazil	168	44
	Venezuela	0	25
Africa North	Libya	2	8
	Morocco	5	9
Africa Sub-Sahara			
Asia – Middle East	Saudi Arabia	13	0
	Turkey	2	65
Asia – Central			
Asia – Indian SC			
Asia – Far East	China	25	488
Australasia	Australia	9	13
Europe	Austria	1	22
	Bulgaria	3	8

Region	Country	Single Purpose Flood Control Dams (No)	Multi-Purpose Dams incl Flood Control
	Croatia	4	15
	Czech Republic	7	48
	France	11	32
	Germany	57	117
	Italy	3	10
	Poland	0	36
	Romania	24	75
	Slovakia	0	25
	Spain	17	9
	Yugoslavia	8	3

The large numbers of flood control dams in USA, Japan and Europe, coupled with earlier observations on the value of land protected as an economic driver for such projects, led to an examination of flood control dam numbers versus gross national product (GNP). The result is presented in Figure 3; however no clear correlation is apparent.

It is emphasised that the above analysis is based on the World Register of Dams, which is an incomplete record. The analysis may thus be as much a reflection of the enthusiasm within individual countries to register their dams with ICOLD as an indication of the world distribution of dams for flood control.

Figure 3: Flood Control Dams vs GNP



3

Case Studies

3.1

General

Information on specific dams set out below has been derived from published technical papers and magazine/newspaper articles. It is the nature such authorship that the subject matter addressed, its technical content and the underlying purpose of the paper vary enormously. Inevitably, this varying level of available detail is carried through to the case study information presented below.

Many papers exist on the design and construction of dams, but rather fewer on their in-service performance in relation to the intention of their development. Technical papers on operational issues are more often triggered by problems experienced and overcome than by performance as planned. There is a wealth of articles by dam enthusiasts and dam sceptics, which are often selective in their choice of evidence.

As noted previously, the costing of flood damage averted is an inexact science; net economic benefits accruing from reduced expenditure on flood protection works, less increased expenditure on scour protection against more erosive waters downstream, is also an area where robust data are scarce. What emerges is a collection of “headline” schemes, some of which may be deemed successful in some measure, others unsuccessful in some (probably other) measure. There remains a “silent majority” of projects beyond the headline schemes whose benefits and adverse consequences are unpublished.

The case studies that follow obviously relate to “headline” schemes, chosen for their diversity. These form the basis of inferences drawn about lessons and guidelines for the future - which may not relate so well to the “silent majority” schemes.

The above discussion highlights the need for post-project appraisal to be undertaken for at least a sample of established major schemes (and all future ones that are implemented). Such appraisal should be directed specifically at in-service achievement of development objectives, and should be carried out according to a standard methodology. Findings should be placed in the public domain.

3.2

Aswan High Dam, Egypt (may be re-ordered in final text)

3.2.1

Setting and Purpose

Aswan High Dam is a 111m high rockfill dam across the River Nile in Southern Egypt, with a gated emergency spillway. Lake Nasser, the reservoir behind it, has a storage volume of 162 000 Mm³ (million cubic metres), and a surface area of 6,540 km² (square kilometres) (2). The upstream end of the main limb of the reservoir extends into Northern Sudan (3). The dam was completed in 1970, and the intended purposes of the project are irrigation, hydropower generation and flood control (2).

3.2.2

Principles of Operation

When the Aswan High Dam Scheme was planned, its reservoir storage was divided into 3 portions (4):

- dead storage (up to water surface elevation 147m): a capacity of 30 km³ (cubic kilometres) to accommodate silt;
- live storage (up to normal operating water surface elevation of 175m): a capacity of 90 km³;
- flood storage (up to full storage water surface elevation of 183m): a capacity of 44 km³.

The flood period at the reservoir site begins in July and continues for about seven months, with its peak in August or September (4). The operating policy as set out in 1973 (4) was that spare capacity for flood control should be ready to reserve any exceptional high flood that might occur, without being forced to release it downstream. Therefore, if the reservoir level were high, it should be emptied to level 176.2m before 1st July, and to 175m before 1st August. It was noted in 1973 that in some years, “waste” releases may need to be made in July or even in June; the comment was made that better flood forecasting data in relation to actual Ethiopian plateau rainfall would enable closer management of reservoir water levels for flood storage (4).

The average floods of typical years can be passed by releasing only irrigation water duties, without waste of water. High floods after reservoir filling are characterised by early (pre-July) arrival at Aswan, and are accommodated by early release of water as above (4).

It is not clear from the references consulted whether:

- reservoir levels were to continue to be held down after 1st August. It is inferred that they were not, so that reservoir levels were allowed to recover towards full storage level after that date;
- the above operating rules have been changed in light of operational experience since 1973.

3.2.3

Hydrological Effects

Based on 92 years of flow record (1869 - 1961), the following “pre-scheme” data were presented in 1973 (4):

- maximum recorded discharges at Aswan: 13,200m³/s (1878);
- yearly average maximum discharge for period: 9,880m³/s;
- inferred 1 in 1000 year flood peak discharge: 15,100m³/s;
- inferred in 10,000 years flood peak discharge 17,000m³/s;
- dry year maximum discharge (estimated from graph): 5,000m³/s (1913);
- average annual runoff 90.9 km³ (range for period of record 41.8 km³ - 134 km³).

The annual runoff figures may be compared with reservoir storage of 90 km³ (live) + 44 km³ (flood) = 134 km³ (see above). It follows that the reservoir’s emergency spillway provision (capable of discharging 5,000 m³/s at a storage level of 183 m) will seldom be called upon.

It is inferred from graphs presented in 1973 (4) that discharges downstream from the dam were planned to be of the order of:

- 6,300 m³/s in an exceptional year such as 1878;
- 2,500 m³/s in average years.

