Water from Roads in Yemen
A Guidance Note

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Abbreviations

MOPH	Ministry of Public Works and Highways
RMF	Road Maintenance Fund
RAP	Rural Access Project
CRU	Community Road Unit
SFD	Social Fund for Developmemt
PWP	Public Works Project

Introduction

Yemen being ranked among the five most water scarce countries, all efforts are required to preserve its water resources. There is history of huge creativity in retaining water in Yemen. This guidance note intends to contribute to this.

It discusses the different ways of retaining and recharging water from roads – making use of on-going investment in road development and rehabiltation to secure local water resources. It argues to take a multi-functional look at roads: whilst roads deliver transport and communication services, they at the same time can contribute to water security, flood control and erosion mitigation. In this way the high investment in road connectiviy in Yemen can even render a much broader impact on livelihoods and economic development.

The guidance note has been prepared as a contribution to the Rural Growth Project. This project – due to start implementation in 2015 - has an important component of developing village access roads where opportunities for road water harvesting should be systematically captured. The guidance note, however, is also meant to contribute a range of other road development programs, including those by MPWH, SHD, CRU, RMF and PWP – varying from feeder roads to new highways.

Making the case for 'roads for water'

The argument for combining road investment with water harvesting is strong. The main points to create water-wise roads are:

- Less damage to roads – water is a major factor causing damage to roads. This can take several shapes: run-off directly damaging roads, down-slope erosion cutting back and affecting road alignments or local residents making modifications to roads so as to collect water but damaging the road in the process. Understanding runoff behaviour in combination with road alignments and road drainage structures, spring and subsurface flows and land and soil properties can reduce costs in road maintenance and lead to less traffic interruption. The safe planning road water harvesting facilities near road bodies will also prevent structural damage to the roads.

- No damage to the agricultural landscape, in particular less erosion and gully formation. Roads hugely disrupt natural drainage patterns and typically concentrate run-off by channelling it through a limited number of culverts and other cross drainage structures. If not done well this may trigger erosion, especially in areas where the soil is relatively thick. Gullies may develop – rutting the landscape and depleting the soil moisture.

- Preventing floods. If run-off from roads is not managed, local flooding and uncontrolled sand deposition results, affecting the livelihood of those that happen to live close to the roads. If done well, however road embankment can compartamentalize the watershed. This can be used to change and slow down run-off patterns and attenuate floods. If not done welll, however roads and cross-drainage facilities can develop into flood corridors and aggravate the impact of high rain run-off.

- Most important, water can be harvested from roads. This will turn a threat into an asset, The water generated from road drainage or from springs that are opened up by road construction or the water and soil moisture retained by fords and road surfaces provides a valuable resource. Capturing this road-water recharge can help drinking water supply, local storage for agriculture and livestock, groundwater recharge, safeguarding soil moisture levels and controlling water tables.

This guidance note is based on the reconnaissance of the 250 kilometer of roads in Yemen, observing the opportunities and threats for 'water from roads', and taking interviews with road side communities. (For an overview of the roads visited see annex 1.) It was found that rroad water harvesting has been successfully introduced in a number of places. Recharge or storage using borrow pits, percolation systems such as deep trenches and percolation ponds meant to increase ground water recharge, side-drain drainage used for irrigation, sand mining, road-side earth ponds are some of the techniques already present in the country. At the same time all these opportunities are used sporadically and that there is a case to combine road development and water harvesting systematically in Yemen.

The expected increased investments in road infrastructure in Yemen offers an important opportunity to make a broad impact and have roads help to improve the availability of water. This document describes both the governance and processes to combine road development with water management as well as how water harvesting from roads can be enhanced through improved road designs and systematically placed water harvesting infrastructure along roads. At the moment a number of such opportunities have been captured by enlightened road engineers and by owners of land along the roads, but this can be done more systematically – as part of new road building programs and as part of the maintenance of existing roads.

Scope of water harvesting from roads

The scope of water harvesting from roads is Yemen is elaborate. Road construction is a prime target of public infrastructure expenditure and is undertaken by several organizations. In Yemen the total asphalt roads under the custody of the Ministry of Public Works and Highways by 2011 executed and planned - is summarized below. In addition considerable work has been done on gravel roads by several agencies (see table 1 and 2)

Table 1: Road program

Type		UNDER CONSTRUCTION	EXECUTED /COMPLETE
International Roads		127 km	3693 km
Main Roads		1015 km	5152 km
Secondary Roads		4451 km	3512 km
Rural Roads		4145 km	2971 km
TOTAL		9738 km	15328 km
Source : MPWH 2011			

Table 2: Recent and on-going road programmes by different agencies

Total Investment in Rural Roads by Different Road Agencies				
Agency	**RAP[1]**	**PWP[2]**	**CRU[3]**	**SFD[4]**
Period	2002 to 2014	1996 to 2013	2008 to 2013	1999 to 2013
Total investment US $	351,905,000	25,972,628	10,726,428	103,504,869
Total Length Km	2220	-	276	3534.43
Period	On-going	-	2014 to 2016	-
Expected and On-going Investment US $	242,725,000	-	14,631,048	-
Total On-going Length Km	1021.7	-	247.3	-

Sources: 1- RAP, Procurement Unit; 2- PWP, IT Unit; 3- CRU, Monitoring Unit; 4- SFD, Rural Feeder Road Unit

In general in the highlands where water is very scarce, there are large opportunites to harvest the water from the culverts and side-drains for a variety of purposes. In several areas where there are sand-stone aquifers and alluvial aquifer many (temporary) springs have opened up with road construction and these need to be safeguarded.

