Dams and Reservoirs
Volume 22 Issue 3 and 4

Dams and Reservoirs 2012 **22**(3 and 4), 129–143
http://dx.doi.org/10.1680/dare.13.00004
Keywords: bridges/dams, barrages & reservoirs/water supply

ice Institution of Civil Engineers publishing

The potential of sand dam road crossings

Ian Neal MSc
Technical and Development Manager, Excellent Development, Brentford, UK

In many African dryland regions, culverts are built under low-volume rural road river crossings. The capacity of culverts is often inadequate to accommodate the peak floods and, over time, sedimentation reduces this capacity further. As a result, culverts are vulnerable to being washed away. Sand dams that incorporate a ford are an alternative to culverts and offer significant benefits. Correctly designed sand dams manage flood flows and are a robust, cost-effective alternative. Among additional benefits, sand dams recharge the aquifer, reduce downstream flood risks and provide a reliable, year-round water supply in water-scarce environments. This paper documents a case study from Kenya where a sand dam acts as both a road crossing and the source for a water pipeline. The paper describes the principles for siting, design and construction of sand dam road crossings, where this approach is appropriate and the barriers and enablers to wider adoption.

1. Introduction

This paper presents the case for using sand dams as a road crossing across seasonal river channels on low-volume rural roads (LVRRs) as an alternative to culverts and vented ford crossings. It documents examples of sand dam and raised drifts river crossings on LVRRs in Makueni County in south-east Kenya, including the example of a sand dam that is both a rural road crossing and a water source for a piped water distribution system. It describes factors to consider in their siting, design and construction and the potential benefits of sand dams over traditional river crossing structures. Finally, it discusses some of the barriers to wider adoption and proposes possible actions to overcome these barriers and enable scaling-up.

2. The importance of rural roads to economic development

The impact of access on poverty has been well defined and quantified. Without physical access, rural communities struggle to access health and education services or take advantage of markets or employment opportunities (see Table 1). In terms of poverty impact, rural roads form the most important part of a national road network in terms of connecting rural communities to basic services and markets (Kingombe, 2011). Across Asia, 80% of the road network consists of rural roads and this pattern is repeated across Africa. In Kenya, as Table 2 shows, 82% of roads are classified as unpaved LVRRs.

Road investment represents a major proportion of development expenditure. By way of illustration, in Makueni County, Kenya, the 2002–2008 district development plan proposed 87% of investment on roads, of which only 1·2% is allocated to maintenance (Figure 1).

3. The importance of maintaining rural roads

Unless rural roads are well maintained, the benefits and the value of the investment will be short-lived. The Kenyan Roads Board found only 10% of Kenyan roads are in good condition and this falls to 5% when looking at unclassified rural roads, with 72% in poor condition (Table 3).

Road deterioration has become a growing issue in many developing countries. The economic argument for prioritising maintenance is well understood and overwhelming (Johannessen, 2008). When it comes to rural roads maintenance, prevention is better than cure. Research by the ASIST AP programme of the International Labour Organisation (ILO) of Asian road networks (Donnges *et al.*, 2007) shows that many countries are failing to provide sufficient funds for effective preventative maintenance and instead continue to prioritise construction of new roads over upkeep of existing roads. As a consequence, the overall value of road assets and length of road network in acceptable condition is falling. The optimal cost of annual maintenance is a small fraction of the construction cost (typically 5–6% per annum for an unpaved rural road).

Assessment and evaluation of rural road maintenance systems by the ILO found this economic case is particularly strong on unsealed low-volume rural roads where it is crucial that maintenance is carried out on a timely and regular basis (i.e. periodic and routine maintenance). However, in reality, only 20% of typical Asian rural roads maintenance programmes consisted of regular, routine maintenance and 80% was spent on emergency, unplanned repairs and reconstruction activities (see Table 4). Again this pattern is repeated in sub-Saharan Africa.

3.1 The importance of drainage on rural roads

There is an old adage that says ‘Three of the most important aspects of road design are drainage, drainage and drainage’. This is especially true of unpaved LVRRs. On paved highways,

Direct benefits of improved rural roads	Wider impacts of improved rural roads
Reduced vehicle operating costs	Improved access to health services
Reduced fares and transport costs	Improved enrolment and attendance at schools
Reduced accident rates	Improved access to and reliability of water supply services
Reduced travel times	Improved quality and reduced cost of health service delivery
Maintains value of road assets	Improved access to farm inputs and agricultural extension
Increased local employment	Reduced cost of goods and services in rural areas
Increased opportunities for small contractors	Improved access or reduced cost of transporting produce to market
	Increased trade and commerce along roadsides
	Improved farm incomes and employment opportunities
	Reduced rural–urban migration
	Improved agricultural productivity and food security
	Increased availability of skilled professionals (e.g. teachers, engineers etc.)
	Reduced work burden on women collecting water and fuel
	Incentive for farmers to grow a surplus for market

Table 1. The benefits and impacts of improved rural roads (Kingombe, 2011)

with high traffic volumes, maintaining the roadway surface is a major priority. However, rural roads have lower traffic volumes and road surface maintenance represents a smaller proportion of spend. For rural roads, the priority is providing and maintaining the drainage system, because on such roads, at this traffic level, the weather causes more damage than does the traffic (Robinson *et al*., 1998). Given the financial constraints rural road authorities in low-income countries operate under, the challenge is to design road river crossings that require less periodic and routine maintenance and are less prone to severe flood damage.

4. Focus on dryland regions

This paper is specifically concerned with LVRRs in drylands, defined as areas with dry-humid, semi-arid and arid climates. This is because sand dams can only be built on seasonal rivers with sufficient sandy sediment, conditions that are only found in dryland climates. As Figure 2 shows, over 40% of the world's land surface is classified as drylands; 35% of the world's population lives in drylands. Most of these people live in the dry sub-humid and semi-arid regions that are best suited to sand dams. In Africa, rural, dryland communities are among the most impoverished, inaccessible and poorly served. Here both physical access and water availability are two of the most important constraints on development. In such conditions, incorporating sand dams as LVRR river crossings offers the potential to improve both physical access and water availability in water-scarce environments.