Peak flows downstream would thus be reduced by 25% - 35% of those prevailing before development. This lower flow would, however, be sustained for considerably longer periods than the pre-scheme flood peaks.

3.2.4

Flood Control Benefits

The Aswan High Dam (AHD) protects both Upper Egypt - where traditionally a system of basin irrigation was practised - and the Delta area, irrigated by means of canals and drains.

During high floods, barriers were usually overtopped and suffered some damage. Disastrous breaches took place along the river banks (in the Delta area) causing great loss of life, cattle and crops (5). Flood protection works were however developed before AHD, so that the 1946 flood passed without any breaching of the Nile banks. However, since AHD it has been possible to drop completely the fight against high floods in Egypt (5).

Unfortunately, we have been unable to quantify the savings due to flood control by AHD accruing from either losses avoided or investment on protection works saved.

The dam also affords protection against low floods - that is, inability to irrigate large tracts of land during years when flood flows fall well below average. The water stored in 1964 and 1975 rescued the country from the (low) floods of 1965, 1966, 1968 and the low series that began in 1980 - for example 1984, which saw the lowest flood for 70 year (5) and presumably would have led to a severe crop production shortfall in the absence of AHD.

The more dependable availability of water associated with flood control by AHD has secured flexibility in agricultural planning and cropping patterns; as a result, the cropped area has increased to about 5.6 Mha (million hectares - 14 million acres) compared with some 3.7 Mha (9.3 million acres) in 1952 (6). Furthermore, productivity per hectare has also increased; for example, the change to perennial irrigation has made it possible to raise two or more crops/year in the former basin irrigation areas, compared with only one crop/year previously (6).

Other flood - control related benefits from AHD include hydropower for electrification of factories, irrigation/drainage pumping stations and some 4,500 villages, and increased navigation/tourism in the River Nile as far upstream as the dam (6).

Whilst quantitative information on the benefits of AHD to the Egyptian economy has not been identified, it is clear that the flood control it affords provides

significant advantages to the county in terms of damage avoidance, dependable food production, employment creation and standard of living.

3.2.5

Flood Control Negative Consequences

A number of adverse effects of AHD are set out in various publications. Chief among them from a flood control perspective area:

- soil fertility changes;
- downstream scour/degradation;
- Mediterranean sea shore erosion;
- effect on Mediterranean fisheries.

Historically, flood-borne silts in Nile derived irrigation water were a rich source of soil nutrients at least in the basin - fed areas (7). The post AHD shortfall is being made up by increased use of artificial fertilisers (6, 7), although the lack of nitrogen in Nile sediments means artificial fertiliser use pre-dates AHD implementation (7).

Of more concern is the persistent waterlogging and subsequent soil salinisation which arise from AHD - attributable to elevated groundwater levels and which drainage projects have not overcome. Agricultural productivity per acre has fallen in recent years due to the high salt content of the soil, although this is more than offset by the increased number of crops raised per year (7).

The reduction of suspended matter in the river downstream of the reservoir has led to increased erosion. This is evident in the form of local scour at meander points. The Egyptian Ministry of Irrigation has a scour monitoring and review programme, and the government considers the problem can be easily controlled (7). It has been suggested that the degradation process is approaching a steady state for the no-flood conditions (5). For increased protection against flood discharges which could be very damaging in terms of scour, a 22km long canal linking Lake Nasser to the Toshka depression was constructed in 1980; this comes into operation when the lake level reaches 178m, and has a capacity of up to 250×10^6 m³/d (2900 m³/s) (5).

Coastal erosion along the Mediterranean is a serious matter; many agriculturally important areas are threatened with inundation by the sea, and need protection (7). Although the Northern Delta has lost land to the Mediterranean since recorded time (sea level has risen about 2m since Roman times, and the Delta seems to be subsiding at a similar rate), entrapment of sediment at AHD has caused an

acceleration of the erosion (7). The main summer resorts along the Mediterranean are subject to gradual deterioration, and economic losses have already been reached in areas near Damietta and Rosetta (5).

A primary concern in relation to seawater intrusion is the need to safeguard groundwater quality. Groundwater supplies used for both drinking and irrigation lie close to the surface, and their contamination by seawater would further increase reliance on the Nile (7).

UNDP has assisted a study of the shore erosion problem, and some remedial works were executed. The Shore Protection Agency was established in 1981 to study and deal with the coastal erosion problem as a socio-economic issue; most of the eroded areas have very successful protection works (6).

Post AHD, Sardinella catches in the Mediterranean off the Delta have dropped from 15,000 tonnes in 1964 to almost nil in 1985 (5). Some 24,000t of fish are harvested annually from Lake Nasser; however, unrefrigerated rail transport from there to the main markets in Northern Egypt was noted in 1986 as a contributory cause of high wastage of this resource.

Perhaps the final word on AHD in this review should be from Marc Lavergne's paper "The Seven Deadly Sins of Egypt's Aswan High Dam" (8). He proposes a solution to the problems associated with the scheme, whereby the storage should be reduced to that necessary to meet the more limited objective of protecting Egypt from the dangers of a high flood. This implies a recognition in principle of the value of dams for flood protection, even though that author may take issue with the level of protection to be provided.

3.3

3.3.1

South Africa : Vaal, Hartbeespoort and Gatiep Dams

Setting and Purpose

The Vaal Dam is a 65m high gravity dam across the Vaal River, with a gated spillway of 25,000 m³/s capacity. Its 2,330 Mm³ reservoir has a 292 km² surface area. The dam was built in 1938 and has been raised by 6m in 1956 and by a further 3m in 1986. Its intended purposes are irrigation and water supply (1)

The Hartbeespoort Dam is a 59m high arch dam across the Crocodile River, with a 193 Mm³ reservoir of 21km² area. Originally completed in 1925, the dam was raised by 2.4m in 1971, when the spillway capacity was increased to 4110 m³/s. It is used for irrigation (1).