In the middle plateau between highlands and low lands there are a lot of shallow wells near the road side. Water harvesting structure can be used to irrigate directly or to recharge the open wells.

In the low lands there is less scope for water harvesting structures as such but road fords and irish bridges can help retain water in the dry river beds and feed wells alongside the wadi beds. Here culverts and cross-drainage structures are also important to guide the subsurface streams.

Figure 1. Water cistern filled by run-off from road-surface

Institutional cooperation

For road infrastructure to become truly multi-purpose, there needs to be close cooperation between those responsible for road development and those for watershed management and agriculture. In some cases (like the Social Fund for Development) these programmes are already combined. In other cases cooperation between the different institutional actors (road programmes, local governments and departments of agriculture) needs to be fostered.

Inclusive planning processes

Road planning and design processes in Yemen currently do not systematically allow for the incorporation of broader water management objectives nor are they necessarily open to local perspectives and ideas.. As a result most road water harvesting structures in place now are adjustments made by local land users and communities to capture the opportunities created with the development of the roads. Ideally, however, the opportunities for road water harvesting would be included from the beginning in the design and planning process of the roads. A more integrated, inclusive and inclusive framework for road planners and designers is required, allowing them to go beyond dealing with protective road drainage only but to incorporate the potential for water harvesting upfront in the design of roads: in the choice for road alignments, in the design of low river crossings, in the development of appurtenant infrastructure such as spring protection and using road embankments for storage and in the systematic and planned conversion of borrow pits and quarries.

This may require the adaptation of road design manuals; 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 location for surface storage. 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.

Community Involvement

Local communities need to be involved in the design phase, so as to indicate local water needs and alert road designers on 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 in reducing the water damage to roads, now the single largest cost item in road repairs. It will help to identify opportunities for improvements but also settle access rights over the newly harvested water.

Figure 2. Road side water pond

Guidance for design

Roads are major interventions in the landscape. They interfere with surface and sub-surface flows and concentrate runoff flows through road surface, side-drains, cross drains and culverts. Depending on landscape typology and land use, road water harvesting techniques will vary. Factors like topography, steepness of slopes, hydrogeology, thickness of the soil all matter importantly.

Similarly, the prevailing local agricultural system is very important. Different livelihood systems have different water harvesting demands. Small holder/household scale irrigation normally supplement rainfed systems. In case rainfall is scarce or not timely enough, water harvesting from roads can supplement water during scarcity and shortage, either by through shallow ground water extraction and from the use of small storage structures. Pastoralist communities seek grazing areas to feed their livestock. In this case, water harvesting techniques which spread flows as sheetflow over extended areas is a preferred option. Road water harvesting is usually used for agriculture or livestock keeping, but it can serve domestic water use as well – provided safety measures are taken such as excluding the first flush and mainly using water from the catchment and not from the road surface.

Box 1: Water quality concerns

One concern in harvesting water from roads is water quality, in particular the probability of occurrence of grease and oil from traffic. As part of the UPGro Catalyst Research grant, water quality was assessed in northern Ethiopia, along the Frewign/Sinkata-Hawzien-Abreha Weatsbeha highway. Using the gravimeter method water samples were analyzed from dug wells and open ponds situated between 10-30 meters from the road at four locations. In none of the samples oil/grease was detected. Based on this there is no cause for immediate concern, but vigilance and caution are required, especially in case of surface water bodies. In case road water harvesting is done for groundwater recharge, soil media may act as a filter to many biological and organic substances.

Depending on different landscapes, drainage and water harvesting techniques vary (see table 3).

Table 3: Roads vs Landscape

	Construction-Maintenance	Drainage characteristics	Erosion susceptibility	Water Harvesting potential
Lowland and plateau	Low cost construction where materials available and stable soils.	In principle – more difficult to drain. Depends on soil characteristics. Road embankment/ foundation can interfere with subsurface and surface flows, especially when no clearly developed drainage pattern	Waterlogging and undermining of road pavements can be a problem. Side drains and embankment stability depend on design standards	Borrow pits, rolling dips, tanks, cross drainage to infiltration areas, hand dug wells, manually drilled shallow boreholes and flood water spreading. Borrow pits can serve as dug-out ponds with natural seepage.
Mountain-Valley	Depending on soil, rock and geologic characteristics, and depends on surface roughness and slope for rural feeder roads Special attention must be taken to the new constructed roads above/below the existing roads Maintenance should address the reason of the damages not just the effects.	Easier to drain at toeslopes and moderate vertical profile slope –Ridge top and valley bottom are harder to drain. The accumulated flow from / to new roads may generate drain problems.	Depending on roughness of surface, soil characteristics and slope. Deep, portable soils and steep slopes are prone to trigger erosion issues and fallen depris, especially side drain scouring/ gullying and sediments accumulation in culverts and ditches and small water way crossing structures.	Several water harvesting techniques can be applied; spring capture, recharge of borrow pits, retention ponds; water cisterns and tanks, side drains/ culvrts leading sheet water flows to nearby fields and terraces, canals from culverts to fields, spillways from road surface to farms.