Suitable sand dam sites are most common on relatively small catchments in the upper and middle courses of river basins in the transition from hills to plains and where a suitable foundation is reasonably close to the surface. In drylands,

Road class: km	Paved	Unpaved	Total
International trunk roads – A	2%	1%	2%
National trunk roads – B	1%	1%	2%
Primary roads – C	2%	3%	5%
Secondary roads – D	1%	6%	7%
Minor roads – E	0%	16%	17%
SPR – special-purpose roads	0%	6%	7%
U – unclassified roads	1%	60%	61%
Total	7%	93%	100%
Low-volume rural roads			

Table 2. Kenyan roads classification (source: Kenyan Roads Board)

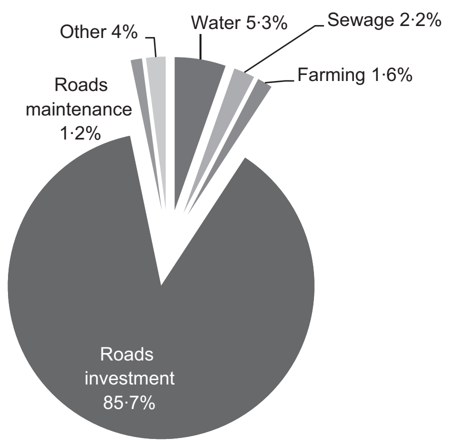

Figure 1. 2002–2008 Makueni district development plan budget

most LVRR river crossings are across seasonal rivers. There are very few LVRRs that cross permanent rivers. In drylands, only larger rivers flow permanently and the cost of a bridge across a permanent river is rarely justified on LVRRs. In other words, in dryland regions, many sites of LVRR river crossings are also suitable sites for sand dams.

5. Traditional LVRR crossings across seasonal rivers

There are three common types of seasonal river crossing used on LVRRs: drifts, culverts and vented fords (also known as causeways).

- **Drifts** (Figure 3) are used to cross small river channels. These are the simplest structures available and are easy to maintain. All of the flow from seasonal floods passes over the road crossing. The road surface is constructed of concrete or stone pitching to resist scour. This protected concrete section of the road must extend so that the level of the road surface is at least 0·5 m above the peak design flood. Where the road level rises above the existing river bed level, they function in a similar way to sand dams.
- **Culverts** are typically used to cross larger rivers than drifts although, as found in Makueni County, drifts can be used to cross large rivers as well. Pipes are laid under the road surface and are designed to allow all of the flow from seasonal floods to pass under the road crossing.
- **Vented fords** (Figure 4) are similar to culverts. At low flows, the water passes under the road but at high flows they act like drifts and allow floods to overtop and flow over the road. Like drifts, the protected, paved section of the road must extend high enough up the river banks to accommodate all of the design flood within the paved road section.

6. Performance of traditional road crossing designs

Designing and constructing road crossings across seasonal rivers in drylands presents unique challenges because of the climate and hydrology of drylands. Rainfall tends to be intense and highly variable both spatially and between years and between dry and wet seasons. Intense localised storms result in high levels of runoff and soil erosion and flash floods that flow down the seasonal river valleys, flowing for just a few days or even hours. Storm hydrographs, that measure river flow over time, tend to be very peaky. That is, the flow rises and falls very quickly especially on the smaller catchments where most LVRR river crossings are found.

Bridges are typically used to cross perennial rivers found in the lower and middle catchments and on all river crossings on larger paved roads. Where unpaved rural roads cross smaller, seasonal rivers, drifts and vented fords are the most common crossing. They are better suited than culverts to dryland regions because of their capacity to accommodate peak floods. It is seldom cost-effective, especially on LVRRs in low income countries, to construct either bridges or culverts with sufficient capacity to cope with peak floods.

Calculating the peak design flood on small seasonal rivers also presents particular challenges in low-income, dryland countries. Very few, if any small rivers are gauged and accurate long-term rainfall data required for modelling peak design floods, is often

Road type and condition	Good	Fair	Poor
Classified	10 651	31 847	19 438
Unclassified	5440	22 165	71 345
Grand total	**16 090**	**54 012**	**90 784**
Classified roads	17%	51%	31%
Unclassified roads (LVRRs)	5%	22%	72%
Total	10%	34%	56%

Table 3. Summary of road conditions (source: Kenyan Roads Board)

	Optimum	Typical
Emergency repairs and reconstruction	20%	80%
Periodic maintenance	40%	10%
Routine maintenance	40%	10%

Table 4. Types of maintenance expenditure (source: ILO)

unavailable or difficult to access. Even where sufficient rainfall data are available, many district authorities lack the human and financial capacity to calculate flood discharges and design individual LVRR river crossings using design models.

As a result, many LVRR river crossings are poorly designed with insufficient flood capacity and are prone to damage by annual floods. In 2009, a team including engineers from Kenya's National Taxpayers Association studied 17 unpaved rural roads projects in four districts (NTA, 2009). Each project was at least 3 years old. It found 41% were in good condition, 29% in fair condition and 29% in poor condition. Inadequate drainage and damaged culverts were noted in all but two of the project reports. Among the common problems observed were culverts with inadequate head walls and aprons, culverts and drifts that were blocked, damaged or washed away and poorly constructed culverts, as shown in Figure 5 and 6. Figure 7 describes some of the common ways poor design and construction can result in damage and failure to LVRR river crossings.

7. Sand dams as an alternative to traditional LVRR crossings

A proven alternative to culverts and vented fords are road crossings that incorporate a sand dam. The main difference with sand dams is that all of the river's flow passes over the road surface, while water below the spillway is held back by the dam. Kenya is the home for the greatest concentration of sand dams in the world, although examples are found in many other countries with similar conditions. Since their introduction to Kenya in the 1950s, at least 1000 sand dams have been built in the Machakos, Kitui and Makueni counties of eastern Kenya, mostly by registered self-help groups supported by Kenyan NGOs (non-government organisation).