The Vaal and Hartbeespoort dams are included here in light of data contained in Pitman and Basson's paper on the operation of reservoirs for flood control (13).

The Gariep Dam is an 88m arch dam across the Orange River, with a combined gated and free overfall spillway of 20,450 m³/s capacity. Its 5674 Mm³ reservoir has a surface area of 360km², and the dam was completed in 1971. Its stated purposes according to the World Register of Dams (1) are irrigation, water supply and hydropower generation; however as part of the Orange River project, it is the subject of a WCD Pilot Case Study. Documentation connected with this shows a predicted (but uncostered) scheme benefit of the Gariep and Van der Kloof dams as reducing damaging floods in the Orange River downstream of Gariep by 50% (14).

3.3.2

Principles of Operation

There is no suggestion in Pitman and Basson's paper of a practice for maintaining a 'flood bank' of unoccupied reservoir storage by operating the Vaal Dam at a reduced level at certain times of year. In the case of Gariep Dam, it is noted in the WCD scoping paper that reservoir levels were not allowed to exceed 80% storage capacity until recent years.

3.3.3

Hydrological Effects

Pitman and Basson put forward an operating regime for Vaal Dam whereby flood forecasting techniques are used to optimise spillway gate operation to minimise downstream flood damage. The Vaal system would be well suited to such an approach, as the reservoir catchment is fairly flat away from its steep upper reaches, so that typical rise times of major flood hydrographs are of the order of five days.

The method was applied to an historic Vaal flood that occurred in 1975, and it is demonstrated in the paper that pre-emptive gate operation in response to flood forecasting would provide sufficient buffer storage to reduce the observed peak daily inflow of about 3,500 m³/s to a peak outflow of about 2600m³/s. In practice, gate operation in 1975 lagged behind the inflow hydrograph, so that peak discharge over the dam exceeded peak day inflow by about 15m³/s.

As a comparator, the small, steep basin of the Hartbeespoort dam, which is subject to intense thunder storms and therefore generates flash floods, was also examined by Pitman and Basson. Here the catchment response time is too short for accurate flood forecasting, and development of buffer storage by pre-release of water during the rising stage of the inflow hydrograph (as at Vaal) was found seldom to

achieve satisfactory attenuation. Instead, an economically justifiable level of flood attenuation was found to be feasible by lowering the reservoir level at the start of the flood season, as at Aswan.

Turning to the Orange River, the practice of not allowing reservoir levels to exceed 80% of storage capacity was discontinued at Gariep and Vanderkloof Dams because it was found that the reservoirs fill up before major inflow floods reach their peaks; the dams were found not to provide significant flood attenuation (14).

Given the slow build-up of major floods it is not clear from the WCD paper whether flood forecasting and changes to gate operation at Gariep Dam, as proposed by Pitman and Basson for Vaal Dam, would afford a measure of flood attenuation in the Orange River. This option is not applicable at Vanderkloof Dam, which has an ungated spillway.

3.3.4

Flood Control Benefits

In practice, no flood potential benefits are currently achieved by the South African dams mentioned above. In theory, following Pitman and Basson's approaches at Vaal and Hartbeespoort Dams could lead to annual net economic benefits of up to £70,000 and £50,000 respectively at 1980 prices (approximately £130,000 and £90,000 at today's prices, using UK inflation indices).

3.3.5

Flood Control Negative Consequences

Not applicable.

3.4

Turkey: Ceyhan Aslantis Project

3.4.1

Setting and Purpose

The Ceyhan Aslantis Project (CAP) is a catchment development scheme in the Ceyhan River Basin. A principal feature of the scheme is the Aslantis Dam, a 95m high earthfill structure with a 13,800 m³/s capacity gated spillway. The capacity of the reservoir is 1150 Mm³, and its surface area is 49km². The dam was completed in 1984 and its intended purposes are irrigation, flood control and hydropower generation (1).

The CAP is the subject of a WCD case study, and information on its flood control performance has been drawn from WCD's full draft report (17).

3.4.2

Principles of Operation

Whilst the dam itself affords some attenuation of floods, the major part of CAP flood protection investment has been on levee provision to increase the river channel capacity downstream of the dam (17). The upper 9m of the water level at the dam is reserved for flood control, and further dams exist upstream.

3.4.3

Hydrological Effects

Floodwaters in the Lower Ceyhan derive from either sub-basin, high-intensity storms or main basin, large area storms combined with snowmelt. Peak flows are also affected by incoming tributary floods whose peaks can coincide with those in the main river at critical locations. Because of the tributary flooding effects, the impact of flood attenuation at the dam does not extend far downstream. Indeed, alleviation works in some tributaries have increased peak flows entering the Ceyhan, exacerbating main channel flooding in some instances (17) (this problem is not related to the dam).

Observed floods since building the dam have occurred in the November - December period, whereas historically flooding occurred March - June. This further demonstrates that sub-basin, high-intensity storm based flooding continues whereas that associated with combined storm and snowmelt is better controlled, following dam construction (17).

The only flood for which reservoir inflow and outflow data are presented occurred in March 1996, when a 750m³/s inflow was attenuated to 231m³/s. However, flooding downstream occurred due to contributions from uncontrolled downstream tributaries, which increased river discharge to 1370 m³/s (16).

The WCD report notes that the nature of recent flooding in the Ceyhan basin shows that the Aslantis Dam is fulfilling its flood protection purpose (16).

3.4.4

Flood Control Benefits

Floods in 1980 and 1984, which caused the loss of 21,500 ha and 2974 ha of crops respectively, have led to an IRR computation of 13.6% for the separately identifiable flood control costs of CAP. Combined snowmelt/rainstorm floods occurred on five occasions in the ten years preceding dam construction, inundating 97,273 ha. In the fifteen years since the dam was built, only two such floods have occurred, inundating 16,579 ha (17).

