



Sana'a University

Water and
Environment Centre



Roads Rain Water Harvesting(RRWH) in Yemen

Towards Development and Management of Roads for Water

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A short course with support of:



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Introduction

Why water harvesting from roads?

1. Road construction is one of the largest public investments.
2. Unmanaged water from roads often leads to negative impacts on all surrounding areas including to the road itself.
3. Water scarcity is a major issue in Yemen and water from road will provide additional alternative to support other water resources.
4. Managing water from roads has economic, social and environmental benefits and opportunities to be tapped.

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

This short course training is initiated following extensive consultations with several water and agriculture sector organizations, and road authority in Yemen, as well as with international partners of WEC involved in the implementation of the Yemen Niche 027, Flood-Based Farming, Roads for Water and other projects.

This short course training includes four training modules as follow:

Module 1: is about Roads Rain Water Harvesting (RRWH) overview at national, regional and international level. It will conduct an overview of the existing traditional roads rainwater harvesting in Yemen and around the world. Also, some road for water experience from different countries will be given

Module 2: is about roads and water, it will describe the roads assets, roads catchment, roads geometric design parameters, roads drainage structures and the effect of water to the road infrastructures.

Module 3: is about techniques of road rainwater harvesting, and will describe all techniques of RRWH that already used in Yemen rural areas and the potential suggested techniques to be used in Yemen. It will present some of the urban RRWH practices and their negative impacts and the potential development.

Module 4: is about economic, social and environmental benefits of road rainwater harvesting. This section will give an overview of the economic, social and environmental benefits of RRWH and the environmental impact assessment (EIA) of road projects globally and locally.

In addition, a one-day field visit to selected road site which include several RRWH techniques and examples of potential calculation of RRWH will be conducted by the participants.

Targeted Audience: this short course is targeted for young and mid-career professionals and decision makers in the water and environment, agricultural and road sectors engaged and/or interested in sustainable Water from Road development and management.

Training Program:

1st day: Roads Rainwater Harvesting Overview

An overview for the existing traditional roads rainwater harvesting in Yemen and around the World will be conducted. Also, some road for water experience from different country will be given

2nd day: Roads and Water

Short description of roads assets, roads catchment, roads geometric design parameters, roads drainage structures and the effect of water to the road infrastructures will be given.

3rd day: Techniques of Roads Rainwater Harvesting

All techniques of RRWH that already used in Yemen rural areas and the potential suggested techniques to be used in Yemen will be described. Also, some of the urban RRWH practices and their negative impacts and the potential development will present. In addition, some examples of potential calculation of RRWH will be given.

4th day: Socio-Economic and Environmental Benefits

An overview of the benefits of RRWH and the Environmental Impact Assessment (EIA) of road projects globally and locally. And introduction to field visit will be discussed.

5th day: Field visit to RRWH road site

One day field visit to selected road site which include several RRWH techniques and examples of potential calculation of RRWH will be conducted by the participant.

6th day: Seminar and closing ceremony

Participants present their 4th and 5th days results to representatives from their respective institutions as well as organizations that supported this short course financially and technically.

Certificate awarding and farewell drinks.

Module1: Roads Rainwater Harvesting Overview

1.1 Background:

Water scarcity, limited water resource and climate change are the main problems facing Yemeni farmers. Drought has been a common occurrence as rainfall has decreased and air temperature has raised. However, droughts affect the livelihoods in general and farmers in particular, and contribute to a lack of food security for most population.

Water and roads are very important issue especially to the road engineers and contractors and the lack of connection between roads and water cause an environmental, economic, technical and social concern.

Environmental concern related to negative effect of the road runoff to the road body as roads are damaged by the force of water and mis design of water drainage structures also the effect of runoff to the nearby landscape as the force of water erode the soil, degrade the terraces and it causes the transfer of cut materials to wadis beds, and dams and reservoirs at the road downstream.

Economical concern related to the increased of the investments cost of water and consequently the roads maintenance works caused by water force and lack of water protection infrastructure.

Technical concern related to the sense of connecting the twins (Water & Roads) in an integrated approach that will be advantageous for integrated infrastructure development.

Social concern related to benefits that will be achieved by the community especially females, farmers and livestock.

Water and landscape in roads projects' construction is very important topic, as known that water is vital factor for the life in all levels and also affect all the construction behavior and maintenance. However, road surfaces may act as a great catchment area in rainy seasons especially in rural areas where water harvesting structures can be established along the alignment of the road, or nearby the road. These water harvesting structures will prevent the road body from deterioration by the accumulated water flow on the road surface and side ditches. Also, it will protect the entire environment and the degradation of soil caused by the water flow at the outlets of the culverts and spillways, in terms of an integrated approach related (local communities and specialist roads engineers) whom have direct interface to the overall landscape along the roadway. In most cases, roads are imposed on the landscape and on the people without much local consultation.

Therefore, increasing community participation and inter-sectoral collaboration on the design have led to more adapted structures, lower construction and maintenance costs.

In Yemen there are no perennial surface water resources, and the country depends entirely on

rainfall, groundwater and flash flooding. The challenge which facing the government with water is defining the best way to control and manage the replenishment and depletion of groundwater resources by improving water harvesting and raise the efficiency of water uses. Since millennia, farmers have practiced sustainable agriculture using available water and land. Through a lot of mountain terraces, elaborate water harvesting techniques, spring irrigation systems and community-managed flood.

Road Runoff Harvesting (RRH) is becoming increasingly important in arid and semi-arid lands in Yemen for crop production, due to increased benefits and farm income resulting from high yields. The runoff water from the road is diverted into channels/ canals and distribution into ditches/ basins or farmland for fruit tree or crop production.

Furthermore, Yemen's topography is known through its rich variety, which is varying from vast plains to steep mountain slopes. It was stated that Yemen has 71,300 kilometers of roads according to Ministry of Public Works and Highways (MoPWH), where some of Yemen roads located in mountainous areas or along the wadis, while road system design is adapted to each environment. The rainwater harvesting potential changes accordingly to each road's location stretches. Meanwhile, some roads are subjected to severe damages as a result of flash flood events throughout the country and by road runoff harvesting the damages are limited or eliminated.

Finally, road water harvesting can be conducted through three types of water harvesting:

- a. Runoff harvesting from roadside drains using Mitre drains,
- b. Runoff harvesting from culverts,
- c. Runoff harvesting from road surface using rolling dips and water bars.

The obtained water can be used in different ways. Many examples exist but standardized design doesn't exist. All of it depends on the landscape characteristics and the final use of the harvested water. Nevertheless, some overall guidance principles can be drawn.

The harvested runoff water can be used as follows, see figure (1.1):

1. Spread over land to provide additional water for crop/grass/tree production. The water can also be directed to planting pits and trenches that are used to grow trees of different kinds. Water is stored in the soil and then directly used by plants.
2. Collected in storage structures such as water harvesting ponds, small earthen dams, old borrow pits, cisterns. The water can be later reused for multiple purposes.
3. Spread over areas with high infiltration (recharge areas) to boost shallow aquifer recharge. Alternatively, the water can be directed in structures such as deep trenches and recharge pits/ponds. The water can be reused through shallow wells or revitalized springs. Figure (1.1) shows how can

road runoff managed.

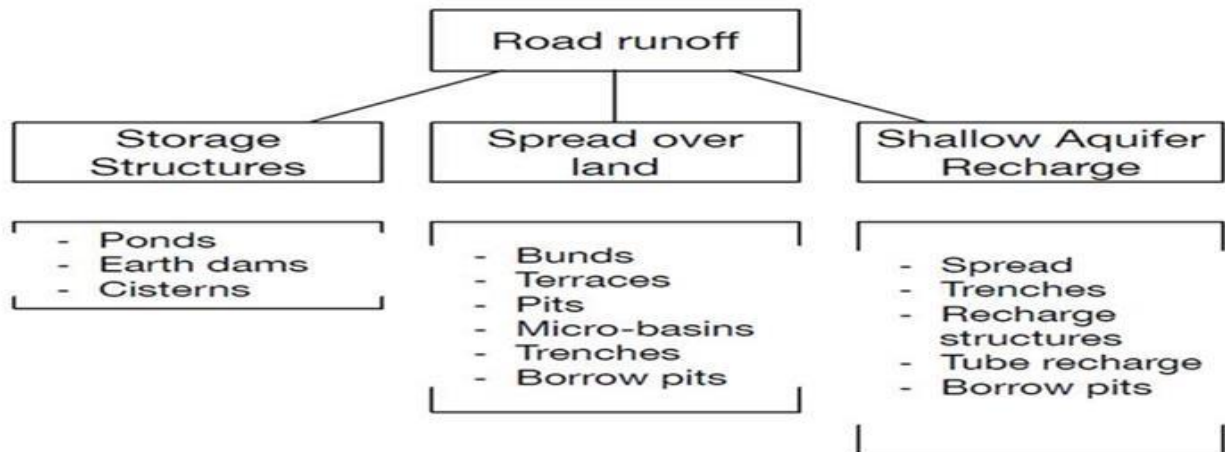


Figure 1-1 How can road runoff managed

1.1.1 Demand Driven and Relevant

Investment programmes in road, land and water development are often narrowly defined in terms of food security, water availability and single interventions. They are rarely informed by a comprehensive road for water wide analysis of the winners and losers. Consequently, many investments have led to unequitable sharing of benefits and costs among various stakeholders (farmers, men, and women) and various sectors (domestic, agriculture, industry, and road). They have also contributed to environmental degradation.

The expected increased investments in road infrastructure in Yemen offer an important opportunity to make a broad impact and have roads help to improve the availability of water. This short course describes both the governance and process 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.

1.1.2 Scope of Water Harvesting From Roads in Yemen

The scope of water harvesting from roads in 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 (MoPWH) by 2011 executed and planned - are summarized below. In addition considerable work has been done on gravel roads by other agencies, see table (1 & 2).

Table 1-1 Yemen's Road Program

No.	Classification	Constructed Length (Km)	Under Construction Length (Km)
1	International links	3647	765
2	Main roads	4067	4940
3	Secondary roads	2220	6200
4	Village access roads	1801	4771
Total		11735	16676
Source : MPWH 2017			

Table 1-2 Recent and On-going Road Programs by Different Agencies

Total Investment in Rural Roads by Different Road Agencies				
Agency	RAP ¹	PWP ²	CRU ³	SFD ⁴
<i>Period</i>	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
<i>Period</i>	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, the highlands where water is very scarce, there are large opportunities 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 had opened up after constructions of roads and these springs are in 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 structures can be used for irrigation or to recharge the open shallow wells. In the low lands there is less scope for water harvesting structures, but road fords and irish bridges can help to retain water in the dry river beds to feed wells alongside the wadi beds. Also, culverts and cross-drainage structures are important to guide the subsurface streams to the safe areas to be used.

1.2 Road Water Harvesting Target:

The road water harvesting is targeted to reduce water shortage around road at rural areas, protect road and road-adjacent land from damage by road runoff, increase productivity of farmers, introduce water harvesting structures on all water and roads ongoing projects and enhance farmer's capacity in RWH. And to mobilize all the communities to participate in watershed conservation and road water harvesting with all concerned departments (water, roads, environment, administration, irrigation, agriculture). Finally, by participating in water harvesting from road short course, the participants will be familiar with

analyzing the impact of the water harvesting from road, and the short and long term benefits and costs of water harvesting and road damage protection.

1.3 Annual Rainfall and Rainy Seasons in Yemen:

The rainfall in Yemen occurs mainly in two seasons: summer and autumn seasons. The first rainfall season (summer season) starts as early as the second half of February to the first half of June (called: Seif season) and reaches its peak in April. The second season (autumn season) from July to the first half of October, and reaches its peak in the period between the first half of July and the first half of September (called: khariief season). The period between early November and early February is a dry period; the occurrence of rainfall in this period is unusual but impossible. The rain fall isohyet for Yemen is mentioned in isohyet map, see figure (1.3).



Credits: (Sharaf&AlAbyadh)

Photo 1.1 Water Cistern Filled By Run-off From Road-surface

The climate zones in Yemen consist of four different climate zones as follows: hyper-arid, arid, semi-arid and sub-humid zones. The sub-humid zone is found in the west mountainous areas, and the hyper-arid zone is covering the desert and coastal areas, the arid and semiarid cover the area between the sub-humid and hyper-arid zones as it's clear in climate zones map, see figure (1.4).

1.4 Traditional Rainwater Harvesting in Yemen

Rainwater harvesting in Yemen is a traditional practice, and in many areas cisterns are used to conserve rain water. The cisterns of Tawaila (rain flood harvesting), or the Tawaila tanks are Aden's best historic sites. According to Huda Al-Kibsi a journalist of Yemen, active cisterns could be found in Beit Bawss, Hababa-Yemen, where the town surrounds the large cistern basin and the water which is coming from the terraces of the buildings is collected. Developing cisterns for domestic and agricultural uses will have tremendous impact on livelihoods in rural communities and help solve to some extent urban water problems. Similarly in Socotra , southern and northern parts of the main island get water from cisterns.

The cisterns are six meters long, four meters wide and three meters deep but there are larger cisterns as well. In many parts of Africa and Middle East, rainwater harvesting is a traditionally practice [3].

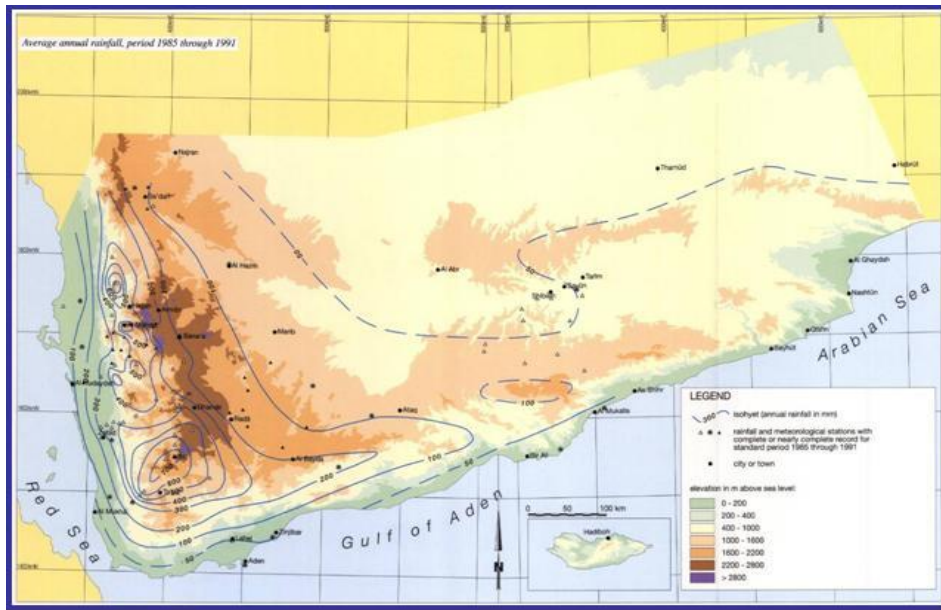


Figure 1.2: Rainfall Isohyets Map

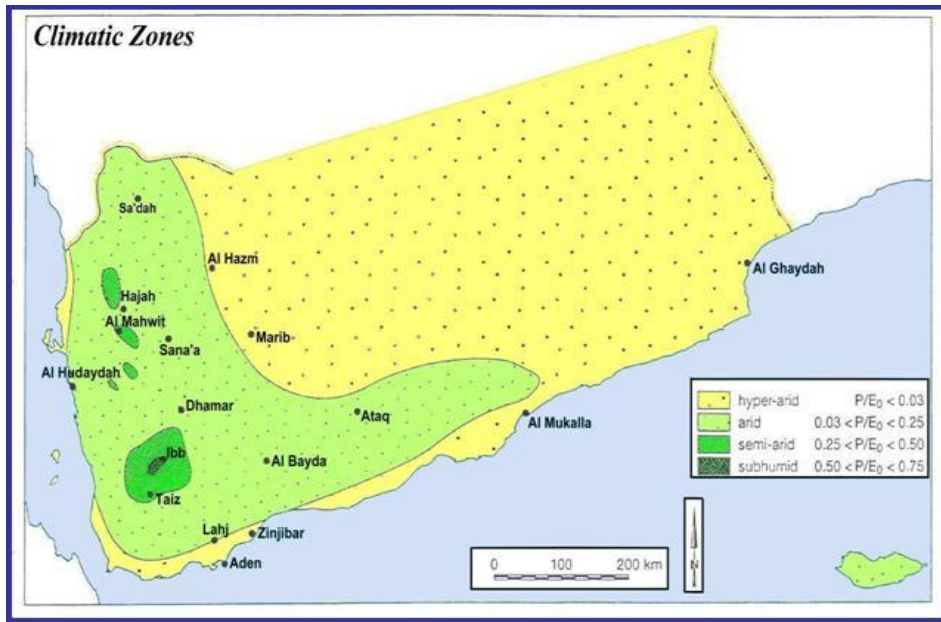


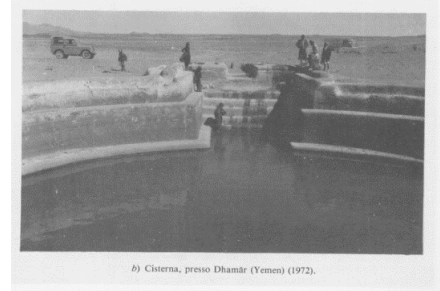
Figure 1.3: Climatic Zones Map

1.4.1 Traditional Roofed Cisterns:

Canal under stone paved road, and underground excavated cisterns as mentioned in Photos (1.2)



Photos from the internet



6) Cisterna, presso Dhamâr (Yemen) (1972).

Photo 1.2 Rainwater harvesting canals to convey water from land & roof and land scape to storage reservoirs, also traditional roofed & ground cisterns, canals under & from stone paved road

1.4.2 Traditional Rain Water Harvesting From Roofs and Streets Around Houses:

Several traditional reservoirs were constructed in the middle areas between houses especially in rural mountainous small towns, photo (1.3).



Photo 1.3 Reservoirs constricted in middle areas between houses to harvest rainwater from roofs & surrounding areas

1.4.3 Traditional Cisterns Over and Underground to Harvest From Road



Photo 1.4 Traditional roofed cisterns and canals

1.4.4 Canal Under Stone Paved Road to Convey Water to Cisterns:



Photo 1.5 Canal under stone paved road to convey rainwater to cisterns

1.4.5 Harvested Rain Water From Road Surface and Drainage to Reservoirs



Photo 1.6 Rainwater harvesting from roads surface and drainage

Module2: Roads and Water

In this module a short description of roads assets, roads catchment, roads geometric design parameters, roads drainage structures, and the effect of water to the road infrastructures. The module is divided into five sections as follows:

- 2.1 Road for Water Impact(problem to solution)
- 2.2 Road Catchment
- 2.3 Roads Geometric Design
- 2.3 Roads Drainage Structures
- 2.4 Roads & Water Damages
- 2.5 Erosion Control Practices

2.1 Road for Water Impact (problems to solutions)

Roads concentrate runoff within watersheds, especially through cross drainage (Culvert), as well as runoff, roads also influence soil moisture and in some cases groundwater. Major problems in Yemen's roads are gullies and erosion at culverts and side drains, photo (2.1). This is especially common when the drainage system downslope of the road is not carefully designed and protected to safely dispose of runoff, especially in sloping areas.



