

Roads for water: the unused potential

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Roads are generally perceived as infrastructure to deliver transport services, but they are more than that. They are major interventions in the hydrology of areas where they are constructed – concentrating runoff and altering subsurface flows. At present, water-related damage constitutes a major cost factor in road maintenance. Using ongoing research from Ethiopia, this article argues to reverse this and turn water from a foe into a friend and integrate water harvesting with road development. Optimized road designs are required – better planning of alignments, making use of road drainage, road surfaces, and river crossings, but also capturing freshly opened springs and systematically including developing storage and enhanced recharge facilities in road-building programmes. Equally important are inclusive planning processes that are sensitive to the multi-functionality of roads but also to the potentially uneven distribution of benefits and the diverse livelihood impacts. There is a need for closer integration of watershed and road-building programmes. With 5.5 million kilometres of roads in sub-Saharan Africa alone, and road building continuing to be one of the largest public investments, the potential of roads for water harvesting is great.

Keywords: water harvesting, roads, inclusive planning, soil moisture, groundwater recharge

ROAD BUILDING AND ROAD MAINTENANCE are among the largest public investments in developing countries: in sub-Saharan Africa alone they are estimated at US\$7 bn annually, an amount that exceeds by far investments in water resource conservation, for instance.

Transport systems are generally equalled to economic development as they ‘unlock’ areas. Roads however also alter the hydrology and soil conditions around them. At present this usually happens blindly and often not necessarily to the

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benefit of the agricultural communities with land in the vicinity of the road. The challenge is how to reverse and make use of this ‘unused potential’ and have road development that is more inclusive, technically and socially.

Roads block, concentrate or disperse surface and subsurface flows of water. This changes the storage and recharge of water. The local agro-ecology is further affected by the erosion and sedimentation that roads may cause. In the process, some farmers gain and others lose. Historic patterns of land and water use are thus affected. The challenge is how to guide this process to the benefit of roadside communities.

Further, roads also suffer from water-related damage. Inadequate drainage not only leads to land degradation, but also jeopardizes road embankments, increases maintenance costs, and reduces road durability. There is great potential to enhance road drainage with the focus on water storage, groundwater recharge, and retention. The win-win case is substantial; in Ethiopia, for instance, 35 per cent of all road damage is caused by water (World Bank, 2006).

Both road design and road-design processes must optimize the use of roads for local water management. In general, roads need to serve not just mobility but inclusive and balanced growth, which requires a rethink of the design and development process.

This article argues for systematically combining water harvesting and road building, turning a threat into an opportunity. It is based on findings of ongoing research in Ethiopia. The article first takes stock of the current effects of road development on water management and then describes a range of opportunities for optimizing road design for water storage and groundwater recharge in semi-arid areas. The range may not be exhaustive, and in other areas, with other physiographic characteristics, there are other linkages to be made between road development and water harvesting. A later section argues the case for changing the process of road development so as to be more inclusive, in terms of water management but also on a number of other fronts. The final section concludes the paper.

Roads and water: foe or friend – examples

The impacts of roads on local water management are extensive and, as they are typically unplanned, these impacts are often disruptive. Roads alter surface water pathways and dissect the surface catchment. This affects the distribution of soil moisture and patterns of recharge of groundwater. Moreover, erosion of local streams due to badly placed or insufficient road drainage can cause severe downstream gullying. These gullies lead to depletion of both soil moisture and shallow groundwater. The sediment that is transported negatively impacts downstream communities, as it blocks irrigation and drainage channels and causes deposition of coarse material in the fields.

Where drainage from roads is inadequate, this may cause waterlogging in the upstream areas of the newly designed roads, destroying crop land and subsequently causing large evaporation (thus reducing the potential to recharge). Waterlogging undermines slope and subgrade stability of roads and, likewise, increases maintenance costs.

Roads not only change surface flows but also alter subsurface shallow groundwater flows. This happens when roads compact the shallow soil strata. The same applies to fords and low causeways which block subsurface flows in dry river beds. These are issues not well understood and better understanding and awareness could turn a problem into a potential. Subsurface flow behaviour varies depending on soil typology and permeability of road subgrades, embankments, and pavements.