3.4.5

Flood Control Negative Effects

There is reference in the WCD report to a flood caused by a gate failure at the dam, although details are not given. The identified potential for increased salinisation in the estuary has apparently not occurred (17).

An unforeseen cost was incurred when pumping facilities were installed to alleviate flooding in a tributary due to backwater effects from the main rivers (17). It is not clear whether this problem is attributable primarily to operation of the reservoir or to the in-channel flood protection works.

3.5

China: Flood Management on the Yellow River

3.5.1

Background

Although the World Register provides details of only 1853 dams in China, it notes that the country has declared some 24671 large dams in operation (1). Of the 1853, 513 are shown as being used exclusively or partially for flood control (see Section 2.3). China's commitment to dams is demonstrated both by the number of over 1600 developed since 1949, and the scale of their principal current project, the Three Gorges Dam (TGD) on the River Yangtze. TGD has been the subject of much international debate, but is not discussed here as it is not due to be commissioned for some years, and its performance in relation to expectation can only be judged some time after that.

China's Yellow River has a long history of channel changes and disastrous floods in its lower reaches, and is thus also known as "China's Sorrow". Since 1947 a concerted effort has been made to manage the river through construction of levees, flood control dams and off-stream retention basins, producing a situation where disasters of the past are largely forgotten.

However, the very high sediment load carried by the river, and the consequent bed deposition that occurs in the lower reaches, mean that levees continually have to be raised to keep flow within the designated channels. It is recorded as having broken through its levees 1593 times, with 26 major course changes, in 2550 years. This equates to two breaches every 3 years, and one course change per century, on average (15).

The great plains through which the river flows have always been densely populated, so that levee failures have historically been disastrous. Some 340,000 perished around Kai Feng in 1642, and an attempt by the nationalist government to thwart the Japanese invasion in 1938 by breaching the Yellow River levee at

Huayuankou inundated 45,000km² of land, drowned 890,000 inhabitants and failed in its military objective. The river course was not re-established for another 9 years; meanwhile 44 towns and cities were inundated as the river course shifted, and 12.5 million people were affected (15).

Sustained effort at levee maintenance and other flood protection works precluded significant breaches between 1947 and at least 1992. However, confinement of the river between levees built in the period since 1855 has raised the bed by some 10m due to sediment deposition, so that the river is now perched high above the surrounding floodplains (15). Today levees shield 120,000km²; some 7.3 Mha of farmland and 78 million people are exposed to possible devastations.

3.5.2

Use of Flood Control Dams

The first significant flood control dam on the Yellow River was commissioned in 1960 at Sanmenxia. In the following 18 months, 1.7km³ of sediment (43% of total storage capacity) was deposited in the reservoir. The resulting enhanced backwater effect on the Weike tributary upstream introduced a flooding threat to Xi'an, China's ancient capital. The dam has subsequently been rebuilt twice and undergone operational changes to help overcome the sedimentation problem; these changes have also greatly reduced its effective flood storage capacity (15).

(Note: the above data do not equate with the reservoir capacity of 35.4km³ quoted for Sanmenxia in the World Register (1)).

Another eight dams have been built in the Yellow River Basin, of which two were demolished because of sedimentation problems. Another two - on the Yihe and Luohe tributaries - have a combined flood storage capacity of 1.7km³ (15).

Subsequently, it has been shown that many historic floods were generated downstream of Sanmenxia, and that larger storms there can produce extraordinary floods which are "outside the control of large dams". Even so, construction of a new dam on the Yellow River at Xiaolangdi has commenced and is scheduled for completion in 2002 (15,1). It is intended for flood control, irrigation, water supply and hydropower generation; reservoir storage capacity will be 12.7km³ (1).

Major multipurpose dams such as Sanmenxia, Liujiaxia and Longyangxia now greatly reduce the risk of flood on the Yellow River (15a). In addition to levees and large dams, the Yellow River flood control armoury includes some 200 off-river retention basins, into which flows can be diverted. One of these has a capacity of

3km³ and is frequently used, despite having to evacuate quickly some 250,000 people living within its confines and potentially suffers crop losses on its 34,000 ha of farmland. The second has a population of some 1.5 million, 160,000 ha of good farmland and an oilfield within its confines, and so had not been used up until 1992 (15).

3.5.3 *Benefits of Flood Control*

These may be inferred from the scale of population and farmland at risk.

3.5.4 *Flood Control Negative Consequences*

The sedimentation problems referred to above are the major adverse impact, which over time reduce the effectiveness of all flood control measures on the Yellow River.

3.6 *China: Flood Control by Yangtze Basin Dams in 1998*

3.6.1 *Back Ground*

In 1998, the Yangtze suffered its worst flooding in terms of flow volumes since 1954. In terms of river stage, flood levels reached in 1998 were higher than in 1954 due to various natural and man made factors (16).

The structural flood control system developed in the Yangtze basin since 1947 played a significant role in the response to the 1998 event, and delivered great benefits in terms of reduced flood losses. The system comprises levees and embankments, reservoirs, diversion works, river training and water and soil conservation measures (16).

3.6.2 *Contribution of Reservoirs to Flood Control*

The flood attenuation performance of dams on the Yangtze, as presented by Daoxi and Siping to the ICOLD 1999 annual meeting in Turkey, is summarised in Table 2 below:

Ref	Dam	Date	Inflow to Reservoir m ³ /s	Outflow m ³ /s	Attenuation m ³ /s	Downstream Stage Reduction (m)	Remarks
1	Geheyang	16/8/98	8200	4000	4200		Peak
1	Geheyang	16/8/98			3700	0.19 at Shashi	8hr average
2	Gezhouba	16/8/98			1900	Addnl 0.08 at Shashi	Peak
Note: Alleviation effect of 1 of 2 did not extend downstream to Jianli							
3	Fengtang))))		
4	Wuqianxi) 23/7/00) 34000) 23300) 10700		Peak

5	Zhexi	23/7/00	7870	1150	6720		Peak
6	Jiangya	23/7/00			2000		Peak
Note: Dams 3-6 stored 2.84km ³ of flood water in period 20-27 July, and reduced stage at Qilisham by about 0.3m. However, they had little impact on the later flood maximum in August.							
7	Danjiangkou		18300		1500	0.1m at Hankou	
Note: Dam 7 was surcharged over the period 10-31 August to retain 3.4km ³ of flood volume above the normal flood season limiting level.							