Credits:
Al-Abyadh



Photo 2.1 Runoff inside Drainage and Cross Drainage Damage in Yemen

The road culverts outlets concentrate water runoff, and generally cause erosion and gully in the land at the road downstream, photo (2.2).

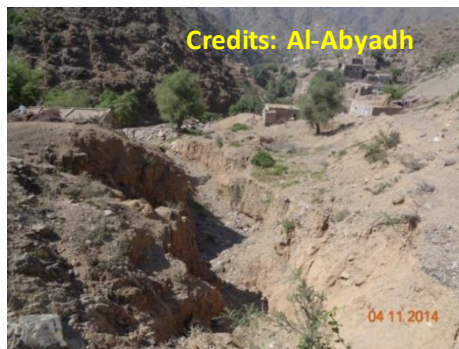


Photo 2.2 Road culverts outlet concentrate water runoff and generally cause erosion and gully

In addition to soil loss, the eroded land suffers from decreased capacity to store water in the form of soil moisture and/or groundwater, figure (2.1). Gullies act as drains removing water from the system to the adjacent land.

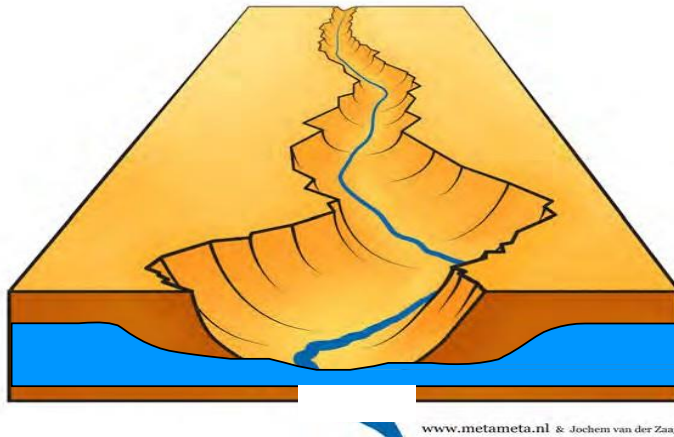


Figure 2-1 Gullies may act as soil moisture and groundwater drainage

Also, road construction can decrease groundwater flow under the road, due to the heavy compaction, which causes reduction of the water-table level and groundwater production on the downside of the road. Furthermore, runoff may cause flooding and sediment transport which negatively impact downstream communities, see figures (2.4 & 2.5). Sedimentations may block irrigation and drainage channels, deposit coarse sand in the fields and reduce duration of design life and capacity of reservoirs.



Photo 2.3 Runoff may cause flooding and sediment transports which cause negatively impact downstream communities



Photo 2.4 Road flooding in West Hararghe, Oromia

Moreover, where drainage from roads is inadequate, this may cause waterlogging, photo (2.5 a & b), damaging crops and roads. Flooding can also happen when too much water is concentrated in too few culverts and the water is not well managed.

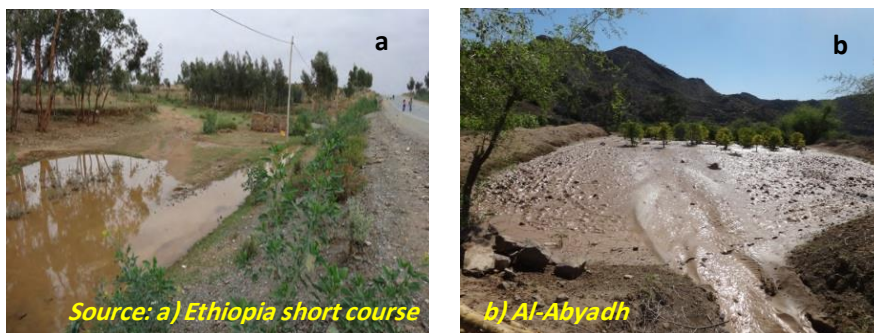


Photo 2.5 Flooding and water logging along roads is a common sight in the rainy season

All these problems are mostly caused by high amounts of rainfall in a very short period of time. Nevertheless, when it doesn't rain many areas are still suffering from water scarcity. This is the turning point where road water challenges can be turned into an opportunity for road managers and roadside communities. The excess road water can be managed and diverted to storage structures such as ponds, and cisterns on the side of the road or spread on the land to increase soil moisture and shallow groundwater recharge. This results in reduced road management costs and additional water resources for roadside communities, photo (2.6 a & b).



Photo 2.6 Water harvesting from road could be water resources for roadside communities

To initiate and sustain a long lasting change, it must be involving all stakeholders in the road path way: agriculture, road and water practitioners, water resources authorities, local governments and roadside communities. In this case, by working all together, integrated solutions deliver the following benefits:

- Moisture levels in soils will increase,
- Shallow groundwater levels will increase,
- Gully expansion will be halted,
- Reduction in flooding,
- Reduction in roads' damage,
- Adapting the spring to be used after road construction.

Many solutions are available and can be adapted and applied to most situations, when all these measures are combined and with the right considerations and management in place, the roads become a flexible tool for climate change resilience, figures (2.2 & 2.3).

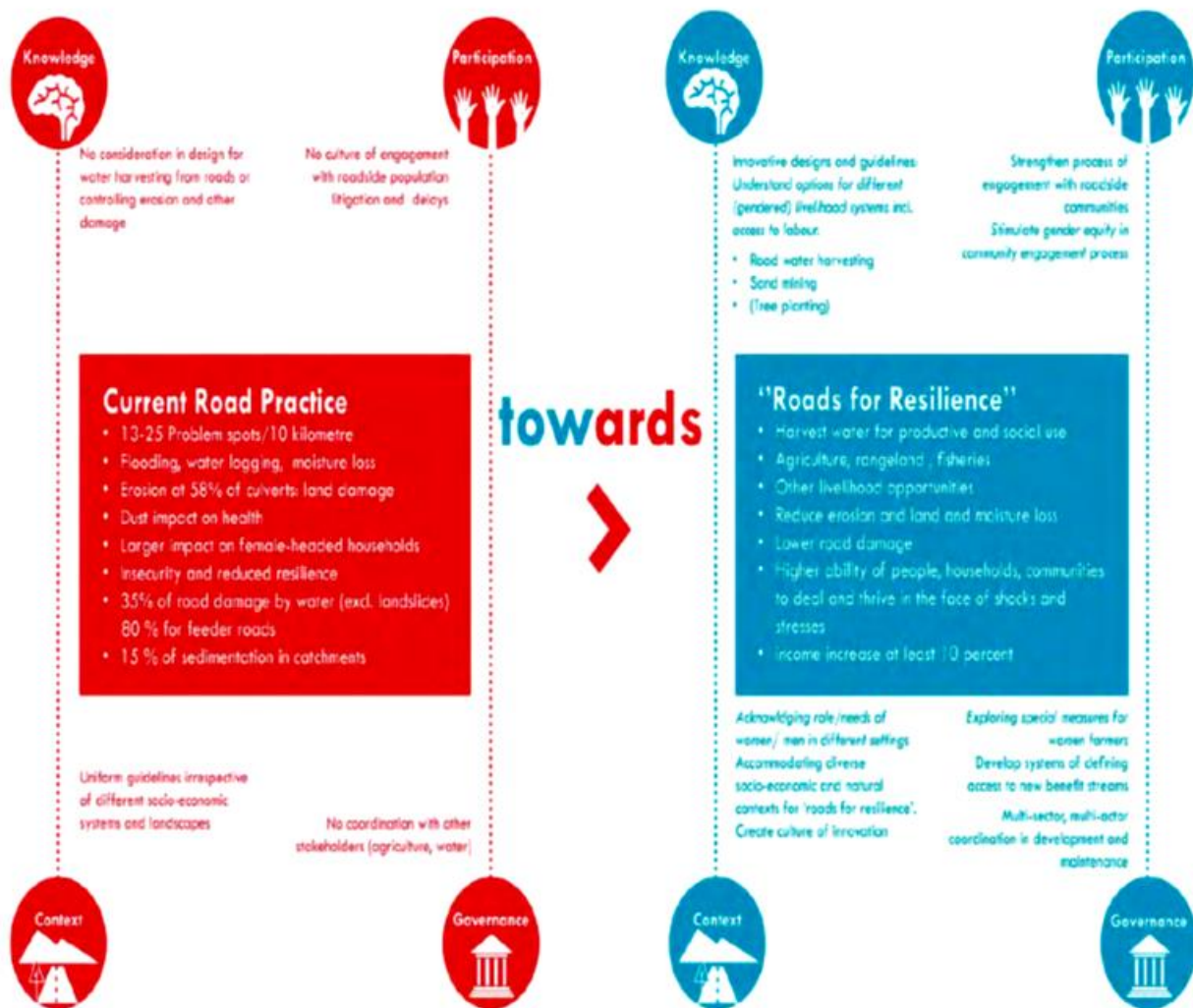


Figure 2-2 From days functional road water management to roads for resilience

sources: Guided Learning on Roads water Management - First Version – December 2016

Adapting to the road



Adjusting the road



Figure 2-3 Road water management solutions

sources: Guided Learning on Roads water Management - First Version – December 2016

2.2 Road Catchment

The water harvesting from roads depends on the catchment slope, soil type, vegetation cover. The road catchment can be classified to three components as follows:

1. **Valley Catchments:** catchments formed by a well-defined valley, either dry or drained by a watercourse (including ephemeral streams) figure (2.4).
2. **Strip Catchments:** catchments with no defined valley, forming a strip of fairly uniform width along the highway boundary, as shown in figure (2.4 and 2.5).
3. **Road Surface Catchment:** catchment defined by the road surface and the Right of Way (ROW) which is an offset distance or a buffer zone along the road depends on the geometric characteristic of the road such as

widening, side shoulder, embankment or cut slope, culverts inlets & outlets, side ditches and spillways. And can be affected by Points of Vertical Interception (PVI) along the vertical profile in means of sag curves points and the Point of Intersection (PI) location along the horizontal curves, in means of cross slopes and horizontal lead outlets figure (2.6).

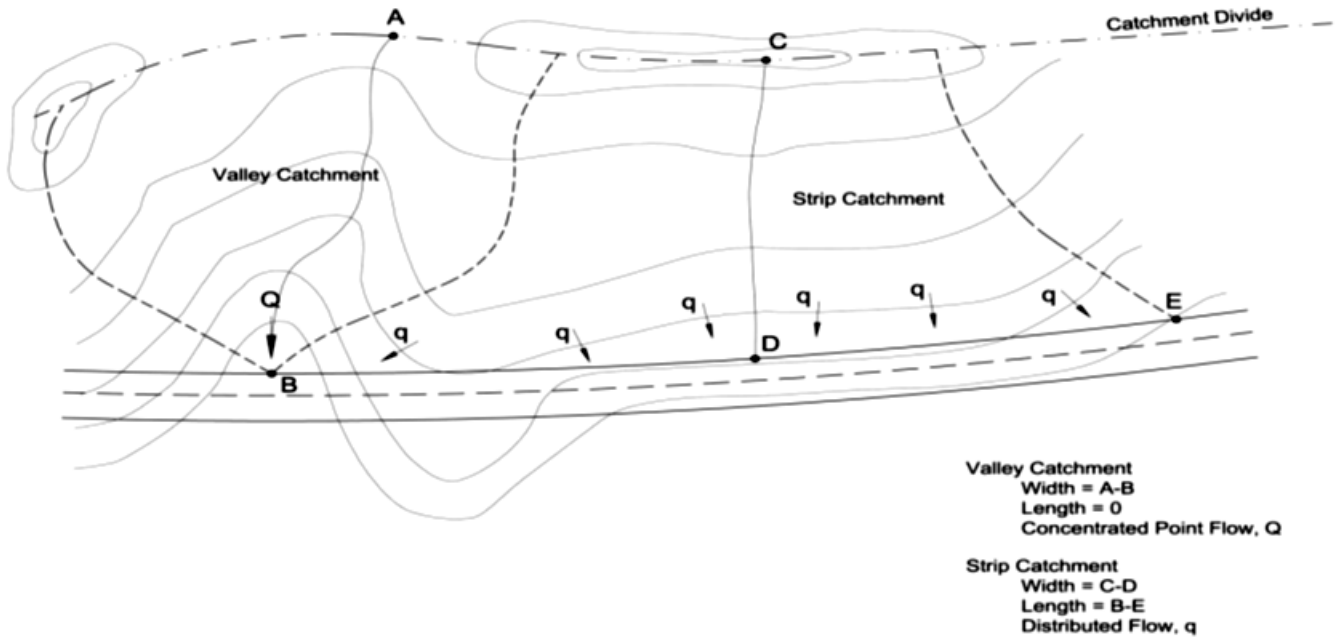


Figure 2-4 Road catchment type

Source: DMRB, Vo. 4 Sec. 2, Part 1 HA 106/04, Drainage of Runoff from Natural Catchment

Developed by: Francesco Sambalino

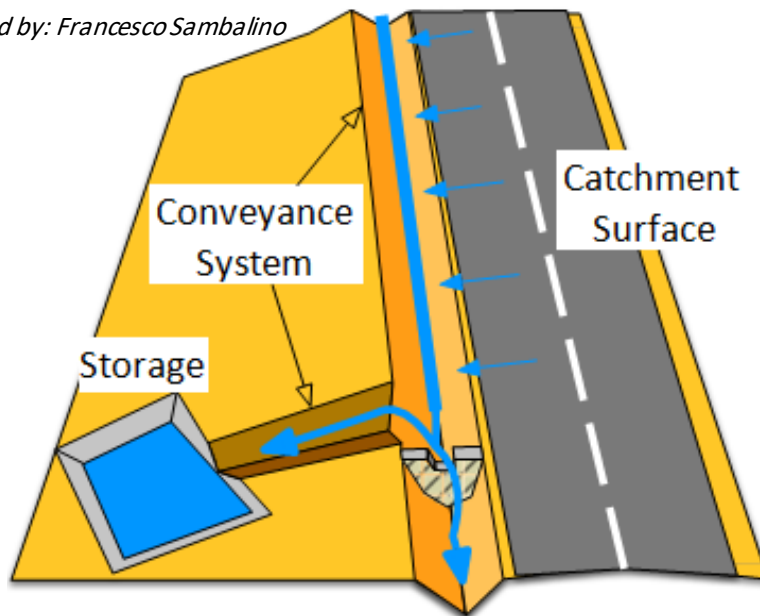


Figure 2-5 A road with drainage ditch adapted to become a water harvesting structure

2.3 Roads Geometric Design

Geometric design is technical matters which consider design parameters such as horizontal radius, cross slope, superelevation, gradient, sight distance, stopping sight distance and design speed. All these factors are determined by terrain type and road classification.

2.3.1 Factors Affecting Road Design and Water Drainage/Harvesting Structures

- Vertical alignments or gradient.
- Horizontal alignments.
- Camber and (cross-slopes or superelevation).
- Cross sections with side drainage.
- Stream crossing structures.
- Pavement type and construction layers.
- Protection works.
- Land use, sub-surface water table (springs) and water rights.

The geometric design drawing include the horizontal alignment, vertical alignment (the natural ground and design level), curve widening and superelevation and cross section at 25 meter intervals. With the culverts locations, figures (2.6& 2.7).

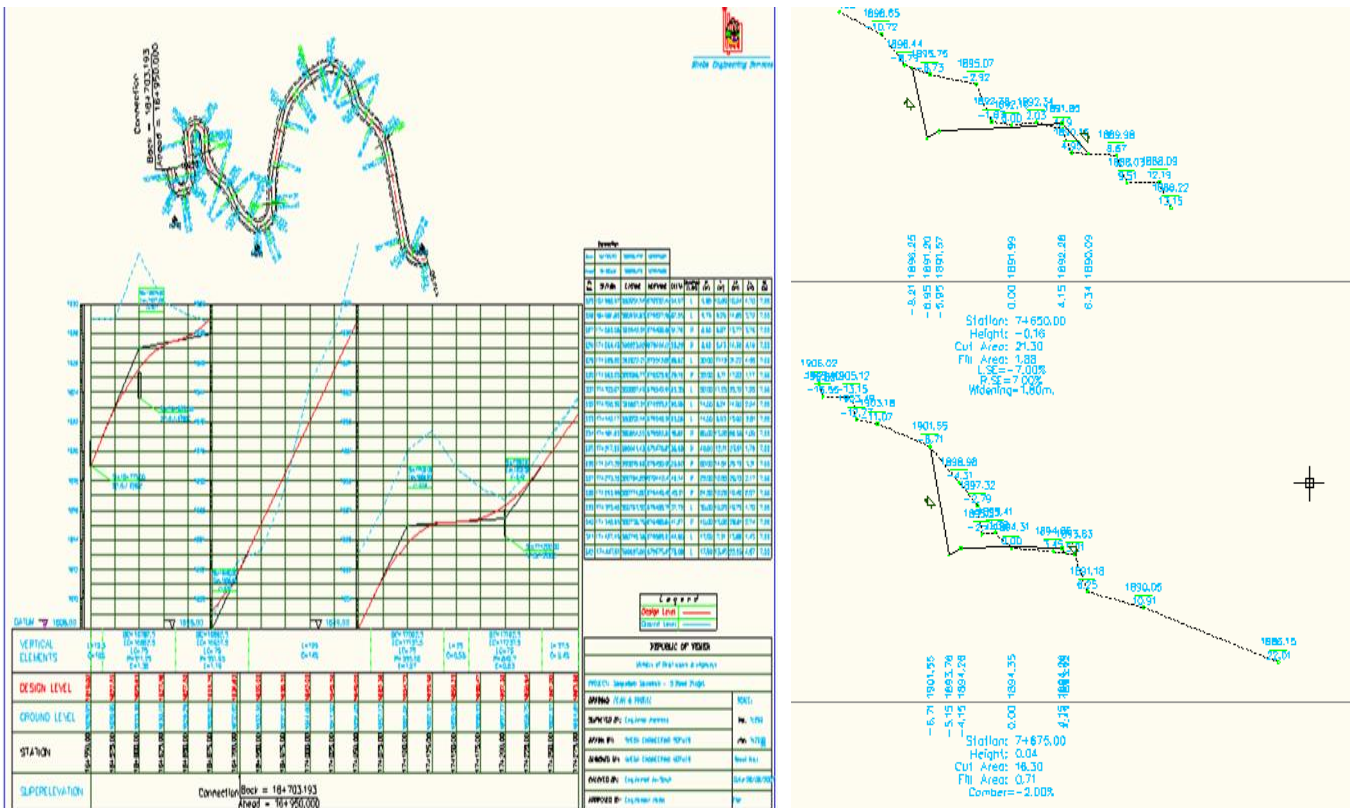


Figure 2-6 Example of road geometric design drawing in a mountainous area

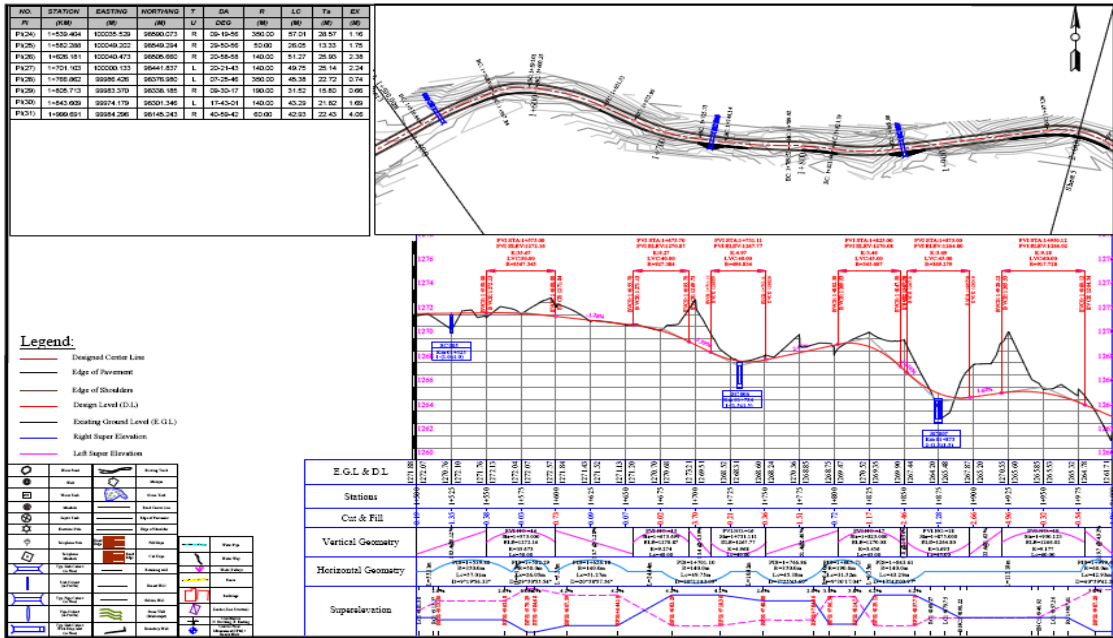


Figure 2-7 Example of road geometric design drawing in mountainous area

2.3.1.1 Elements of Vertical Alignment

The two main components of vertical alignment are:

- Vertical curvature, which is governed by sight distance and comfort criteria,
- Gradient which is related to vehicle performance and level of service.