They are simple, low-cost and low-maintenance structures that provide an improved, year-round, local water supply for domestic and farming use. Seasonal rains quickly fill the dam with sediment laden water. The sediment consists of silt and sand. The heavier sand sinks behind the dam, while the lighter silt remains suspended in the water and is carried over the dam and downstream. Sand accumulates until the dam is completely full of sand up to the spillway. The stages are shown in Figure 8. Water is stored within

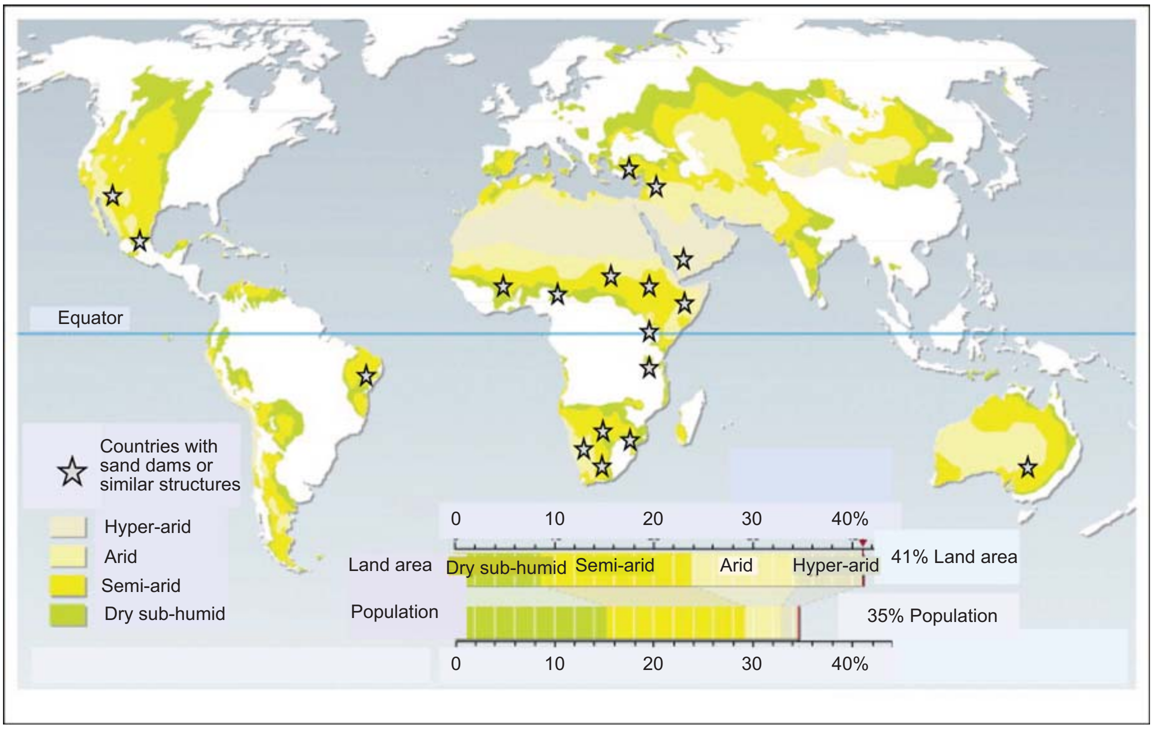

Figure 2. The world's drylands regions

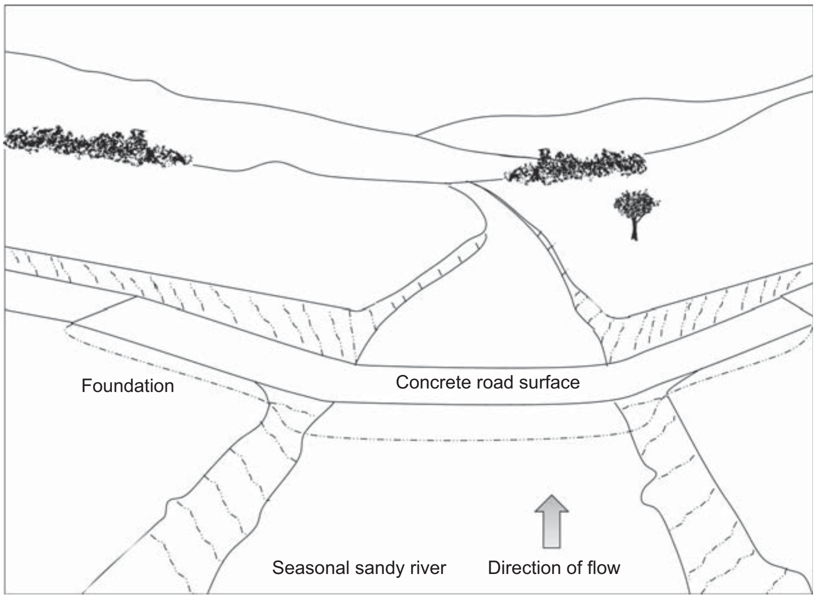

Figure 3. A traditional drift road crossing

the sand, making up 25–40% of the total volume of the aquifer. The sand filters the water and the lack of open water surface reduces contamination and evaporation and prevents water-borne parasites such as mosquitoes from breeding.

