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Water Management and Reservoirs in India and Sri Lanka

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Water storage and distribution technologies have played an important role in the histories of southern India and Sri Lanka. Given the variability in rainfall and the relatively dry conditions over much of the region, it would have been difficult for southern Asian agriculture, diet, and cuisine – particularly the heavy emphasis placed on rice – to have taken the forms they did without the historical development of water management techniques. Moreover, debates about the efficiency, sustainability, and equitability of modern "big dam" projects versus "traditional" methods of providing much-needed domestic and agricultural water continue to dominate Indian politics today. Here, we review historical forms of water management in South India and Sri Lanka, paying particular attention to ancient reservoir systems.

South India and Sri Lanka are dominated by a monsoonal climate, whereby the southwest (or advancing monsoon) generally brings rains between the months of June and October, and the northeast (retreating monsoon) in November and December. In addition to monsoon strength, a variety of topographic factors relate to the distribution and concentration of rainfall across the region. Parts of the southwestern and western coasts of India receive between 3,000 and 3,200 mm of rainfall a year due to the orographic (related to, or caused by, physical geography, such as mountains or sloping terrain) effects of the Western Ghats – South India's most pronounced north–south ranging mountain chain. On the eastern side of the Ghats, however, a rain shadow is created that markedly reduces the amount of precipitation in the central areas of the southern peninsula. For example, Bangalore – the capital city of the modern state of Karnataka – receives an average of around 850 mm of rainfall per year, while Hyderabad – the capital of Andhra Pradesh – receives an average of only 700 mm of rainfall. Indeed, much of the area within the orographic rain shadow of the Western Ghats can be considered a semiarid climate, with average rainfall levels falling as low as 400 mm (India Meteorological Department 1981). Sri Lanka's topography creates a similar pattern in which the southwestern coastal areas receive the bulk of the advancing monsoon and the northern and eastern coasts – largely in the rain shadow of Sri Lanka's central highlands – receive precipitation from the shorter, retreating monsoon. However, it is important to note that actual rainfall in all parts of Indian peninsula and Sri Lanka can show significant intra- and interannual variability as a result of being dependent on the relative strength of the monsoon.

South Indian and Sri Lankan reservoirs include a range of facilities constructed for the purposes of collecting and storing water, generally for agricultural production. These consist of artificial embankments built across paths of gravity water flow, whether intermittent streams, rivers, or simply slopes that might carry runoff after a monsoon rain. Reservoirs may or may not involve excavation of a basin to contain this water, but they are all storage or storage/distribution devices built on a relatively large-scale and meant to contain water behind an embankment or dam, rather than within its major construction. In this sense, we make a distinction between cisterns (which collect and store water within a rock-cut or other constructed facility), wells (which tap the water table), reservoirs, and tanks. The term "tank" is widespread in the South Asian literature, indiscriminately used to describe almost any water-holding feature, although the term most frequently refers either to reservoirs or to temple tanks – large masonry structures that hold water for ritual ablutions and other functions associated with temple worship. Temple tanks often derive their water from the water table. As such, temple tanks and reservoirs are wholly different in construction, morphology, and operation, similar only in their capacities as water-holding devices and in certain parallels of meaning and symbolism (Morrison in press).

Early Forms of Water Management in South India and Sri Lanka

The earliest culturally significant water catchment features in South India were not constructed reservoirs (in the terminology outlined above), but seasonal pooling basins, or cisterns, which developed naturally from the differential weathering of bedrock. In

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geomorphological terms, these are known variably as gnammas, rock pools, or weathering pits, and are considered to be characteristic features of residual hills and inselbergs – isolated hills composed of resistant rocks (e.g., granite or gneiss) that express pronounced topographic relief from a surrounding plain – throughout the heavily weathered terrain of the tropics and subtropics (Thomas 1994; see also Porembski and Barthlott 2000). In South Asia, such basins occur on the granitic gneiss hills that characterize much of the central and southern portions of the Indian peninsula, as well as parts of Sri Lanka (e.g., Fernando 1976). Indeed, because granite and gneiss are particularly impermeable rock types, the bare hills of South India generate large volumes of runoff water during the heavy monsoon months that collects in such depressions (Fig. 1).