The cross section of a roadway is made up of:

- Number and width of lanes;
- Shoulder width;
- Cross slopes;
- Pavement type;
- Side slopes;
- Drainage;
- Right-of-way width.

As examples of road cross section, cross slope, superelevation drawing and road cross section typical drawing, see figure (2.8)

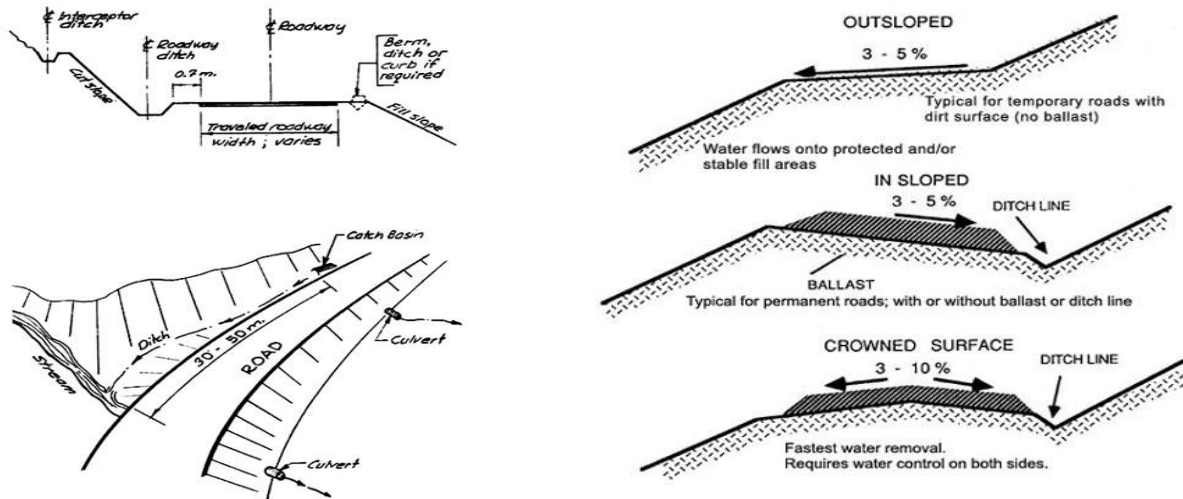


Figure 2-8 Examples of road cross section, cross slope, superelevation drawing

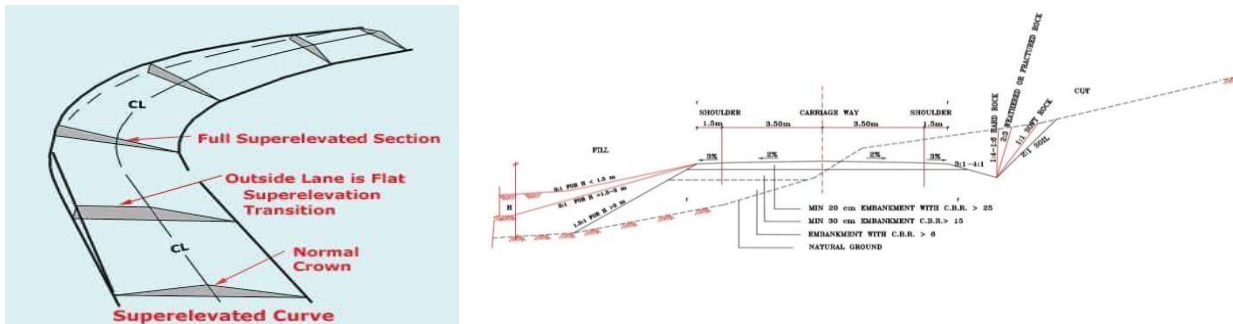


Figure 2-9 Road cross section typical drawing

2.3.2 Road Geometric Design Issues :

- Use of relaxed geometric standards.
- Huge variance between road design profile and the adjacent land use.
- Lack of integrated road geometric design and water drainage structures design such as:
 1. Lack of details of the ditch lead out or discharge points.
 2. Lack of design of protection works (almost all protection works of the road defined after the asphalt layer construction).
 3. Use of typical drawings for drainage structures.
 4. Neglecting the social consultation about water rights and water uses with the stakeholders along roads.
- Budget constraint is an important issue for integrated road and water design.

2.4 Roads Drainage Structures

The road drainage structures are the structures that collect and drain the water from the road body and nearby areas to protect the road from damages. There are several types of road drainage structures used to drain the water and it depends on the land's topography.

Major objectives of roads drainage:

- The speedy removal of surface water to provide safety and minimum nuisance;
- Provision of effective sub-surface drainage to maximize longevity of the pavement and its associated earthworks;
- Minimization of the impact of the runoff on the receiving environment.

(AASHTO, 2001), indicated that 'Highway drainage facilities carry water across the right-of-way and remove storm water from the roadway itself'. As the drainage facilities include bridges, culverts, channels, curbs, gutters, and various types of drains.

Drainage Structures can be categorized to the following:

- Stream Crossing Structures: including bridges, culverts and irish crossing
- Side Drains: including side ditches (earth, lined rip-rap, concrete), lead out or mitres, catch drains,
- Erosion Control Structures: including channels, curbs, chutes and spillways.
- Water Rights Structures: including small pipe culverts, irrigation pipes, humps and spillways.



Credits:
Al-Abyadh



Photo 2.7 Drainage component example

2.4.1 Bridges

Bridge is road cross drainage used when the span of culvert more than 6m, and in premanent water stream channel or rivers.

In Yemen there are several traditional bridges built from local materials, as shown in photo (2.8) a traditional arch stone bridge in road Sana'a Al-Hodiadah main road. In addition to modern bridges as the Steel Girder Bridge in Al Mahweet – Al-Hodiadah road, as shown in photo (2.9).



Credits: Al-Abyadh



Photo 2.8 Arch stone traditional bridge



Credits: Al-Abyadh

Photo 2.9 Steel girder bridge

2.4.2 Culverts

A culvert is a drainage structure to convey surface water across or away from the road embankment under the road surface. Also a Pipe culvert may be placed across and under the road to evacuate side ditches wherever necessary or in few cases used for crossing a wadi flow from one side of the road to another.

In Yemen there are unique stone girders roofed and arch culverts, as shown in photo (2.9). Also culverts may be either pipe or box culverts. They may consist of a single or multiple barrels/cells. Examples of culverts in mountains areas and flat areas are illustrated in photo (2.10 & 2.11).



Credits: Al-Abyadh



Photo 2.10 Stone roofed traditional culvert



Photo 2.11 Culverts in mountains area



Photo 2.12 Culvert in costline and flat area

There are a lot of of road culvert grades types which depend on the location, grade and layout of the inlet and outlet as shown in figure (2.10). A typical drawing of reinforced pipe culvert in Yemen is illustrated in figure (2.11) . and a typical drawing and cross section of pipe culvert outlet and spillway protection works details are shown in figure (2.12)

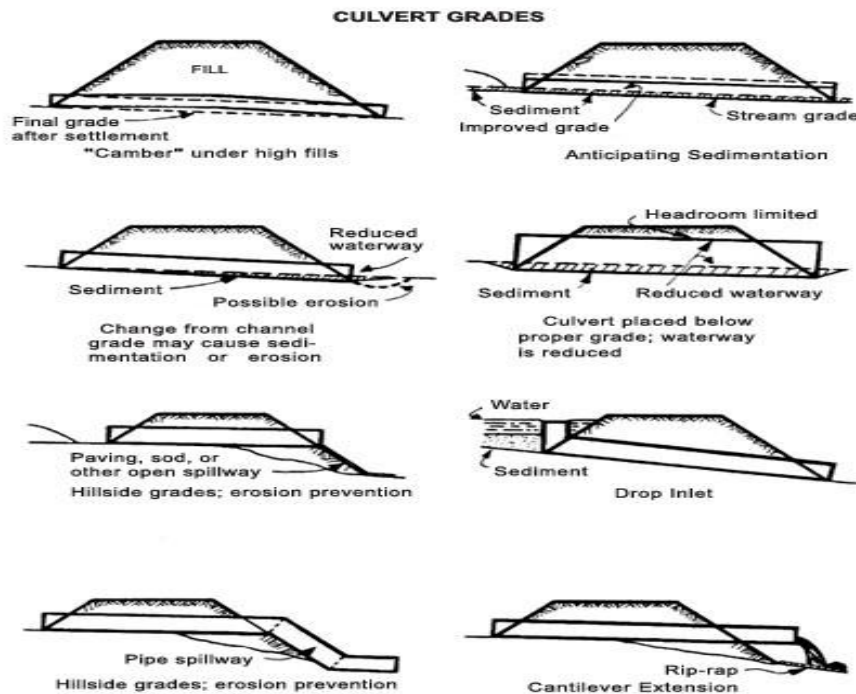


Figure 2-10 Types of road culvert grades

SOURCE: (HYDRAULIC DESIGN OF HIGHWAY CULVERTS, THIRD EDITION, APRIL 2012

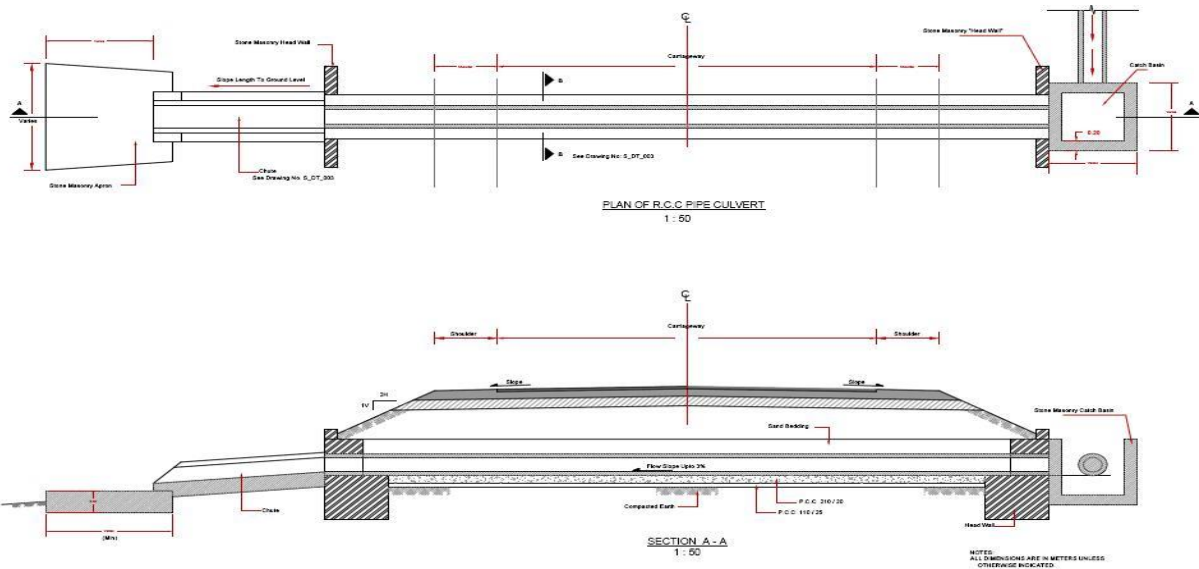


Figure 2-12 Typical drawing of reinforced pipe culvert

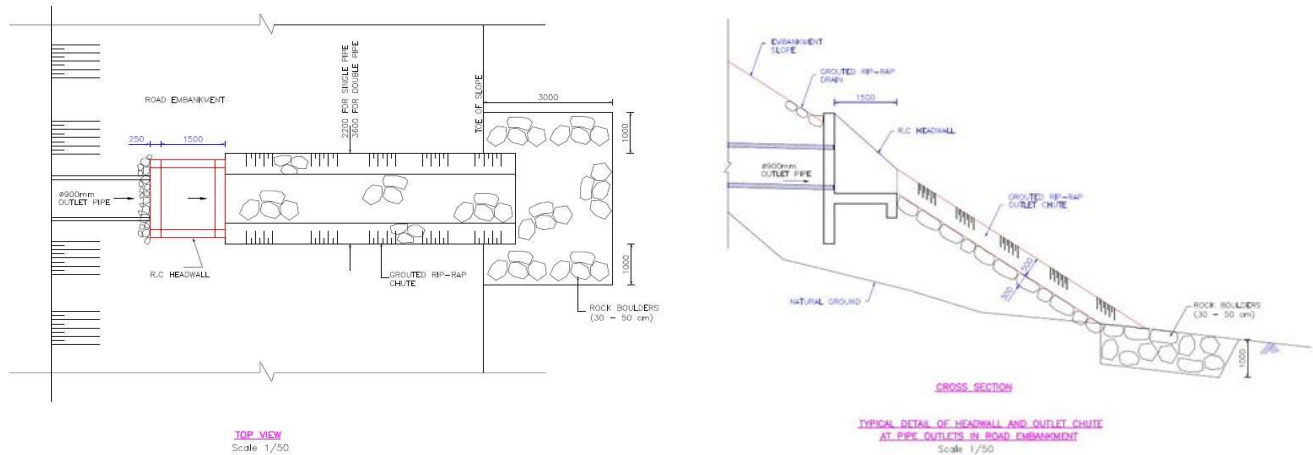


Figure 2-11 Typical drawing and cross section of pipe culvert outlet and spillway protection works

2.4.3 Irish Crossing

The Irish crossing is constructed through the road to convey flow from one side of the road to the other side. Flow can be wadi flow crossing or side ditches/barriers discharge.

There are four types of typical drawing of Irish Crossing which used in Yemen in rural roads especially when the road pass along seasonal water streams or (Wadis).

The types are according to wadi bed slope and the head water height of the wadi water.

Guidelines for choosing type of Irish Crossing

- Irish Crossing type (A) for natural bed slope $> 1\%$
- Irish Crossing type (B) for natural bed $0.6\% < \text{Slope} < 1\%$
- Irish Crossing type (C) for natural bed slope $< 0.6\%$

- Touch grade crossing (D) for small $Q < 5.0\text{m}^3/\text{Sec}$.
 (And max. height of water 0.2m. And max. velocity 1.0m./Sec. And max slope 0.6%)

Table (2-1) give a guidance for determining Hw, Slope, Velocity.

Figure (2.13) show the typical drawing of Irish crossing profile with elemnts and figure (2.14) shows the typical Irish Crossing cross section details.

Table 2-1 Velocity, Slope & Hw

TABLE OF VELOCITY W.R.T. SLOPE & Hw						
SLOPE \ Hw	V.m / SEC.					
	0.5	0.4	0.3	0.2	0.15	C.1m
2%	3.50	3.00	2.50	1.90	1.60	1.20
1%	2.20	2.10	1.80	1.35	1.10	0.85
0.8%	2.00	1.90	1.60	1.20	1.00	0.75
0.6%	1.70	1.60	1.40	1.00	0.85	0.65
0.5%	1.60	1.50	1.25	0.95	0.80	0.60
0.4%	1.40	1.30	1.10	0.85	0.70	0.55
0.2%	1.00	0.95	0.80	0.60	0.50	0.38

NOTES:

I- $Q25 = Hw \times L \times V$ m /sec.

II- $L = \text{LENGTH OF I.C} = \frac{Q}{Hw \cdot V}$ IN METERS

III- L FOR TYPE - D TO BE INCREASED BY 20m.