A typical Kenyan sand dam is 2–3 m high from the bedrock to the spillway and spans a 10–30 m wide river channel. Such dams store in the region of 2–10 million litres of water held in the pores between the sand grains. However, this varies considerably. The largest dams are over 5 m in height, span 50 m wide river beds and are 100 m in length from wing tip to wing tip, while the smallest are only 5 m wide and 1 m high. Figures 9–11 show how a sand dam and an LVRR crossing may be combined into one structure. Figure 9 shows

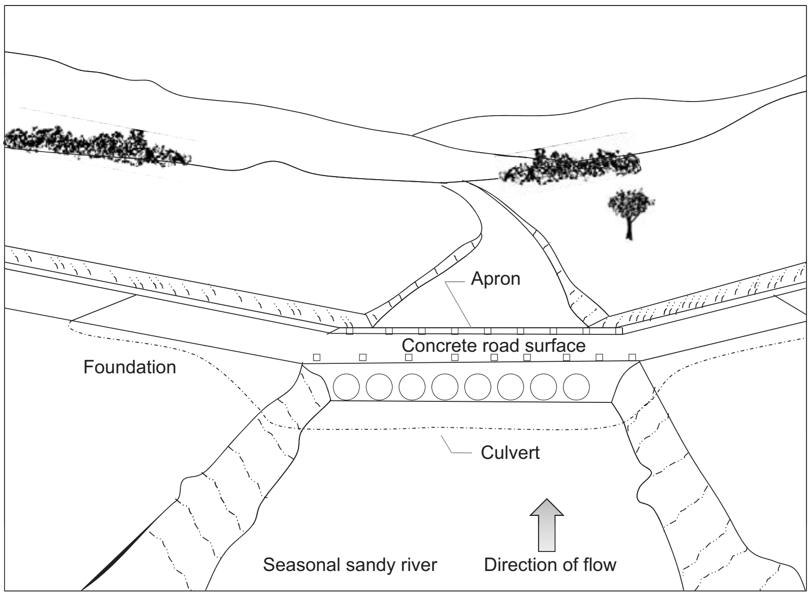

Figure 4. A vented ford road crossing

Figure 5. A restricted culvert in India: without regular maintenance to remove sediment and flotsam, the capacity of a culvert is greatly reduced

the dam before it has filled with sand; Figure 10 once it has matured and filled with sand; and Figure 11 shows the crossing in cross-section.

8. Case study: LVRR river crossings in Makueni County, Kenya

In 2012, the author toured Makueni County in Kenya with the district roads engineer in order to study a range of LVRR seasonal river crossings. The study shows the technical feasibility of sand dam road crossings and their potential to create year-round water sources.

8.1 Dam 1: Kako and Kyaluma sand dam road crossing and water source

The sand dam road crossing shown in Figures 12 and 13 was constructed in 1994. The river channel immediately upstream of the dam is 35 m wide. The dam, however, is located on a bend in the river and is sited on a rock spur that runs at an angle to the main river flow. Consequently the dam spillway is 80 m in width. The spillway has a 1 m step and the total length of the dam is 100 m. Despite being set at an angle with a relatively small spillway cross section, the dam is in good condition with no evidence of scour at the limits of the dam. The sand dam is designed to supply ten water kiosks in the neighbouring villages, three secondary and three primary schools and a health centre. The water flows through an infiltration gallery to a shallow off-take well and then pumped into the piped network, using a mechanised pump, at the rate of approximately 50 m^3/day.

Figure 6. A failed culvert river crossing. A combination of insufficient flood capacity, poor headwall construction and unpaved road surface caused this culvert in India to fail. The river eroded a new channel to the left-hand side of this culvert

Figure 14 shows a typical configuration of infiltration gallery, shallow well and hand pump. On small dams a shallow well and hand pump can serve around 300 people. On larger dams, a shallow well and mechanised pump can serve 3000 people. Where yield of the dam allows this can be increased further by a series of infiltration galleries and pumps (Hussey, 2007). Water for livestock watering, small-scale irrigation or fish ponds can be abstracted by foot or small mechanised pumps from holes scooped in the sand.

8.2 Dams 2, 3 and 4: Recently constructed drifts and elevated drifts

The river crossings recently constructed in Makueni County by the Rural Roads Deptartment provide an interesting case study. In the past 3 years over 30 river crossings of 100 m or more have been constructed in the county. Recognising the potential to capture water behind a drift, over the past 6 years, there has been a conscious move away from constructing culverts towards constructing drifts even on larger rivers and elevating the height of the drift in order to impound more sand and water upstream of the drift. In this way, the larger elevated drifts act as sand dams. Figures 15–17 show three drifts that illustrate the range of drifts found across the county.

Dam 4 (Figure 17) is an interesting example. Initially constructed as a culvert, floods eroded the far river bank and caused the river to divert around the culvert, cutting a new 50 m wide channel. When the crossing was repaired, the crossing and paved section of the road was extended to a point above the peak design flood, to prevent the river diverting again. The far bank was then planted with grasses and trees to encourage sedimentation and the river to follow its original course. Then the culvert openings were filled in, essentially converting the culvert into a drift and causing sand to be deposited upstream of the drift.

9. Recommendations for siting and design of sand dam road crossings

The following guidance is based on the advice in ‘Sand dams: a practical guide’ (Maddrell and Neal, 2012) and the process and experience of Excellent Development, a UK development agency and its Kenyan partner agencies. Over the past 10 years, these organisations have supported over 100 community-based

