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Ancient dams, settlement archaeology and Buddhist propagation in central India: the hydrological background*

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Abstract A group of ancient dams (*c.* second–first century BC) was located during an archaeological study of the Sanchi area in central India. Comparison of reservoir volumes with estimated inflows suggests that their design was based on hydrological understanding.

Key words ancient dam design; water balance; rice irrigation; Buddhism and social change; urbanization

Barrages antiques, archéologie et propagation du Bouddhisme en Inde centrale: influence de l'état de l'art hydrologique

Résumé Un ensemble de barrages antiques (*c.* deuxième–premier siècle av. JC) a été localisé lors d'une étude archéologique de la région de Sanchi en Inde centrale. La comparaison entre les capacités des réservoirs et les débits entrant estimés suggère qu'ils ont été dimensionnés à partir d'un savoir hydrologique.

Mots clefs dimensionnement de barrage antique; bilan hydrologique; irrigation rizicole; Bouddhisme et changement social; urbanisation

INTRODUCTION

Very few ancient dams in India have been studied on the ground; the subject has been dominated by a textual and epigraphic framework of analysis. Notable exceptions include the Chola reservoirs in south India (Venkayya, 1906) and the well-known Junagarh Dam in western India (Mehta, 1968). During an archaeological survey of the Sanchi area in central India, a number of ancient embankments were located and studied. Archaeological evidence suggested that these embankments were contemporary with the Buddhist monastic sites near which they are situated, and that more than half are dated between about the second and first centuries BC, with others between the first and 10th centuries AD. A joint archaeological and hydrological study revealed that the dams appear to have been designed not only with a sophisticated knowledge of dam engineering but also with an understanding of the principles of basin water balance. This raises important questions about the role of water resources

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management in the spread of institutionalized Buddhism and accelerated urban growth in ancient India.

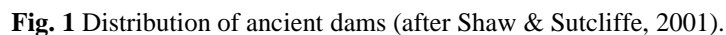
BACKGROUND TO FIELD WORK

Although the monumental remains of Sanchi and other Buddhist sites in the area have been the subject of much attention since their discovery nearly 200 years ago (notably Cunningham, 1854; Marshall, 1940), relatively little attention has been paid to the surrounding landscape, the rural settlement pattern and the ancient land use of the area. An archaeological survey carried out over two seasons in 1998–2000 covered an area of about 750 km² within a radius of about 15 km of Sanchi (Shaw, 2001). These field investigations had the aim of using settlement archaeology to illuminate Buddhist history, and in particular to provide evidence on social and religious change in central India from the third century BC. During this study some 120 settlements and 35 previously unrecorded Buddhist monastic sites were noted, together with 16 ancient dams (Shaw & Sutcliffe, 2001) which form the subject of this paper.

The dam below the major monastic site on Sanchi hill (Fig. 1) had been examined by Marshall (1918, 1940); the embankment runs for about 350 m between Sanchi hill and Nagauri hill to the south, and for over 1000 m from Nagauri hill to the west. Marshall (1940, p.13) noted that “agriculture was not of course an occupation in which the monks themselves were allowed to take part”. However, the evidence of a further 15 unrecorded embankments within the Sanchi area, a number of which are associated with monastic settlements, not only provides empirical evidence for understanding the history of ancient Indian irrigation, but also raises questions about the socio-economic and religious infrastructure which supported the construction and management of the Sanchi dams. These topics are discussed more fully elsewhere (Shaw, 2001), but an analysis of the relative positions of ancient dams, contemporary settlements and monastic sites provides evidence for reconsidering the separation of Buddhist monks from the agricultural infrastructure. However, the emphasis of this paper is on the hydrological understanding implicit in the design and construction of the set of embankments.

PHYSICAL SETTING

The Sanchi area is situated within the Betwa basin in central India, which was the subject of a comprehensive hydrological and hydrogeological study by Indian and British scientists between 1976 and 1980 (Sutcliffe *et al.*, 1981; Sutcliffe & Green, 1986; Hodnett & Bell, 1986). Thus the present physical background to the area is well known. Underlying the whole Betwa basin are Pre-Cambrian rocks of Bundelkhand granite, but these are exposed well to the north of Sanchi. Vindhyan Sandstones of Cambrian age overlie the granite, and outcrop to the southwest of Sanchi, where they form flat-topped or gently dipping hills with deeply incised scarps. Much of the basin is occupied by Deccan Trap basalt, whose flows spread over the land surface to a depth of 300 m; except in the hill areas, the Deccan Trap is covered by a plain of yellow clay and black cotton soil derived from basalt weathering. There is a shallow aquifer within the surface weathered zone of the basalt and soils.