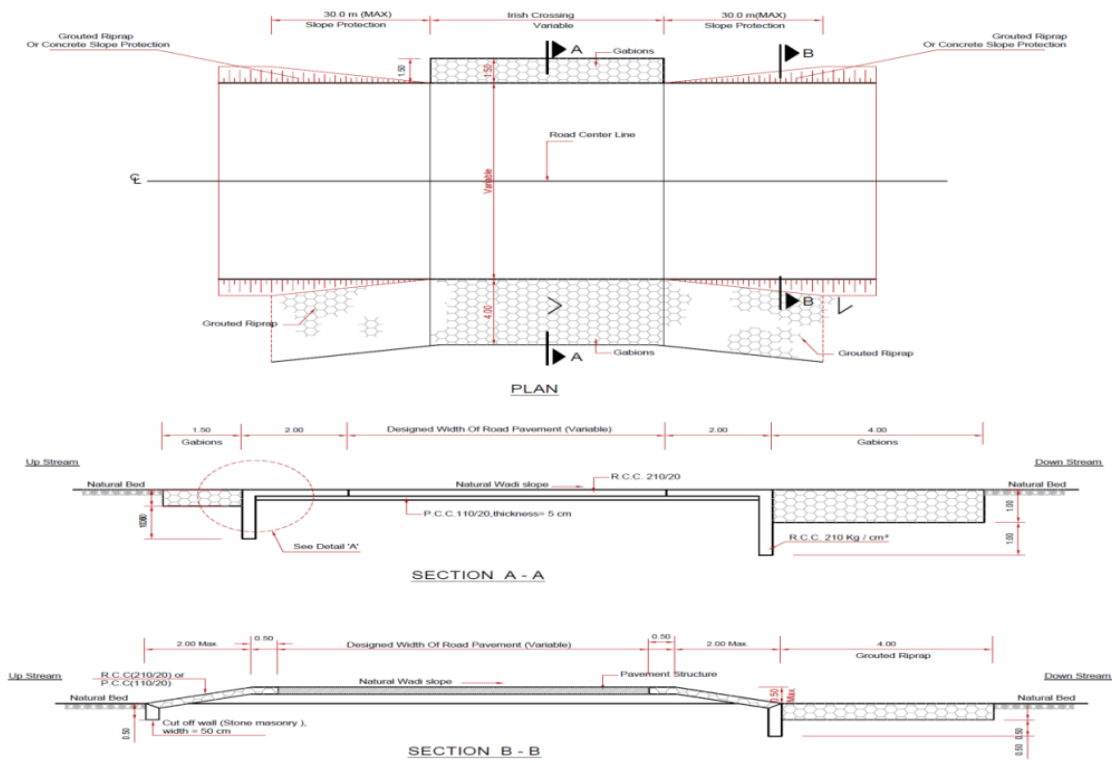


Figure 2-13 Irish crossing typical drawing

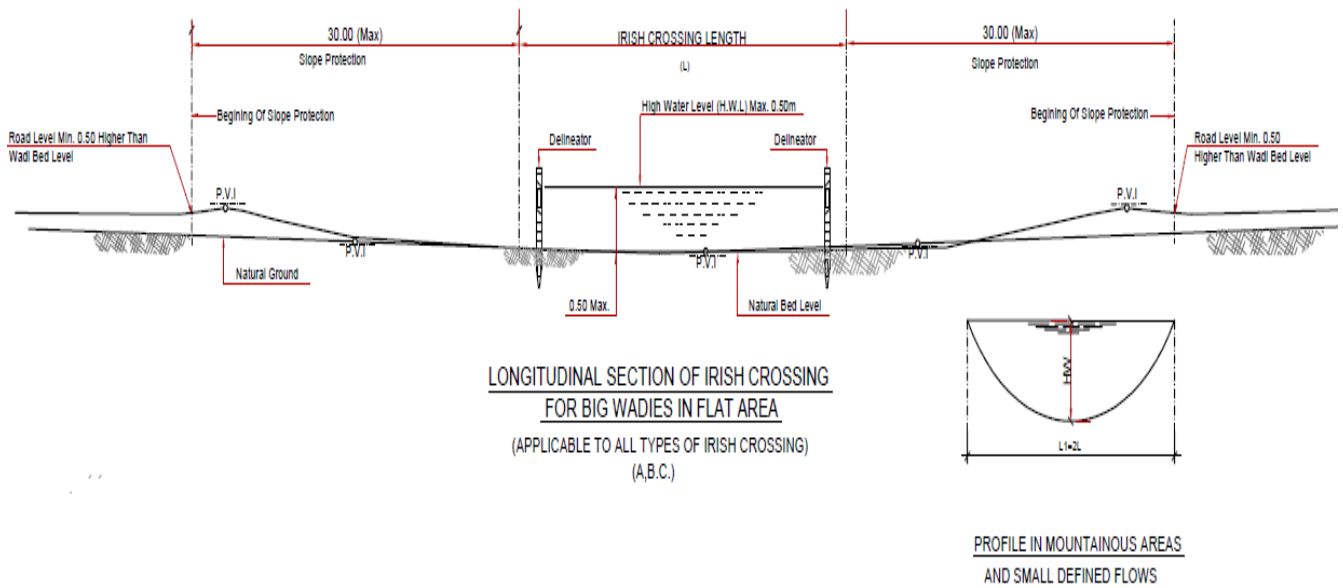


Figure 2-14 Typical drawing of irish crossing profile

The following are typical notes for Irish Crossing:

- Length of Irish crossing (L) to be fixed according to natural bed slope of wadi and max. height of water at crossing = 0.5m.
- Type of Irish Crossing to be fixed according to slope of bed of wadi and consequently water velocity fixing max. height of water.
- Cross road slope at Irish Crossing should be along the slope direction and level of wadi bed. There are guidelines to be followed for road in curve at crossing.
- Profile of road at Irish Crossing should be adjusted according to what is given in longitudinal section of Irish Crossing, distance "L" should be straight and horizontal and suitable vertical curves to be adjusted at both sides in slope protection region according to High Water Level (H.W.L) and profile conditions. (In case of skew flow, distance "L" should be straight on the natural bed levels.) Profile in mountainous areas can be adjusted according to guidelines as one curve ($L_1=2L$).
- Special cases to be considered separately (I.e. Deep Wadies, Crossing the road at small angle, etc.)
- High delineators to be put on each side of I.C at every 10.00m as detailed.
- The pavement cross section and subgrade CBR value at Irish Crossing and their approaches shall comply with the appropriate pavement relevant drawings.
- Slope protection for Irish Crossing shall be reinforced concrete up to 0.4 m above finished level of Irish Crossing and grouted riprap thereafter.
- Exact location of Irish Crossing to be determined by the engineer on site.



Photo 2.13 Example of irish crossing in flat terrain

Major Problems in Irish Crossing

- Scour and collapse of Irish crossing structure due to the huge concentrated seasonal floods.
- Sedimentation and transmitted of wadi boulders and debris along Irish crossing

- Erosion and scour in Irish crossing are costly as the outlet was extending with quantities more than the design typical. Photos (2.14 & 2.15) show some problems and damages to Irish crossing.



Photo 2.14 Show the sedimentation problem on arch bridge



Photo 2.15 Scour of wadi Hamidha (Al-Mahweet gov.) irish crossing structure due to the huge seasonal floods and the extended protection works

2.4.4 Side Drains & Mitre Drains

The function of road side drain is to collect surface water from the roadway surface and road side catchment and convey it to an outlet. It can be a trapezoidal shape at the toe of the cut sections to drain the platform and/or embankment water. An example of side drain is illustrated in photos (2.16 & 2.17).

Mitre Drain: the Mitre drain leads the water out of the side drains and safely disperses it onto adjoining land as shown in figure (2.16). Also, photo (2.18) shows another example of side drain and mitre drain or lead out ditch. Low runoff volumes and speed should be achieved at each discharge point to minimize erosion. Therefore, to limit erosion it's important to build mitre drains at short and regular intervals: as frequent as every 20 meters (MWI,2015).

A small barrier is required to ensure that water flows out of the side drain into the mitre drain, photo (2.16). The angle between the mitre drain and the side drain should preferably be 30 degrees, but not greater than 45 degrees. The desirable gradient of mitre drains is 2%. The gradients shouldn't exceed 5% otherwise there may be erosion in the drain or on the land where the water is discharged. The drain must proceed gradually across the land, getting shallower as it progresses. Stones may need to be laid at the end of the drain to help prevent erosion (Sambalino and Neal, 2016).

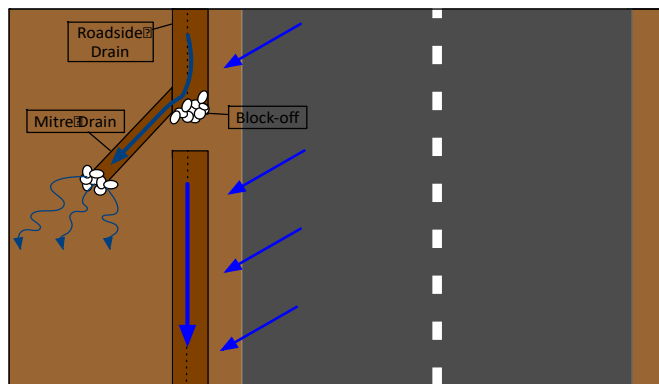


Figure 2-15 Water diversion from roadside drain using a mitre drain

Source: Sambalino et al. 2016

Scour Check: scour check is a small structure placed across the drain on steep gradients and is designed to slow down the flow of water to prevent erosion of drain invert and slopes.

The appropriate distance between scour-checks depend on the road gradients and it's shown in the table below.

Table 2-2 Interval of scour-checks depending on the road gradient

Road gradients	Scour check interval
4	Not required
5	20
6	15
7	10
8	8
9	7
10	6

Roadside barriers: it serves the same purpose as ditches that are used where mountains are steep with no houses, terraces or crossing roads anticipated.

Use of V-section and or trapezoidal lateral ditches as required in order to convey drainage water and to protect the sub-grade and pavement.

Moreover, where the road is benched into the mountain side, drains will be provided on the uphill side only, and will be located at the outer edge of the shoulder. Also, where the road is on embankment, no lateral drains will be required.

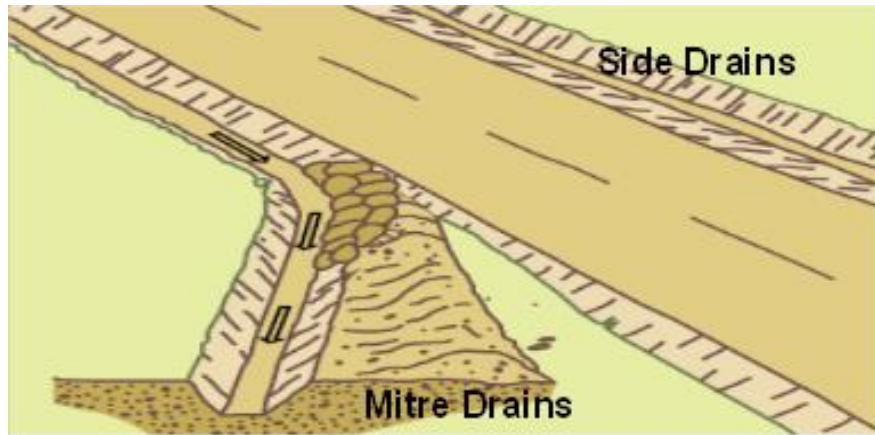


Photo 2.16 Mitre drains



Photo 2.17 Side drain



Photo 2.18 Side drains and lead out drain (mitre drain)

However, where slopes exceed around 5%, the drains will be lined with stone pitching, in order to avoid erosion problems. Where slopes exceed about 8%, simple in-ditch energy dissipaters will be provided at appropriate intervals. Table (2-3) shows the allowable ditch length and the recommended type of discharge. Figure (2-16) shows the side drains protection work typical (rip-rap and stone lined).

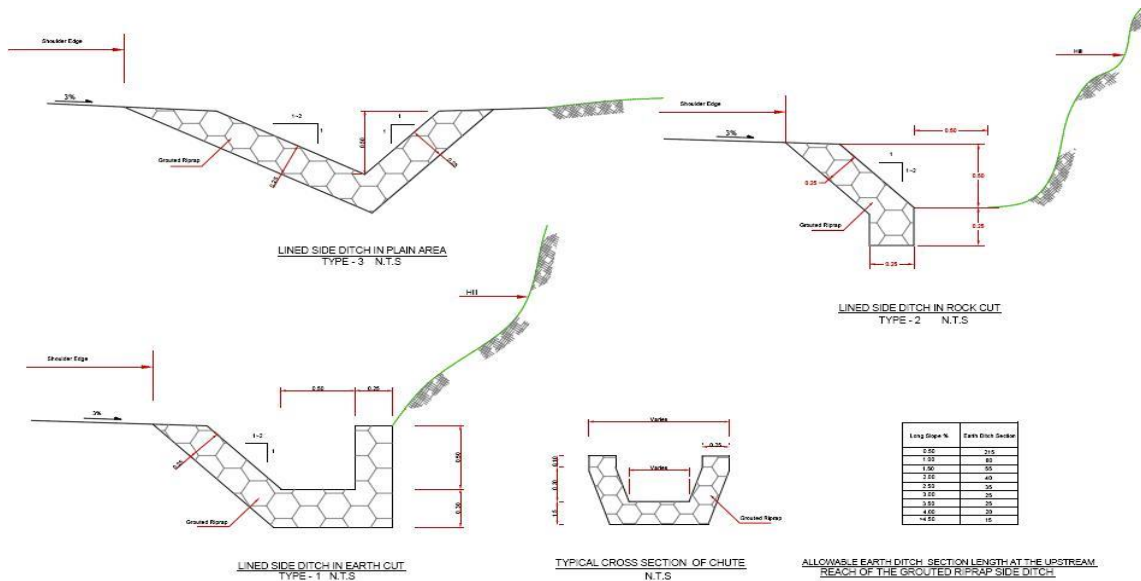


Figure 2-16 Side drains protection work typical (rip-rap and stone lined)

Table 2-3 The Allowable Ditch Length And The Recommended Type Of Discharge

GUIDE TABLE FOR DITCHES & DISCHARGE TYPES

Long. Slope	Allowable Ditch Length	Recommended Type of Discharge	
		Bumps	Culverts
%	Up to	No.	No.
0.50	285	1	-
1.00	400	1	-
1.0 - 2.0	400	1	-
	575	2	-
2.0 - 3.5	175	1	-
	350	2	-
	750	-	1x1.0x1.0
3.5 - 5.0	125	1	-
	250	2	-
	750	-	1x1.0x1.0
	900	-	1x1.5x1.0
5.0 - 7.5	80	1	-
	150	2	-
	750	-	1x1.0x1.0
	1100	-	1x1.5x1.0
7.5 - 10.0	60	1	-
	125	2	-
	750	-	1x1.0x1.0
	1100	-	1x1.5x1.0
	1275	-	2x1.0x1.0

Lined ditches are used when velocity exceeds 1.0 m/s. Velocity can be checked using Manning equation. Table (2-4) provides the maximum allowable length and earth ditch (formation range from sand to silty clay). Side ditches may be triangular, trapezoidal or a combination of both.

Table 2-4 Allowable Earth Ditch Section Length At The Upstream Reach Of The Grouted Riprap Side Ditch

Long slope %	Earth ditch Section
0.50	215
1.00	80
1.50	55
2.00	40
2.50	35
3.00	25
3.50	25
4.00	20
>4.50	15

Typical Side Drains & Mitre Drains Clarification Notes:

- Location of discharge points of side ditches / barriers shall be determined by project manager/resident engineer on site according to the local conditions and water harvesting needs.

- The type of road side drainage, i.e. ditch or barrier, shall be determined by project manager/resident engineer on site depending on adjacent land use (steep hills, terraces, plain ...) and according to locals preferences, as shown in photo (2.18).
- Roadside ditches should be provided at cut sections shown on road profiles, wherever an adjacent area is discharging to the road, and as directed by the project manager/resident engineer on site.

2.4.5 Catch-water Drains

Catch water drain is a ditch constructed on the uphill side designed to intercept or collect and drain away surface runoff water flowing towards the road from the uphill side, and lead it to a suitable point of disposal. Figure (2.17) shows the cross section of catch-water drain.

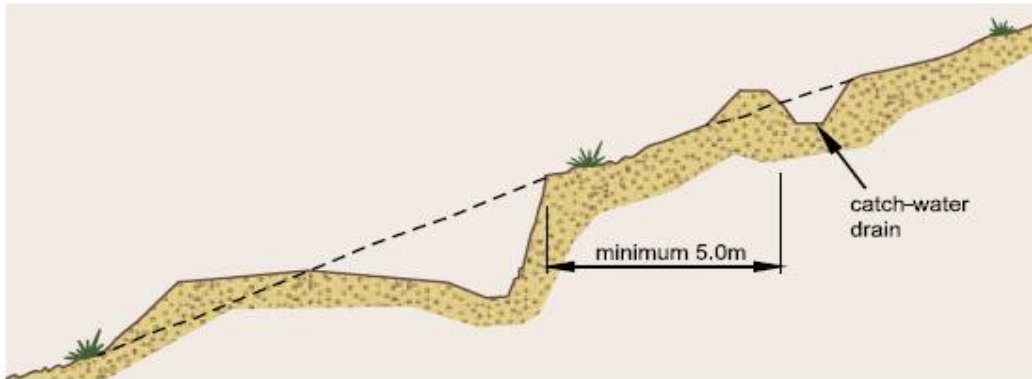


Figure 2-17 Catch water rain typical (road drainage ch 7)

2.4.6 Spillways and Chutes Drainage Structures:

Spillways and Chutes are used in the following locations:

- High fill to collect runoff.
- Lead-out drains to prevent erosion.
- At culverts outlets to prevent erosion.
- Up-slope steep cut section.
- At the retaining walls to drain the surface water.
- As ditch in mountain road

Photos(2.19), (2.20) show different spillways types. And figure (2.18) shows typical drawing of chutes and spillways protection work cross section.



Photo 2.19 Spillway from lead out ditch

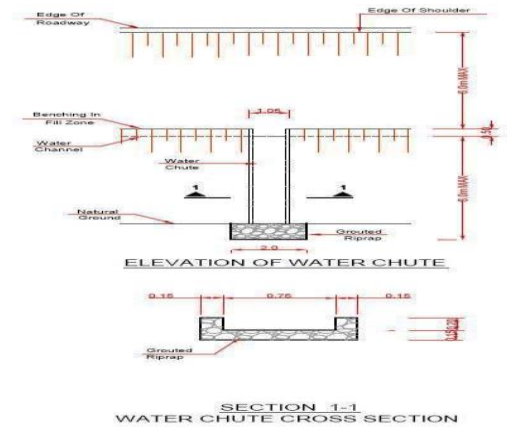
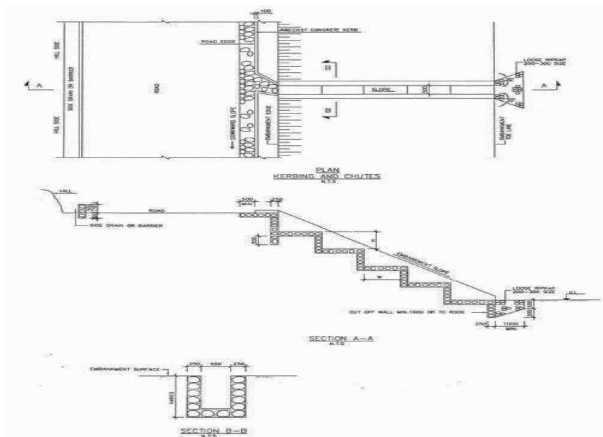


Figure 2-18 Chutes and spillway drainage protection works typical



Spillway from up-slope and from outer shoulder along retaining wall, photos credits: Al-Abyadh



Spillway at the retaining wall and cascade spillway at the culvert outlet, photos credits: Al-Abyadh

Photo 2.20 Typical drawing of chutes and spillways protection work cross section

2.4.7 Humps

Humps are placed across the surface of the road to direct water to agricultural lands for water harvesting and water rights purposes. These typically range of height(5-15)cm. photo (2.21) shows an example of earth and rubber bumps.



Photo 2.21 Earth and rubber bumps

2.4.8 Irrigation Pipes

Used to save water irrigation rights as the road split the agriculture land or the farmer have more than one farm along the road sides sometimes the need of irrigation pipe to connect the farms is raised during road construction. Photo (2.22) shows an example of irrigation pipe under the road embankment.



Photo 2.22 Small Plastic pipe used for irrigation purposes

2.4.9 Water Rights / Management Structures

Sometimes water structures should be adopted to cope with water rights issues or to act as water management structures to save natural water stream ways and local traditional water rights . In photo (2.23) the culvert outlet was built with 90° angle to cope with water rights issues in the outlet landscape, if it was built without this consideration land acquisition and social problems may occur.



Photo 2.23 Water diversion culvert with 90° angle to cope water rights issues

2.5 Roads Damages Due to Floods Water:

2.5.1 Erosion

Erosion is a major concern of road damage and it may lead to various failure to the road infrastructure. This may be caused due to poor construction of embankment fills, cut slope being too steep, properties of in-situ material of the soil, loss of vegetation cover and the lack of hydrological studies and hydraulic design.

The erosion may occur at:

- Culverts outlets due to the concentration of water or overloaded floods,
- Side shoulder layer,
- Road surface and embankments,
- Lead out ditches,
- Road cut-side section and degradation of the upstream terraces,
- Road side drainage ditch and side protection works.

Photos from (2.24) to (2.29) show some documented cases of road erosion in culverts outlets, road embankments, road cut sections and at road side ditches, from several roads in Yemen.