A recent survey of the upgraded Freweign-Hawzien-Abreha Weatsbeha-Wukro Road, Ethiopia (Tigray region), may serve as an illustration of these points. The road extends over a 50-km stretch and is currently being upgraded from gravel to asphalt pavement. The region through which the road crosses has high variability of rainfall in time and space. Food insecurity has been a major challenge in the area adjacent

Table 1 Effects of water from Freweign-Hawzien-Abreha Weatsbeha-Wukro road

<i>Issue</i>	<i>Scale and effect</i>
Gully erosion at downstream sides of culverts	A total of 111 culverts were constructed along the route. Out of these, gully erosion was documented in 65 locations. In only 15 culvert locations, water from the culverts was channelled to soil/water conservation structures (deep trenches, check-dams and ponds). In eight locations, water from culverts caused severe flooding of farmlands and damage to shallow hand-dug wells.
Sedimentation on upstream sites of culverts	At 10 culvert locations along the route, sedimentation was documented at upstream sides of the culverts. In some cases the sedimentation was moved to downstream areas, affecting the lay of the land and soil fertility.
Waterlogging	Waterlogging issues were documented at 35 locations along the road alignment. The waterlogged areas include farmlands and grazing lands. The causes for waterlogging include design problems: in many cases culverts were located at elevations higher than the ground level in the upstream areas, and in other cases culverts were located at lower elevation than the downstream ground level. At certain sites cross-drainage systems were not provided at all.
Erosion of side drains	In 25 locations along the route, erosion of side drains was documented with negative impacts on the surrounding farmlands.
Flooding of dwelling houses	In three locations, runoff from roadside drains and culverts has caused flooding of dwelling houses.
Irish bridges/fords	A total of four Irish bridges were documented and in two of the sites hand-dug wells have been developed for small-scale irrigation at the upstream side of the road.
Bridges	In the whole route 13 bridges were documented. These are areas with larger stream/river discharge and most of them are associated with deeper river erosion, which eventually caused a drop in the groundwater table along the vicinity of streams.
Sand mining	In 13 locations small-scale sand mining activities were documented along the route in relatively flat areas where runoff deposits sand sediments.
Borrow pits	Several borrow pits were used, yet these were at off-stream locations thus could not be used as a storage reservoir or recharge facility. The borrow pits were also not landscaped and mainly remained as rutted structures in the land.

to the road for a long time. Small-scale irrigation, mainly using shallow groundwater from dug wells, is rapidly expanding, especially since 2000. At present, because of the shortage of reliable wells, farmers are able to irrigate not more than 30 per cent of the land in the dry period. In the rainy season the entire area is covered with food crops and legumes. Consequently challenges arise for the disposal of runoff generated by the road as there is hardly any land uncovered.

Silt to sandy soils and the weathered sandstones are the main shallow groundwater aquifers in the area. Shallow groundwater resources are being used for small-scale irrigation as well as for water supply. The water table depth varies. At the end of the rainy season, the water table stands at less than 1 metre below the ground surface. In the dry season, however, the water level drops to 8–10 m depth and some dug wells fall dry. There is great need to buffer the area and make optimal use of the water generated by the road infrastructure.

An assessment of the impact of the Freweign-Hawzien-Abreha Weatsbeha-Wukro Road on the surrounding area is given in Table 1, showing a diversity of issues.

In the case of the Freweign-Hawzien-Abreha Weatsbeha-Wukro road, the most pressing problems that developed with the upgrading of the road are:

- Uncontrolled flooding downstream from culvert outlets, causing damage to houses, ponds, and dug wells, scouring out of the existing gullies and direct damage to farmlands and crops.
- Waterlogging along different stretches of the road, resulting in the flooding of houses and farmland and weakening of road embankments. The road design should take this into consideration in order to enhance the road integrity, taking into account that this could be an opportunity for shallow groundwater recharge.
- Sedimentation and siltation, especially in the upstream side of road embankments.
- Erosion of side drains and culvert outlet channels causing new gully formation, particularly in areas of high slopes and concentrated runoff.
- Drying-up of shallow wells at the downside of the road due to compaction of soil top layers, blocking the subsurface flow in the landscape.

The damage caused by uncontrolled runoff, through flooding and gulying (see Figure 1), led in several cases to local conflicts, with farmers trying to divert excess flows from one area to another to avoid damage from flooding and gully development in their own land. Some of the issues that emerged in the Freweign-Hawzien-Abreha Weatsbeha-Wukro roads are typical for asphalted highways, such as the interference of the road foundation with subsurface



Figure 1 Waterlogging behind a road embankment along the Freweign-Hawzien road, Northern Ethiopia

Credit: photo by Kifle Woldearegay, July 2013

flows. In the case of unpaved rural feeder roads, a different set of issues is expected to occur. The local land use along the road also determines the challenges of water management along the road. As the area between Freweign and Wukro is intensely cultivated in the rainy season, there are very few areas for road water discharge to freely spill over. Where roads traverse rangeland areas instead of cropland, the situation will be different and moisture retentions and flood water spreading may positively affect the quality of the grazing ground.