Sanchi hill is an outcrop of Vindhyan Sandstone at the boundary between the sandstone hills to the south and west and the basalt-floored valley of yellow and black cotton soils to the north and east. The area to the south and west of Sanchi, with its extensive hill ranges separated by short valleys, is more suited to the construction of low embankments than the predominantly flat areas to the north and east (Fig. 1). The hills define basins providing runoff into the dam sites, while the soils of the plains are suitable for irrigated agriculture. Thus a total of 16 ancient dams were concentrated in an area of about 400 km² around Sanchi; these embankments would have formed reservoirs fed by runoff from the hillsides and located close to areas which could be

irrigated. The flat topography is less suitable for reservoirs to the north and east of Sanchi; the only dams east of Sanchi are located among the line of hills around the Buddhist monastic sites at Andher and Morel Khurd.

The soils on the sandstone hills are thin, up to 0.3 m thick, and sandy; the present vegetation consists of broad-leaved, deciduous forest species such as teak and sal (*Shorea robusta*) in the wetter areas tending towards acacia in the drier areas. The “black cotton soils” of the plains are now used for agriculture. The depth of the black soils and the underlying yellow clay is generally between 2 and 10 m but may be deeper in the central part of the basin. The clay content gives rise to high soil moisture storage capacity; the soils have marked swelling and shrinking cycles, and during the dry season they crack to depths of 1.5–2 m under cultivation and up to 6 m under deeper-rooted perennial grass and scrub. The cracks are up to 75 mm wide at the surface and the soil therefore recharges rapidly at the onset of the monsoon.

PRESENT CLIMATE

The present climate of the Betwa basin, including the Sanchi area, is highly seasonal with an annual rainfall ranging from over 1300 mm in the hills to the east of Vidisha to less than 900 mm in the north of the basin near Jhansi, some 250 km north of Vidisha (Fig. 2); the average over the whole Betwa basin is about 1140 mm, with 90% of the

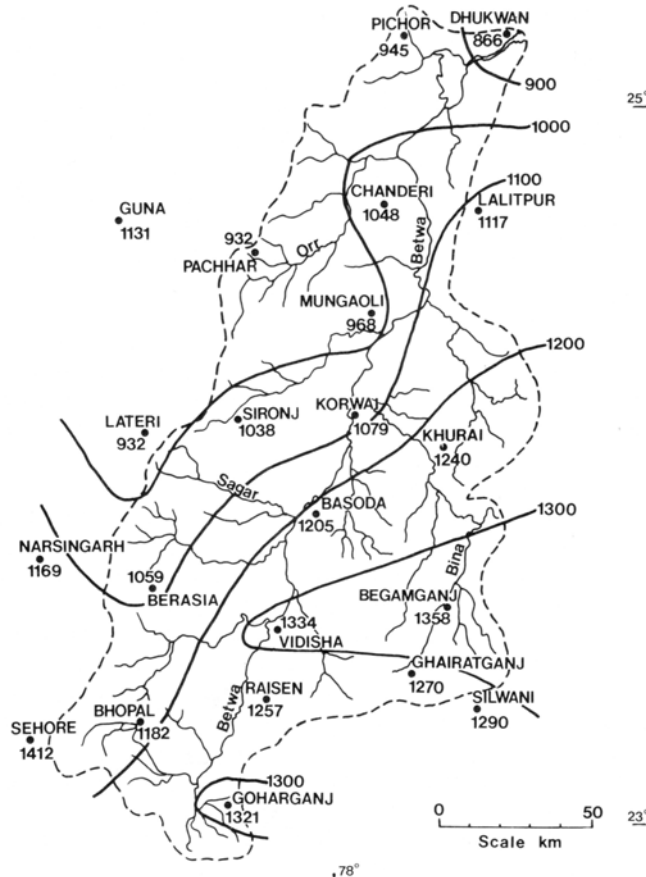
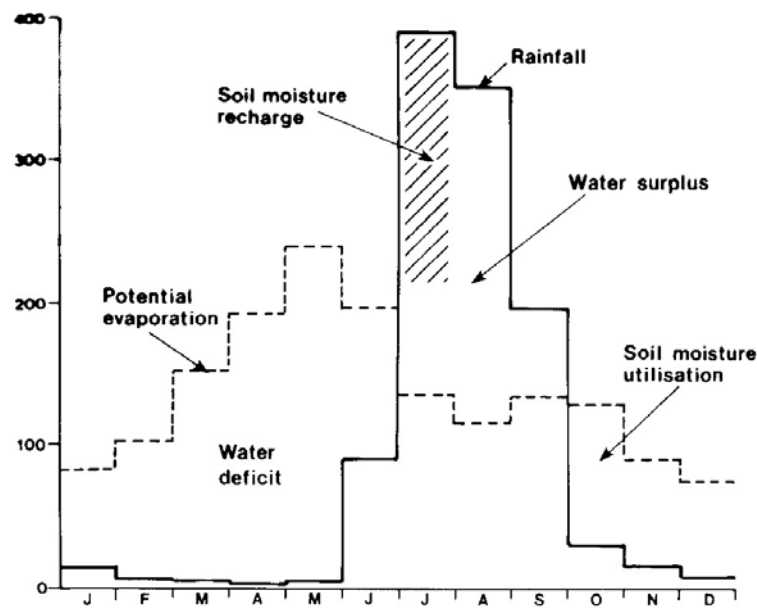