Water retaining rock pools appear to have taken on cultural significance as early as the Iron Age (1000–500 BCE) in several regions of South India. During this period, mortuary and ritual sites were often marked by the construction of megalith monuments, and a clear cultural association between such ritual constructions and seasonal water basins can be established. Large concentrations of elaborately constructed megaliths – ranging from dolmen cists, stone circles, rock cairns, platform enclosures, stone spirals, and more – appear to have been deliberately placed adjacent to water basins in hilltop locations. Perhaps the most striking example of such an association occurs at the site of Hire Benkal in northern Karnataka, where hundreds of megaliths are found near a broad shallow water basin that likely began as a rock pool and was subsequently expanded by quarrying activities for the construction of monuments (Fig. 2).

Water Management and Reservoirs in India and Sri Lanka. Fig. 1 A rock pool at VMS 579 – an Iron Age occupational site in the Koppal district of northern Karnataka. Notice the artifact debris in the foreground (photo by Andrew M. Bauer).

Water Management and Reservoirs in India and Sri Lanka. Fig. 2 The site of Hire Benkal, showing dolmen cists on the quarried banks of a basin feature that likely began as a natural rock pool (photo by Andrew M. Bauer).

Additional sites also demonstrate associations between water and culturally significant ritual places. For example, a brick platform structure enclosed by granite boulders at Bandibassapa Camp, also a large megalithic complex in northern Karnataka, appears to have been situated adjacent to a rock pool that was later modified. Moreover, Gordon and Allchin (1955) reported 80 megaliths at a site near Bilebhavi where they identified two "tanks" (cisterns), one of which was "lined with stone slabs." They also recorded a similar construction on a hilltop megalith site near Koppal (Gordon and Allchin 1955: 99). The association between megaliths and water basins has also been noticed in Tamil Nadu and Sri Lanka (cf. Seneviratne 1984; Myrdal-Runebjer 1996), suggesting a ritual importance to water, and possibly a sacred dimension to early water management throughout much of the region.

Although rock pools likely served as the earliest water retention features in the region, it is clear that during the Iron Age humans began deliberately expanding pooling basins and creating them through activities of quarrying, excavation, and the construction of embankments, or bunds. This is evidenced not only at megalithic ritual sites, such as Hire Benkal, but also at settlement sites, where both cobble lined basins and constructed bunds are present. At the Iron Age habitation site of Kadebakele (northern Karnataka), for example, inhabitants modified the drainage pattern on top of a granitic hill to form a water catchment basin. Excavations in this reservoir show that it collected and held water for only part of the year, partially a consequence of the reservoir's relatively small catchment area of .027 km^2. The facility also experienced major drying episodes as well as significant siltation. Nevertheless, it certainly provided much-needed water to local residents at certain times.

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It is difficult to say to what extent these early water retention features may have supported cultivation. Most are quite small and lack provisions for water distribution necessary for large-scale agriculture. Moreover, they are often perched atop high hills with little cultivable land. However, some early reservoirs do occur within natural drainage ways, occasionally in association with check dams and at the base of topographic features where seasonal water could potentially be pooled for crop production. In fact, Devaraj et al. (1995: 66) report "interlaced, hydraulically laminated" deposits behind a "rammed" earthen construction near the base of a granite outcrop at Watgal – a Neolithic (3000–1000 BCE) to Iron Age (1000–500 BCE) period settlement site in northern Karnataka.[1] It is difficult to characterize the entire range of variability in form and function of early water management constructions without more systematic work. Indeed, few regions have been systematically studied, and the patterns described above may not hold true across the entire region. Nevertheless, it is clear that water retention techniques began to be practiced in a variety of settings during the Iron Age (see also Allchin 1954). In addition, the development of water management technology during this period generally coincided with the introduction of new cultigens – including rice cultivation – suggesting that water retaining features became increasingly important to agricultural production by the end of the first millennium BCE.

In the first millennium AD there is stronger evidence for the construction of larger reservoirs that were used to meet the hydrological requirements of cultivation. A series of reservoir walls have been reported in the environs surrounding Sanchi – a well-known Buddhist monastic site in west-central Madhya Pradesh spanning the third century BCE to the twelfth century AD. These reservoir features are built of earthen embankments reinforced by stone masonry, with dams reaching nearly 6 m in height and expanding across drainage valleys, in some cases exceeding 1 km in length. Moreover, catchment areas range from 0.74 to 17 km^2 (Shaw and Sutcliffe 2001), potentially damming considerably more water than the Iron Age reservoirs discussed above. Artifact associations, as well as the proximity of the embankments to the site of Sanchi, have allowed scholars to suggest that several of these features were constructed as early as the second century BCE, while others were built throughout the first millennium AD (Marshall 1940: 13; Shaw and Sutcliffe 2001).