There were also several good examples of water harvesting from the Freweign-Hawzien-Abreha Weatsbeha-Wukro road. Where culverts were placed in suitable locations, runoff leads water to storage reservoirs, recharge structures or directly to land. Similarly ponds were constructed for livestock watering and groundwater recharge (see Figure 2).



Figure 2 Pond used to harvest runoff from culverts for livestock and groundwater recharge in Wukro area, Tigray, northern Ethiopia
Credit: photo by Kifle Woldearegay, July 2013

The unused potential: optimizing road designs

To use the potential of roads for water harvesting there is a need to optimize road designs. Road development changes runoff patterns and roads generate runoff from their own surfaces as well. Roads also directly affect the water-bearing strata: fords or Irish bridges across rivers impede the subsurface flow and, in mountain stretches, roads open up local aquifers. The negative impacts of roads can be turned around and changed into benefits. Inclusive planning processes, and better and integrated road designs can optimize groundwater recharge and retention and in the process limit water-related damage.

Optimized designs can particularly improve water storage in the vicinity of the road, in open ponds and cisterns, but also as secure soil moisture and as shallow groundwater. The availability of very shallow groundwater within the suction depth of low cost centrifugal pumps (i.e. less than 7–10 m) is particularly important. More secure water availability at these shallow depths makes it possible to support local productive and consumptive uses by small farmers.

In Table 2 a menu of options is given to optimize water harvesting from roads in semi-arid environments, where the water from roads can be a main contributor to water security. In other agro-ecological landscapes other options may apply for water harvesting from roads. These optimizing opportunities are described below.

Table 2 Water harvesting from roads: options for semi-arid areas

<i>Component</i>	<i>Design options</i>
Road alignments	Location within the catchment determines water harvesting opportunities from roads
Road surfaces	Harvest water directly from road surface from lead-off drains and rolling dips In flat areas use low filtrating stone bunds Storages and enhanced recharge structures on runoff paths Ability to flush away contaminated first floods from roads Roadside vegetation to intercept some contaminants
Cross-drainage and culverts	Divide the road runoff into smaller flows Use grade reversal and in- and out-sloping to keep runoff manageable Prevent gullying of drainage stream with check-dams and armouring Direct the runoff to storage and recharge areas Storages and enhanced recharge structures on runoff paths
Roadside drains	Selecting road template so as to collect runoff in drains Storages and enhanced recharge structures on lead-off drains
Borrow pits	Use borrow pits for storage, recharge or as seepage ponds Access ramps and landscaping of borrow pits
Road foundation	Especially on tarmac roads use permeable substrata or lateral or transversal drains
Newly opened springs	Collect newly opened spring flows in cisterns or storage reservoirs that are adequately dimensioned and have spillways facilities
Fords (Irish bridges) and flood water spreading weirs	Combine fords/Irish bridges with sand dams Use fords to stabilize dry river beds Use access roads to create flood water spreading weirs
Roadside vegetation	Use vegetation (combined with filtrating bunds) to slow down runoff, control erosion, and increase infiltration Use vegetation to fix contaminants
Managing and harvesting sediment	Controlled sand harvesting from fords cum sand dams and from sand traps

Planning road alignments

Road alignments should be carefully planned. They determine the pattern of runoff and determine which areas are served by water harvesting and recharge. The slope of the road affects the speed of surface runoff and the sediment load it can carry. There are several variables to take into consideration: topography, soil structure, and local rainfall patterns all determine runoff behaviour.

Often roads are placed in valley bottoms for reasons of easy access and construction. Flat valley bottoms are more difficult to drain. Roads placed at the lowest point in a valley also cannot harvest water or route runoff to storage or recharge areas. Instead, it is recommended to build roads, if feasible, at the toes of hills, as slopes ranging between 5 and 40 per cent gradient are easier to drain and thus maintain (Zeedyk, 2006). The runoff, moreover, can be reused in a lower-lying area.

Using road surfaces

While road alignments change the natural runoff patterns, water can also be harvested directly from the road surface itself. The amount of water generated from the road surface depends on the road grade as well as the width and surface of the road. Experiments have shown that a concrete or asphalt paved highway will have a rainwater collection efficiency (RCE, or runoff coefficient) of 0.65 to 0.75. For an unpaved road, the RCE is more variable, ranging from 0.25–0.30 in semi-arid areas up to 0.80 during heavy storms. In humid or sub-humid areas, due to the frequent rain and higher soil moistures, the RCE from unpaved roads is high (pers. comm. Zhu Qiang).