Fig. 2 Average annual rainfall, mm: Betwa basin, 1926–1975 (after Sutcliffe *et al.*, 1981).

Table 1 Average rainfall over Betwa basin (1926–1975) and evaporation at Bhopal, mm (after Sutcliffe *et al.*, 1981).

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Rainfall	15	7	66	2	5	111	390	351	196	31	15	8	1138
Potential transpiration	83	102	152	193	241	197	134	115	133	127	90	75	1643
Open water evaporation	113	135	193	241	293	237	164	143	167	165	123	103	2077

**Fig. 3** Seasonal rainfall and potential transpiration, Betwa basin, mm (after Sutcliffe *et al.*, 1981).

rainfall occurring between the middle of June and the end of September (Table 1). The seasonal distribution of average rainfall is illustrated in Fig. 3.

The open water evaporation, and also potential transpiration, were estimated by the Penman method using climate averages from Bhopal, which can be taken as typical of the basin. The monthly values and the transpiration averages are included in Table 1 and Fig. 3, respectively. The annual transpiration is 1640 mm, with values low in winter, rising to a peak in May as the temperature increases and decreasing in July–September during the monsoon. The seasonal climate cycle is illustrated in Fig. 3 by the monthly balance between rainfall and potential transpiration. There is a period of water deficit from January to June, when potential transpiration exceeds rainfall and deciduous trees lose their leaves, followed by a period from July to September when rainfall exceeds transpiration during the monsoon. A period of soil moisture recharge is followed by a period of water surplus when most of the regional runoff and local groundwater recharge occurs. After October, when potential transpiration again exceeds rainfall, crop and vegetation transpiration relies largely on the soil moisture storage, which depends on soil capacity and rooting depth, and can be estimated as about 200 mm from a programme of soil moisture measurements and water balance studies (Sutcliffe *et al.*, 1981; Hodnett & Bell, 1986).

DRAINAGE PATTERN AND RUNOFF

The River Betwa flows through the Sanchi area from the hilly area in the southwest, and is joined just north of Vidisha by the Bes tributary which drains an area to the west. To the east of Vidisha the River Nion drains an area of some 1000 km²; this tributary is important as it was studied as a sample basin during the Betwa investigation; river flows were measured in 1978–1980, in addition to rainfall, soil moisture storage and groundwater levels over a network of sites (Sutcliffe & Green, 1986). As well as providing access to water, the high banks of the Bes and the smaller streams provide settlement sites which are relatively free from monsoon flooding.

The runoff from the Betwa basin was measured over a period of 50 years, from 1926 to 1975, at Dhukwan Reservoir at the lower end of the basin of 20 600 km²; the average runoff over this period was 351 mm, compared with the average basin rainfall of 1138 mm. This runoff, like the monsoon rainfall, is concentrated between June and September, though there is some residual baseflow from groundwater reserves after the monsoon. The basin rainfall has varied widely from year to year, from 745 mm in 1966 to 1539 mm in 1961; the standard deviation over the 50-year period was 211 mm or 18.5% of the mean. As the residual of the hydrological cycle, the standard deviation of the runoff is relatively high at 157 mm or 44.7% of the average runoff. The relation between basin rainfall and runoff, derived from records from the whole Betwa basin and measurements from individual tributaries during the Betwa project (Sutcliffe & Green, 1981), provides a means of estimating runoff from monsoon rainfall.