Although dating features such as reservoir walls remain problematic without direct geochronological assessment (e.g., radiocarbon, optically stimulated luminescence, etc.) or inscriptional data, textual references from the Early Historic Period suggest that reservoir construction was prevalent in some parts of India, and in South Asia more generally, during this time. For example, Chakravarti's (1998) analysis of the *Arthaśāstra* – an economic and political treatise composed sometime in the late centuries BCE or early centuries AD – suggests that Mauryan rulers (ca. 324–185 BCE) were concerned with establishing irrigation works. Moreover, numerous inscriptions and textual references indicate that the construction of reservoirs and irrigation facilities underwent remarkable development in Sri Lanka during the Early Historic Period, particularly on the island's drier north and east sides. Northeast of Sigiriya, the Minneriya reservoir built during the reign of Mahasena (AD 276–303) is particularly noteworthy. This reservoir – fed by a canal as well as surface runoff – consisted of an embankment nearly 2 km in length and at places exceeded over 13 m in height. Inscriptions dated to the reign of Mahasena's successor speak of "three harvests of [rice] paddy per year," suggesting a marked impact on agricultural production (Gunawardana 1971: 8).

Middle Period Reservoirs: The "Traditional" System

It is should be clear from the above discussion that reservoirs and water storage features have a long history in South India, and South Asia more generally. However, the proliferation of large reservoir construction for the purposes of agricultural intensification is most salient in South India after the Early Historic Period, and in Sri Lanka only slightly earlier.

Numerous textual sources clearly indicate that reservoirs played an important role in the Early Middle Period (AD 500–1300). Although small dam-and-basin facilities for water impoundment continued to be built and used, Middle Period reservoirs typically consist of masonry-faced earthen dams thrown up across valleys, at the base of hills, and in other locations where seasonal runoff and small streams could be captured (Fig. 3) (Morrison 1993, in press). Like the Minneriya reservoir in Sri Lanka, some were supplied by canals, which took off via diversion weirs or anicuts, from perennial rivers or intermittent streams. Water was moved downstream from reservoirs to agricultural fields through masonry-lined tunnels under the embankments, which were regulated by sluice gates (Figs. 4 and 5). Some water was also released over specially constructed waste weirs, facilities which range from boulder-filled cuts to elaborately built spillways (Fig. 6). Although the focus was clearly on the storage and downstream distribution of water, reservoir beds were also sometimes used for cultivation and reservoirs served as important sources of

[1] However, it is important to note that the authors do not identify this feature as a reservoir, or attribute it with any water retaining "function."

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Water Management and Reservoirs in India and Sri Lanka. Fig. 3 A Middle Period reservoir embankment and sluice gate used to dam a valley below the Iron Age site of Hire Benkal (photo by Andrew M. Bauer).

fish, silt and clay, and water for livestock. Reservoirs were also used to raise the water table around them, an important function even when the bed failed to fill. In fact, we have documented a consistent (but not universal) pattern of wells down-slope from sluice gates (Morrison in press).

Reservoirs were particularly important in the far south, in present-day Tamil Nadu, where many of them were supplied by river-fed canals (Ludden 1999). There it is possible to see perhaps the greatest elaboration of the so-called "system reservoirs" – long chains of reservoir facilities that flow one into the other, linking large areas into tightly knit watersheds (Sharma and Sharma 1990; see also Mosse 2003). Unfortunately, none of these systems has been specifically analyzed on the ground to determine precise construction sequences, so although we know of many specific single-reservoir projects dating as early as the seventh century AD, we cannot say exactly how the overall system functioned at this time or even how much of the landscape was under reservoir irrigation. It should be noted, however, that Early Middle Period reservoirs, "traditional" by any reckoning, ranged widely in size from very small ponds to vast "seas," the latter falling well within the contemporary definition of a "large dam."[2]

Similar to the "systems reservoirs" of Tamil Nadu, large Sri Lankan Early Middle Period reservoirs were linked through vast networks of canals. The Minneriya reservoir, for example, was connected to other facilities via the construction of a "great canal" during the reign of Aggabodhi I (ca. AD 571–604), and composite maps of the irrigation facilities around Sigiriya show that it fed at least two large reservoirs – the Kaudulla and Kantalai reservoirs. Moreover, detailed survey has shown that smaller dam-and-basin features were also probably constructed and maintained throughout the period (Myrdal-Runebjer 1996). Again, it is difficult to know how the overall systems functioned simultaneously. However, it is clear that Middle Period rulers and elite made demonstrative efforts to construct new irrigation facilities and repair older ones. In fact, the Minneriya inflow and outflow canals were repaired at least several times in the early centuries of the second millennium AD (Myrdal-Runebjer 1996; see also Brohier 1934; Gunawardana 1971).