It is noted that different reservoirs fulfil different functions in helping to control Yangtze floods, according to their location in the basin can cut flood peaks, and others can retain flood volumes; however many can hardly play any role in flood control (16).

In the Jin jiang reach, flood peaks are relatively sharp and thin. Attenuation or retention of tributary floods to reduce the risk of peak coincidence in the main stream is thus feasible. Around Chenglingji, however, the flood composition is more complex and processes are relatively flat, so flow retention in tributaries is valuable (16).

Under normal circumstances, only Geheyan Dam has reserved flood storage for controlling peak flows in the main stream. It is posited that greater reserve flood storage provision in the Yangtze basin would be useful (16).

3.7

Honduras: El Cajon Dam

3.7.1

Setting and Purpose

El Cajon is a 234 m high arch dam across the Comayagua River in North Western Honduras. It has a combined gated/free discharge spillway, of 5900m³/s capacity. The reservoir that the dam impounds has a storage of 7085 Mm³ and surface area of 109.7 km². The dam was completed in 1984, and the intended purposes of the project are hydropower generation, irrigation, flood control and recreation (2).

3.7.2

Principles of Operation

We have not found details of reservoir level restrictions to provide for flood storage at the start of the flood season.

3.7.3

Hydrological Effects

The incoming flood from the reservoir catchment during Hurricane Mitch has been estimated at 9800 m³/s, which is quoted as 70% of the probable maximum flood (PMF) (9). Thus the PMF inflow assumed for the site is taken as 14000m³/s. This may be compared with the peak spillway discharge of 5900 m³/s.

3.7.4

Flood Control Benefits

The dam performed well during the Hurricane Mitch event in 1998. At the start, the reservoir level was 13m below full supply and within 70 hours it had risen by 16m, to retain over 1.5km³ of floodwater within the reservoir. The maximum discharge experienced downstream was 1200 m³/sec, compared with the 9800 m³/s peak inflow. Had the latter flow entered the highly populated alluvial plains downstream, an “inconceivable disaster” would have resulted (9), in terms of loss of life and livelihoods.

The devastation caused by Hurricane Mitch in Honduras is outlined by (10). The reference does not highlight the alleviation benefits of El Cajon but does note that the filling of its reservoir by the flood will reduce the threat of electricity blackouts in the coming dry season.

One year on from Mitch, a newspaper article notes that flood discharge over El Cajon dam had “forced the (Honduran) Government to order the evacuation of seven towns....”. A storm had led to an unusually heavy flow of water into the reservoir, so that “1000 cubic metres of water per second were released as a disaster prevention measure (11)”. The article does not indicate what the reservoir inflow was but, bearing in mind that Mitch caused an inflow estimated at 9800 m³/s, it is likely to have significantly exceeded the 1000m³/s discharge triggered by the later storm. Thus El Cajon again attenuated the flooding from its catchment.

As with Aswan, flood control at El Cajon is likely also to have led to improved agricultural production through manageable irrigation.

3.7.5

Flood Control Negative Consequences

Although it is likely that increased erosion and reduced silt deposition on former washlands now occur downstream of El Cajon, such problems are not specifically highlighted in mainstream anti dam literature such as “Silenced Rivers” (12). The latter makes mention only of the high rate of sedimentation of reservoirs such as El Cajon; effects of this on flood attenuation performance are discussed in Section 2.1.

3.8

Korea: Namgang Dam

3.8.1

Setting and Purpose

Namgang Dam comprises a 34m high rockfill structure across the Nam River near Chinja City. It has a (gated) spillway capacity of 800m³/s, and a reservoir of 309km³ storage capacity and 28.2 km² area. It replaces a smaller dam at the same

site which was found to afford inadequate protection against minor flooding downstream; the decision to develop it followed Typhoon Thelma in 1987. It was completed in 1992 and, although its primary purpose is flood control, it also provides water for irrigation, water supply, hydropower generation and river compensation flow (18).

3.8.2

Principles of Operation

The dam has been designed to attenuate a 10400 m³/s inflow (1 in 200 year flood) to an 800 m³/s down river outflow. This is achieved by diverting 3250m³/s down a relief channel to Sacheon Bay, and storing the balance of the flood in the reservoir. For this to work (18):

- the top 5.0m of the reservoir is reserved for flood storage;
- the discharge through the Sacheon diversion particularly, but also over the dam, is increased at a much greater rate than the initial inflow hydrograph rise, to lower the reservoir by an additional 5m in advance of the flood peak (see Figure 4).

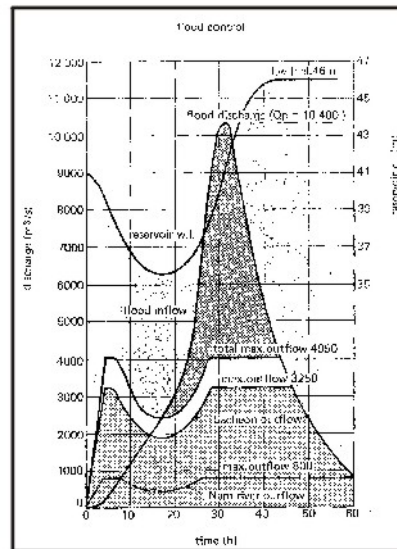


Figure 4 Graph showing the fluctuation of reservoir level and the outflows through the project components

3.8.3

Hydrological Effects

The catchment area at the damsite is 2285km², and the average annual rainfall is 1417mm (18). Average annual runoff is quoted as 2031.19m³ (64.4 m³/s average) and it is inferred from the stated compensation flow provision from the reservoir that flow is maintained at a minimum of about 4m³/s (122.1Mm³/yr).