This can provide an indication of the possible effect on runoff of historical changes of climate and particularly rainfall. Since the present climate and runoff provide the basis for studying the ancient dams and reservoirs, the evidence for change over the past 2000 years should be considered. There is little palaeo-ecological evidence for the early historic period, and the main focus of enquiry has been a major phase of aridification attributed to the third/second millennium BC (Singh, 1971). However, various studies have indicated the beginning of an arid phase in the second millennium BC, reaching present levels of aridity about 100 AD (Fuller, 2000). Although it is hoped to obtain evidence during further research in the area, it will be seen later that the hydrological discussion focuses on the correlation between reservoir capacities and basin runoff volumes, which should be affected less by historical changes in local rainfall and thus runoff depths.

The present hydrological behaviour of the smaller streams in the Sanchi area is illustrated by a study of the Nion at Kuakheri (Sutcliffe & Green, 1986), based on detailed measurement of the major components during 1978 and 1979. The records for 1978, which include measurements from a network of soil moisture sites and groundwater observation wells, show that the reaction of the basin to the monsoon may be divided into four phases: these may be described as periods of initial soil moisture recharge when evaporation is negligible; combined soil moisture and groundwater recharge with evaporation and some runoff; runoff and evaporation after soil and groundwater storage has been replenished; and recession when some runoff is maintained from groundwater storage and evaporation from soil moisture. The 1978 rainfall was about average and the measured runoff was 555 mm from the basin of 921 km². The same sequence was observed though the timing was delayed in 1979, when the monsoon rainfall was exceptionally low at 40% of average; soil moisture

recharge was little below the 1978 value, but runoff was much reduced at 80 mm. After the monsoon the soil moisture storage declined steadily, but the basin evaporation was maintained by the initial storage of over 200 mm. This hydrological regime is reflected in the present land use of the area, and throws light on the role of the ancient reservoirs in the historic land use.

CHARACTERISTICS OF SANCHI DAMS

The dams in the Sanchi area are prominent and easily identifiable archaeological features of the landscape. However, with the exception of two dams (5 and 10, Fig. 1) which have been restored, they are all in a ruinous state and show signs of breaching at sites where natural drainage channels cross the embankments. The dams have not been excavated, but they consist of an earthen core, generally derived from black cotton soil, reinforced by facing of dressed sandstone masonry, especially on the upstream face. In some places the facing slabs are laid horizontally; in other places the slabs are interlocked, with most blocks laid parallel to the face, with head-on slabs slotted in perpendicular to the embankment (Figs 4 and 5). Dam heights range from 1 to 6 m, with flat downstream sections apparently designed to make the dams resistant to overtopping (Parker, 1909); some dam widths are as much as 60 m. At least two of the higher dams (7 and 12) have spillway channels cut in the rock adjacent to the artificial embankment.

The dams are not isolated features, but form part of a series of “early historic complexes”. Typically a Buddhist stupa or monastic site is found on a nearby hilltop, with a village settlement on the lower slopes or on an adjacent mound. The Sanchi



Fig. 4 Devrajpur dam: horizontally laid dam facing (after Shaw & Sutcliffe, 2001).



Fig. 5 Devrajpur dam: interlocked stone facing (after Shaw & Sutcliffe, 2001).

complex is typical of this arrangement, with the monastic monuments on the hill, and with one part of the embankment linking Sanchi hill with Nagauri hill, where an ancient stone quarry, painted rock-shelters, scatters of microliths and early historic pottery attest to a long occupational sequence. A second embankment links Nagauri with a hillside settlement to the west. A similar relationship links dams, settlements and monastic sites throughout the area.

CHRONOLOGY

Irrigation structures are difficult to date because of the nature of their construction, with building material derived from several sources and subsequent restoration. It is not surprising that Marshall (1940) could not provide a precise date for the construction of the embankment (no. 14) below Sanchi hill, but his rough estimate of second century BC, in keeping with the second and most prolific phase of building activity at Sanchi and neighbouring Buddhist sites, is supported by data from the present study. A number of potsherds dating to *c.* third–second century BC were found in a modern cutting through the eastern dam, and the presence of the same ware at nearby settlements situates the dam within a network of sites including the monastic complex on Sanchi hill and the hillside settlement at Nagauri. However, the pottery dating (Shaw, 2001) is open to revision when a proper excavated ceramic sequence is established for the area; an earlier date cannot be ruled out.