Photo 2.24 Erosion at culverts outlet due to the concentration of water



Photo 2.25 Erosion at road embankment due to concentrated huge flood at the wadi beside the road ROW



Photo 2.26 Erosion at road embankment due to concentrated of huge flood at the wadi beside the road ROW and due to the Prosopis Julifora (mesquite tree obstruction of the wadi flood waterway)



Photo 2.27 Erosion at road cut section



Photo 2.28 Erosion at road side drainage ditch and side protection works



Photo 2.29 Erosion at side shoulder and embankment

2.5.2 Scour

Scour is a second major concern of road damage and it may lead to various failure to the road infrastructure.

The scour may occur due to the overloaded floods at:

- (a) Culverts outlets;

(b) Downstream of Irish Crossing;

(c) Road embankments near floods streams (floods channels).

The photos from (2.30) to (2.32) show the effect of scour along the Irish Crossing and at a culvert outlet that exist in several roads in Yemen due to floods flows nearby the roads.



Photo 2.30 Scour at the Irish Crossing outlet due to the concentration of wadi flood water



Photo 2.31 Scour and collapse of wadi Mawr Irish Crossing structure due to the huge seasonal floods



Photo 2.32 Scour and erosion at culvert outlet in wadi Lahima (Al-Mahweet Gov.) box culvert structure due to the overload floods

2.5.3 Sedimentation

Sedimentation and siltation at the culverts inlets or outlets due to: the transmitted sediments, lack of routine maintenance, inadequate culvert design or location or sometimes due to farmers attitude to protect their farms, photo (2.33) shows different cases of road culvert sedimentation .



Photo 2.33 Sedimentation and siltation at culverts outlets/inlets

2.5.4 Land Slide

Land slides were occurred in the cut or embankments sections where the road bank materials is loss, the cut section slopes are inadequate, and the excessive steepness of cut slopes is excess. Also, Landslides is found in the deficiency of drainage, the modification of water flows, loss of vegetation cover and excessive slope loading.

The following issues should be considered :

1. Use of appropriate cut side slope including cut benches and catch water drains due to the cut height and soil type. Photo(2.34)shows the landslide of road loss rock bank cut.
2. Protect the slopes by available ways such as retaining walls, gabions, terraces, stone dry walls, vegetation or stabilization techniques.



Photo 2.34 Land slide of loss rock cut causing disturbance and failure of retaining walls

2.5.5 Failure of Road Pavement

The surface runoff, sub-surface water flow and higher ground water table are the main factors of road layer pavement failure in means of weakening the load bearing capacity of the road pavement. The stagnation of water in depressions to road pavement (flat surfaces) leads to infiltrate water into the lower (base) layers. As water infiltrates through the road embankment, it soaks and softens the gravel and base course, or the subgrade material causing the layers to be failed by the punching effect of the traffic load. Photo(2.35) shows the effect of water on the pavement layers. Meanwhile, the poor construction resulting from poor workmanship, material, inadequate level of construction and poor supervision result in weakness of the road pavement or drainage structures which will accelerate the deterioration and failure.



Credits: Abdulqader Badi

Photo 2.35 Pavement failure in Mori – Daksam road (Socotra island)

2.6 Erosion Control Practice

Protection against water related erosion from roads is major issue. Erosion near roads cause damages to the landscape and particularly the rills and gullies is formed which creates a loss of soil moisture. Design of suitable roads drainage systems play a key role in avoiding erosion. Especially where deep sandy to silty soils are erosion prone and require special attention if the 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 gulying and road foundation subsidence, see photos (2.36 – 2.45).

The major factor for the prevention of soil erosion and siltation of watercourses is the control of the volume, location, and speed of water flows in the vicinity of exposed soils and slopes. Some important drainage mitigation measures are as follows:

- Cutoff drains to catch water before it reaches critical areas, and diverting drains, which avoid excessive concentration of flow;
- Concrete dissipation structures designed to slow fast-running water storm in drains, and hence reduce its downstream erosive potential;
- Natural materials for energy dissipation in drains, including various combinations of sticks, hay bales, rocks, and plantings. Most of these require ongoing maintenance;
- Settlement basins, which allow silt, pollutants and road rubbish to settle out of runoff water before it flows into downstream watercourses;
- Clearing the culverts will ensure that cross-drainage work properly and is not impeding flows that would cause up-hill damage;
- Spread water immediately downstream of the gully so as to dissipate its energy and where the slope and land allows serve adjacent farms;
- Protect the water way up-slope and down-slope from the culvert and avoid that it scours the streams;
- 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;
- 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 riling 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 channeled directly to land, to borrow pits and deep trenches or to storage ponds.



Photo 2.36 Erosion Control at side shoulder embankment using lined spillway(left) and controlled road run-off using curb barriers and spillway (right)



Photo 2.37 Erosion Control at culvert outlet by using semi-circular stone masonry wall



Photo 2.38 Erosion Control at culvert Inlet by using Sand bag to control the flood and the Outlet by using dry stone wall and earth longitudinal canal



Photo 2.39 Erosion control at culvert outlet/inlet by using dry stone check wall

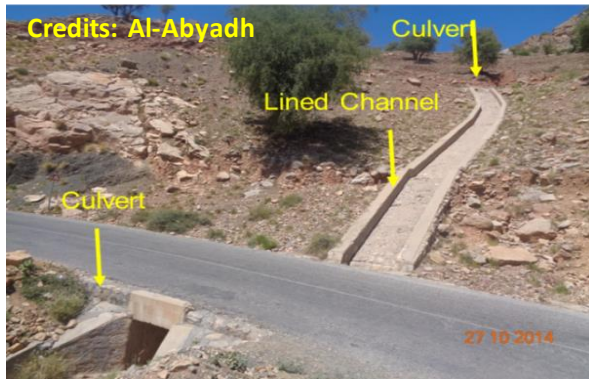


Photo 2.40 Erosion control using lined channel between culverts in mountains area



Photo 2.41 Erosion Control at culvert Inlet using gabions walls & Erosion Control at cut side of the culvert outlet using gabions walls and erosion protection riprap cascade spillway



Photo 2.42 Temporary rock scour checks in a rip-rapped side ditches



Photo 2.43 Erosion protection reinforced concrete wall when the road embankment pass near water course (wadi)



Photo 2.44 Example of Land Slide Protection Terraced Stone Masonry Walls at road cut side section



Photo 2.45 Scour and debris control at irish crossing using dry check stone wall at the upstream side of the water course. It minimizes the accumulation of debris materials along the road surface and reduce the scour effect at the outlet

At a larger scale, the 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.

2.7 Roads and Spate Irrigation in the Floodplains

Floodplains have a big importance in Yemen's Wadis, which depend on the seasonal floods/spate water for irrigation and groundwater recharge. Flood water plays a positive and negative role. The positive role includes the damage to infrastructure and houses, lost lives and crops, while the positive role includes the benefits from sedimentation which provides fertile lands, flushing of stagnant water and pollutants and opportunities for flood-based farming, distribution of moisture.

Roads are vital in floodplains as infrastructure to deliver transport services for people who live and work in that areas. Floodplains cover 125,000 ha from the cultivated areas of Yemen. So, many technical structures established to construct the roads according to hydrogeological and topographic conditions, land use and water rights which include:

- Stream Crossing Structures: include Bridges, Culverts and Irish Crossing
- Side Drains: include side ditches (earth, lined rip-rap, concrete), lead out or Mitres, catch drains,
- Erosion Control Structures: include Channels, Curbs, Chutes and Spillways.
- Water Rights Structures: include small pipe culverts, irrigation pipes, humps and spillways.

2.7.1 Stream Crossing Structures

2.7.1.1 Bridges

The bridges are common structures as shown in photo (2.46) in Yemeni's Wadis which help to:

- Supporting water flowing in the main streams and acceptable with water rights in flood areas;
- Facilitating the flood water movement between wadi areas;
- Helping in spread the surface water and groundwater recharge.

2.7.1.2 Culverts

The culverts are most common structures used in spate irrigation areas of Yemen which designed under ground surface, see photos (2-47).

- Culverts allow flowing the water between canals and some fields;
- It's acceptable with water rights in flood areas;
- Some culverts provided with doors to control the water movements according to distribution system and water rights between the canals, sub-canals and fields.

Credits: Zolail



Photo 2.46 Using the bridges in Wadi Zabid to facilitate the floods movement in main-canals



Credits: Zolail

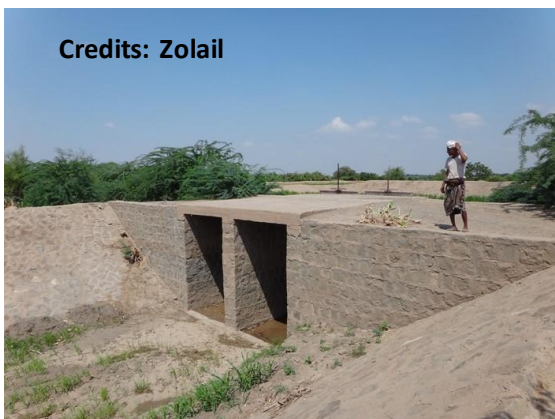


Photo 2.47 Using the Culverts provided with control gates in Wadi Zabid to facilitate distribute floods in sub-canals

2.7.2 Side Drains

Side irrigation canals are used to transfer the irrigation water from main wadi's to the sub-areas it may be earth, lined rip-rap or concrete canals. A lot of diversion structures were installed in the canals to divert the irrigation water using culverts with gates integrated with the road structure, see photos (2-48).



Photo 2.48 Side irrigation canals in Tihama Wadis

Module3: Techniques of Roads Rainwater Harvesting

All techniques of RRWH that already used in Yemen urban rural areas and potential suggested techniques will be described in this module. Also, some of the urban RRWH practices and their negative impacts and potential development will be presented. In addition, some examples of potential calculation of RRWH will be given.

Water harvesting is a common method to collect water and can be applied in many different ways. A common definition of water harvesting is:

‘The collection and management of floodwater and rainwater runoff to increase water availability for domestic and agricultural uses as well as ecosystem sustenance’

Several road water management solutions are mentioned in module two which clarify all solution techniques, as shown in figures (2.8 & 2.9). These management solutions are available and can be adapted and applied to most situations as techniques used to adapting road for water harvesting.

There are several techniques are used in Yemen for roads rainwater harvesting as mentioned below in table (3.1):

Table 3-1 Techniques are used for roads rainwater harvesting in Yemen

A. RRWH Practice	
1	Water harvesting from cross drains
2	Water harvesting from side drains
3	Water harvesting from road surfaces
4	Use of borrow pits and quarries for storage or recharge
5	Spring capture
6	Roads body as retention dams / small retention ponds
7	Roads side plantation
B. Potential RRWH	
1	Clever road foundations
2	Ford/irish crossing for retaining groundwater, water spreading or river stabilization
3	Sand and soil harvesting from roads
4	Roads as flood control mechanisms
5	Potential road water harvesting
C. Urban road rainwater harvesting	

3.1 RRWH Practice

3.1.1 Water Harvesting From Cross Drains

The purpose of culverts is to evacuate water away from road embankment. This is often done without taking opportunities consideration for the road drainage structures to direct this water for irrigation, water storage and groundwater recharge. One may even improve that by moving a road higher or lower on the slope to optimize the benefits of the water that is collected from the road surface and nearby area. The road alignment chosen will also determine the natural drains that are dissected and its location where it can be dissected. In addition to the opportunities for retaining water in the river beds through road fords and/or irish bridges as sand dams and for groundwater recharge . Moreover, rain water harvesting by diverting the runoff water from the culvert outlet directly to storage ponds, or reservoirs, or recharge pits, as shown in figure (3.1)

*Credits: illustration by Jochem van der Zaag
(www.metameta.nl)*

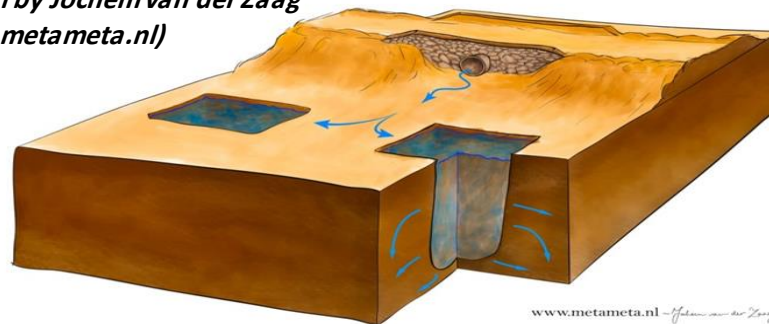


Figure 3-1 Guiding water from culvert to recharge ponds

The design of the road drainage structures has a large impact on the run-off patterns of landscape nearby the road.. The location, size and number of road culverts determine drainage patterns in road 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 in Yemen. On the other hand where a large number of culverts are constructed in well space, the run-off will be spread more evenly over the landscape, serving more points but with lower flows.

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 agriculture land, a storage reservoir or recharge pond or pits, as shown in figure (3.1) . There are many examples for culverts that are used for rainwater harvesting such as:

a. Direct Irrigation to Farms

Most of the time the rainwater runoff diverted to the farms from the culverts directly as it's clear in photo (3.2).



Photo 3.1 Direct diversion and irrigation from culvert outlet to sorghum farm

b. Indirect Irrigation to Farms Using Earth or Lined Channels:

Sometimes, if the fields are far away from the culvert outlet the runoff is diverted to the field and convey by channel as shown in photo (3.3).



Photo 3.2 Indirect diversion from culvert outlet using earth channel to Almonds farm

c. Direct Storage to Ponds Either in The Culvert Inlets or Outlets:

Third practice of rain water harvesting is by diverting the runoff water from the culvert outlet directly to storage ponds, or reservoirs see photo (3.3) or by closing the culvert inlet and diverts runoff to the ponds or reservoirs, see photo (3.4).

Moreover, the runoff harvested water is directed to storage systems using catch basin and polyethylene pipe from culvert outlet, see photo (3.5).



Photo 3.3 Direct storage at the culvert outlet



Photo 3.4 Direct storage using the protection cyclopean concrete wall and by closing the culvert inlet



Photo 3.5 Harvested runoff directed to the storage system using catch basin and polyethylene pipe from culvert outlet

3.1.2 Road Water Harvesting From Side Drains:

The harvested rainwater from side-drains can be diverted 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 recharge case the collected water percolates through the soil and recharges the groundwater aquifers. Apart from the diverting water to the recharge pond, it is used to feed a series of soak pits or infiltration trenches which are constructed to improve recharge process.

The advantage of using such recharge and storage systems along the road drain is to control and store runoff peak discharges. When the water is applied to the field directly, the moisture storage techniques, which is common in spate irrigation are most appropriated: mulching and deep ploughing. These techniques are applied in semi-arid areas to ensure the availability of water later in the plants growing season (van Steenberg et al., 2010). Moreover, water spreads from down-slope side-drains by spillways, which is known as mitre drains or side-drains, see photos (3.6, 3.7 and 3.8).



Photo 3.6 Ponds harvesting water from side drains



Photo 3.7 Road-run-off collected respectively from (up-slope) side drainage and from escape in down-slope side drain



Photo 3.8 Cistern filled from road recharge and stone blocking first flush, Al Wastah

The road down-slope drains can be used for direct rainwater harvesting along roads. The water from the road drain may be routed directly to the land to recharge structures, small reservoirs improved structures (Kubbinga, 2012).

Low volumes of flow and low velocities should be achieved at each discharge point to minimize erosion. To limit erosion, it is important to create regular mitre-drains, by paving the drain with riprap, planting vegetation or using scour check. Also, runoff water from the side drains should be discharged as frequently as possible. If the water can be discharged on the same side of the road as the drain, a turnout or mitre-drain is used to divert the water into adjacent land or structures (such as ponds), see figure (3.2).

A block-off (scour check) is required to ensure that water flows out of the side drain into the mitre drain (figure 3.2). The angle between the mitre drain and the side drain should preferably be 30 degrees, but not greater than 45 degrees. Mitre drains are needed to reduce the amount of water accumulating in side drains and to upload it safely to the side of the road. All are commonly built in a sequence.

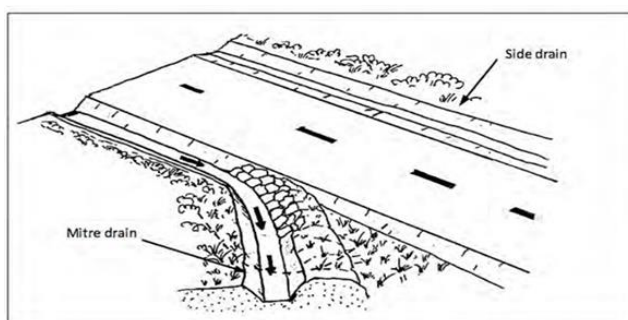


Figure 3-2 Mitre-drain diverting water from main road side drain, to a stable area, and into storage or recharge structures

The desirable slope of the mitre drains is 2%. The gradient should not exceed 5%, otherwise may be erosion occurs in the drain or on the land where the water is discharged. The drain should lead gradually across the land, getting shallower and shallower. Stones may need to be laid at the

end of the drain to prevent erosion. Where soils are very erodible, it may be preferable to increase side drain capacity to convey runoff to the next available safe discharge point (could be a recharge or water harvesting pond) rather than to construct side drain turnouts or relief culverts on erodible slopes. With the extra volumes of water that this entails, the design of these less frequent safe discharge points will usually be more expensive.

In mountainous terrain, it may be necessary to accept steeper gradients. In such cases, appropriate soil erosion measures should be considered. While in flat terrain, a small gradient of 1% or even 0.5% may be necessary to discharge water, or to avoid very long drains. These low gradients should only be used when absolutely necessary. The slope should be continuous with no high or low spots. For flat sections of road, mitre drains are required at frequent intervals of 50m to minimize silting. It is therefore advised to always consult land owners before discharging water in their land. On roads situated in flatter areas, such as alluvial plains and valleys, so-called flat drains can be used. Typically, in flat drain areas, where sheet flow runoff is more common 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 stones to decrease runoff speed and to spread runoff gently to the adjacent fields. This prevents the development of ruts and gullies, while at the same time improving moisture content in adjacent lands, see photo (3.9)

Credits: Al-Abyadh



Photo 3.9 Low permeable bunds made of stones to decrease runoff speed and to spread runoff gently to the adjacent fields

3.1.3 Water Harvesting From Road Surfaces:

Different road cross slopes and side drainage design are used depending on the terrain as shown in figure(3.3). In flat terrain a crown section is used. On rolling gentle cross slopes (less than 15%) the road is sloped downhill (at 4-6% slope) with no upslope drain. In steeper terrain the road is sloping towards the upslope drain which is used and then carried under the road by a culvert.