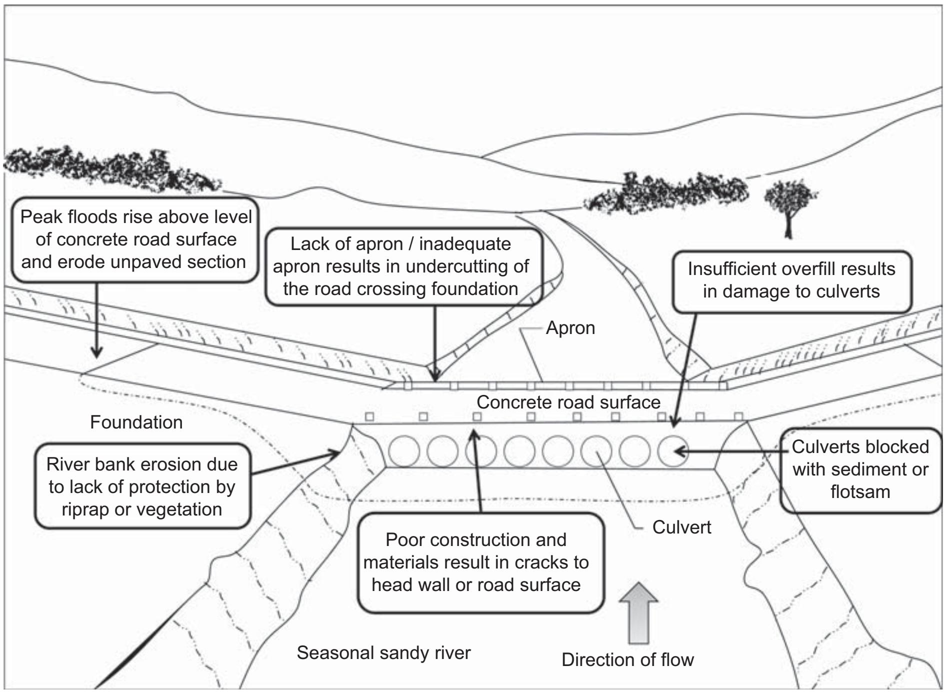

Figure 7. Common causes of damage and failure to low-volume rural road river crossings

organisations in Makueni and Machakos counties, Kenya to construct over 400 sand dams.

9.1 Sand dam siting

As stated, sand dam road crossings can only be built in dryland regions across seasonal rivers with sufficient sandy sediment. As with culverts and vented fords, it is recommended that sand dams are sited so that they are perpendicular to the river on a reasonably straight section of river. However, as dam 1 illustrates, this is not essential provided the dam does not redirect the river and the river continues to follow its previous course.

9.2 Sand dam foundations

Sites where the bedrock or suitable stable foundation is at or close to the river bed are preferred since this keeps construction costs to a minimum. Where foundations must be excavated into the existing river bed, the costs increase significantly (Table 5). Forty percent of these costs consist of community-based labour.

Figure 18 shows cross-sectional design of an elevated drift typical of Makueni County. Note that where the drift is not constructed on top of bedrock, the footing of the drift is excavated at least 1·5 m below the existing river bed level. The mass of the drift prevents movement or undermining of the drift's foundation. However, sand dams can raise the upstream river bed level 5 m or more above the original level of the river bed; that is, significantly higher than the elevated drifts constructed in Makueni. Where a dam impounds a significant depth of water and is intended to create a water source, it is strongly recommended the dam forms a seal with the bedrock/ foundation and that this foundation extends into the river banks to a point 1·5 m wider than the annual flood width. Beyond this point, the foundation should gradually rise towards the surface. Where the river bed consists of compacted subsoil, the foundation should be excavated into this layer.

9.3 Sand dam spillway design

It is essential that the sand dam does not cause the river to spread or divert. To achieve this, a stepped spillway is used. Each spillway is designed to accommodate the three different design flood flows shown in Figure 19. The central spillway accommodates a flow equivalent to the flow when the river is flowing at the top of the river banks prior to the dam's construction. The width of this central spillway should be approximately 1·5 m inside the river banks.

The width and position of the second spillway corresponds to the width of the annual flood and the combined capacity of the central and second spillways is equivalent to this annual flood. On larger rivers where the design flood exceeds the annual flood for a significant time, a third spillway accommodates this flow. On smaller rivers, less than 10 m in width, this third spillway is

Figure 8. Mbuani dam in the Nzyaa Muysio Valley, Mbuani District, Makueni County, Kenya at different stages: (a) original site; (b) immediately following construction; (c) dam filled with water; (d) a mature dam filled with sand

rarely required, although dams should always be monitored after significant rains and the spillway extended as required. A return period of 50 years is recommended for the peak design flood.

Hydrological models can be used to calculate these design flows provided the required rainfall and catchment data and technical capacity are available (Alderson, 2006). However, in the absence of this data and capacity, it is possible to estimate these flows through a combination of field observations and local knowledge of flood flows: essentially asking local people with a deep and long knowledge of the river about the frequency, duration and magnitude of floods. Interestingly, this is the approach used in Makueni County to estimate the peak flood levels that the river crossings must accommodate.

The spillway of the elevated drifts of Makueni is defined by the profile and extent of the paved section of the road. The more the drift is elevated above the original river bed, the more the upstream river bed will rise and the river will be encouraged to spread beyond its banks. Hence it is recommended to incorporate a stepped spillway in this design.

9.4 Sand dam apron

To prevent the river undermining the foundation, a concrete platform/apron or gabions extending for 2 m from the base should be constructed downstream of the crossing.

9.5 Construction method

Most sand dams in Kenya are constructed of rubble masonry with steel reinforcement. The Makueni drifts are constructed of reinforced concrete. Both structures rely on their mass for their stability. Either construction method is suitable for sand dam road crossings.

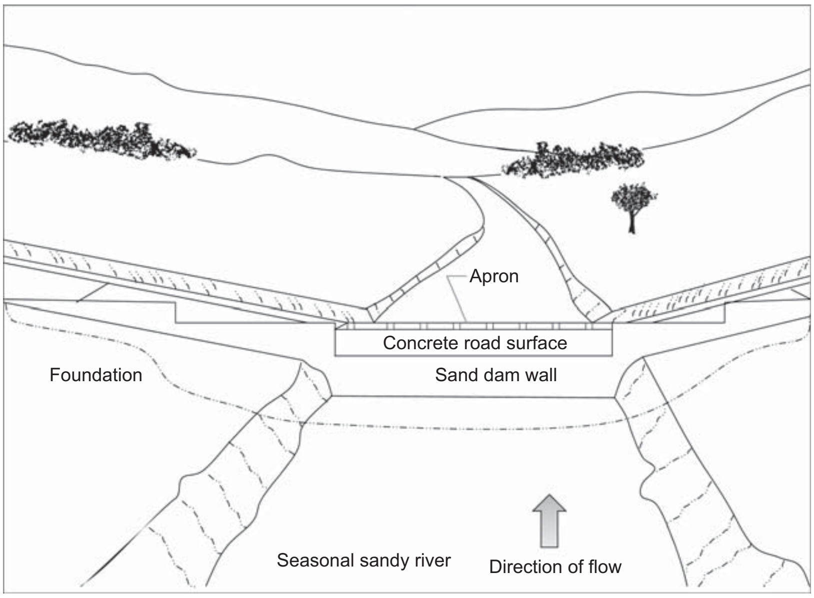

Figure 9. An immature sand dam road crossing

10. The benefits of sand dam road crossings

To understand the potential benefits of sand dam road crossings it is necessary to understand their advantages over traditional culverts as well as the direct and indirect benefits of increased water availability.