Because of the Sacheon diversion (not a common feature type with flood control dams), and abstraction for water supply and irrigation, the annual flow volume downstream of the dam will be significantly reduced from the 2031 km³ average quoted above. Furthermore, as with all dams, flow variability will be greatly reduced.

3.8.4

Flood Control Benefits

The safeguarding of the Sacheon diversion, and a system for warning of impending large discharges through it, are critical to the success of the Namgang Scheme. However, from the perspective of attenuation by the reservoir, storage coupled with discharge of the flood waters reduces total peak outflow of a 10400 m³/s flood to 4050 m³/s.

We have found no data on the extent of land and nature of use which enjoys greater security against flooding as a result of the Namgang Dam. However, the reduction in peak flows of up to 9600 m³/s (92%) is very significant indeed.

We have found no data on whether the scheme is achieving its core objective of obviating minor flooding problems downstream, although it appears likely.

3.8.5

Flood Control Negative Consequences

The rate at which the discharge in the Sacheon diversion increases (from 0 to 3250 m³/s in less than 5 hours) is potentially dangerous. Other impacts on downstream morphology, ecology and water quality will also occur as a result of storage and flow regime changes.

3.9

Spain: Segura River Basin

3.9.1

Scheme Outline

The 19000 km² Segura basin in South-East Spain is characterised by frequent and alternating prolonged droughts and major floods. The latter are associated with intense downpours in spring and autumn, and have caused quite serious disasters. Because agricultural produce is derived from herbaceous crops and commands a high price, economic consequences of crop damage by floods can also be high. A

comprehensive plan including 13 dams and 10 canal systems has been developed to reduce the risk of flood damage to villages, roads and farmland. Those already built have proved extremely effective (19).

Two reservoirs were built in the catchment before 1900, and systematic construction of headwater reservoirs commenced with the 20th century. Some eight dams already existed when the flood control plan was drawn up. The efficiency of these in controlling flood waters led to a greater feeling of security against floods, so that farming encroached into formerly flood-prone areas, constraining the river channel and its conveyance capacity. In some places this is now as low as 100 m³/s, compared with a 1 in 50 year flood of 2000m³/s. The economic success enjoyed by farmers also led to growth in the number and size of villages. Current Spanish land legislation precludes enlarging the river channel to improve its flood capacity by a realistic margin (19).

Hydrological studies showed that flood routing in most tributary catchments would be necessary; although they are relatively small (100 - 350 km²), the specific yield associated with sudden showers of a 1: 50 year return period can be as high as 6m³/s/km². Such rainfall over even one catchment area could cause a significant flood peak in the main river, therefore (19). However, the storms are of short duration so that the generated floods are “flashy” and have low total volumes (19). In such circumstances, storage offers significant attenuation benefits.

The dams proposed have as far as possible been sited at the downstream ends of tributaries. They range from a 6.5m raising of an existing structure, through to an 80m high fill dam. However, most are concrete dams of 25-50m height. Reservoirs range in size from 2.5 - 50 Mm³, although eight of the thirteen are of less than 10Mm³ capacity.

Ten spillways are to be gated for increased operational flexibility, whilst the remaining three are uncontrolled because they feed into a downstream reservoir which has spillway gates. Spillway capacities have been designed for the 1: 500 year flood with the exception of those associated with embankment dams and concrete dams of greater than 50m high which have been designed to accommodate the probable maximum flood (PMF). The 1: 500 year spillway design flows range from 65m³/s to 1200 m³/s, whilst the largest PMF spillway can pass 3000 m³/s (19).

3.9.2

Flood Control Benefits

A 1: 500 year peak outflow spillway capability suggests that considerable attenuation of the 1: 50 year flood will occur. The latter could be of the order of 2000m³/sec off an unregulated 350km² subcatchment.

Estimates of total avoided direct costs (damage to crops, housing and infrastructure) and indirect costs (disruption) suggest that accumulated benefits over the operational life of the works will exceed initial investment costs by a factor of five.

3.9.3

Flood Control Negative Consequences

The scheme proposed is comprehensive and will lead to further changes in flow regime, water quality, downstream morphology, and ecology. These cannot at present be quantified.

3.10

Norway: Glomna - Lagen Case Study

3.10.1

Background

The Glomna - Laigen Basin (GLB) is one of the case studies included within the WCD work programme. Information presented below has been deduced from the GLB case study scoping report (20) and should be updated as more output from the study becomes available.

There are a number of dams and lake reservoirs in GLB, for hydropower generation, navigation and flood control purposes.

Floods in Norway are associated with the spring snowmelt. In addition, flash flood periods may occur during summer and autumn periods due to heavy rain (20).

Norwegian rivers are steep, high energy watercourses running through narrow valleys. Their floodplains are relatively small, but subject to intensive land use by the several user interests (agriculture, settlements, road and railroad building). Consequently, flood protection measures have been executed in many rivers and lakes throughout the 19th and 20th centuries. The most common types of measures have been flood banks, bank revetments, channelisation, degradation and erosion control measures (20).

Although most of the larger regulation dams in Norway are built and used mainly for hydropower purposes, flood protection considerations were important in the planning processes and for the decisions to build several of the dams with lake

reservoirs early in the 20th century. In addition the licensing conditions of several hydropower reservoirs give permission to pre-release water from hydropower reservoirs to prepare space for anticipated floodwater volumes (20).