Main techniques

A number of techniques are available to optimize the use of roads for water, as described below:

1	Water harvesting from cross drains and side drains
2	Water harvesting from road surfaces
3	Use of borrow pits and quarries for storage or recharge
4	Clever road foundations
5	Spring capture
6	Ford/irish crossing for retaining groundwater, water spreading or river stabilization
7	Sand and soil harvesting from roads
8	Erosion protection from roads
9	Roads as flood control mechanisms
10	Roads body as retention dams / small retention ponds

1. Water harvesting from cross drains and side drains

The purpose of culverts and side drains is to evacuate water away from road structures. This is often done without taking into consideration the opportunities that these road drainage structures have for direct irrigation , for water storage and for groundwater recharge. One may even argue that by moving a road higher or lower on the slope the water that is collected by the road and the area that it is redistributed to can be optimized. The road alignment chosen willl also determine the natural drains that are dissected and the location where they are dissected and hence the opportunities for retaining water in the river beds through road fords and/or irish bridges.

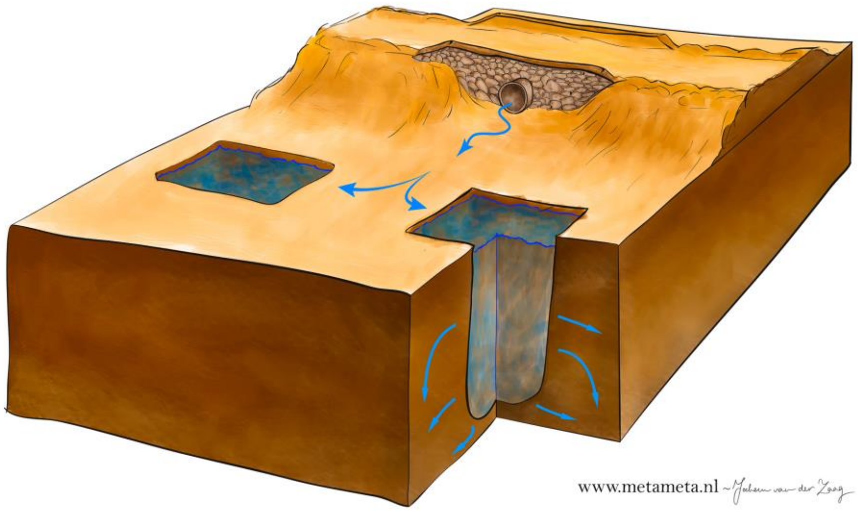


Figure 3. Guiding water from culvert to recharge ponds

The design of the road drainage structures has a large impact on the run-off patterns in a landscape. They determine where run-off is collected and how it is concentrated. Culverts (under-pavement cross drainage structures) play a main role in this regard. The location, size and number of road culverts determine drainage patterns in roaded catchments. If the number of culverts is limited and they are connected to up-slope side drains, run-off will be concentrated in a limited number of points. This may bring the risk of local flooding, erosion or siltation during high rainfall events, which inadvertently happen, also in Yemen. On the other hand where a large number of culverts are constructed, well spaced, the run-off will be spread more evenly over the landscape, serving more points but with lower flows. In addition to the the culverts water is also spread from down-slope side-drains by spill-ways (also know as mitre drains or side-drains).