10.1 The advantages of sand dam road crossings over culverts

There are many examples of sand dams in eastern Kenya that have withstood the ravages of time and annual floods over many years, even decades without the need for any repair or

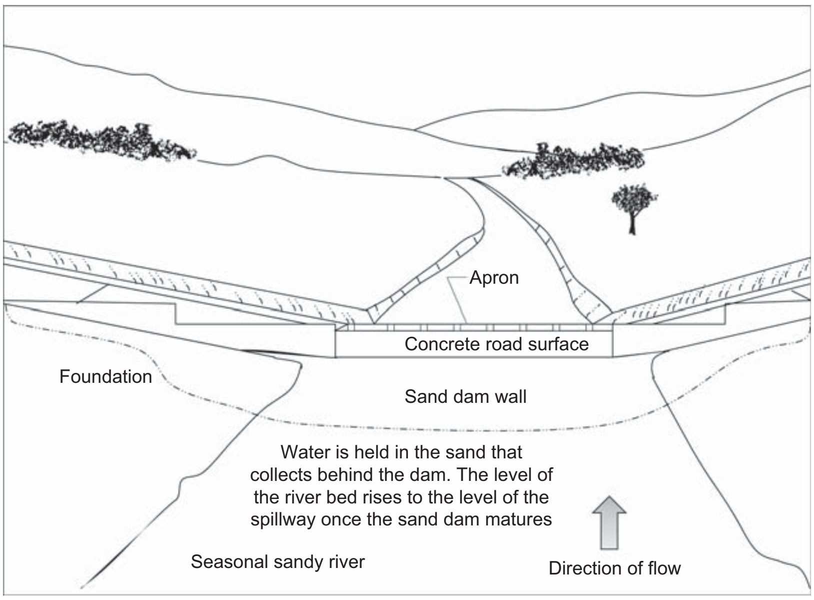

Figure 10. A mature sand dam road crossing

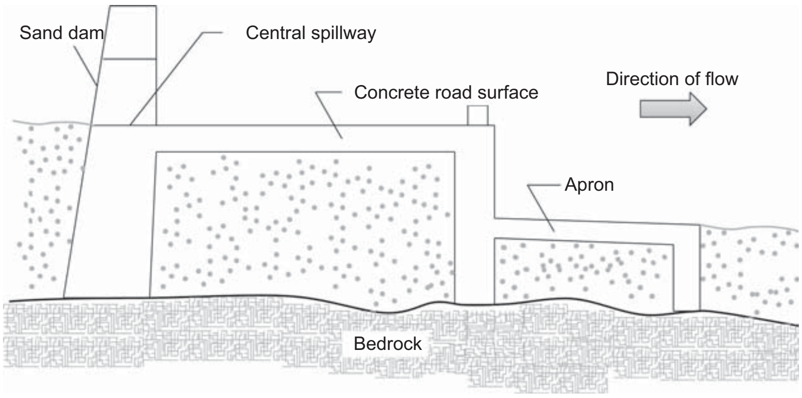

Figure 11. A cross-section of a sand dam road crossing

maintenance and are as strong today as the day they were built. Equally, there are examples of correctly designed and constructed drifts and vented fords which are equally resilient. However, as the National Taxpayers Association studies found (NTA, 2012a, 2012b), there are also many examples of road-river crossings that have not been well designed and/or constructed and which are seriously damaged within a few years of construction. Similarly poorly designed and constructed sand dams are equally prone to flood damage. So, while the economic case for ensuring road-river crossing structures are better designed and built and better able to withstand peak floods is overwhelming, this argument applies equally to culverts, drifts and sand dams.

However, where sand dams have an advantage over culverts from a road engineering perspective is that sand dams require less periodic maintenance than culverts. Not only does this reduce the cost of maintenance, but, as shown in Table 3, periodic maintenance in low-income countries is rarely adequate. As a result, culverts are more prone to severe flood damage and hence sand dams offer a potentially more resilient and cost-effective solution. Further research on their respective costs and functionality is needed.

10.2 The benefits of increased water availability

Sand dams are one of the lowest-cost forms of rainwater harvesting. First and foremost, sand dams create year-round water source in water scarce environments. They save time and reduce the burden of collecting water. This in turn creates wider benefits and opportunities. Sand dams enable dry season irrigated vegetable and tree nurseries and livestock watering (Mutuku, 2012). Numerous studies of sand dam programmes, such as Lasage *et al.* (2008) summarised in Table 6, show that sand dams improve water availability, food security and nutrition, health, incomes and school attendance.

10.3 Environmental benefits

Dryland regions are particularly vulnerable to the impacts of climate change and environmental degradation. Sand dams build resilience of dryland communities to cope with shocks such as droughts and floods.

Figure 12. A sand dam road crossing between Kako and Kyaluma villages, Mbooni East sub-district, Makueni County, Kenya including shallow well and pump house

Figure 13. The view from below the dam shown in Figure 12. The spillway is 80 m wide, 1 m high and 2·5 m above the river bed

Sand dams rejuvenate the riverine ecology: The water held behind the dam spreads horizontally, recharging the aquifer above and below the dam to create a permanent increase in the water table. This transforms the local ecology allowing trees to naturally colonise the river banks.

Research on Kenyan dams (Hut *et al.*, 2008) shows that only 1–3% of the river's discharge is retained behind any individual dam, the remainder continues its natural course towards the ocean (Aerts *et al.*, 2007). While downstream flows are marginally reduced during the rainy season, seepage around the dam increases downstream dry season flows.