Runoff generated by the road surface can be diverted to recharge areas or storage ponds through the use of drainage techniques. The most common road surface drainage methods are rolling dips, lead-off ditches, and flat land drains. Rolling dips are a preferred technique in dirt roads (Zeediijk, 2006). Part of the road and the adjacent area is excavated so as to evacuate the road runoff towards adjacent land: this is the 'dip'. The excavated material from the dip is used to create a

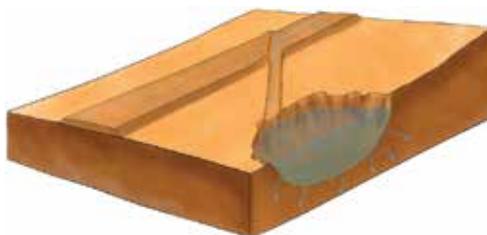


Figure 3 Rolling dip evacuating runoff generated by road to nearby pond
 Credit: illustration by Jochem van der Zaag
 (www.metameta.nl)

higher area in the dirt road, making the road undulate slightly and so creating different drainage segments (see Figure 3). Rolling dips are excavated cross-drains at gentle gradients – between 3 and 15 per cent. Rolling dips collect road surface runoff and divert it away from the road. The same can be done by lead-off drains placed in roadside drains (see below). In areas with permeable soils, infiltration of runoff from these drainage systems can serve to recharge shallow aquifers. The recharge areas can also be 'enhanced' by the development of infiltration trenches, eye-brow structures or swales.

For roads situated in flatter areas, such as alluvial plains and valleys, where soil permeability and infiltration capacity are typically higher, so-called flat drains can be used. Typically in flat drain areas, where sheet flow runoff is more usual than concentrated runoff, low stone bunds can be added along the roads, so as to reduce water velocity and increase infiltration. Low permeable bunds can be made of boulder rocks (also called filtering bunds, or *diguette filtrante* in French) to decrease runoff speed and to spread runoff gently to the adjacent fields (Bender, 2009). This prevents the development of ruts and gullies, while at same time improving moisture content in adjacent lands.

Water pollution is a concern in road-runoff harvesting, especially where water is harvested directly from the road surface. Pollution may consist of heavy metals, hydro-carbons such as polyaromatic hydrocarbons (PAHs), particulate material, and detergents that have accumulated on the roads from the traffic passing by. Other



Figure 4 Runoff from culverts being channelled to deep trenches in Hawzien area, Tigray, northern Ethiopia

Credit: photo by Kifle Woldearegay, July 2013

sources of contaminants (including sodium and organic material) are the wear and tear of the pavement materials, spillover from road maintenance, and damage to road equipment (WHO, 1989; Folkesson et al., 2008). As a rule, road surface runoff is not to be used for domestic use. Where there is a long dry season before the onset of the first showers of the rainy season, pollutants concentrated in the pavement over time are flushed away. Hence the first flushes carry a high contaminant load.

Cross-drainage and culverts

While road embankments concentrate runoff, the location and number of cross-drains determines how and where the runoff is redistributed. A large number of smaller cross-drainage structures will spread the runoff more evenly, but will also come at a cost.

Furthermore, the dimensions of the cross-drainage structures determine the velocity of the runoff. Smaller orifices may slow down the volume released but will also cause impounding on the higher side of the road, with the risk of waterlogging of adjacent farmland.

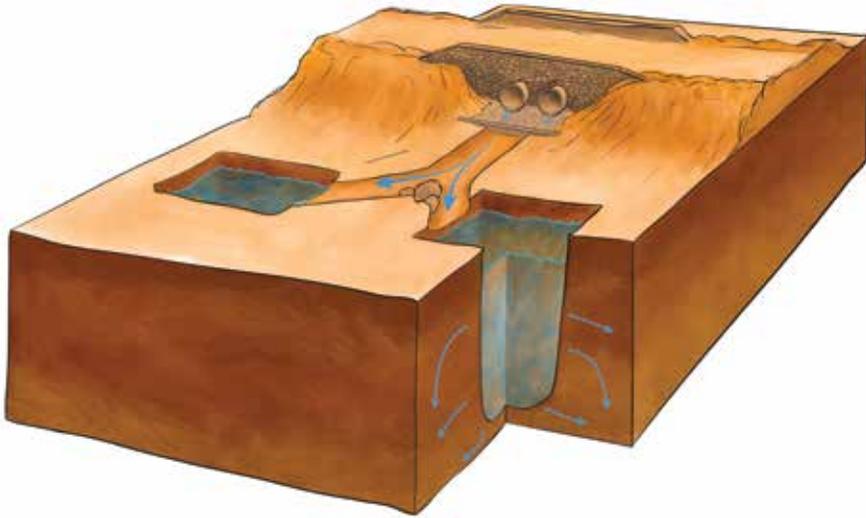


Figure 5 Culvert water flow diverted to infiltration and storage structures
Credit: illustration by Jochem van der Zaag (www.metameta.nl)

Cross-drainage and lateral drains can be planned to direct upstream runoff to recharge zones and prevent gulying on the downstream side of the road. Cross-drainage can go either under the road pavement by culverts (mandatory for tarmac roads) or over it (in dirt roads). Culverts are structures that drain runoff under road pavements (see Figure 5). Their setup is critical, as incorrect placement or undersized culverts can cause gulying or trigger sediment deposition. Lead-out drains have the same function as culverts; however, they drain the flow over the road pavement and are common in dirt roads.