A group of serpent (*naga*) sculptures, ranging in date from second century BC to 10th century AD, provide additional markers; 21 *nagas* were noted during the survey, 15 of them previously unrecorded. The *nagas* were ancient serpent deities, a number of

which in the Sanchi area appear to have been incorporated into both the Buddhist and Hindu “landscape”. However, in most cases their traditional identity as nature spirits is revealed by their close links to sources of water; of the 16 groups whose original provenance is known, seven are associated with reservoirs, five with village tanks, and four with rivers or streams. A number remain *in situ* beside ancient water bodies, and provide terminal dates for the latter. Once these links have been used to build a chronological framework for the Sanchi area, gaps can be filled by other indicators like dam morphology, shape and size of stone facing, and positioning within the surrounding archaeological complex.

The earliest surviving serpent sculptures in the Sanchi area are a *naga* and *nagini* (male and female) couple, which originally stood on the ancient Gulgaon embankment (dam 10). Both sculptures can be assigned to around mid-first century BC (Williams, 1976), providing a terminal date for the embankment itself. Another almost identical couple, of which only the male is still in its original position on Nagauri hill (Shaw, 2000, Fig. 14), would have stood just metres from the water-body of reservoir 14 before the breaching of the dam. The close similarities of apparel and ornamentation suggest a similar date to the Gulgaon couple. This suggests a terminal date of *c.* 50 BC for the embankment, though an earlier date cannot be ruled out. A previously unrecorded *naga*, in the form of Balarama, a prototypical form of the Hindu God Vishnu, stands on dam 5 at Chandna (Shaw & Sutcliffe, 2002, Fig. 13); the treatment is similar to the Vidisha Kubera *yaksha*, datable to around the end of the first century BC (Chandra, 1966), making it the earliest non-Buddhist sculpture in Vidisha’s rural hinterland. Follow-up field study has shown that the facing is similar to Nagauri and other sites, and the dam is probably as old.

Another previously unrecorded *naga* from a slightly later period is found at Morel Kala (dam 12; Shaw & Sutcliffe, 2001, Fig. 15); though only the lower half remains, similarity with early Kushana sculptures from the Mathura region and in particular to the Sarnath Bodhisattva (Williams, 1982, pl. 6), suggests a date of *c.* second century AD. This comparatively late date accords with the advanced design and appearance of the dam, which at 6 m is the highest in the region. A previously unrecorded three-headed *nagakal* or snake deity in animal form (Fig. 6) near dam 7 at Devrajpur is assignable to around the fifth century AD, though it is possible that the dam belongs to a somewhat earlier period on the basis of the chronology of the nearby *stupa* and settlement. In all, similar evidence was used to establish a tentative chronology for seven of the dams (5, 7, 9, 10, 11, 12, 14). The remaining dams with no link with the *naga* cult were positioned within the same framework on the basis of dam morphology, stone-facing type and immediate archaeological context. For example, four of the dams (1, 2, 8, 15) are directly associated with major settlements, clearly datable to the early centuries BC. Another four (4, 6, 13, 16) are associated with early monastic sites, which were established in *c.* second–first century BC during the second major phase of Buddhist propagation in the area. These dates clearly require corroboration through excavation, but the provisional chronology presented in Table 2 shows that the majority appear to belong to the *c.* second century BC time bracket.

The evidence for dating the continued use of the dams is more sparse, and is the subject of on-going research. It seems that flood damage rather than sedimentation was the likely physical cause of disuse. Other reasons are provided by evidence for radical depopulation following a series of recorded famines from the 14th century onward.



Fig. 6 Devrajpur Dam: Nagakal in animal form (after Shaw & Sutcliffe, 2001).

The earlier decline of Buddhism in the area, possibly around the 10th century AD, must also have had a devastating effect on the local economy; just as, by extension, the construction of the dams cannot be divorced from the establishment of Buddhism and the acceleration of urban development suggested by the archaeological patterns in the Sanchi area (Shaw, 2001). However, limited archaeological evidence for later use of dams is provided by fragments of 10/11th century Hindu temples, which could have been destroyed during Muslim invasions of 13/14th centuries, which were observed in hydraulic structures at the Morel Kala dam (no. 12).