The south eastern part of Norway, and especially the GLB, experienced a severe flood in early June 1995 whose economic cost has been estimated at NOK 1.8 billion. As a consequence of the 1995 flood a Commission on Flood Protection Measures was established to recommend measures for reducing the vulnerability of society as a whole to floods and flooding (20).

3.10.2

Flood Control Benefits

The flood reduction capacity of regulation reservoirs in the GLB is demonstrated by the flood level reductions in Lake Oyeren in 1995. Calculations indicate that the flood culmination level in Lake Oyeren would have been 2 metres higher without the headwater dams/reservoirs of the G&L basin for the actual flood in 1995. In addition the flood level would have been another 2.20 metres higher without the excavation of the outlet of the Lake Oyeren reservoir upstream the dam at Solbergfoss done after a flood in 1967.

The flood reducing option of the regulation dams has a considerable economic value by reducing damages on floodplain settlements, agricultural areas and crops, and infrastructure elements (roads, railroads, telecommunication). In flood situations even small reductions in flood culmination levels may give significant reduction of the flood damages, for example, if utilisation of a regulation reservoir prevents overtopping or breakdown of flood dykes (20).

An optimal utilisation of dams and reservoirs in the G&L basin for flood reduction purposes can not be performed within the frames of the granted licences for regulation for each of the dams/reservoirs. Situations like this show the importance of a basin-wide Water Management Association (WMA) for the running of the watercourse through critical floods events. It also demonstrates the importance of a tight co-operation between the WMA and the public authorities (NVE and the local municipalities) for optimising flood protection efforts and for having functional emergency planning systems in critical flood situations (20).

3.10.3

Flood Control Negative Consequences

General comments as for other sections apply.

3.11

3.11.1

United States: Folsom Dam, California

Setting and Purpose

Folsom Dam is a 104m high gravity dam across the American River. It impounds a reservoir of 1246Mm³ storage and 48km² area, and has a gated spillway of 4856 m³/s capacity. It was completed in 1956, and is a multipurpose facility providing water for irrigation, public supply and hydropower as well as being used for flood control and recreation (1). Its flood control purpose safeguards part of the city of Sacramento (21).

3.11.2

Principles of Operation

It is understood from a paper describing the reservoir's flood attenuation performance during a 1986 event that the reservoir was then intended to be operated with a reserve storage of 490 Mm³ for floodwater (21). The same paper makes reference to a maximum release capability (spillway design discharge) at that time of 3250 m³/s, rather than the 4856 m³/s quoted above; thus it appears the spillway has been modified in light of the 1986 experience.

The reservoir as originally designed was intended to attenuate a peak inflow of 9620 m³/s to peak outflow of 3250 m³/s. This was to be achieved by:

- taking 490 Mm³ into storage;
- full and prompt use of the release capacity.

The importance of the second point was emphasised by the designers (US Corp of Engineers), who noted that a 12 hour delay in the initiation of releases would have the same effect on flood control as diminishing the flood storage provision by 123 Mm³ (21).

3.11.3

Hydrological Effects

These are demonstrated by reference to the February 1986 flood event. The following sequence of events is noted in the paper (21) (see also Figure 5a)

- 12 February: reservoir reserve storage only 370 Mm³;

"Worst storms of season" and "record low pressure systems" forecast for California.
- 14 February: reserve storage still only 370 Mm³.
Flooding in nearby catchments and heavy rain on Folsom catchment.

- 16 February: inflow to reservoir has increased to 1700 m³/s, and reserve storage declined to 278 km³ before increases in discharge above 570 m³/s started to be implemented at 1400 hours.
- 18 February: discharge rate increased to 3250 m³/s design limit at 0200, by which time the reserve storage had declined to 146 Mm³, whilst two more days of heavy rain were forecast. Upstream cofferdam collapsed at 1400, releasing an additional 120 Mm³ of water (most of remaining flood storage volume) as inflow rose to peak of 4920 m³/s. Releases increased to 3540 m³/s.

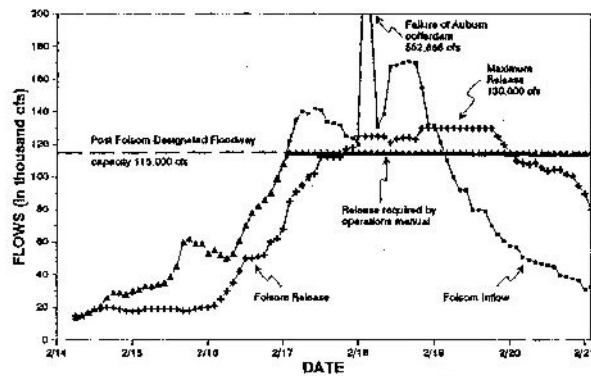


Figure 5a: *Folsom Dam Operation during 1986 Flood*

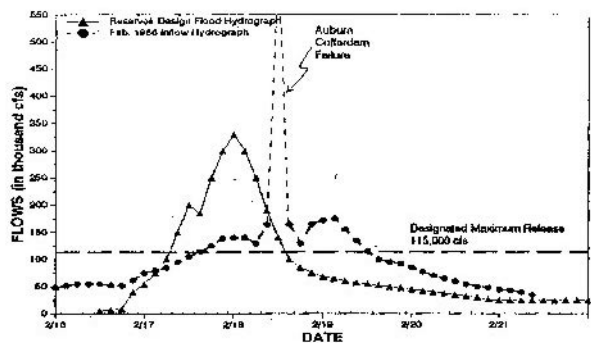


Figure 5b: *Comparison of February 1986 Flood with Reservoir Design Flood for Folsom Dam*

At this stage, the rain ceased, and the flood was controlled by reservoir surcharging and sustaining the release rate at 3680 m³/s (13% over design maximum). Damage was apparently confined to severe erosion of levees in a few places downstream, although adequate freeboard was maintained. Record stages occurred at the American River confluence with the Sacramento River, and it is suggested that this was in fact due to the delay in initiating full discharge at Folsom (21).