Sand dams can contribute to increasing the longevity, yield and power generating capacity of downstream reservoirs.

The sudden failure of open water dams can significantly threaten downstream life and property. This is not an issue with sand dams since any failure does not result in a sudden release of impounded water.

10.4 Realising the combined benefits of sand dam road crossings

There already exists a strong business case for constructing sand dams in rural drylands as a method of providing water for domestic and production purposes. By integrating sand dams within LVRR river crossings, the opportunity arises to both improve rural roads infrastructure and increase water availability in drylands while sharing costs between rural road and water funding authorities.

The key to unlocking this potential is building greater awareness and closer dialogue and co-operation between these authorities at both the local and national scale. Although the cost of sand dam road crossings that include an integrated improved water point will be marginally more than the cost of constructing a vented ford or drift alone, in most cases, the wider benefits will justify the additional cost. The challenge is to gather the evidence to demonstrate this business case and develop the support and funding mechanisms that overcome the barriers to wider adoption. Table 7 proposes some actions to enable wider adoption.

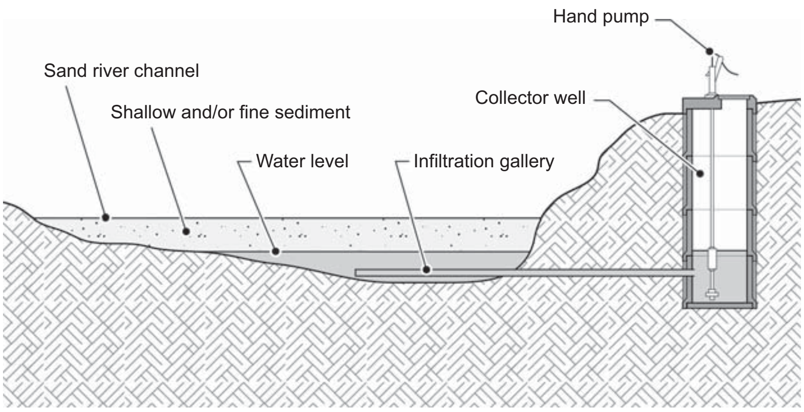

Figure 14. Infiltration gallery, shallow well and hand pump configuration (Dabane Trust/Ken Chatterton)

Figure 15. Dam 2, a small 24 m length drift

Figure 16. Dam 3, 80 m drift, built on bedrock

Figure 17. Dam 4, 200 m repaired and adapted culvert

	Kenyan Shilling/m	US$/m
Dam 2, small drift, constructed on bedrock. Little or no elevation above the existing river bed level	35 000	430
Dam 3, large drift, constructed on bedrock, elevated 1 m above the existing river bed	60 000	740
Dam 4, large drift, constructed on excavated foundations at least 1·5 m into existing river bed and elevated 1 m above the existing river bed	130 000	1600

Table 5. Typical costs of drift construction per metre (Makueni County, Kenya)

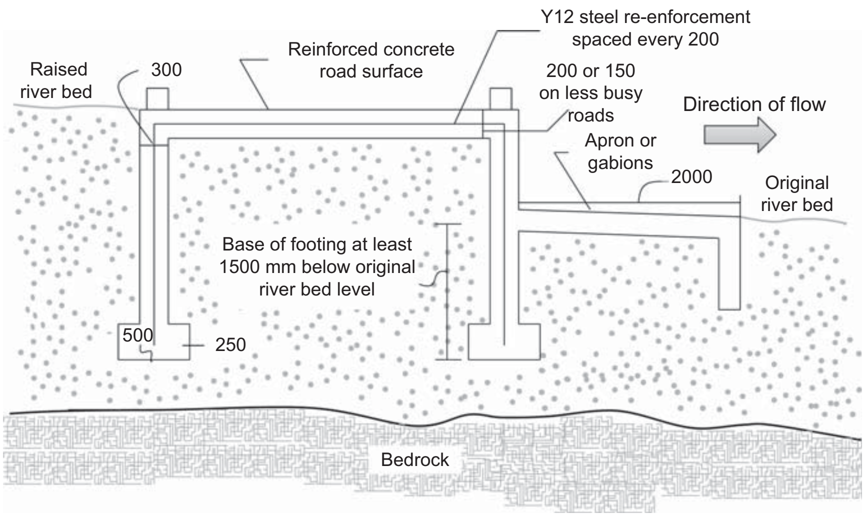

Figure 18. A cross-section of a raised drift crossing (based on Makueni Rural Roads Department guidance, dimensions in mm)

11. Conclusion

This paper outlines how, in suitable dryland areas, sand dams can be integrated within LVRR river crossings. In Makueni, Machakos and Kitui counties in Kenya over 1000 sand dams have been built. This experience demonstrates that when correctly designed and built, sand dams are robust, low-maintenance structures that provide significant long-term benefits. The example of the Kako-Kyalama sand dam road crossing demonstrates the technical feasibility of the approach and the huge potential to abstract water from such crossings. The elevated drifts, introduced over the past 6 years by the Makueni Rural Roads Deptartment effectively function as sand dams. They provide further evidence that the approach is technically feasible even on crossings over 100 m in length.