RESERVOIR AREAS AND VOLUMES

In order to deduce the roles of the reservoirs, their areas and volumes were estimated by field measurement and map work, though precise estimates would require a number of detailed contour surveys (e.g. Meigh, 1995). The heights (h) of the dams were measured, with an allowance of 20 cm added to allow for erosion for well-preserved sites and higher allowances for others. Dam lengths (l) were also measured in the field; these were clear as dams were built between hills. The gradients (α) of the reservoir floors were estimated from 1:50 000 contour maps, although the contour intervals were relatively coarse at 20 m. The gross volumes of the reservoirs were estimated from these three dimensions (h , l , α) using a simple model of the reservoir shape. The

Table 2 Dam dimensions (after Shaw & Sutcliffe, 2001).

No.	Name	Orientation Map reference		Phase	Stone facing average dimensions (m)	Dam dimensions (m)		Reservoir dimensions (m)		Area (km ²)		Volume (m ³ × 10 ⁶)	
						Height	Length	Gradient	Length	Reservoir	Catchment	Reservoir	Runoff
1	Barla	W–E	N23°24'; E77°44'	2nd–1st century BC	1.10 × 0.30 × 0.56	2	500	0.007	285	0.14	0.74	0.142	0.37
2	Besar Talai	N–S	N23°24'; E77°39'	2nd–1st century BC	No surviving facing	3	1000	0.00233	1290	1.29	8.53	1.935	4.265
3	Bhauliya	W–E	N23°26'; E77°47'	?	No surviving facing	1	500	0.002	500	0.25	2.06	0.125	1.03
4	Bighan	W–E	N23°32'; E77°44'	2nd–1st century BC	0.60 × 0.20 × 0.30	2.2	250	0.002	1100	0.28	1.5	0.302	0.75
5	Chandna	NE–SW	N23°24'; E77°49'	2nd–1st century BC	0.30 × 0.10 × 0.20	6	450	/	/	0.25	1.29	0.75	0.645
6	Dargawan	N–S	N23°29'; E77°43'	2nd–1st century BC	1.0 × 0.30 × 0.45	2.1	300	0.00848	250	0.08	0.38	0.0787	0.19
7	Devrajpur	W–E	N23°27'; E77°52'	5th century AD	1.0 × 0.20 × 0.70	4	1100	0.0029	1380	1.52	13.49	3.036	6.745
8	Dhakna	NW–SE	N23°27'; E77°42'	2nd–1st century BC	1.10 × 0.25 × 0.52	4.5	630	0.00714	630	0.40	4.11	0.893	2.055
9	Ferozpur	NE–SW	N23°29'; E77°40'	5th century AD	0.30 × 0.10 × 0.28	4	500	0.003	1333	1	17	2	8.5
10	Gulgaon	N–S	N23°29'; E77°42'	2nd–1st century BC	1.60 × 0.38 × 0.60	1.5	600	0.006	250	0.15	4.295	0.113	2.148
11	Pathari Kativarat	N–S	N23°28'; E77°49'	10th century AD	0.80 × 0.20 × 0.35	1.5	80	0.003	500	0.04	0.37	0.03	0.185
12	Morel Kala	N–S	N23°24'; E77°51'	2nd century AD	1.20 × 0.20 × 0.50	6	350	0.0024	2500	0.88	12.83	2.625	6.415
13	Morel Khurd	W–E	N23°26'; E77°49'	2nd–1st century BC	1.60 × 0.26 × 0.60	3.6	1100	/	/	0.6	2	1.08	1
14	Nagauri (2)	N–S/W–E	N23°28'; E77°44'	2nd–1st century BC	1.70 × 0.40 × 0.60	2.8	350 / 1050	0.00222	1261	1.32	7.63	1.854	3.815
15	Naroda	W–E	N23°28'; E77°40'	2nd–1st century BC	1.60 × 0.40 × 0.55	2.2	500	0.005	440	0.22	1.185	0.242	0.592
16	Swami par	N–S	N23°28'; E77°43'	2nd–1st century BC	1.12 × 0.36 × 0.57	2.3	500	0.003	770	0.39	1.95	0.443	0.975

reservoir outline was assumed to be rectangular, with the width corresponding to l and the length to h/α ; the area is lh/α and the mean depth is $h/2$ and the volume $lh^2/2\alpha$. Alternative assumptions include an isosceles triangle with the dam forming the base, with a mean depth of $2h/3$ but a smaller area; a triangle with the dam at the apex would have a mean depth of $h/3$ but a larger area. The rectangular assumption provides a consistent set of estimates which lies between the two extremes. The dimensions of the embankments are listed in Table 2, and the calculated areas and volumes are included in the table.