This pattern of extensive reservoir use in Sri Lanka and the far south of the Indian peninsula contrasts with that of drier regions in the northern interior of the subcontinent (Karnataka and parts of Andhra Pradesh). In these northern regions, reservoirs were (and are) almost exclusively runoff-fed and, given lower rainfall, they are generally not as closely spaced as those of the southern Tamil country. Still, many regions saw the use of both system and isolated reservoirs. In the area we have studied in northern Karnataka, reservoirs seem to have been only a minor component of Early Middle Period agricultural strategies. However, by the Late Middle Period (1300–1700 AD), and especially with the expansion of the large but loosely knit empire of Vijayanagara (ca. AD 1330–1600) across much of the peninsula, reservoir irrigation expanded considerably, especially in the drier zones where it had previously been limited. In and around the eponymous capital city of this empire, urban foundations in the early fourteenth century and the subsequent expansion of settlement and population explosion in the region propelled reservoirs into increasingly important components of larger agrarian and political strategies (Fig. 7). Important from the start of the Vijayanagara period, reservoirs also constituted a key form of agricultural intensification in the sixteenth century, or Late Vijayanagara period, especially in regions where canal irrigation was not feasible (Morrison 1995, 2001).

Reservoirs played variable roles in the processes of Vijayanagara agricultural intensification and change; this variation was structured as much by political factors and settlement dynamics as by environmental variables such as runoff and soil conditions. What is common to most parts of the urban hinterland, however, is the way in which the vast majority of reservoirs fell out of use after (in some cases, during) the Vijayanagara period. Very few of the reservoirs from the original system still effectively function, though there are a few notable "living" reservoirs with long histories of maintenance

[2] Crest length ≥ 500 m, maximum flood discharge ≥ 2,000 $m^3 s^{-1}$, "especially difficult foundation problems" or "unusual design" (ICOLD World Register of Dams 1998).

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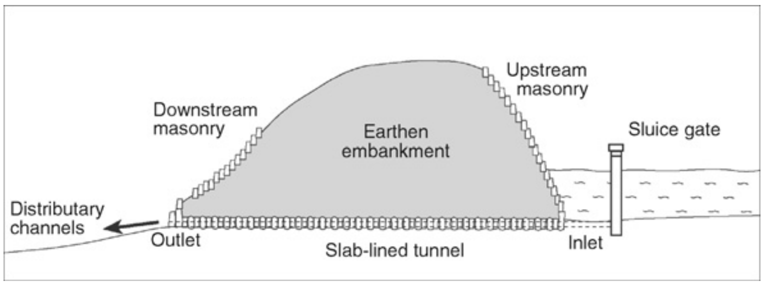

Water Management and Reservoirs in India and Sri Lanka. Fig. 4 Diagrammatic cross-section of a reservoir embankment and sluice gate.

Water Management and Reservoirs in India and Sri Lanka. Fig. 5 The northern sluice of the Daroji reservoir, south of Vijayanagara. This "double sluice" construction became prominent in the sixteenth century, when the Daroji embankment was constructed. This sluice and reservoir have been maintained and continue to operate (photo by Kathleen D. Morrison).

and reconstruction (Morrison 1993, 1995). For example, the Daroji reservoir, the terminus of one of the largest systems in our study area, continues to collect runoff from a catchment area of 955 km^2 and provides water for downstream agricultural fields (Fig. 8).

Research on Middle Period reservoirs includes analyses of pollen and charcoal from reservoir sediments (which allow the reconstruction of fire and vegetation histories), sedimentological studies of reservoir fill and changes to erosional regimes and local hydrology, and stylistic analyses of sluice and embankment construction (e.g., Morrison 1994, 1995; Myrdal-Runebjer 1994, 1996). In addition, we have

Water Management and Reservoirs in India and Sri Lanka. Fig. 6 Masonry waste weir, or spillway, to regulate high water levels at the edge of a Middle Period reservoir embankment near the village of Kurugodu (photo by Kathleen D. Morrison).