Grade reversals is another simple technique which can be used to improve road drainage (Zeediijk, 2006). It is the frequent use of different grades, uphill and downhill, to drain out runoff. Sloping of the road profile, alternating out-sloping (tilting the road outwards, towards the road fill) and in-sloping (tilting the road inwards, towards the fill slope) are other techniques to drain road surfaces.

All road drainage structures can be used not only for cross-drainage but also as the water source for borrow pits and storage ponds or for enhanced recharge areas (Figure 4). In steep areas check dams or armouring may be provided on the drains leading from the road to avoid stream scouring and gully formation.

Roadside drains

Besides culverts and cross-drains, roadside drains are important sources for water. The shape of the road is important – in particular the presence of a berm. The road template may be either in-sloped with water draining into an uphill side drain, or they may be out-sloped shedding water on the down-slope side, either continuously or into a side drain. A berm may be placed on an out-sloped road profile – it will keep

water longer on the road surface, which may not necessarily be desirable. Crowned or elevated road cross-sections drain water on both sides of the road.

It is the water from down-slope drains that can be used for water harvesting directly along the stretch of the roads. The water from the road drain may be routed directly to the land (a practice that is common but not universal) or to soak pits, small reservoirs or ditches or other improved structures (Kubbinga, 2012). The advantage of using such recharge and storage systems along the road drain is that they help accommodate and store peak discharges. When the water is applied to the field directly, moisture storage techniques common in spate irrigation are most appropriate: mulching and deep ploughing in semi-arid areas will ensure the availability of water later in the growing season (van Steenberg et al., 2010).

Scouring of roadside drains needs to be avoided. This can be done by creating regular lead-offs or escapes and by paving the drain with rip rap for instance in steep sections or by planting vegetation.

Borrow pits

Borrow pits can be systematically used as recharge, storage or seepage ponds. Borrow pits are excavations done to collect materials – sand, gravel, soil – for road construction and are usually located very near to the road itself. After the road is finished, if not refilled, borrow pits are left unused. However they may be filled with water after rains. Thus they can act as water storage if properly combined with road drainage, leading runoff to the storage ponds. The shape and size of the ponds are relevant: round shapes maximize effective storage; deeper ponds have less evaporation loss. Access ramps will facilitate the collection of water.

Depending on the soil conditions and geology, borrow pits can also be used as recharge ponds. The charm of these uses is that the additional storage is created at no additional cost (Nissen-Petersen, 2006).

In areas with permanent shallow groundwater the borrow pits also serve as dug-out ponds, filled with the water seeping in from the adjacent shallow aquifers. Such ponds have become an important source of water for irrigation or livestock in dry flood-plain areas, in Ghana and South Sudan.

Permeability of road foundations

Road foundations, if compacted, may interfere with the base subsurface flows that feed shallow wells. The road foundation depends on the road type and the traffic it is designed to support. Tarmac roads may have impervious bases 2–5 m thick, but such compacted road foundations are not common for dirt roads. The impermeable subgrades and road foundation of tarmac roads can block subsurface flows altering the availability of shallow groundwater and drying up shallow wells on the lower end of the road and increasing water tables on the upper end of the road.

Groundwater drainage systems and placement of cross-drains can help modify this phenomenon. Permeable subgrades or lateral drains (water table lowering, e.g. trench drains and California drains), transverse drains in rigid pavements,

earthworks drains (e.g. drainage spurs and cut-off drains), and pavement under-drains can be used to control flows entering the road subgrade and foundation (Santinho Faisca et al., 2008). These structures have the primary objective to protect the road from water intrusion in the road structure. However, careful placement of these structures allows control of water tables and by-pass road blocking from upstream to the downstream. When combined with water storage (e.g. hand-dug wells), drainage systems can be converted into water harvesting systems.

Fords and flood water spreading weirs

When dirt roads cross dry river beds or water streams it is common to construct fords (also known as low causeways, drifts or Irish bridges). These road crossings can help retain groundwater upstream of the road crossing and increase bank infiltration.

These structures can have multiple functions. The first obvious one is to allow road traffic to cross the dry river bed. The fords can, however, also double up as a proxy sand dam, trapping coarse sediment behind them and creating small local aquifers that can store and retain water.