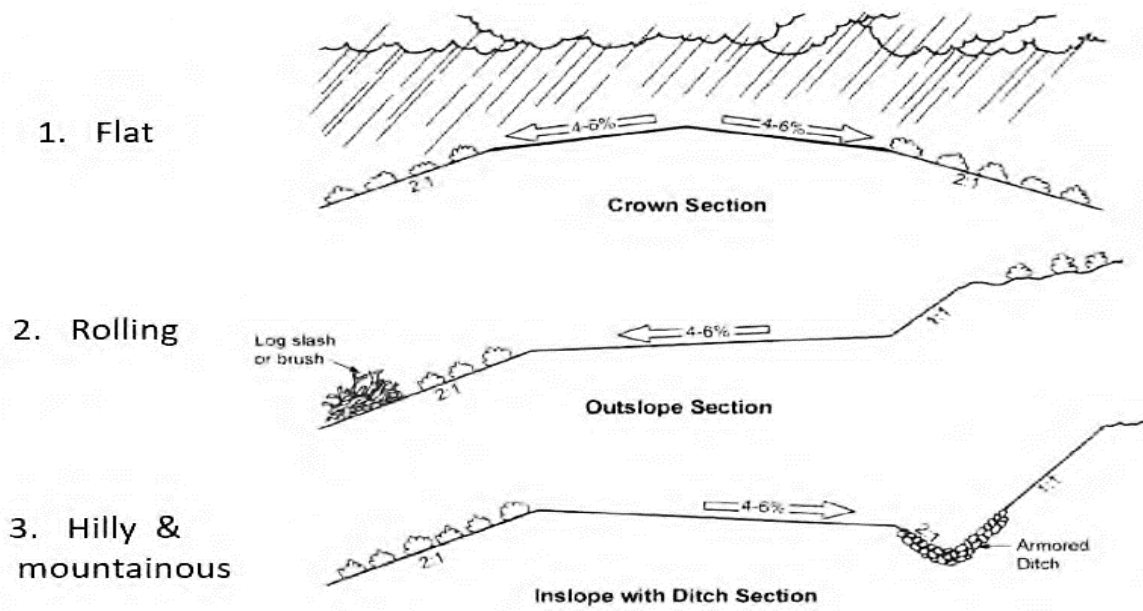


Figure 3-3 Different drainage is suggested for different types of terrains

Water can be harvested directly from the road surface itself. The amount of water generated from the road surface depends on the road grade or slope, figure (3.3) as well as the width and surface of the road and the runoff coefficient of the road surface. A well graded and compacted surface will generate most runoff.

Experiments have shown that a concrete or asphalt paved highway will have a rainwater collection efficiency (RCE, or runoff coefficient) of (0.65–0.75). 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. And in humid or sub-humid areas, due to the frequent rain and higher soil moistures, the RCE from unpaved roads is high. 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, humps, curbs or barriers, spillways and chutes, see photos (3.10 & 3.11).



Photo 3.10 common road surface drainage method



Photo 3.11 Earth hump as road surface drainage methods

Rolling Dips

The function of a rolling dip is to collect surface runoff from the roadway and/or road ditch and direct the flow across and away from the roadway on the down slope. Rolling dips are a preferred technique in dirt roads (Zeedijk, 2006). The excavated material from the dip is used to create a higher area in the dirt road, making the road undulate slightly and so creating different drainage segments, see figure (3.4 & 3.5). Rolling dips are excavated cross-drains at gentle gradients(2-5%). Rolling dips collect road surface runoff and divert it away from the road. A rolling dip is a broadly angled dip drain with a cross slope of (4-8%), steep enough to flush away accumulating sediments. It is important to maintain slope and velocity of flow to prevent puddling and sedimentation. They additionally can drain upslope drainage water to the downside. Rolling dips are unsuited to terrain that is too flat (road grade less than 3% or cross slope less than 5%) or too steep (greater than 15%). Rolling dips are built perpendicular to the road or ideally with an angle of maximum 25 degrees.

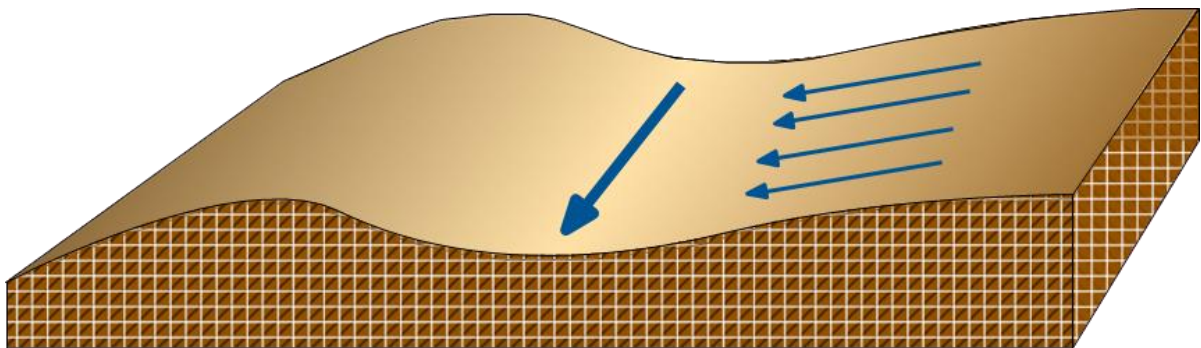
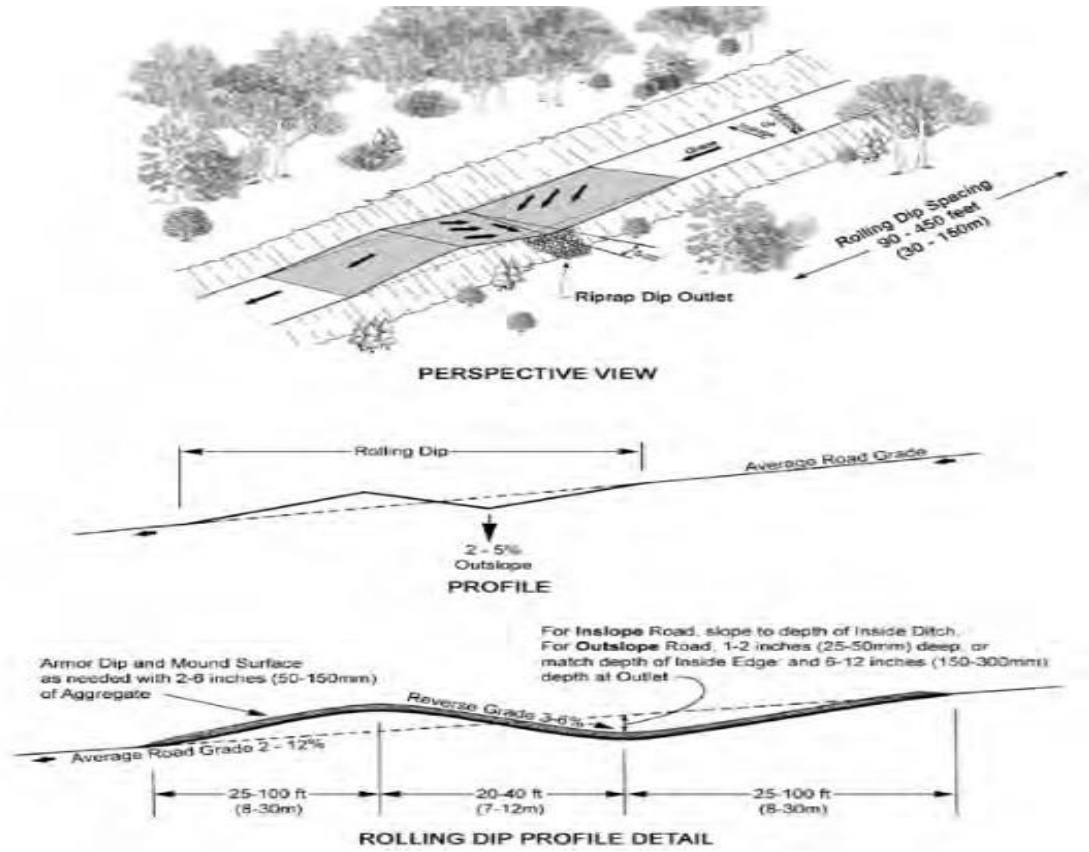


Figure 3-4 Drawing of a typical rolling dip layout

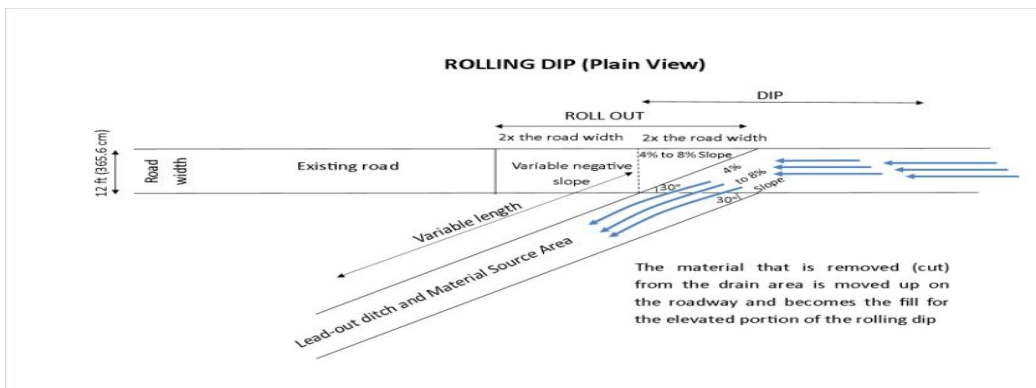
At the bottom of the dip it might be necessary to add some armoring in the form of broken stones rip-rap or gravel. This is a must when the excavation reaches softer soils beneath the road. Rolling dips are commonly constructed in multiples along the same road. In this case it is advised to keep a minimum and maximum distance between dips. In figure (3.4) typical dimensions are provided. The outlet of the rolling dip shall be carefully protected to avoid erosion. The collected water can be brought to reservoirs, recharge areas or spread over fields.

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, figure (3.5). 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 beneficial use of the water. In the mountain areas water from road surface is also collected at road bends.

The outlet of the rolling dip shall be carefully protected to avoid erosion by placing stones or planting grasses. The collected water exiting the rolling dips can be brought to reservoirs, recharge areas or spread over fields.



Rolling dips layout and shape



Rolling dip to divert run-off from earthen and gravel roads to adjacent areas or storage

Figure 3-5 Models of rolling dips

The effectiveness of road surface water spreading can be improved by constructing small flood water guiders along road side 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, photo (3.12). Sometimes earth and plastic humps are used for diverting water to fields or to outside road, photo (3.13 & 3.14).



Photo 3.12 Flood water guider from roads (left) and stepped intake (right)



Photo 3.13 Runoff is directed to storage ponds or underground cisterns using catch basins and underground pipes (left), and runoff is directed to irrigated farms using temporary humps (right)

Credits: Al-Abyadh



Photo 3.14 Earth and Plastic humps for water diverting

Rural Roads can be used as channels to guide water to specific water harvesting location and by using spillways, photo (3.15).

Credits: Al-Abyadh



Photo 3.15 Direct irrigation from road surface and water harvested from side curbs / barrier

3.1.4 Use of Borrow Pits and Quarries for Storage or Recharge:

Runoff water may be collected in specially made reservoirs or ponds, but it is also possible to make use of existing depressions for runoff collection. In case of road water development, borrow pits and quarries can be systematically used as storage or recharge ponds.

Borrow pits are excavated to use the materials sand, gravel, soil - for road construction – for the foundation and for the mixing materials. It is usually located very near to the road bath war and body. After the road construction is finished, if it's 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 to it, e.g. (farmers in wadi Tabab AlKhabt - Mahweet district, Yemen) are using a borrow pit in the wadi near the road from Qanawis to Al-Mahweet as retention and recharge pond (left), Borrow pit become as recharge ponds near Al-Rojom, right photo (3.16). 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.

Credits: Al-Abyadh



Photo 3.16 Using a borrow pit in Wadi Tabab near the road as retention and recharge pond (left)

To be technically feasible and economically sound water harvesting ponds should be built on slopes below 15%. The higher the slope the lower is the amount of water per cubic meter of soil excavated. The ponds are best situated in areas with a high content of clay although not all clays are favorable. Kaolinite and Illite are good clays, whereas the shrink-and-swell Montmorillonite clays should be avoided because of the high instability and initial permeability that characterize it. As a general rule, the best soil for pond construction need to have: 50% sand, <40% silt, >30% clay. It's important to avoid rocky, sandy, calcic and sodic soils. It is thus suggested to auger the soil to find what is the sub-soil composition.

3.1.5 Spring Capture:

When the roads cross hilly areas and 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, so care should be taken that they are not ruined by the road construction or for instance buried behind hill protection works. If they aren't harnessed, road-side spring in turn can damage road foundations and pavement or hill protection walls. Alternatively it is not uncommon for local water users to re-excavate such local springs and damage the roads in the process, e.g. neglecting spring source requirements lead the land users to dig the retaining wall, photo

(3.17), photos at the middle and left, to catch the spring flow which disappeared after the road construction and hill protection works. In other instances springs are re-excavated (photo on the right) after erosion of road inner side.



Photo 3.17 Pictures show neglecting the spring during road construction works in Yemen

If there is enough space along road side, 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 of spring is large, the water from springs may be taken underneath the roads' surfaces by pipe or box culvert to a downslope surface storage structure, either an open ponds or a cistern, with the overflow taken to a recharge area. It is important to estimate the discharge of these springs 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, photo (3.18). Also, some springs in uperslope of the road are drained to the longitudinal inside road drain, photo (3.19) this drain for domestic.

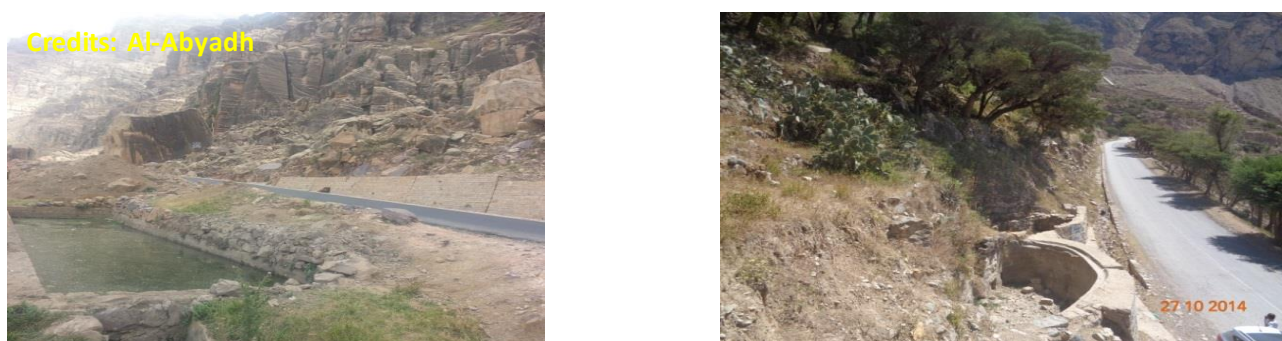


Photo 3.18 Pond storing spring water at down-slope accessed by a pipe (left) and spring water protection box up-slope (right)



Photo 3.19 water spring water at uper slope of the road and drain to longtiudinal inside drain

It's crucial to protect the catchment of the spring and the spring head from pollution, and to arrange for the spring water to be delivered at a appropriate height so that water falls with gravity directly into a container. An inspection of the ground upstream of the spring is essential to make sure that there's no danger of pollution or, if there'e, to identify measures to prevent it.

To protect the spring, a fenced inner protection zone(with a raduis of 10-20 m), should be established and all activities posing a risk of contamination should be restricted(e.g. farming, grazing, firing, application of pesticides and fertilizers, construction of latrines, use of chemicals. Etc). the area should only be planted with grass. All trees and bushes should be uprooted since roots can damage the catchment by cracking the structures or by blocking the pipes.

Springs can be protected by installing a spring tapping, a spring box and a drainage system. Moreover, a surface water drainage ditch should be dug above and around the spring area to avoid surface water runoff from polluting the source. If the area around a spring intake is unstable or exposed to erosion, gabions or drystone mansory can be used to stablize the area.

3.1.6 Using Roads Body As Retention Dams/Small Retention Ponds:

The road body may be used as retention or recharge dam, photo (3.20). 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, photo (3.21).



Photo 3.20 Road body used as recharge dam in asphalt road



Photo 3.21 Potential location of small rural feeder road crossing small wadi stream and the road body may act as recharge/storage dam

In some cases the road embankment can also be used as part of the water harvesting pond 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 undermine by the stored water. Also, the culvert may be blocked in order to fill the up-slope pond, photo (3.22).

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



Photo 3.22 Road embankment used as water harvesting body with riprap protection works

3.1.7 Roads Side Plantation:

Roadside vegetation is any vegetation growing on a road side. Planting trees, shrubs and grasses along the road alleviates the negative effect of roads on the local environment (MetaMeta,2016).

Benefits of Roadside Planting:

- Reducing soil erosion: stabilized the land soils,
- Removing dust and other pollutants from the air, protect crops, road-side and communities from sand dense and Wind break,
- Flood control: slow down the flood water flows and absorb road run-off,
- Improving water quality by ability of vegetation to trap sediment and increase water infiltration,
- Increasing road stability: vegetation helps to lower groundwater tables that may affect the road embankment pavement stabilization,
- Safety: reinforcing road alignment, serving as crash barriers, protecting view planes and reducing wind speeds,
- Carbon dioxide sequestration,
- Providing important pollinator habitat (honey production),
- Providing shade and keep the road cool for road users.

The planting beside road is clear from photos (3.23), (3.24) and (3.25)

A number of considerations will aid the planting of roadside vegetation and will contribute to high tree survival rates. The following criteria in particular should be considered during selection of sites for roadside vegetation

purposes:

1. Planting sites should have access to water sources – this can also be the water harvested from the roadside.
2. Sites with established animal paths should not be considered, as protection of the saplings will be difficult.
3. Sites with nearby households engaged in farming or other activities should have priority.
4. Sites should have preferably easy access to a tree growing nursery.
5. Nearby communities should have a positive attitude towards the benefits from the plantations (firewood, fruits, bee-keeping).
6. Planting sites shall be at reasonable distance from farmlands as well as from the edge of the road.

The effect of the shade on crops (direction of the sun) will be taken into account when deciding location.

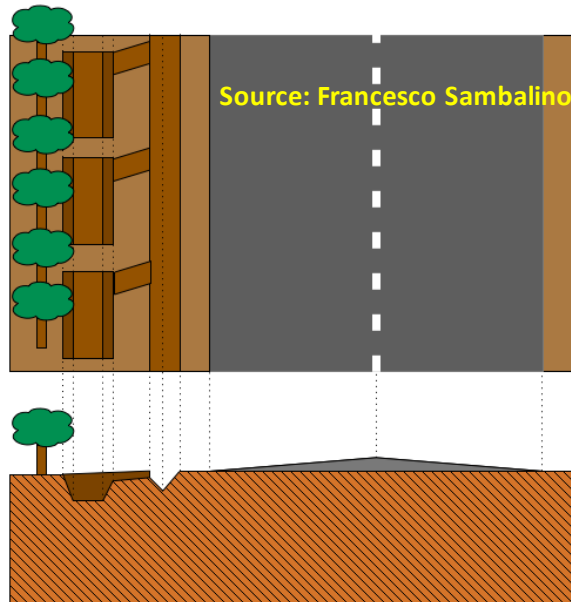


Figure 3-6 Infiltration trenches collecting road run-off to enhance the growth of seedlings

The selection of species will determine the plant spacing, i.e. the distance between established shrubs and trees. Shrubs, for instance, grow at much closer spacing than trees, and this should be taken into consideration when determining the combination of species to be planted. For row-plantings in general, larger trees are planted 3-5 m apart, larger shrubs 2.5-4 m apart and lower shrubs are placed 1.5-2.5 m apart. Single-row plantations should only be used on land of highest value and where space is limited. When possible, it is preferable to have plantations of 2 to 4 rows to protect a larger area. However, 1 and 2 row plantations are cost-effective options but require a uniform and high survival rate.