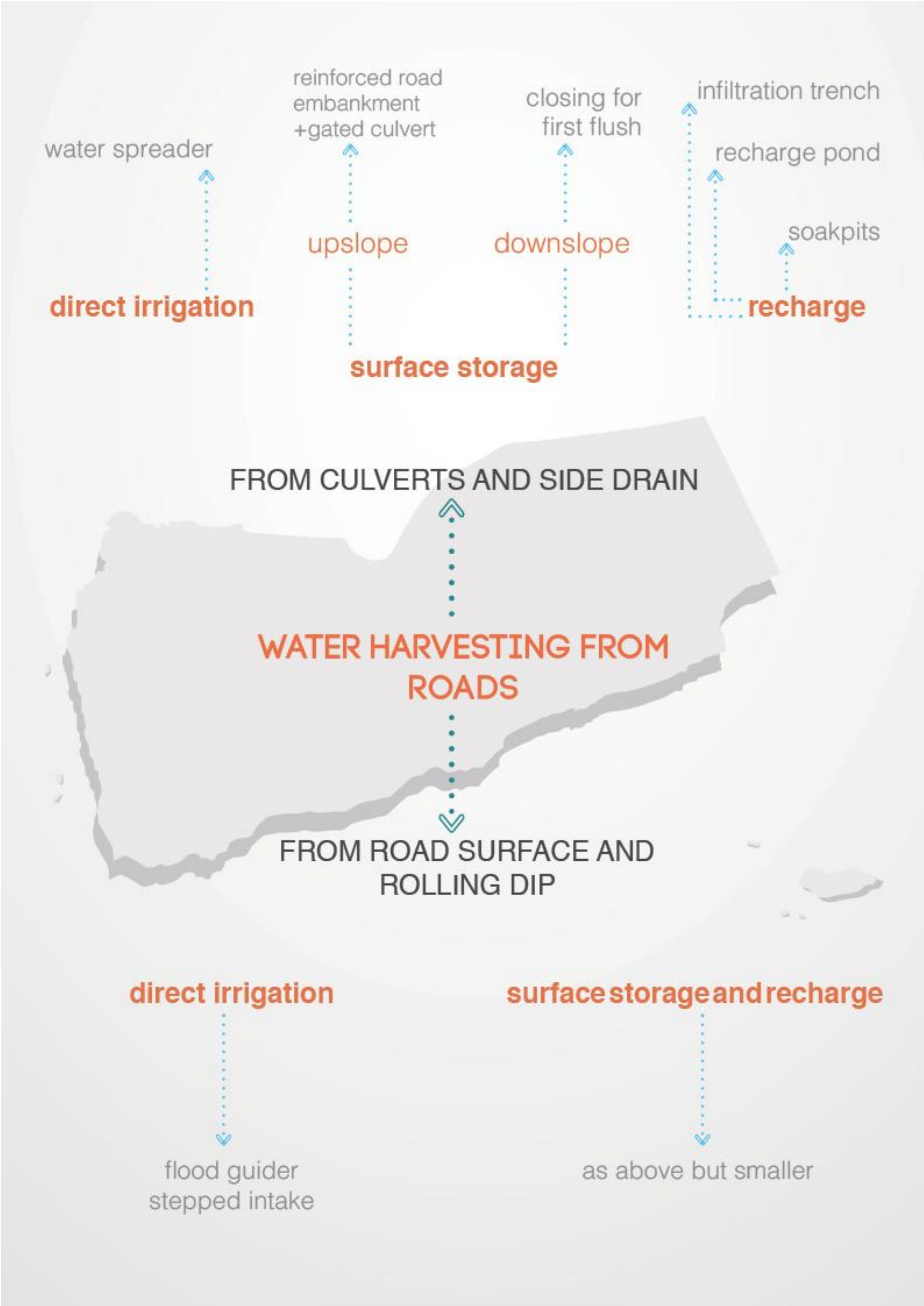

Figure 4 & 5. Ponds harvesting water from side drains


Figure 6 & 7. Road-run-off collected respectively from (up-slope) side draij and from escape in down-slope side drain

The water from side-drains can be led directly to farm land or spread over grazing land, either through spillways or directly from the drain. It can also be used to feed into storage ponds or recharge ponds. In the latter case the collected water percolates and recharges the aquifers. Apart from leading water to recharge pond, a series of soak pits or infiltration trenches can be used as well. 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 Steenbergen et al., 2010).

In case of culverts the discharge is often quite large. If the water is led directly to farm land, it is often done by spreading the water coming out of the culvert over a large area or leading it to a storage reservoir or recharge pond (see figure 3) or a series of soak pits. There are many examples where farmers with the help sometimes of different programs have lined the storage pond to avoid water seeping away and being available to directly supply water to orchards for instance. In some cases the storage reservoir has been roofed, turning it into a cistern with minimal evapration losses. Another important addition, in particular where water is used for high-end uses is to be able to direct the first flush of water harvested from the roads, away from the storage resevorir, as this first water usually

Figure 8 & 9 Cistern filled from road recharge and stone blocking first flush, Al Wastah


reinforced road
embankment
+gated culvert
closing for
first flush
infiltration trench
water spreader
recharge pond
upslope
downslope
soakpits
direct irrigation
recharge
surface storage
FROM CULVERTS AND SIDE DRAIN
WATER HARVESTING FROM ROADS
FROM ROAD SURFACE AND ROLLING DIP
direct irrigation
surface storage and recharge
flood guider
stepped intake
as above but smaller

2. Water harvesting from road surfaces

Water can be collected from side drains or culverts, but run-off can also be collected directly from the road-surface. The relatively impervious surface of the road generates considerable run-off during rain-showers that can be also be led directy to land or collected in storage ponds or recharge structures.

Figure 10 & 11. Direct irrigation from road surface and water harvested from side curbs

Particularly in sloped feeder roads the use of rolling dips and lead-out ditches is recommended. These are structures oblique humps in the road surface where rain-water is collected and led to the land adjacent to the roads. The purpose is to protect the roads but obviously the water discharged from the rolling-dips is also valuable for the land adjacent to the road. Hence the location of the rolling dips should be take into account the benefiicial use of the water. In the mountain areas water from road surface also is collected at road bends.

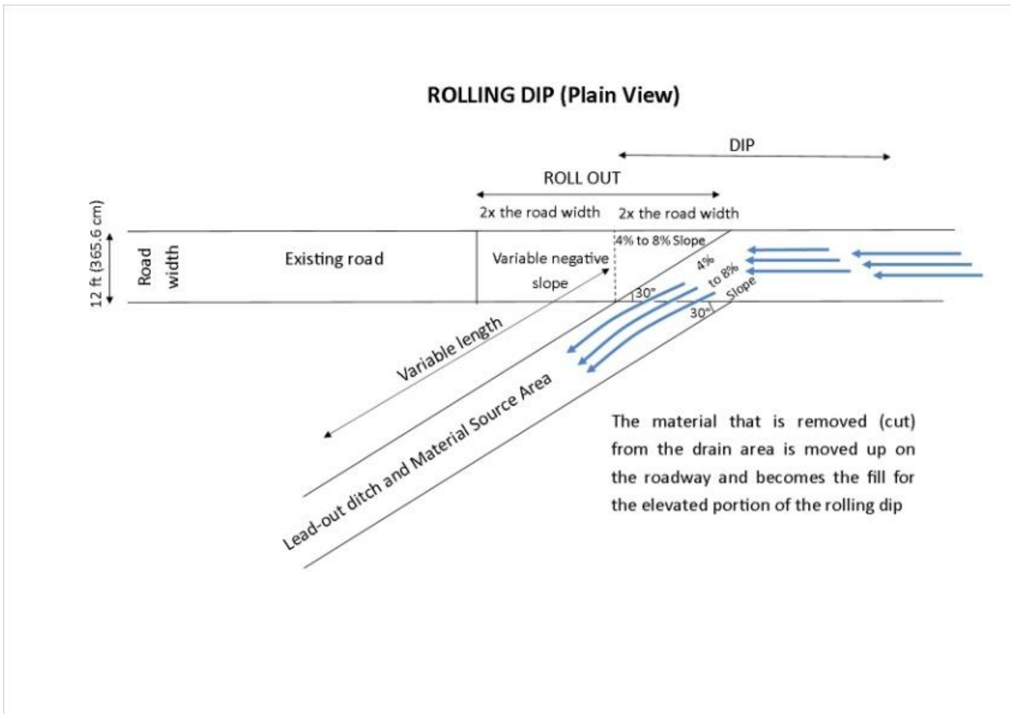


Figure 12. Rolling dip to divert road run-off from earthen and gravel roads

The effectiveness of road surface water spreading can be improved by constructing small flood water guiders along side the roads that guide the water towards the farm land – sometimes directly to furrows or field channels. Also the intake to land can be improved, especially when there is a level difference, by a stepped intake.