Depending on the depth of the river bed, the fords will also slow down subsurface flows and retain groundwater upstream – allowing the development of wells or the construction of infiltration galleries to access the water retained upstream of the ford. This capacity to store and retain shallow groundwater is very relevant in arid regions and improves water access and availability. The golden rules of sand dams apply to such multi-purpose fords as well (Neal, 2012):

- The road crossing must be built on bedrock or impermeable foundation.
- Their width should exceed annual flood levels by a safe margin.
- The height of the spillway on the ford-cum-sand dam must be such that it allows the river to pass over at high discharges and deposit coarse material behind the dam.
- The road crossing must be built so as not to change the river course, and preferably be placed at a right angle to the river bed.

Fords combined with roads also have another function which is to stabilize the river bed of dry ephemeral rivers. As dry rivers are prone to short-term violent flooding, they may scour out and become rutted. This affects the capacity of river beds to store water. It also makes it more difficult to build flood diversion structures, as is common in so-called spate irrigation, where short duration floods and peak flows are used to irrigate land, supply storage ponds or recharge shallow aquifers.

One step up from a ford for water retention is flood water spreading weirs (BMZ et al., 2012). These flood water spreading weirs – introduced in different Sahelian countries – spread water over a large area, enriching soil moisture and shallow aquifers. When combined with roads, the weir itself doubles up as a ford and the road embankments help to spread the controlled flood water over a large area (see Figure 6).

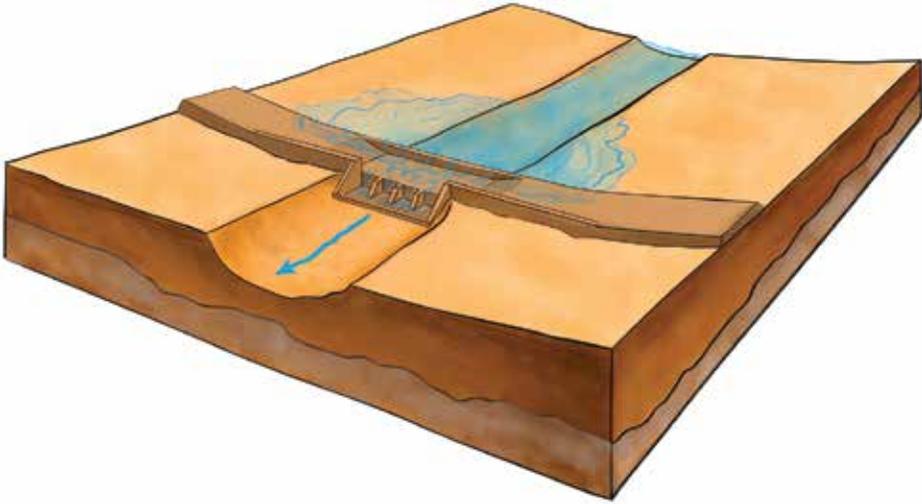


Figure 6 Irish bridge combined with flood water spreading weir

Credit: based on Bender's seuil-radier, 2009

Spring capture

When roads cross hilly areas and the roads are made in deep cut of terrain, excavation may open springs in mountain aquifers. These newly opened springs can damage cut slopes and erode land. Drainage masks protect cut slopes from spring flows infiltrating water to the road drainage system. Likewise, protection boxes for newly opened springs collect the spring water and can either be diverted to infiltration structures (such as soakaways) or used directly in surface storage structures, either open ponds or cisterns. It is important to estimate the discharge of these spring flows so as to properly dimension the collection tanks and create spillover structures. The newly opened springs can be used as water supply sources in semi-arid regions.

Use roadside vegetation

Roadside vegetation will help slow down runoff, capture sediment, and fix pollutants. Vegetation is a natural barrier against runoff and erosion and will help increase infiltration (Bender, 2009). Moreover, soils with good structure are more resilient to land degradation. Vegetation is thus relevant to control runoff and stabilize land surrounding the road. Additionally, vegetation fixes pollutants carried by the water. Rock bunds can be combined with planted vegetation. Side drains can also be designed in combination with vegetation to favour infiltration.

Managed sand harvesting

Harvesting sediment from runoff-sediment deposition in road pavements, drainage systems, and downstream fields is a common issue, increasing road maintenance

costs. However, when considering structures such as Irish bridges or sand traps, sand can be harvested and used for construction purposes. Governments identifying such places for legal sand harvesting also reduce the negative impact of illegal sand mining activities otherwise taking place uncontrolled in more vulnerable parts of the river.

Structures such as Irish bridges act as artificial sand deposits, collecting sand and sediment in the sand dam (upstream) and sand trap (downstream) (Nissen-Petersen, 2006). It is important that sand harvesters remove the sand from the sand dam in horizontal layers, in order to not disturb the river flow. Similarly, sand traps can be emptied. As these structures can be used as a source of construction material for nearby projects, maintenance costs can be partly earned back.