Photo 3.23 Road side plantation using semi arch bunds in the road shoulder in mountainous areas



Photo 3.24 Water harvesting from road surfaces and road side plantation using terraces and semi arch bunds in mountainous areas (almonds trees)



Photo 3.25 Road side plantation in flat areas (banana trees)

Slope Protection Through Bio-engineering or Vetiver Hedges

Bio-engineering is the use of vegetation for slope stabilisation, and control of run off and their effects (soil erosion and transportation of sediments). Examples include: planting grass lines along contours, vertically or diagonally, jute netting together with seedling, brush layering, live check dams, and vegetated stone pitching (Devkota et al. 2014).

Grass plantations protect the slopes with their roots and provide surface cover, reducing surface runoff and catching sediments. To establish grass plantations rooted stem cuttings or clumps grown from seeds are planted over the slope in different ways (e.g. along contour lines, vertically, diagonally or randomly). Vetiver grass (*Chrysopogon zizanioides*) has been widely used to protect slopes. Its deep roots make the grass able to withstand high runoff speeds and volumes. In grass plantations the spacing of the line increases as slope increased (1 m for slope $< 30^\circ$, 1 m - 1.5 m for slope $> 30^\circ$ & $< 45^\circ$, 1.5 m - 2 m for slope $> 45^\circ$). The spacing also depends on the root system of the plant to be used.



Photo 3.26 bio-engineering along roadside in Nepal

Source: S. Devkota, 2014) and b) vetiver grass plantation to prevent erosion (source: Vetiver Network)

Live check dams are built by planting woody cuttings of shrubs or large tree species across a gully, generally following the contours. These form a barrier to trap sediments and reduce runoff speed. After some time, a small terrace will be formed in the floor of the gully. The maximum slope of the gully should be 45°. The spacing of live check dams is between 3 to 5 meters and depends on the slope profile and the depth of the gully. Other measures are brush layering (placing Woody cuttings in lines across the slope following the contour), gabion walls combined with vegetation and vegetative stone pitching (dry stone walling combined with vegetation planted in the gaps between the stones).

3.2 Potential Road Rainwater Harvesting

3.2.1 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 that is designed to support. Tarmac roads may have impervious bases of typically (2-5)m thickness, 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 to 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 percolation 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, photo (3.27). Moreover, by using a clever permeable road foundation this problem can be avoided.



Photo 3.27 Road embankment (left), interferes with base subsurface spring flow; the intercepted water appeared on the other side (middle picture), the spring flow point (right)

3.2.2 Ford and Irish Crossing

The Ford and Irish crossing is used beside road crossing water stream for slow subsurface flow and increasing groundwater recharge, water spreading and river stabilization.

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 Irish bridge has one or more drainage pipes through it.

The fords and Irish bridges are important not just as road crossings but they can also help slow subsurface flow, increase groundwater recharge upstream of the road crossing and increase bank infiltration. The fords and Irish bridges in fact can double up as a proxy sand dam. It can be made with additional elevation from the river bed to increase sand dam storage in the upstream. 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 increase 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 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 hilly 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 system areas, this is a vital function. If riverbeds are stabilized 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 construction 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, photo (3.28).



Photo 3.28 Ford in lowland at Wadi Siham near Waqar village (left) and ford in highland at Wadi Al Hamdhh (right)

3.2.3 Sand and Soil Harvesting:

The run-off flow 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 functioning. This could add to maintenance costs, but in many cases the soil and sand collected also represents a value as it can be used for construction purposes or for land development..

Structures as fords and Irish bridges also act to collect sediment and form sand dam (at upstream) and sand trap (at 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 as in figure (3.7).

Source: www.metameta.nl

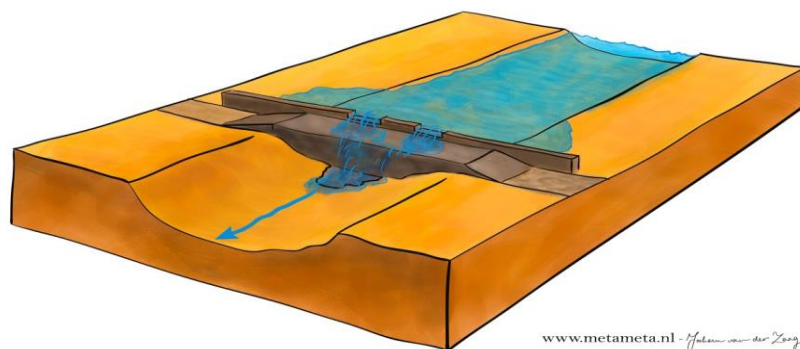


Figure 3-7 Road crossing become sand dam

3.2.4 Roads As Flood Control Mechanisms:

Roads subgrades and embankments act as dikes and in principle compartmentalize 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 are important and they 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 areas surrounding it, photos (3.29 & 3.30).



Credits: Al-Abyadh



Photo 3.29 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)



Credits: Al-Abyadh



Photo 3.30 Earthen roads risk developing into a flood path – proper design with rolling dips and spill overs required

Al-Abyadh, 2018 provided an overview of roads structures and their potential function in road rainwater harvesting in Yemen as in the following table (3.2).

Table 3-2 Roads structures, functions and their relation to potential rainwater harvesting

No.	Road Structure	sub-structure	Potential Function	Potential Harvesting
1	Road Surface	Temporary Humps (mud, sand, stones or a piece of cloth)	Intercept and divert surface rainwater in dirt and asphalt roads	Divert and harvest surface rainwater
		Rolling dips	Intercept and divert surface rainwater in rural dirt and stone paved roads	Divert and harvest surface rainwater
		Longitudinal Curbs	Channelled and lead out surface rainwater	Channel, divert and harvest surface rainwater

No.	Road Structure	sub-structure	Potential Function	Potential Harvesting
		Catch basin with under road pipes	Divert surface rainwater	Divert and harvest surface rainwater from inner side to the other side.
2	Road-side	Embankment	Reduce erosion and retain rainwater	- Plant embankments using half-moon stone bunds (micro-catchment) or other methods.
		Spillways	Control and lead out flow	- Control and direct floods for irrigation, restore or recharge
3	Side-drains	Ditches	Collect and drain water	- cistern near the ditch with partial blockage - catch basin and pipes to transport water - intake irrigation canals
		Mitre Drain	Lead out ditch flow	- direct irrigation - restore or recharge
		Mini check dams	Reduced (flow speeds / scour) and sand capture	- Sand harvesting
		Catch water drains	Collect water parallel to road alignment	- Irrigation, restore or recharge
4	Culverts	Outlet	Discharge cross streams and side drain	- direct irrigation or by using canals and flood control structure - restore or recharge to tanks or reservoir
		Inlet	Collect cross streams and side drain	- retain, recharge and flood control by using sluice gate and raise or close the culvert inlet
5	Drifts	Fords	Flood control, water spreading or river stabilization.	- retain, recharge, flood control and sand harvesting
		Irish crossing	Flood control, water spreading, river stabilization and sand dams.	- retain, recharge, flood control and sand harvesting
6	Bridge*	Foundations and columns	Water diversion	Spate irrigation using gates and diversion structures
7	Roads body*	Road embankment	Retention dams	Reinforced or masonry protected embankments.

No.	Road Structure	sub-structure	Potential Function	Potential Harvesting
		Road drainage structures	Flood control	using sluice gates and raise the culverts inlets
		Road sub-grade and sub-base layers	Control base subsurface flows	Using clever permeable / filter foundation
8	Borrow pit location and quarries sites		Recharge, storage or retention.	- Recharge, storage or retention ponds. - Rock quarries access small stones may be used to construct terraces with stone mulching
* star structures are potential structures need more research and integrated design with road construction				

3.2.5 Potential Calculations of RRWH

Road area:	1000m length and 4m width	The volume of rainwater running off from a 1 km long murrum or tarmac road from a rain shower of 30 mm, can be estimated as follows:
Road surface:	Murrum or soil	
Run-off efficiency:	80%	
Rainfall:	30mm	

$(1,000\text{m} \times 4\text{m} \times 80 \times 30\text{mm})/100 = 96,000 \text{ litres} = 96 \text{ m}^3 \text{ from 1km road}$

3.2.5.1 Potential of Rainwater Harvesting from 36 km of Maghrabah Manakah Bab Bahil Road:

The study watersheds area consists of 27 sub-catchment areas with total area of 73.13 km². The main road passed through 17 sub-catchment areas with total area of 53.58 km². The road natural catchment area (catchment above the road surface) is 9.85 km². Figure (3.36) shows a case study by (Al-Abyadh, 2017) on the road of Maghrabah Manakah – Bab Bahil, defines the potential road rainwater harvesting and its methodology was described in figure (3.37)

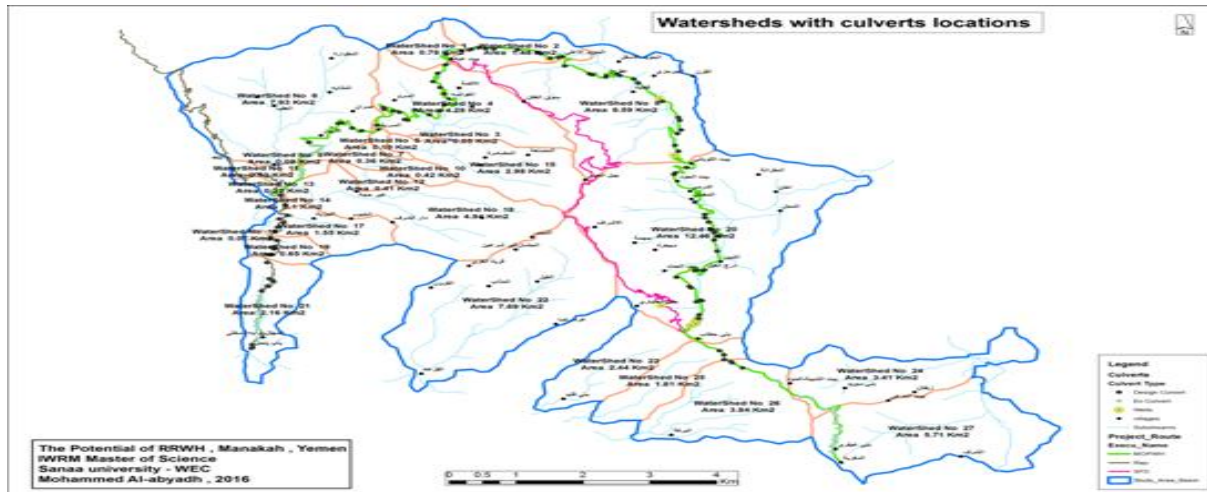


Figure 3-8 Potintional water havesting watershed with culvert locations

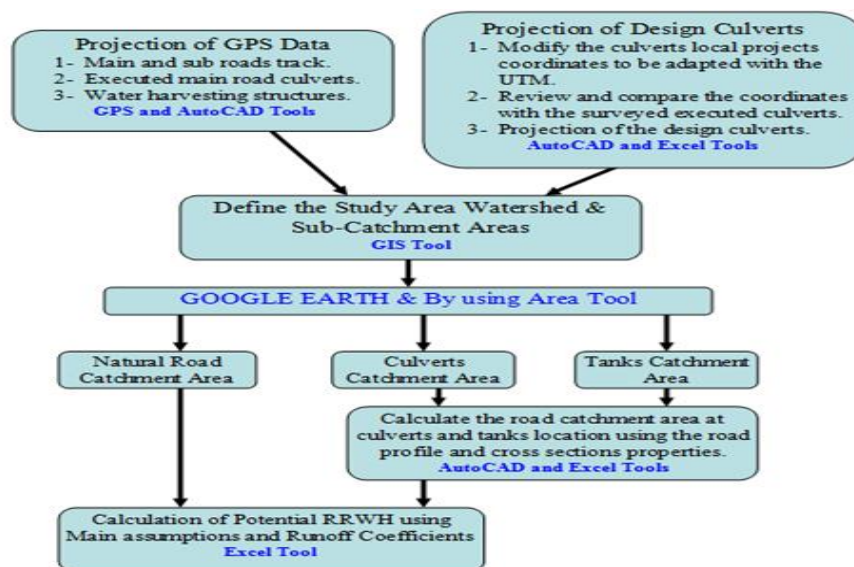


Figure 3-9 Potential RRWH calculation methodology chart

Main Assumptions:

$$\text{Water Harvesting}(m^3) = \text{Catchment Area}(m^2) * P_d(m) * K * E$$

The average annual rainfall is estimated (P_d) = 371 mm

Efficiency Factor (E) 0.7,

Runoff Coefficient (K) 0.65

Ben Kubbinga formula, 2012 for calculating the harvested rainwater is used.

A detailed calculation of the sub-catchment areas and road natural catchment areas with the culverts number and type in each sub-catchment were conducted as in table (3.3).

The potential RRWH which generated from the 36 km of the road natural catchment is 1,662,729.25 m³

The estimated potential RRWH quantity from the main road surface is 60,769.8 m³ and from the road natural catchment 9.85 Km² is 1,662,729.25 m³.

Table 3-3 Detailed calculations of the sub-catchment areas and road natural catchment areas with the culverts number and type

No.	Sub-Catchment Category	Sub-Catchment Area (Km2) (1)	Road Natural Catchment Area (Km2) (2)	Percentage of (2) from (1)	No. of Culverts	Culvert Type
1	27	5.71	0.38	6.65%	10	Executed
2	24	3.41	0.11	3.23%	4	Executed
3	26	3.84	0.26	6.77%	4	1 Executed / 3 Design
4	25	1.81	0.22	12.15%	3	Design
5	20	12.46	2.54	20.39%	23	Design
6	9	6.59	2.86	43.40%	15	Design
7	2	1.48	0.36	24.01%	10	Design
8	1	0.78	0.09	11.54%	2	Design
9	4	4.28	0.64	14.95%	16	Design
10	6	7.93	0.66	8.32%	10	5 Executed / 5 Design
11	8	0.08	0.02	25.00%	1	Executed
12	11	0.53	0.16	30.19%	3	Executed
13	13	0.22	0.02	8.00%	1	Design
14	14	0.1	0.07	70.00%	1	Design
15	17	1.55	0.31	20.00%	5	Design
16	19	0.65	0.49	75.38%	6	Design
17	21	2.16	0.66	30.56%	19	12 Executed / 7 Design
Total		53.58	9.85	18.38%	133	

3.2.5.1.1 Potential of Rainwater Harvesting from 10km from Maghrabah Manakah Bab Bahil Road:

For the same road the RRWH potential were calculated at 40 culverts points through 10km of the road and with reference to culverts catchment characteristics and cross section.

Two catchments were defined as follows:

- 1- Road catchment: road surface catchment width= 10m width, catchment length and slope were calculated for each culvert by using the road profile and culverts location.
- 2- Culverts catchment: the concentrated flow from the catchments upper the culverts.

The main assumption were considered with the following differences:

- 1- Road surface runoff factor of 0.85,
- 2- Culverts catchment runoff factor varies according to catchment characteristics and slopes,

The total potential RRWH which generated from 10 km at 40 culverts location equal to 529,178.31 m³ (from culverts catchment 516,474.44 m³ & from road catchment 12,703.87 m³).

Table 3-4 A sample of calculation for the Potential RRWH at culverts locations for the main road and culvert outlets potential type

watershed sub-catchment Km2	No	Culverts Station	Culverts catchment Type	Culvert Outlet type	Culverts Catchment Coefficient					Culverts Catchment Area m2	HW Culverts m3	Longitudinal Catchment length m	Road Surface Catchment Area m2	HW Road Surface m3
					A Relief	B Soil Infiltration	C Vegetal Cover	D Surface Storage	TO TAL C					
5.71	1	335	sub-stream	steep & dawn terraces	0.4	0.2	0.15	0.2	0.95	18695	4612.336925	175	1750	386.30375
	2	510	sub-stream	steep	0.4	0.2	0.15	0.2	0.95	27770	6851.27555	60	600	132.447
	3	570	sub-stream	steep	0.4	0.2	0.15	0.2	0.95	30637.7	7558.780155	120	1200	264.894
	4	690	sub-stream	sub-stream	0.4	0.2	0.15	0.2	0.95	25759	6355.131685	60	600	132.447
	5	750	sub-stream	steep	0.4	0.2	0.15	0.2	0.95	21284	5251.08206	50	500	110.3725
	6	800	sub-stream	Terraces & near Tank	0.4	0.2	0.15	0.2	0.95	59290.79	14627.92725	100	1000	220.745
	7	1025	sub - catchment	dawn terraces	0.4	0.15	0.1	0.1	0.75	28418.85	5535.281509	155	1550	342.15475
	8	1180	sub-stream	dawn terraces	0.4	0.2	0.15	0.2	0.95	63224.9	15598.5312	220	2200	485.639
	9	1400	sub - catchment	Terraces & Tank	0.4	0.15	0.1	0.1	0.75	21898	4265.18295	75	750	165.55875
	10	1475	sub - catchment	Terraces	0.4	0.15	0.1	0.1	0.75	31606.84	6156.222281	425	4250	938.16625
3.41	11	1900	sub - catchment	Terraces & Steep	0.4	0.15	0.1	0.1	0.75	14400	2804.75	25	250	55.18625
	12	1925	sub - catchment	Terraces & Steep	0.4	0.15	0.1	0.1	0.75	38000	7401.45	175	1750	386.30375
	13	2275	sub - catchment	Terraces & Steep	0.4	0.15	0.1	0.1	0.75	6800	1285.515	175	1750	386.30375
	14	2475	sub - catchment	Terraces & Steep	0.4	0.15	0.1	0.1	0.75	16000	3116.4	50	500	110.3725
3.84	15	3025	sub - catchment	Terraces & Tank	0.4	0.15	0.1	0.1	0.75	22950	4470.09525	300	3000	662.235
	16	3675	stream	Steep slope	0.4	0.2	0.15	0.2	0.95	54050	13334.94575	375	3750	827.79375
	17	3675	stream	Steep slope	0.4	0.2	0.15	0.2	0.95	25175	6211.050125	100	1000	220.745
	18	3910	stream	Steep slope	0.4	0.2	0.15	0.2	0.95	16500	4070.7975	35	350	77.26075
1.81	19	4025	sub - catchment	Terraces & Steep	0.4	0.15	0.1	0.1	0.75	18000	3505.95	115	1150	253.85675
	20	4150	stream	Terraces	0.4	0.2	0.15	0.2	0.95	48825	12045.8598	125	1250	275.93125
	21	4275	sub - catchment	Terraces	0.4	0.15	0.1	0.1	0.75	50375	9811.790525	125	1250	275.93125
	22	5675	sub - catchment	Terraces & Tank	0.2	0.15	0.1	0.1	0.55	222725	31812.92538	125	1250	275.93125
12.46	23	5775	sub - catchment	Terraces	0.2	0.15	0.1	0.1	0.55	132275	18893.49963	100	1000	220.745
	24	6175	stream	road	0.2	0.15	0.1	0.1	0.55	242875	34691.05063	225	2250	496.67625
	25	6250	road	Terraces	0.4	0.2	0.15	0.2	0.95	40000	9968.6	75	750	165.55875
	26	6325	sub - catchment	tank	0.2	0.05	0.05	0.05	0.35	74250	6748.95375	75	750	165.55875
	27	6725	stream	stream	0.4	0.15	0.1	0.1	0.75	55575	10824.62063	225	2250	496.67625
	28	6775	stream	stream	0.4	0.15	0.05	0.05	0.65	61950	10457.46975	125	1250	275.93125
	29	7100	stream	stream	0.2	0.05	0.05	0.05	0.35	128700	11698.1855	200	2000	441.49
	30	7735	road	road	0.3	0.2	0.15	0.2	0.85	28500	6291.2325	75	750	165.55875
	31	7850	road	road	0.3	0.2	0.15	0.2	0.85	3000	662.235	115	1150	253.85675
	32	8150	sub - catchment	Terraces	0.2	0.05	0.05	0.05	0.35	18000	1636.11	50	500	110.3725
	33	8775	sub - catchment	Terraces	0.2	0.05	0.05	0.05	0.35	107200	9743.944	500	5000	1103.725
	34	9075	sub - catchment	Terraces	0.2	0.05	0.05	0.05	0.35	39900	3626.7105	125	1250	275.93125
	35	9200	sub - catchment	Terraces	0.2	0.05	0.05	0.05	0.35	36750	3340.39125	125	1250	275.93125
	36	9400	stream	stream	0.2	0.05	0.05	0.05	0.35	380975	34628.72263	75	750	165.55875
	37	9510	stream	stream	0.2	0.05	0.05	0.05	0.35	801350	72838.70825	165	1650	364.22925
	38	9925	sub - catchment	sub - catchment	0.2	0.05	0.05	0.05	0.35	47200	4290.244	100	1000	220.745
	39	9775	stream	stream	0.2	0.05	0.05	0.05	0.35	462825	42068.47838	150	1500	331.1175
	40	10010	stream	stream	0.2	0.05	0.05	0.05	0.35	632400	57481.998	85	850	187.63325
										516,474.44			12,703.87	

Potential of rainwater harvesting from culvert at station 1+400 along Maghrabah Manakah Bab Bahil Road :

The farmer uses rainwater from (1*1) box culvert outlet and store the harvested water in a tank to irrigate Qat terraces.