Through the use of labour-based construction and use of small-scale contractors, sand dam road crossings increase local employment and incomes during implementation. The key to unlocking their wider development potential relies on closer collaboration between rural roads authorities and the other

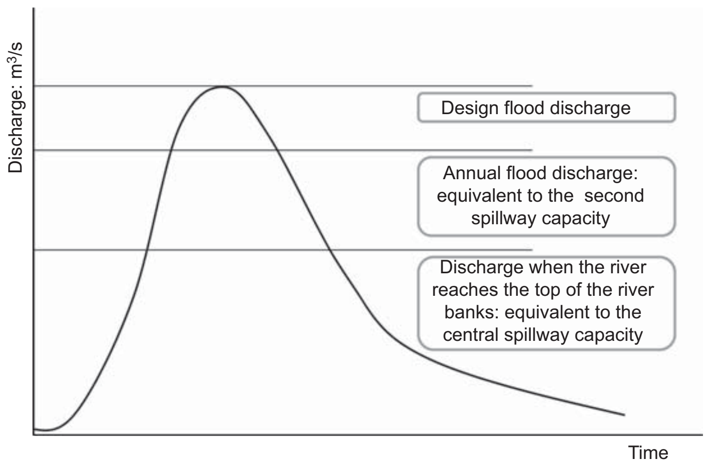

Figure 19. Design storm hydrograph in relation to spillway capacities

	Kindu (dam)		Koma (no dam)	
Indicators	1995	2005	1995	2005
Access to drinking water wet season: km	1	1	1	1
Access to drinking water dry season: km	3	1	4	4
Domestic water use: l/day	61	91	136	117
People exposed to drought	420	−	600	600
Health	0	+	0	0
Households with irrigated crops: %	37	68	38	38
Agricultural water conservation: l/day	220	440	160	110
Brick and basket production: Ksh/year	1500	4500	−	−
Household incomes: Ksh/year	15 000	24 000	15 000	15 000
Vegetation density/biodiversity	0	+	0	0/−

Table 6. Summary of sand dam benefits (Lasage *et al.*, 2008); 1000 Ksh = US$14; 0, unchanged; +, slightly improved; −, slightly deteriorated

Primary goal	Example measures
Increase technical knowledge	Integrate into existing study exchange programmes Integrate into road engineering training programmes Produce technical guidance and design standards
Demonstrate business case	Conduct value for money and functional assessments of existing LVRR river crossings Conduct cost benefit analysis of sand dam road crossings
Increase implementation and management capacity	Provide training to small contractors and NGOs Strengthen capacity of community-based organisations to manage and operate sand dam water points Involve end-user groups in planning and implementation
Increase linkages and synergies	Increase national inter-agency dialogue and collaboration Increase local inter-agency dialogue and collaboration Promote inter-agency cost sharing Share knowledge between road and water engineers and between state, private sector, NGO and academic actors
Funding mechanisms	Promote increased use of labour-based methods Align use of community labour with rural social protection programmes such as TASAF (Tanzania Social Action Fund) 3 in Tanzania Explore innovative funding such as payments for watershed services, green water credit and carbon credit mechanisms Integrate approach within wider programmes such as climate and disaster resilience, conservation farming or livestock development programmes

Table 7. Intervention examples to promote wider adoption

sectors that contribute to rural development and by strengthening local community organisations such that they have the capacity to manage and operate the infrastructure. Finally, further research is required to demonstrate the business case for the approach and to experiment with innovative funding mechanisms.

REFERENCES

Aerts J, Lasage R, Beets W, de Moel H, Mutiso G, Mutiso S and de Vries A (2007) Robustness of sand storage dams under climate change, vadose zone. *Vadose Zone Journal* **6(3)**: 572–580.

Alderson A (2006) *The Collection and Discharge of Stormwater from the Road Infrastructure.* Austroads, ARRB Group Ltd, Melbourne, Australia.

Donnges C, Edmonds G and Johannessen B (2007) *Rural Road Maintenance – Sustaining the Benefits of Improved Access (SETP 19)*. International Labour Office, Bangkok, Thailand.

Hussey SW (2007) *Water from Sand Rivers: Guidelines for Abstraction.* Water, Engineering and Development Centre, Loughborough University, Loughborough, UK. See http://wedc.lboro.ac.uk/resources/books/Water_From_Sand_Rivers_-_Contents.pdf (accessed on 20/12/2012).

Hut R, Ertsen M, Joeman N *et al*. (2008) Effects of sand storage dams on groundwater levels with examples from Kenya. *Physics and Chemistry of the Earth* **33(1–2)**: 56–66.

Johannessen B (2008) *Building Rural Roads*. International Labour Office, Bangkok, Thailand.

Kingombe C (2011) *Achieving Pro-poor Growth Through Investment in Rural Feeder Roads: The Role of Impact Evaluation.* ODI Publications, London, UK.

Lasage R, Aerts J, Mutiso G and De Vries A (2008) Potential for community based adaptation to droughts: sand dams in Kitui, Kenya. *Physics and Chemistry of the Earth* **33(1–2)**: 67–73.

Maddrell S and Neal I (2012) *Sand Dams, a Practical Guide.* Excellent, Brentford, UK. See http://www.excellentdevelopment.com/articles/excellent-news/excellent-development-launch-the-sand-dam-manual (accessed on 20/11/2012).

Mutuku NB (2012) *Impact of Sand Dams on Social Economic Status of the Local Inhabitants. A case of Kitui Central Division, Kenya*. LAP Lambert Academic Publishing, Saarbrucken, Germany.

NTA (National Taxpayers Association) (2009) *Citizen's Report Card on Rural Roads: Getting Value for Money on Investments in Rural Roads Infrastructure.* NTA, Nairobi, Kenya. See http://www.nta.or.ke/nta-reports/citizen-report-cards/eastern-province/cat_view/86-eastern-province?limit=5&order=hits&dir=ASC (accessed on 20-11-2012).

NTA (2012a) *Citizen's Constituency Development Fund Report Card for Mwingi South Constituency, Kitui County.* NTA, Nairobi, Kenya. See http://www.nta.or.ke/nta-reports/citizen-report-cards/eastern-province/cat_view/86-eastern-province?limit=5&order=hits&dir=ASC (accessed on 20/11/2012).

NTA (2012b) *Citizen's Local Authority Transfer Fund Report Card for Makueni County Council, Makueni County.* NTA, Nairobi, Kenya. See http://www.nta.or.ke/nta-reports/citizen-report-cards/eastern-province/cat_view/86-eastern-province?limit=5&order=hits&dir=ASC (accessed on 20/11/2012).

Robinson R, Danielson U and Snaith M (1998) *Road Maintenance Management: Concepts and Systems.* MacMillan, Basingstoke, UK.