Inclusive planning: roads as development corridors

The links between roads and development are multi-dimensional. Mobility and access are obviously the prime functions of road infrastructure and it is normally assumed that roads reduce poverty associated with spatial isolation and promote economic productivity but also access to health and educational services (World Bank, 1994; Venables and Limao, 1999; Crawford et al., 2003; Pomfret, 2006; Bryceson et al., 2008; Ericson, 2008).

In reality, the effects of roads go beyond these; one main example is described above: roads affect the hydrology, can cause erosion, and they change the immediate environment. In terms of where people benefit or suffer, the effects of roads are unevenly distributed (Wilson 2004; Demenge 2011). The impacts are particularly mixed at the local level; those living along the roads do not necessarily benefit from the road (Riverson et al., 1991; Fishbein, 2001; Mahapa and Mashiri, 2001; IFPRI, 2005; de Grassi, 2005). The environment may suffer from the opening of new and unprotected areas. Also, local hydrology may be affected: an example is the severe gullyng from road runoff (Jungerius et al., 2002).

These effects may partly undo the positive impacts that are created by better access. Where benefits occur, they are not evenly distributed as farmers' ability to benefit from roads depends on their initial assets: individual landholdings, security of holding, access to transport, and the presence of development projects.

Road runoff harvesting can have several environmental impacts, which in turn can have a positive effect in the surrounding communities. Table 3 summarizes positive environmental impacts derived from road runoff harvesting.

There is still a lack of systematic evidence regarding the consequences of roads in terms of broader and inclusive development (van de Walle, 2000). As a result, 'short-term and long-term distributive impacts of transport projects, particularly on low-income groups, are not well understood' (De Grassi, 2005: 53). Roads may affect the safety of those living close by. Roads may change land property values, but original inhabitants may be disenfranchised. Roads also create employment in construction and maintenance, but for whom and how depends on the way the work is organized and the precautions taken for occupational safety.

Table 3 Environmental impacts of road water harvesting systems

<i>Environmental impact</i>	<i>Ecosystem services</i>	<i>Impact in local communities</i>
Increased plant growth and diversity	Biological production, carbon storage, more biodiversity	More availability of wood and fodder
Increased soil biodiversity	Improved nutrient cycles, more biodiversity	Higher agricultural production and diversity of crops
Increased insect diversity (bees and other insects)	More pollination, more biodiversity	Additional sources of income (such as production of honey)
Increased soil moisture and stream flows	Water availability	Increased water and food security
Increased amount of soil nutrients and reduced soil erosion	Nutrient availability, flood regulation	Greater agricultural production and resilience to extreme climate events

Source: based on Kubbinga, 2012

To trigger development, roads need to be accompanied by adequate policies – such as education, demonstration schemes, and access to credit – and the right set of conditions – such as existing markets and employment opportunities (Demenge, 2011: 311). Water provision, through water harvesting and storage, is another intervention that would increase the benefits of roads for local communities and improve livelihoods.

If done well, road water harvesting can have several beneficial effects for both women and men in rural communities (Ngigi, 2003). Impacts of road water harvesting techniques on rural livelihoods concern: increase in agricultural productivity and water availability; larger diversity of production – in terms of crop choices, agro-forestry, and small livestock; improved environmental protection and conservation; improved health and nutrition; economic empowerment and social integration; and new sources of income, for instance, from sand harvesting (Ngigi, 2003; Nissen-Petersen, 2006; Kubbinga, 2012).

Gender issues need special attention with respect to rainwater harvesting systems due to their direct impact on the lives of rural women (Malesu et al., 2006). The systems release women from the burden of collecting water over long distances. Examples described by Ngigi (2003) show that, thanks to rainwater harvesting, women have become economically empowered, since the time saved from fetching water was allocated to other activities such as acquiring skills in home economics and management, microfinance, agribusiness, and leadership.

In addition, new emerging roles in a community that can be directly related to rainwater harvesting have been identified. Examples from Kenya include young men collecting water from the dams for sale and youth groups who specialize in constructing ponds (Malesu et al., 2006). The implementation of road runoff harvesting systems can therefore increase the employment possibilities in an area.

The use of road runoff harvesting structures can also enforce social cohesion and knowledge exchange. In an example showed by Kubbinga (2012), after the

implementation of different road water harvesting measures, farmers decided to invest jointly in a greenhouse with drip irrigation systems.