In some cases, the assumptions were adjusted to take account of local conditions. In dams 5 and 13, the reservoirs had been restored and the areas were estimated directly from maps. A number of tributaries converge at dam 9, and the estimated area took account of this. As expected, the relationship is close between reservoir areas and volumes, expressed by $V = 1.81A^{1.28}$, with the volume V in $\text{m}^3 \times 10^6$ and the area A in km^2 . This is similar to the relationship derived from surveyed small dams in Botswana (Meigh, 1995), which was $V = 2.35A^{1.25}$.

RESERVOIR INFLOW

In order to estimate the inflows to the reservoir sites, the areas of the upstream basins were measured from 1:50 000 maps and are included in Table 2. As the reservoirs are confined to a small area around Vidisha, where the present 50-year average annual rainfall is 1334 mm, with 1230 mm in the monsoon months June–September, this may be taken as typical of the area and corresponds to an average runoff depth of 500 mm (Sutcliffe & Green, 1981). The annual inflow volumes have been estimated from the measured basin areas and this depth and are included in Table 2. These volumes are of course based on modern rainfall and basin conditions, and would have been affected by climate change. However, it is the correspondence between the two sets of volumes which is important. The evidence shows that reservoir capacities are strongly related to average inflows; consistent under- or over-estimation of either would not affect this result.

Reservoir volumes and estimated runoff volumes are compared in Fig. 7, which shows that the average runoff is sufficient to fill the reservoirs in nearly all cases. In fact, the equation linking runoff volumes Q to reservoir volume V , both in $\text{m}^3 \times 10^6$, is $Q = 2.38V + 0.353$, with a highly significant correlation coefficient (R^2) of 0.792. This implies that the runoff is sufficient to fill the reservoirs twice in an average year, or that the average reservoir would be filled in nine out of 10 years if the runoff were normally distributed with the present basin-wide CV of 45%. It is perhaps more important to note that the reservoir sizes are reasonably well adapted to the drainage basins and the available runoff. There is no evidence of serial construction of the embankments, which suggests that they were constructed to an appropriate size with an empirical understanding of the principles of water balance.

FLOOD CONTROL AND WATER DISTRIBUTION

Several of the Sanchi dams show evidence of spillways or control structures. Dam 7 at Devrajpur has a spillway channel cut into the rock (Fig. 8) where the artificial