Various studies followed the above event, and the main thrust of the referenced paper is to take issue with some of the US Corps of Engineers' findings in relation to flood severity (21). Whilst it appears that the peak reservoir flow was well below the design peak of 9620 m³/s (340,000 ft³/sec - see Figure 5b), it is equally apparent that when cofferdam collapse is taken into account, the flood volume was as large or larger than that of the design event.

The key point to note is that a flood of this volume was successfully controlled despite apparent failure to follow the correct reservoir operating procedure in terms of reserve storage provision and discharge management. It seems likely that a shorter-duration, more intense event such as the design flood would also have been successfully controlled, if the reservoir were properly operated.

3.11.4

Flood Control Benefits

It is inferred from the reference paper that the reservoir prevented significant flooding and consequent damage to property and threats to health and life in Sacramento. The quantity of damage avoided is not stated.

3.11.5

Flood Control Negative Consequences

By maintaining a reserve storage for flood control of Folsom, the performance of the dam for its other functions - water supply, irrigation, hydropower generation recreation - is compromised. The fact that the reserve storage was less than the designers intended at flood onset demonstrates the uneasy nature of such compromise in the operation of multipurpose reservoirs.

Whereas the flood control benefits relate to human health and economic welfare, the adverse affects - downstream water quality, flow regime, morphology and ecology - are predominantly environmental. We have not found specific details of the adverse impacts of Folsom Dam, but there is a wealth of generic material on the benefits and disbenefits of dams in the continental US.

4 Reservoir Failure

The large volumes of water stored in reservoirs can in some cases cause floods as large or larger than those they are intended to avert. It is therefore helpful to set in context the likelihood of such occurrences. The findings of an analysis carried out in 1993 (which concluded that flooding was the most common cause of failure) is presented in Table 3 below (22).

Table 3 - Analysis of Failures of Operational Dams

Class	Sample Size	Number of Failures	% Failures
Embankments pre-1930	4500	70	1.6
Embankments post-1930	11,000	60	0.5
Total	15,500	130	0.8

The table shows that:

- the overall probability of failure of embankment dams equates to less than 1%;
- modern (post 1930) dams probability of failure is about 0.5%.

It is noted in the referenced paper that failure to open spillway gates has been a cause of several dam failures (22). Such a failure is exemplified by Tous Dam in Spain. This rockfill structure overtopped during a flood in 1982 because a power failure prevented mechanical gate opening, and manual opening was too slow (23). More than 20 lost their lives in the ensuing flood.

Tous dam has since been rebuilt (24).

5 Lessons that can be Learned for Planning, Design and Operation

5.1 *Conclusions from Case Studies*

On the basis of the case studies reviewed above, the following broad conclusions are drawn:

- the practice of using dams for flood control is well established and widely adopted under the full range of climatic conditions;
- effective schemes can significantly reduce flood stage and/or peak flows downstream for as far as the regulated part of the catchment represents a reasonable proportion of the whole;
- in the case of multipurpose schemes, there is conflict between flood control and water using functions;
- the effectiveness of such dams in attenuating floods will depend upon:
 - correct hydrological analysis;
 - proportion of catchment they command;
 - storage allocated for flood control vs. volume of floods (so a smaller reservoir would suffice on a catchment characterised by flash floods than would be needed for longer-duration events);
 - discharge controls;
 - in relationship of the particular scheme with other flood control measures in the catchment;
- in some cases, performance relies upon early rapid opening of spillway gates, leading to a rapid build-up of downstream flows which may take residents by surprise - particularly as the very presence of the reservoir will have reduced peoples consciousness of flooding and its potential consequences;

- downstream water quality, flow regime, morphology and ecology are all affected, with consequent potential changes to aquatic food production (river, marine and reservoir fisheries) and soil fertility.

A specific dam will not necessarily provide a guaranteed solution to every flooding problem in a catchment. Rather, it is a potentially very useful component within an integrated flood control strategy for a river basin.

5.2

Lessons Drawn from Conclusions

The lessons drawn from the above are:

1. The hydrometeorological and hydrological processes in the catchment must be properly understood.
2. Dams should be looked at realistically with other flood control measures to develop an integrated and cost-effective solution to flooding problems. Such study should take account of the implications of, and for, pre-existing flood control works, as well as (1) above.
3. Dams and other flood control measures can reduce the risk of flooding downstream, but will not eliminate it entirely.

Development controls and other measures that properly address the residual risks need to be formulated and enforced.

4. Operating rules should be enshrined in entitlement licences, with a system of fines for non-compliance which negates the potential economic gain associated with breaching such rules (eg gaining extra hydropower revenue by encroaching into flood storage).
5. Downstream residents should be educated about scheme operating principles, particularly in relation to rapid discharge increases, and a warning system instituted.
6. Standby systems should be provided to operate the gates as quickly as may be necessary in the event of power failure or breakdown.

6

Policy Guidelines

Policy guidelines should revolve around establishing the potential usefulness of a dam to alleviate flooding in a particular catchment. This should be approached by reference to the relationship between catchment flood hydrology, and reservoir characteristics. Thus, for example, a reservoir for a “flashy” catchment would be more effective if it could store a significant proportion of the flood volume.

The issue of how to prepare downstream residents for sudden flow increases may need to be addressed in some cases. If such sudden changes are a main feature of a scheme, and a significant number of people may be affected but cannot easily be warned and moved in the time available, then the scheme should be reconsidered.

As with all planning exercises, the issue of risk and risk management should be incorporated into the process. Progressing a project from the position that its benefits are unassailable, and that nothing can go wrong, is as arrogant as it is illusory.

7

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