Currently, most road construction works have no provision for the storage of runoff water generated from road drainage (Nissen-Petersen, 2006). Moreover, roads are often built with little consideration for hydrology, let alone for groundwater: 'many rural road projects do not require a formal Environmental Impact Assessment and consequently little, if any, importance is given to environmental issues during planning, design or construction' (Griffiths et al., 2000: 1). If at all, impact assessment is defensive, minimizing damage rather than proactively using all possible development impact. Effectively, poorly designed roads result in rain erosion that damages roads and makes them impassable, forcing motorists to pass through the fields, creating permanent damage. Cut-off channels to divert water from the road to the fields also create gullies, carry away the topsoil, and often turn fields into 'a desolate moon landscape' (Nissen-Petersen, 2006: ix). In this way, 'fertile farmland is being washed away every year by uncontrolled rainwater running off roads' (ibid.). Hence, poorly engineered roads negatively affect people's assets and livelihoods.

Apart from better designs, it is also important to be sensitive to the distributional differences of water harvesting between communities located in the vicinity of the road and communities further away. These inequalities can be the source of conflict and need to be addressed properly. New water harvesting systems may intercept runoff at the upstream part of the catchments, thus depriving downstream users of the water resources (Malesu et al., 2006) or alternatively they can dump peak excess water in the downstream areas. To minimize conflicts, equitable distribution of runoff from a common catchment needs to be understood, both from surface flows and underground stream flows.

Positive impacts in the environment reduce people's vulnerability by providing more livelihood options to rely on in case crops or landscapes are negatively affected by calamities.

There are, however, several barriers related to implementation of water harvesting from roads. Increased costs related to modification of standard designs (especially river crossings) may hamper the implementation of the proposed techniques. Likewise, insufficient maintenance budgets may trigger inadequate performance of water harvesting structures. These barriers could be tackled by applying several approaches such as: shared costs between different government institutions (roads authorities, water and agriculture ministries, etc.), involving beneficiary communities in maintenance (thus alleviating construction and maintenance costs), and inclusion of water harvesting in other programmes (food security or irrigation for instance). A holistic perspective in terms of benefits and outputs may justify an increased expenditure.

On the other hand, the techniques described in this paper are novel. Therefore there might be cases of insufficient technical knowledge and lack of awareness of the large potential at stake. In this sense, development of technical guidelines, capacity building for roads experts, mapping of potential areas of intervention, and advocacy at political and decision-making levels are key issues to address. The

former approaches may enable better inclusiveness of road engineers and road design processes in combination with water harvesting and road development.

Conclusions

There is an estimated 5.5 million kilometres of roads in sub-Saharan Africa. Of this, 2.36 million kilometres are located in dry lands, 1.57 million kilometres in range lands, and 0.80 million kilometres in cultivated areas (Kubbinga, 2012). In other parts of the world there is a similar vast potential for water harvesting, from existing and newly built roads, which can be developed.

Ethiopia is one of the sub-Saharan African (SSA) countries which has been undertaking massive road construction and is planning for more road infrastructure development in the next years. In Ethiopia, road intensity is low, even by African standards, averaging 40 km per 1,000 km² in 2010 (World Bank Development Indicators, 2013) against 204 km per 1,000 km² for Africa (World Bank, 2010). In recent years, road construction has accelerated. In 2012 total road building, through federal and regional programmes, was planned at 5,000 kilometres – both metalled roads and unmetalled feeder roads.

Road projects have the potential to endow road communities with additional water and soil resources. There is a variety of water harvesting techniques that can be combined with road building and at the same time decisions on road alignments, the use of reverse grades, the placement of cross-drainage structures, and location of fords also have a major impact on how easy it is to harvest water from roads and retain it in shallow aquifers or the soil profile. There is also a need to better understand the potential of road water harvesting from feeder roads versus main highways and roads in agricultural versus pastoral areas.

For road infrastructure to become truly multipurpose, there needs to be close cooperation between those responsible for road development and those for watershed management and agriculture. Moreover, local communities need to be involved in the design phase, so as to indicate local water needs and alert different authorities and road designers to opportunities and constraints for water capture along roads. This will require a different style of working for road engineers, but it may go a long way to reducing water damage to roads, now the single largest cost item in road repairs.

To systematically include water harvesting in roads a more *integrated, inclusive and dynamic* framework for road planners and designers is required, allowing them to include: the manipulation of runoff in the design packages, moving beyond dealing with protective road drainage only; the adaptation of road design manuals, including the main parameters for changed road design; matching up with water harvesting programmes; and a different approach to site investigation and reconnaissance, for instance, taking into account the location of recharge areas and the security and ownership of land. At the same time, water harvesting from roads should be a standard element in watershed programmes, including the protection of sensitive road sections by those responsible for watershed protection. Complementary or co-financing programmes may be developed that increase value to both parties.

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