Water Management and Reservoirs in India and Sri Lanka. Fig. 7 Small Middle Period reservoir and sluice gate in the Daroji Valley, south of Vijayanagara (photo by Kathleen D. Morrison).

also considered tens of thousands of textual and inscriptional records describing facility construction and maintenance as well as conflicts over water, land, labor,

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Water Management and Reservoirs in India and Sri Lanka. Fig. 8 ASTER satellite image of the Daroji reservoir first built in the sixteenth century, south of Vijayanagara. Notice the strong growth of agricultural crops indicated by the reflection of near-infrared wavelengths (shown here in red) downstream from the embankment. Vegetation growth is also occurring on the edges of the reservoir as receding water exposes moisture retaining sediments (data originally obtained from NASA).

Water Management and Reservoirs in India and Sri Lanka. Fig. 9 Photo showing the accumulation of an estimated 2–3 m of silt and clay, to near the top of a sluice gate. This reservoir is adjacent to the village of Avinamodugu, south of Vijayanagara (photo by Kathleen D. Morrison).

and rule (Kotraiah 1995; Morrison 1995; Morrison and Lycett 1994, 1997). All of these diverse lines of evidence suggest that Middle Period reservoirs, like their contemporary and colonial counterparts (Mosse 2003: 45–46), were highly unreliable sources of irrigation. Runoff-fed reservoirs, in particular, may fail to fill in dry years; in the drier districts, this meant not only that reservoirs could usually not support wet crops such as rice, but also that dry crops such as millets might not be assisted by the facility. The situation was somewhat better in areas of higher rainfall, but everywhere in southern India reservoirs are marked by high evaporation rates, high siltation rates, and ongoing maintenance challenges (Fig. 9).

Reservoirs, Politics, and Contemporary Development

Across much of South Asia, contemporary "big dam" projects have come under attack as the legacies of high modernist social and environmental engineering (cf. Gadgil and Guha 2000; Scott 1998). In India, well-organized and highly visible social protests have been made against specific projects such as the Sardar Sarovar project and others along the Narmada River. Often, antidam groups suggest that the answer to sustainable and equable development lies in a return to a "traditional" system of technology and management. It is not our purpose to argue the case for "modern" or "traditional" forms of water distribution. Rather, we wish to suggest that arguments that hinge on the dichotomies of large/small, equitable/inequitable, and political/apolitical that often accompany distinctions between "modern" and "traditional" forms of water management are inappropriate.

The notion that large political dam projects are entirely a product of modernity is decidedly incorrect. This is no clearer than in South India, where some Middle Period reservoirs were created with embankments more than 3.5 km in length and over 15 m in height. As already noted, the Daroji reservoir in northern Karnataka pooled runoff over a total catchment area of nearly 1,000 km^2; however, size alone is not the issue. Both small and large reservoirs were deeply political projects, tied to networks of patronage and power. Middle Period reservoir construction was sponsored by a wide range of political leaders from kings (rarely) to local chiefs (commonly) and was also connected with Hindu temples in a number of ways (Morrison 1995; Morrison and Lycett 1994, 1997). Moreover, even during the Iron Age and Early Historic Periods, shifts from a reliance on rain-fed agriculture to reservoir irrigation would have produced a new material order on the landscape that was necessarily related to sociopolitical fields. Indeed, the questions – how was labor mobilized? Who had access to irrigation water? And how was this decided? – are entirely appropriate in examining the entire history of water management. The answers to these questions undoubtedly had sociopolitical ramifications for ancient inhabitants. This may have especially been the case when irrigation accompanied the introduction of new cultigens and cultural values of cuisine shifted. It is not difficult to imagine the profound

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social consequences of being a dry-farming millet producer/consumer versus a wet-farming rice producer/consumer when rice was a high status cultigen and the preferred donation to Hindu temple gods during the Middle Period, for example.

The above considerations of the (un)reliability and the political nature of historic reservoirs of South India and Sri Lanka are not to suggest that these impressive systems have no contemporary value with regard to (re) developing water management strategies. Quite the opposite is true: work on the 3,000-year history of irrigation in southern India shows both success and failure in equal measure, portents for a reasonably hopeful future. Thus, although there is no simple solution to the water problems of the dry tropics of South Asia, surely an informed perspective on the actual historical experiences of the region must provide a more secure basis for future planning than either a romantic and unrealistic view of "tradition" or a blind faith in "modern" science and technology.

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