Figure 13. & 14. Flood water guider from roads (left) and stepped intake (right)

3. Use of borrow pits and quarries for storage or recharge

Water may be collected in specially made reservoirs or ponds, but it is also possible to make use of existing depressions.

In case of road water development, borrow pits and quarries can be systematically used as storage or seepage ponds. Borrow pits are excavations done to collect materials - sand, gravel, soil - for road construction – for the foundation and for mixing material. They are usually located very near to the road body. After the road is finished, if not refilled, borrow pits and quarries are often left unused. However the borrow pits and quarries may be converted into reservoirs and filled with water after rains or road run-off may be directed towards them. 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. In the excavation or reshaping of the borrow pits these parameters may already be included.

Figure 15. & 16: Farmers in Wadi Tabab AlKhabt - Mahweet district (Yemen) using a borrow pit in wadi Tabab near the road from Qanawis to Al-Mahweet as retention and recharge pond (left) Borrow pit cum recharge ponds near l-Rojom (right)

Box 2: Excavated soil and the use small rocks

Where a road is made in cut, the excavation material may consist of fertile top soil. This fertile soil can be put to useful purpose again. It may be given as compensation to owners of land adjacent to roads. Farmers who lost land due to road construction may benefit from excavated top soil as this can be used to build up new fertile land.

An additional use of especially the smaller rocks that are extracted from the stone quarries developed as part of road construction concerns their use in 'stone mulching'. Especially in the coffee areas in Yemen small rocks are placed all around the tree seedling covering the entire landscape. The purpose of this spectacular practice is to drastically reduce soil evaporation and also encourage the formation of dew, as the stones cool off considerably at night.

Figure 17. & 18 Stone mulching from local quarry material

4. Clever road foundations

Road foundations 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 of typically 2-5 m thick, but such compacted road foundations are not common for dirt roads. Impermeable subgrades and road foundations can block local springs and 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 up-slope side of the road, even causing water logging and potential damage to the road body. This is particular issue in some of the mid-high lands.

Groundwater drainage systems and placement of cross-drains can help revert this situation. Permeable subgrades or a series of small lateral drains (also called 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 up-slope to down-slope.

Figure 19. & 20. & 21. Road embankment (left) interferes with base subsurface spring flow; the intercepted water appeared on the other side (picture at the middle) of the spring flow point (picture at the right): by using a clever permeable road foundation this problem can be avoided.

5. Spring capture

When roads cross hilly areas and the roads are laid in deep cut,, excavation may open springs from mountain aquifers. In Yemen the areas with sandstone and alluvial aquifer are particularly rich in springs. In other cases, the road alignment may pass or cross existing springs.

These springs need to be protected, as they are precious sources of local water supply. Many springs have been in use for several decades and user rights have developed for them Care should taken that they are not ruined by the road construction or for instance buried behind hill protection works.. If they are not harnessed, road-side spring in turn can damage road foundations and pavement or hill protection walls. Alternatvely it is not uncommon for local water users to reexcavate such local springs and damage the roads in the process..

Figure 22. & 23. & 24. Neglecting spring source requirements lead to land users to dig the retaining wall (picture at the middle and left) to follow the spring flow which disappeared after the road construction and hilll portection works. In other instances springs are re-excavated (picture on the right) after erosion

If space along side the road allows, protection boxes should be constructed up-slope to collect the spring water. Drainage masks should protect cut slopes around the springs. If space is limited and discharge is large, the water from the springs may be taken underneath the roads surface by pipe or box culvert to a downslope surface storage structure, either an open ponds or a cistern, with the overlfow taken to a recharge area. It is important to estimate the discharge of these spring flows so as to properly dimension the collection tanks and create spill-over structures. The existing and newly opened springs are valuable high quality water supply sources, suitable usually for human consumption.

Figure 25. & 26. Pond storing spring water at down-slope accessed by a pipe (left) and spring water protection box up-slope (right)

<u>6. Ford and irish crossing for retaining groundwater, water spreading or river stabilization</u>

When roads cross dry river beds or water streams it is common to construct fords (also known as low causeways or drifts) or Irish bridges. The differences between fords and Irish bridges is that the latter have one or more drainage pipes, whereas fords have not.

The fords and Irish bridges are important not just as road crossings but they can also help retain groundwater upstream of the road crossing and can increase bank infiltration. The fords and irish bridges in fact can double up as a proxy sand dam. They can be made at additional elevation from the river bed to create more upsteam sand storage. Over time they will be trapping coarse sediment behind them and creating small local upstream 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 build on bedrock or impermeable foundation.
- Their width should exceed annual flood levels with a safe margin.
- The height of the spillway on the ford-cum-sand dams must be such that it allows the river to pass over at high discharges and at the same time deposit coarse material behind the dam. This may be achieved by gradually closing a V-notch in the structure
- The road crossing must be built so as not to change the river course, and preferably be placed at a right angle with the river bed.
- Attention should be paid to the downstream material of the ford particular in hillly areas so as to avoid scour and the over-turning and failure of the road crossing.