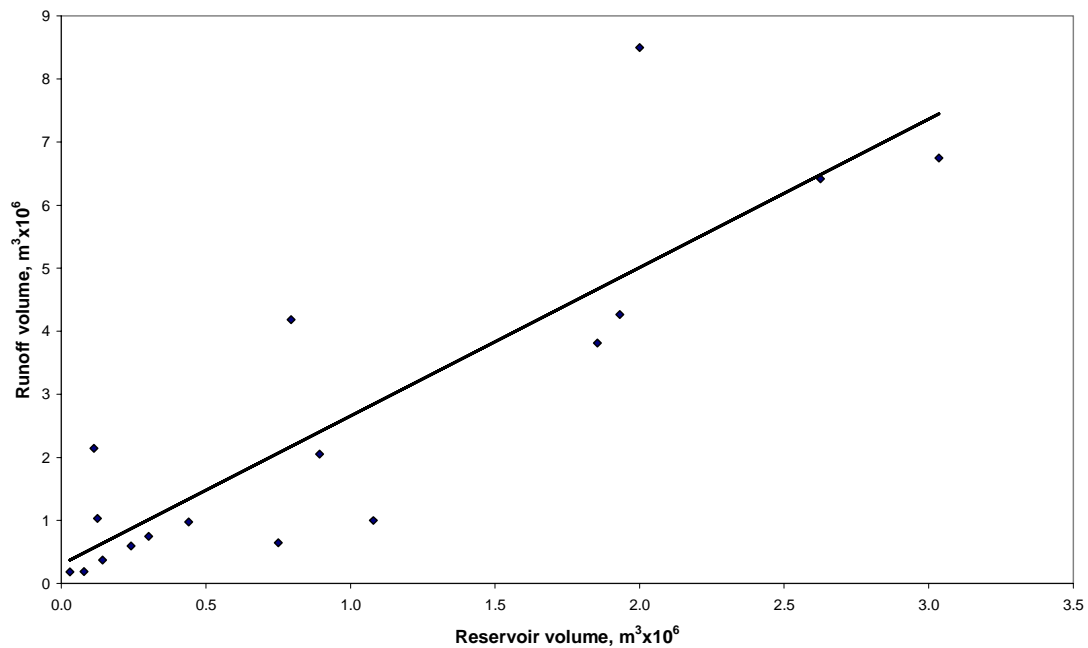


Fig. 7 Sanchi reservoirs: gross volumes and runoff (after Shaw & Sutcliffe, 2001).



Fig. 8 Devrajpur Dam: spillway (after Shaw & Sutcliffe, 2001).

embankment abuts on the original hillside. This is clearly intended as a relief channel to prevent damage caused by overtopping during exceptional inflows, though it has not prevented damage to the embankment at some period at the point where the natural drainage channel has caused a breach. It is interesting to make an approximate comparison between the spillway capacity and likely flood flows. An adaptation of the

“rational formula” can make use of a map of India showing 24-h rainfall depths of 50-year return period (India Meteorological Department, 1972). The depth of 240 mm over a basin of 13.5 km², with an assumed 70% runoff coefficient and spread over 24 h to allow for reservoir storage, would correspond to a discharge of 26.5 m³ s⁻¹. With a spillway of average width of 8.8 m, treated as a broad-crested weir, this discharge would require a depth of 1.5 m, which is slightly more than the spillway depth of about 1.3 m. Thus the spillway would be likely to pass large but not extreme floods. The size design of the reservoirs, the detailed masonry construction, and the existence of spillways at the higher dams, indicate a level of sophistication comparable with contemporary hydraulic expertise on a larger scale in Sri Lanka, whose early Buddhist history is closely linked to central India.

LAND USE AND IRRIGATION

If it is accepted that the size of the reservoirs implies that they were designed for irrigation rather than domestic supply, it remains to speculate on the possible land-use systems with which they were associated. The reservoir volumes suggest that they were designed for the irrigation of rice, although this needs corroboration by specialist archaeobotanical research.

The evidence of modern agriculture in the area makes it unlikely that irrigation would have been required for wheat. This is because the storage in the black cotton soils provides sufficient moisture for winter wheat to be grown without irrigation. At the time of the Betwa project, the land use was largely based on autumn cultivation of wheat, though some pulses and gram were also grown. Field investigation (Hodnett & Bell, 1986) showed that the soil moisture storage, recharged each year by the monsoon, was adequate, supplemented by winter rains, to provide water to the crop, which was planted in October and harvested in March. The seasonal range of soil moisture under crops was about 200 mm, and it was noted in 1979 that soil moisture recharge occurred even in a year when monsoon rainfall was less than half the average.

Because the yield of irrigated rice would be much greater than wheat or other crops, it is interesting to consider the impact which the introduction of rice would have had on the local economy. The dams would have played an important role in supporting increased population levels during the early-historic period, which seem to be implied by local settlement patterns and indeed the distribution of large monastic sites. The relative positioning of dams and Buddhist monastic sites throughout the area raises interesting questions. While Marshall (1940) was reluctant to challenge the textual prohibition of monks owning or managing agricultural land, on the basis of a single reservoir, the spatial relationships between the large number of dams, monasteries and cult-spots throughout the Sanchi area provide an empirical basis for considering the possible emergence of interactive support systems between monastic and lay sections of society during the early centuries BC. The dams are therefore part of a larger body of material for understanding the dynamics of social and cultural change between *c.* third century BC and fifth century AD, and for relating the spread of Buddhism to other key processes such as urbanization and agrarian expansion.

CONCLUSIONS

While these suggestions require further investigation, the study has demonstrated that the ancient reservoirs in the Sanchi area were designed for irrigation, presumably of rice. Their size is in harmony with local drainage basins and runoff volumes, while some of the larger dams reveal an acquaintance with problems of flood control. This suggests that they were built by engineers with experience of reservoir irrigation. The deduction that they were built for rice irrigation throws light on the history of rice in central India. Through an integrated study of irrigation works, land use, settlement patterns and Buddhist monasteries, interesting questions have been raised regarding the relations between monastic and lay sections of society.

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