The culvert outlet ends with an earthen pond as temporary sedimentation and storage facility where the farmer transfer the water to the harvesting tank by gravity using a plastic tube, photo(3.30).



Photo 3.31 The farmer transfer the water to the harvesting tank by gravity using a plastic tube

Catchment area: the catchment is 75m length from station 1475 to station 1400.

- 1- Road catchment area is 750 m² .
- 2- Culvert catchment area is 21,898 m² .

Potential Harvested Rainwater:

The annual rainfall is 0.371m, runoff catchment coefficient is 0.75, and efficiency factor is 0.7.

Potential harvested rainwater= 4430.742 m³

Tank's volume= (20 * 10 * 5)= 1000 m³

Qat Terraces Area:

- (1) New terraces area= 3174 m² with about 260 trees,
 - (2) Old terraces area= 7726.92 m² with about 330 trees,
- Total area = 10,900.92 m² and total trees = 590.

Qat Crop Requirements: Per tree 100 liter per irrigation as each season about three irrigations where conducted. For this location Qat water requirement by assuming the trees irrigated three times per season (farmers have estimated the needs about 100 liter for each tree in each irrigation)= 100 * 590 * 3= 177,000 liter= 177 m³

Total RRWH= 4430.742 m³

Qat Needs=177 m³

3.3 Urban Road Rainwater Harvesting (RRWH) Practices:

In urban areas RRWH became very important especially during rainy seasons despite the challenges and negative impacts that may influence the RRWH process.

There are a lot of RRWH practices noticed in Sana'a city, and were either implemented by Sana'a municipality or as individual initiatives by people. These practices include:

- a. Recharge Ponds:
 1. Along the Sana's Saylah (multi-function stone paved wadi) which passes through Sana'a city from the South to the North
 2. In some public gardens and Sana'a university.
- b. Diverting Rainwater from Street Surface.

Several urban RRWH practices and their negative impacts and their potential development are clarified as following:

1. Recharge Ponds Near the Presidency Palace, photo (3.32).



Photo 3.32 Recharge Ponds near the presidency palace

Negative Impacts:

- i. A number of boys were drowned in the lake.
- ii. Accumulation of garbage and wastes and the consequence pollution.

2. Recharge Ponds in Al-Qadisayah Area, photo(3.33).



Photo 3.33 Recharge Ponds in Al-Qadisayah area

Negative Impacts:

- i. Accumulation of garbage and wastes that cause pollution and spreading of water borne diseases.

3. Recharge Ponds at Al-Thawrah park, photo(3.34).



Photo 3.34 Recharge Ponds at Al-Thawrah park

Negative Impacts:

- i. A number of kids were drowned in the lake due to absent of awareness and no safety fences around the lake.

4. Water Harvesting From Road Surface for Nursery Trees, photo(3.35).



Photo 3.35 Water harvesting from Road Surface to trees nursery

5. Water Harvesting From Road Surface to Side Tree Block at House Garden, photo (3.36).



Photo 3.36 Water harvesting from Road Surface to side tree block (house garden)

6. Water Harvesting From Road Surface For Tree Block At Side Shoulder(Road side Plantation),photo (3.37) .



Credits: Al-Abyadh



Photo 3.37 Water harvesting from Road Surface to side shoulder tree block

7. Water Harvesting From Road Surface To The Yard Of The Cemetery, photo (3.38).



Credits: Al-Abyadh



Photo 3.38 Water harvesting from Road Surface to the yard of the cemetery

- Potential Water Harvesting From Urban Roads Or Streets:

Water tunnel tanks were not able to pump the accumulated rainwater in the tanks despite the small and limited catchment area, due to the lack of electricity and services during the aggression war period and it formed water pool. Water tunnel tanks may act as harvesting structure temporarily or storage tanks may be constructed near the tunnels, photo (3.39) and figure (3.9).



Photo 3.39 Water tunnel tanks may act as harvesting structure temporarily

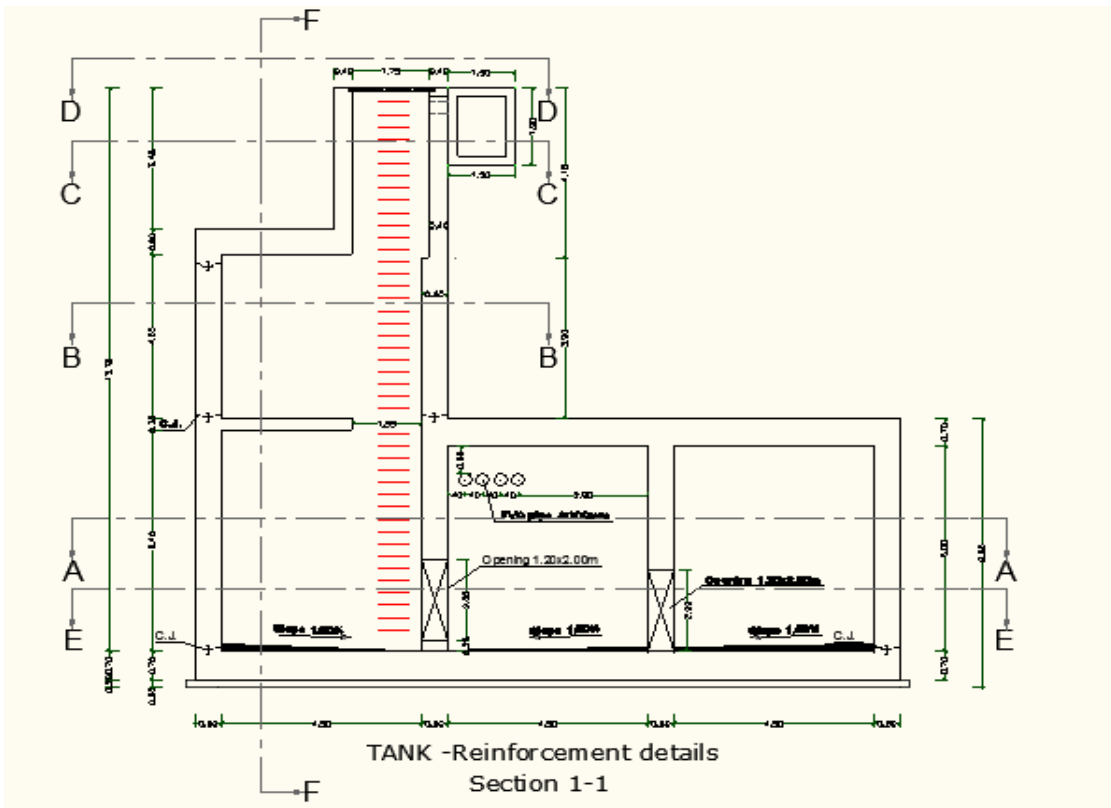


Figure 3-10 Cross section of drainage storage tank constructed nearby the tunnels surface

Module4: Economic, Social and Environmental Benefits of Road Rainwater Harvesting

4.1 Introduction

The shortage of water in arid zones represents the most serious obstacle to poverty reduction because it limits the extent to which poor producers of crops and live- stock can take advantage of opportunities arising from emerging markets, trade, and globalization. Water shortage in arid zones limits the variety and quantity of crop and livestock products a smallholder can produce, thus narrowing their range of options. Furthermore, poor smallholder producers seldom use productivity enhancing inputs, such as improved seed varieties and fertilizers, due to high risks associated with variability of water availability for plant growth. This, together with the fluctuations in yields, make it harder for poor farmers to participate in emerging market economies.

Most regions in Yemen are suffering from severe water shortages that arise from many factors, e.g. low rainfall and uneven distribution, high losses due to evaporation and runoff, and increased demand on water due to population growth. One problem in these regions is the soil crust formation, which reduces water infiltration; however, surface crusts are an important characteristic for WH technology. The susceptibility to seal is common in many arid and semi-arid soils, where the soil surface is characterized by low organic matter, high silt contents, and low aggregate stability (Abu-Awwad, 1997).

Water harvesting has been used for many years in different areas worldwide to solve the problem of water scarcity in arid and semi-arid areas (Abu-Awwad and Shatanawi, 1997). Runoff farming, which includes concentrating rainfall water on a small area, effectively increases the amount of water to about (2–4) times the normal annual precipitation, is highly recommended for the production of many crops.

The purpose of rainwater management in an arid region includes conserving moisture in the root zone, storing water in the soil profile, and harvesting excess runoff for supplemental irrigation of rainfed crops. Because only a portion of the rainwater can be stored in the soil profile, the excess runoff water needs to be harvested in farm structures to meet the irrigation requirements of crops and other water- consuming activities in the area such as livestock watering.

Some farmers have regenerated small areas of rangeland with fodder shrub species to reduce the risk of feed shortage and in some cases to make productive use of unproductive land. Vallerani techniques of mechanized WH have succeeded in efficiently and successfully establishing productive plant communities that provide grazing for livestock. Evidence from farmers suggests that, in some cases, the profits from fodder shrub pasture may be greater than that for annual species native pastures on unaffected land. Adoption, however, has not been widespread, perhaps because of the risk of financial losses in pioneering new farming systems. This lack of widespread confidence may be partly addressed by providing information to growers on the economics of fodder shrub pasture, based on rigorous analysis. Economic information can also be useful to

researchers to help identifying the characteristics of new grazing systems that needed to maximize net returns to producers.

The pollutants are transferred away from the road mainly via road-surface runoff and aerial transport but also with percolation through the pavement. Runoff pollution is a much studied issue whereas much less is known about pollutants percolating through the pavement and embankment into the groundwater and surface water.

The vast majority of the pollutants stay close to the road where they accumulate in vegetation, soil and also animals. To some extent, pollutants are transported further away mainly by aerial transport but also by water movement. In ecosystems receiving traffic pollutants, various ecosystem compartments and ecological processes will be affected.

Water is one of the most important transport media for the pollutants. Soil and water are the main targets of the pollutants. Human beings, animals and plants are dependent on water of good quality, and legislation typically puts much emphasis on the protection of groundwater and surface water. Given the dense road network and rapidly increasing traffic, protecting the environment from road and traffic pollutants and securing a good water quality is an area of increasing concern to road planners and engineers.

4.2 Road Development And Rainwater Harvesting Impact On Livelihoods And Poverty:

The development of 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. Water provision, through water harvesting and storage, is another intervention that would increase the benefits of roads for local communities and improve livelihoods. If that has done well, the road water harvesting can have several beneficial effects for both women and men in rural communities (Ngigi, 2003). The impacts of road water harvesting techniques on rural livelihoods concern:

- i. 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;
- ii. Improve 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).

Moreover, 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 rainwater harvesting systems release women from the burden of collecting water over long distances. An examples described by (Ngigi, 2003) show that, 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 specialized in constructing ponds (malesu et al., 2006). The implementation of road runoff harvesting systems can therefore increase the employment possibilities in an area. Also, the use of road runoff harvesting structures can also enforce social cohesion and knowledge exchange, 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). Where 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). In this way, fertile farmland is being washed away every year by uncontrolled rainwater running off roads. Hence, poorly engineered roads negatively affect people's assets and livelihoods.

Further, a better designs is also important to be sensitive for 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. However, 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.

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

However, there are several barriers related to implementation of water harvesting from roads such as:

1. Increased costs related to modification of standard designs (especially river crossings) may hamper the implementation of the proposed techniques;
2. 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 including of water harvesting in other programs (food security or irrigation for instance). A holistic perspective in terms of benefits and outputs may justify an increased expenditure.

4.3 Road Design, Construction And Infrastructure And Rainwater Harvesting:

There is a variety of water harvesting techniques that can be combined with road construction 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.

In order 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; at the same time, water harvesting from roads should be a standard element in watershed programs, including the protection of sensitive road sections by those responsible for watershed protection.

There are several impacts and benefits for rainwater harvesting from roads surface and nearby areas as:

1. Roads will affect the natural surface and subsurface drainage pattern of a watershed or individual hill slope. Provision for adequate drainage is of paramount importance in road design and cannot be overemphasized. The presence of excess water or moisture within the roadway will adversely affect the engineering properties of the materials with which it was constructed. Cut or fill failures, road surface erosion, and weakened subgrades followed by a mass failure are all products of inadequate or poorly designed drainage.
2. Removal of rainwater from the carriageway: Water has a number of unhelpful characteristics which impact on highway performance:
 - a) Spray from rainwater being thrown up by car wheels can reduce visibility which can lead to delay in reacting to events on the carriageway.
 - b) Drag on car wheels from local rainwater ponding can alter the balance of vehicles travelling at speed which can be alarming or causing skidding.
 - c) Standing water effectively acts as a jackhammer on the wearing course right through to the sub-base when vehicles pass over head.
 - d) In extreme storms, rainwater can simply wash away roads on embankment should the culvert become blocked or lack capacity.
3. Surface Drainage: The channels should be located and shaped to minimize the potential for traffic hazards and accommodate the anticipated storm-water flows. Drainage inlets should be provided as needed to prevent ponding and limit the spread of water into traffic lanes.
4. Water logging: when water from any source finds no path to escape or drain out and create a hazardous situation is known as water logging. Excessive rainfall, inadequate drainage sections, conventional drainage system with low capacity and gravity, natural siltation, absence of inlets and outlets, indefinite drainage outlets, lack of proper maintenance of existing drainage system, and over and above disposal of solid waste into the drains and drainage paths are accounted for the prime causes of water logging. From the observation of road network, it has been found that during rainy season many roads are affected by water logging. This is cause due to absence of any drainage system, improper maintenance of drainage facilities etc.
5. Hydrological effects of road development:
 - a) Increasing in erosion of local streams and road sides drainages;
 - b) Sedimentation/siltation of reservoirs, farm lands, etc;
 - c) Alter sub-surface shallow groundwater flows;
 - d) Water logging in the upstream areas;
 - e) Water from culvert causing downstream gully erosion and even endangering the road;
 - f) A culvert damaged by flood (overtopping of flood);
 - g) Roadside erosion leading to gully development;

- h) Water from culverts damaging farmlands;
- i) Rainfall triggered landslides causing road failures;

The way forward:

- a) There is a strong need for the different sectors to work together for addressing the issues of roads and water.
- b) Roads, NRM, environment, and water resources development sectors.
- c) There is a great potential to turn the negative effects (of water from roads) to positive through introduction of appropriate WH.
- d) Water demand is increasing because of the on-going developments; hence the need to use roads to manage water.
- e) Options of WH from road need to be integrated as part of road design and construction procedures as well as land and water development.
- f) Emerging conflicts over water use from roads need to be given due attention.
- g) The unused potentials, road water harvesting.
- h) The road water harvesting will Save the environment, Save the road, share in solving water security problem and livelihood improvement.

4.4 Socio-Economic Benefits:

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.

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).

The rainwater harvesting systems has direct impact on the lives of rural women (malesu et al., 2006). These systems release women from the burden of collecting water over long distances that show 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. The following are some of the socio-economic benefits from RRWH:

- The RRWH will increase the availability and utilization of water in the areas nearby roads, photo (4.1).



Photo 4.1 The RRWH will increase the availability and utilization of water

- Providing a source for water in drought periods for domestic use, watering livestock, construction works or supplementary irrigation for cash crop, etc, photo(4.2).



Photo 4.2 Provide a source for water in drought periods

- Enhancing agricultural productivity from fields irrigated by road run-off water: retentions and flood water spreading may positively affect the quality of the grazing ground. Also, if 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, photo(4.3).



Photo 4.3 Culverts and hump leads runoff water to storage reservoirs, recharge structures or directly to land

- Providing income from sale of harvested water, tree seedlings, timber, firewood, fruits, sand harvesting and bee keeping, etc. (photo 4.4)



Credits: Al-Abyadh



Photo 4.4 Provide income from sale of timber and firewood(left), provide income from bee keeping(right)

- Opening and capturing springs: where 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 the cut slopes and erode land. Drainage masks protect cut slopes from spring 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.



Photo 4.5 Boys filling jerry cans with water from spring in road cut section in mountains area

- Stone mulching from rock shaping: an additional use of especially the smaller rocks that are extracted from the stone quarries developed as part of stone paved road construction concerns their use in 'stone mulching'. Especially in the coffee plants areas in Yemen, where is a 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, photo(4.6).



Photo 4.6 Stone mulching from local quarry material by using the access rock from rock shaping which used to pave rural roads

- Excavated soil: 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.

4.5 Benefits For Environment And Roads

Road runoff harvesting can have several environmental impacts, which in turn can have a positive effect in the surrounding communities. The following table (4.1) summarizes some of the positive environmental impacts derived from road runoff harvesting.

Table 4-1 Environmental impact of road water harvesting systems

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 cycles,	Improved nutrient, 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

(Source : based on Kubbinga, 2012)

Moreover, RRWH benefits would be as following:

- Helping planting the area which would improve the stabilization of the road slopes, protecting the road sections from erosion & damage, mitigating landslide in mountain areas and mitigating the sand dunes creeping, see photos(4.7 – 4.11).
- Maintaining esthetic value of landscape nearby roads,
- Recharging the shallow groundwater and hand-dug wells near subsurface dams,
- Cessation of gully expansion and reduction in flooding,
- Improving road resilience to climate change impacts,
- Reducing road maintenance costs.



Photo 4.7 Road side plantation will act as soil stabilization and mitigate landslide of the road slopes in mountain areas



Photo 4.8 Road side plantation in flat areas may protect the road embankment from erosion



Photo 4.9 Road side plantation in flat areas may mitigate the sand dunes creeping



Photo 4.10 Roadside plantation to maintain esthetic value of landscape nearby roads



Photo 4.11 Recharge of hand-dug wells near culvert outlet in water stream

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