Fords combined with roads also have another function, which is to stabilize the river bed of dry ephemeral rivers. Particularly in spate irrigation systems this is a vital function. If riverbeds are stablized by the ford or irish bridges the river will generally remain stable and it will not be subject to deep scouring. This will help the contruction of temporary spate water diversion structures from stones, sand or brushwood.

In some areas the road crossing can also be used to spread floods. The elevated ford is extended to roads embankments on either side, spreading the water over a large area – serving to recharge and add soil moisture.

Figure 27 and 28. Ford in lowland at Wadi Siham near Waqar village (left) and ford in highland at Wadi Al Hamdhh (right)

7. Sand and soil harvesting

The run-off carried through the road structures carry sediments of varying particle sizes. These sediments get deposited in different structures – very much behind the scour checks in side drains or in front of culvert inlets for instance or behind fords that double up as sand dams.

Particularly at culvert inlets and scour checks this sediment should be removed to ensure the structures keep functiong. This could add to maintenance costs, but in many cases the soil and sand collected also represents a vlaue as it can be used for construction purposes or for land development..

Structures as fords and Irish bridges also act to collecti and and sediment 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 make sure that a new layer of coarse sand is deposited. If the sand activated from a sand dam in pits then these pits will fill with fine clays and the storage capacity of the sand dams will be lost.

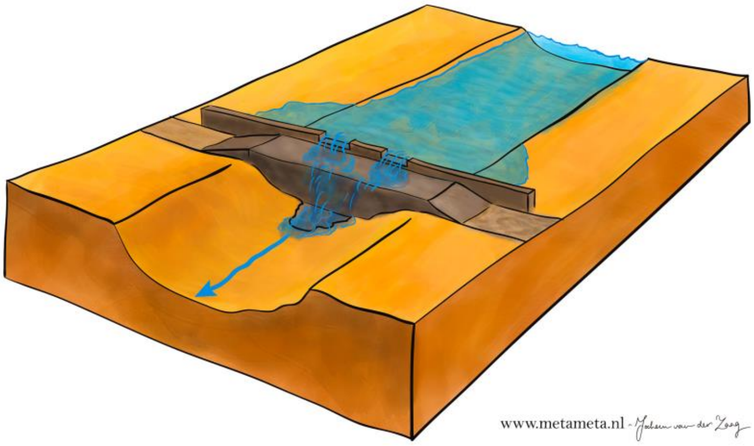


Figure 29. Road crossing cum sand dam

8. Erosion protection from roads

Protection against water related erosion from roads is major issue. Erosion near roads cause to damage to the landscape and particularly the rills and gullies that come about create a loss of soil moisutre.

Design of roads drainage systems play a key role in avoiding erosion. Especially deep sandy to silty soils are erosion prone require special attention if roads are going to be laid on them. Other factors such as water pressure build-up within soil/rock mass, slope instability and concentrated flows by road drainage systems ought to be addressed in order to avoid erosion processes such as gullying and road foundation subsidence.

Figure 30. & 31. Erosion from uncontrolled run-off (left) and controlled road run-off (right)

A major source or erosion is from gullies that develop at the outlet of culverts. These gullies may 'eat back' into the landscape – ultimately threatening the road body itself There are several ways to control this downstream erosion. One is to spread water immediately downstream of the gully so as to dissipate its energy and where the slope and land allows serve adjacent farms. Another protection is to protect the water way up-slope and down-slope from the culvert and avoid that it scours the streams.

Of special concern is the up-slope erosion. This may be accelerated if the cross-drainage from the roads is impeded – for instance because culvert are blocked by rocks and stones. Clearning the culverts will ensure that cross-drainage work properly and is not impeding flows that would cause up-hill damage.

Figure 32. & 33. Blocked culvert inlets

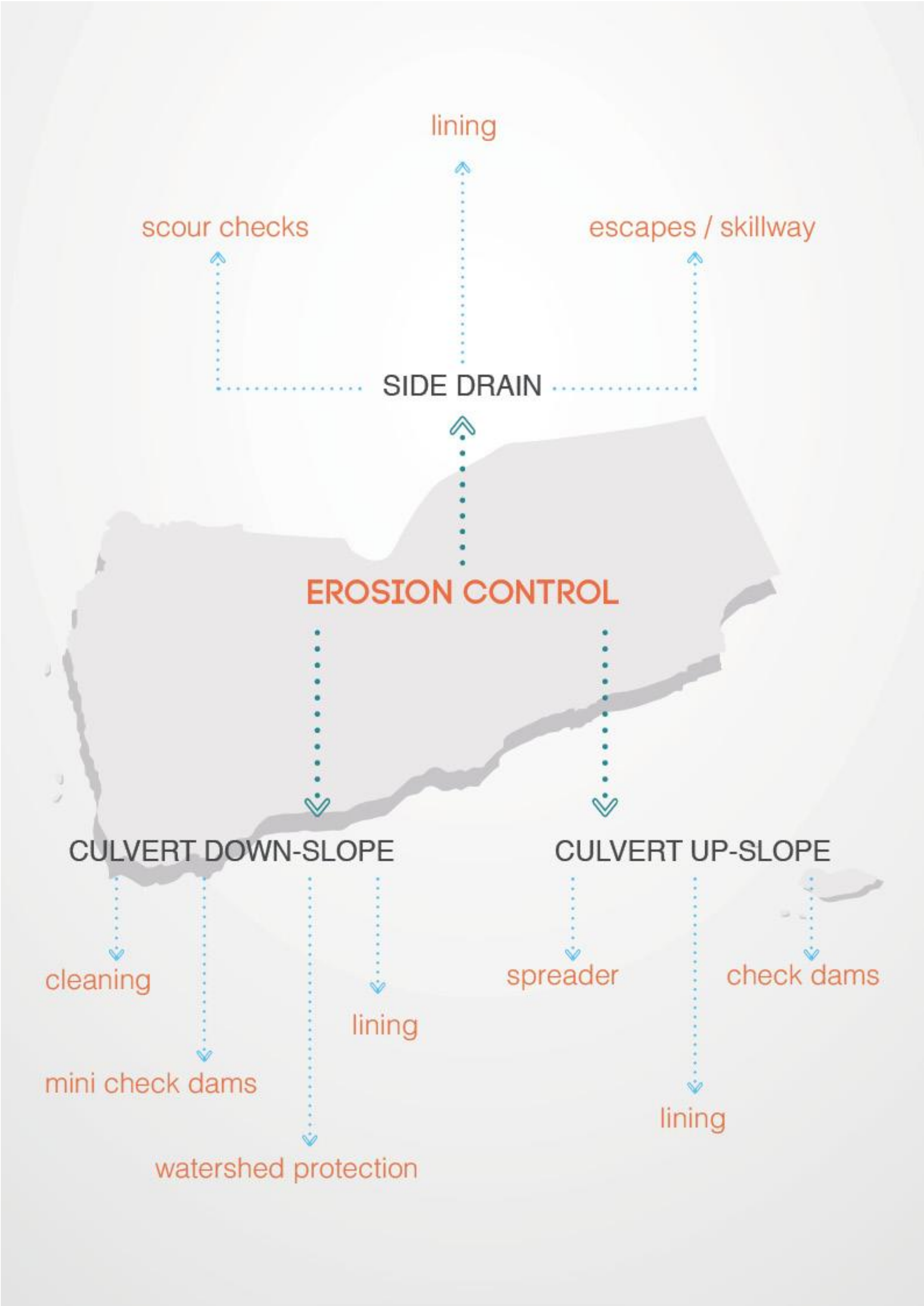
Where there is no side-drain, as in unpaved roads, a line of stones may be placed along the road on the down-slope side, serving as a scour check. Such a line of stones will ensure that water is spread gently across the down-slope area, avoiding rilling or erosion. In some cases low vegetation may serve the same purpose.

A range of techniques can avoid and/or tackle erosion processes. Runoff from the upper catchment and road surface pavement is normally drained through culverts and side-drains. These flows can be chanelled directly to land, to borrow pits and deep trenches or to storage ponds. In steep side drains or downstream gullies by scour checks. Gully erosion can be treated by regreening with vegetation, aiming to stabilize gullies and streams. Scour checks are simple and cheap structures meant to prevent scouring and gullying of side drains. In critical sections side drains may be lined.

Figure 34. & 35. Lined road drains


Figure 37. & 38. Temporary rock scour checks in a rip-rapped side ditches

At a larger scale, erosion mitigation can be implemented through effective watershed management. In this regard several interventions are recommended; priority for upper catchment treatment, early treatment of gullies and minimization of gully heads (gully plugging) and rehabilitation of affected areas through simple, cheap, flexible and local available materials are possible solutions. Involvement of different stakeholders and main governmental offices and agencies working on watershed protection is essential. Making the multiple use of roads part of water harvesting in watershed management is essential.


lining
scour checks
escapes / skillway
SIDE DRAIN
EROSION CONTROL
CULVERT DOWN-SLOPE
CULVERT UP-SLOPE
cleaning
mini check dams
watershed protection
lining
spreader
check dams
lining

9. Roads as flood control mechanisms

Roads subgrades and embankments act as dikes and they in principle compartimentlize the land scape. In areas prone to periodical floods – roads may serve as flood regulators. The location of roads and the main cross-drainage infrastructure is important and it can help to attenuate the floods.

It is also important, especially in hilly areas, that earthen roads are constructed adequately, with ample drainage for instance in the form of rolling dips. If not roads, may develop easily into flood paths and natural drains – destroying the roads and the area surrounding it.

Figure 39. & 40. The embankment was protected by concrete and there is a small temporary bund to retain the water in the upstream (the potential is using gates in the culverts inlets).

Figure 41. and 42 : Earthen roads risk developing into a flood path – proper design with rolling dips and spill overs required.

10. Roads body as retention dams / small retention ponds

The road body may be used as dam body and as such create a retention pond (see also box 3). The dam spillway can be small bridge, depression or culvert in the tarmac roads. The road body in combination with the landscape can form a retention dam.

Figure 43. & 44. Road body used as recharge dam in asphalt road

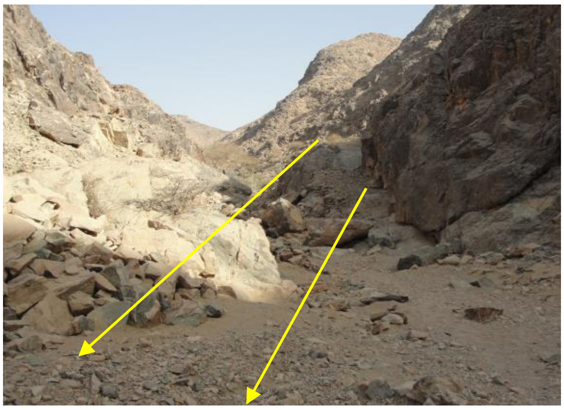


Figure 45. & 46. Potential location of small rural feeder road crossing small wadi stream and the road body may act as recharge/storage dam

Box 3: Road embankment as part of reservoir

In some cases the road embankment can also used as part of the water harvesting body, if this is placed up-slope of the road. Generally the road body needs extra protection with rip rap shoulders to avoid the road body is undermined by the stored water. The culvert may be blocked in order to fill the up-slope pond. In other countries gates are sometimes provided on the culverts to release excess water.

There is a need in general to design the road water harvesting structures as integral part of the road development works so as to optimize the functionality and also avoid that road water harvesting facilities undermine road stability.

Conclusions and recommendations

This note proposed a novel approach on water resource management and road development. There are a number of enablers that will help this approach to mature.

Process - Integrated processes combining road development and natural resource management are key for successful implementation of water management and road construction – including a close interaction with roadside communities.

Capacity building – water harvesting from roads is a novel concept: new knowledge and know how is required. Road engineers, agricultural and natural resource management experts, water managers, watershed professionals are the target groups for. Moreover water harvesting in roads may be included in university curricula and in vocational training.

New design standards - road design standards with a holistic landscape/watershed approach are needed. Clever combinations of surface and ground water drainage with water harvesting structures and natural resource management techniques must be included in design principles for rural roads.

International organizations such as IFAD can 'pave the way' – to ensure negative effects of roads are not only reduced but also reversed into assets and that new design processes and techniques are incorporated in the road investment programs that they support. Benefits from water harvesting in roads are ample. As shown from Yemen but also from experiences in other countries these are amongst others - erosion management preventing damage to roads and the surrounding landscape, road water harvesting structures used to recharge the shallow ground water, surface water storage through borrow pits and shallow ponds can supply domestic and livestock watering activities, increase in sand mining activities, improved flood control and flood spreading through embankments/fords/low causeways/water spreading weirs, re-greening of grazing lands, community involvement and labour generation through O & M practices, reduced maintenance costs due to more resilient roads, benefits for local communities making use of water for irrigation and other marketable goods, additional water supply sources through sand dams and spring capturing.

Additional resources/tools

For more information and related literature refer to the following website;

www.roadsforwater.org

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Annex 1: Roads surveyed for the Guidance Note

Road section	Length (kilometre)	Terrain (hilly, flat)	Material - tarmac - stone paving - dirt road	No of road water harvesting structures	No of critical spots (and type, erosion, flooding etc)
Amran – Hajjah	45	Hilly	Old Asphalt Road	about 9 water harvesting structure, more than 6 springs.	A lot of erosion spots in culverts outlets and blockage in culverts inlet
Hababah – AlTawilah	24	Hilly	New Constructed Asphalt Road	One water harvesting structure, small earth check dams and a lot of spring water collecting structures	A lot of erosion spots in the cut side and in the access materials due to excavations and at the culverts outlets
Al-Sobaha - Luluwah	12	Flat Plain	Asphalt Road	One water harvesting structure, road as dam and a lot of potential locations for water harvesting	Limited erosion in some culverts outlets
Sana'a - Mahweet Road	100	Hilly	Old Asphalt Road	1 borrow pit about 10 water harvesting structure	A lot of Soil erosion in small bridges and culverts outlets,
Qanawis-Mahweet Road	20&60	Flat &Hilly	Asphalt Road	1 borrow pit about 14 water harvesting structure More than 20 diverting water to farms from road surface, drain ditch end and side curbed shoulder	2 spots of flooding in Irish Crossing A lot of Soil erosion in culverts outlets, drain ditch end, side curbed shoulder end and road cut section side.
Bait Shahthy (Feeder Rural Roads - Branches)	1.3	Hilly	Dirt Road (Planned to be stone paved by CRU)	1 water harvesting pond	Erosion from/in road surface.
Marawa'a - Wager - Qutay'	24	Flat	Asphalt Road	None	Erosion in the sides of the roads by flooding from road surface and some culverts.

Doum Village (Feeder Rural Road)	0.80	Flat	Stone Paving	None	Flooding during rainy seasons prevents traffic to enter the village before the intervention. Erosion in the sides of the roads by flooding crossing.
Bait Saied Village (Feeder Rural Road)	1.9	Flat	Tarmac(Base Course) (planed to be paved)	None	Erosion in the road surface and sides of the roads by flooding
Zaghfah Village (Feeder Rural Road)	0.85	Flat	Stone Paving	None	Flooding during rainy seasons prevents traffic to enter the village before the intervention. Erosion in the sides of the roads by flooding crossing.
AlSahili Village (Feeder Rural Road)	2.5	Flat	Stone Paving & Dirt	Only some irrigation canals under the stone paving	Flooding during rainy seasons prevents traffic to enter the village before the intervention. Erosion in the sides of the roads by flooding crossing.
Arah &Alshalal (Feeder Rural Roads - Branches)	8.5	Hilly	Stone Paving	Only spring canals under the stone paving and some humps for diverting water to farms from road surface	1 critical spots of flooding in Irish Crossing
Bait Rase' (Feeder Rural Road)	9	Hilly	Dirt road with stone paving in critical rough sections	Some initiatives to divert water to farms	A lot of water streams crossing the road and water erosion
Bani Araf Road	4.2	Hilly	Dirt road with stone paving in critical rough sections	2 water harvesting structure, dry stone curbed to direct water	A lot of water streams crossing the road and water erosion
Bait La'fi	3.5	Hilly	Dirt road	3 water harvesting structure and water retention technique in terraces using small rocks cover	A lot of water streams crossing the road and water erosion in the road surface and at outer edge

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