INTEGRATING CLIMATE CHANGE ADAPTATION AND WATER MANAGEMENT IN THE DESIGN AND CONSTRUCTION OF ROADS

Roads for Water Assessment in Bolivia

1. Introduction

This report[1] assesses the scope for making use of roads for building climate resilience and improved water management in Bolivia. Roads have a major impact on surface and subsurface hydrology: they change how water moves through the land. In the process, they affect the condition of the roads and the area surrounding it. At present this is often causing problems such as erosion, landslides, flooding. Water is also the main cause of damage to roads: globally 35% of the damage to paved roads is attributed to water; for unpaved roads this is close to 80%. This is also the situation in Bolivia, with some areas experiencing up to 2000 mm of rainfall per year. Moreover, Bolivia is subject to droughts that will be exacerbated by climate change.

This negative relationship between water and roads can be turned around. Precisely because of the close linkage between roads and water management, roads can become instruments of climate resilience by controlling run-off around roads and using opportunities for water harvesting. There is a range of opportunities that can be systematically introduced in road development, rehabilitation and maintenance. This report aims to give an overview of the most promising opportunities in Bolivia. By following this approach, a triple-win can be generated:

- The damage to roads and down time of road connections can be reduced;
- The damage that is caused by uncontrolled road drainage in the shape of sedimentation, erosion and local flooding can be reduced;
- The water that is captured by the road bodies, if guided properly, can be used productively for agriculture and livestock,

The assessment is based on a mission to Bolivia from 4th to 14th of December 2017[2]. The mission consisted of fieldwork (figure 1) and discussions with national level stakeholders and a Stakeholders Workshop on 13th of December 2017. The mission is part of the program "*Integrating Climate Change Adaptation And Water Management In The Design And Construction Of Roads*". It is a contribution to the World Bank project "Road Sector Capacity Development Project" which aims at enhancing Bolivia's national road sector management and improve the condition of the country's primary paved road network.

[1] This assessment was undertaken by MetaMeta. The Mission was carried out by Marta Agujetas Perez (Water Management Expert), Francesco Sambalino (Water Harvesting Expert), Fabricio del Rio (Environmental Expert) and Angela Paola (Civil engineer).

[2] The mission program is given in annex 1; the workshop program in annex 2 and the outcomes of the discussion during the workshop in annex 3.

Figure 1 Route visited to assess road and water challenges and opportunities (Source: own elaboration)

The field visit included a wide variety of landscapes, from very high rainfall areas (close to 2000 mm/year) to areas with severe water scarcity, each one with its own problems and solutions. Specific solutions for dry areas (such El Chaco and Tarija) were erosion and water scarcity are more common are shown in section 4. Section 5 focuses on high rainfall areas (such as El Sillar) where the challenges for road infrastructure are enormous.

2. Road sector in Bolivia

The road network in Bolivia is classified into three groups of roads according to their importance and level of service: Main Road Network, Complementary Network and the Local Network. Bolivia has a total road extension of 74.831 Km, being 19.285 Km part of the Complementary Network and administrated by the regional governments, 39.492 Km are local roads administrated by municipalities, and 16.054 Km are considered part of the Main Road Network (Red Vial Fundamental in Spanish) and are administrated by the Bolivian Roads Administration (ABC in Spanish) (ABC-BID, 2017).

Table 1 Main Road Network distribution by Department (Region) (Source: ABC,2011)

Department (Region)	Length (Km)	%
Beni	2.045,34	12,5
Chuquisaca	785,16	4,8
Cochabamba	1.256,83	7,7
La Paz	2.858,64	17,5
Oruro	1.172,09	7,2
Pando	525,33	3,2
Potosi	1.739,05	10,6
Santa Cruz	4.727,22	28,9
Tarija	1.233,08	7,5
Total	**16.342,73**	**100**

Source: Modified from ABC

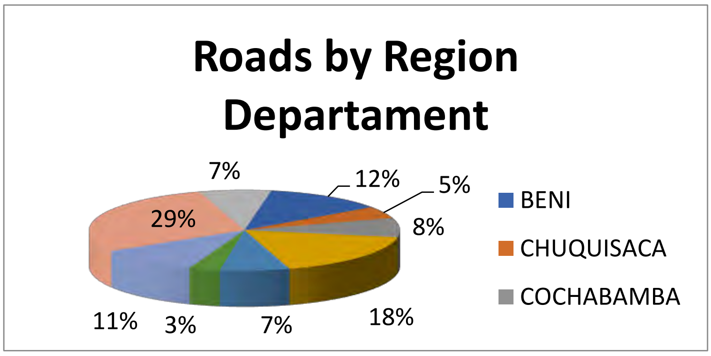

Figure 2 Percentage of roads by Department

The Main Road Network (MRN) in 2011 was composed as follows: 33,7% of paved roads; 45,4% dirt roads; 16,3% roads under construction and 4,6% roads without final design (Supreme decree 2079, 2014). Regionally, the MRN is not equally distributed, with Santa Cruz holding more than one quarter of the total roads, La Paz more than 15% and the rest of the departments with less than 15% of the roads network. By 2017, there was an increase in the total surface of paved roads, from the total of 16,350 km, 40.5% are paved roads, 34.4% are dirt roads, 19.2% are under construction and 6% are on design phase (Table 2).

Table 2 ABC Type of roads per district in Bolivia (Source: ABC,2017)

Tipe of road	**Paved road**	**Dirt road**	**Under construction**	**On design**	**Total (km)**	**%**
Beni	393,75	946,89	627,20	77,50	2.045,34	12,5
Chuquisaca	457,15	126,58	201,43	0,00	785,16	4,8
Cochabamba	627,69	171,61	351,84	105,70	1.256,83	7,7
La Paz	661,83	1.217,98	556,52	422,32	2.858,64	17,5
Oruro	821,20	125,15	225,74	0,00	1.172,09	7,2
Pando	32,67	297,09	195,57	0,00	525,33	3,2
Potosi	846,58	357,21	535,26	0,00	1.739,05	10,6
Santa Cruz	2.088,13	1.927,28	358,08	353,73	4.727,22	28,9
Tarija	688,58	454,71	89,80	0,00	1.233,08	7,5
Total	6.617,56	5.624,49	3.141,43	959,25	16.342,73	100,0
%	40,5	34,4	19,2	5,9	100,0	

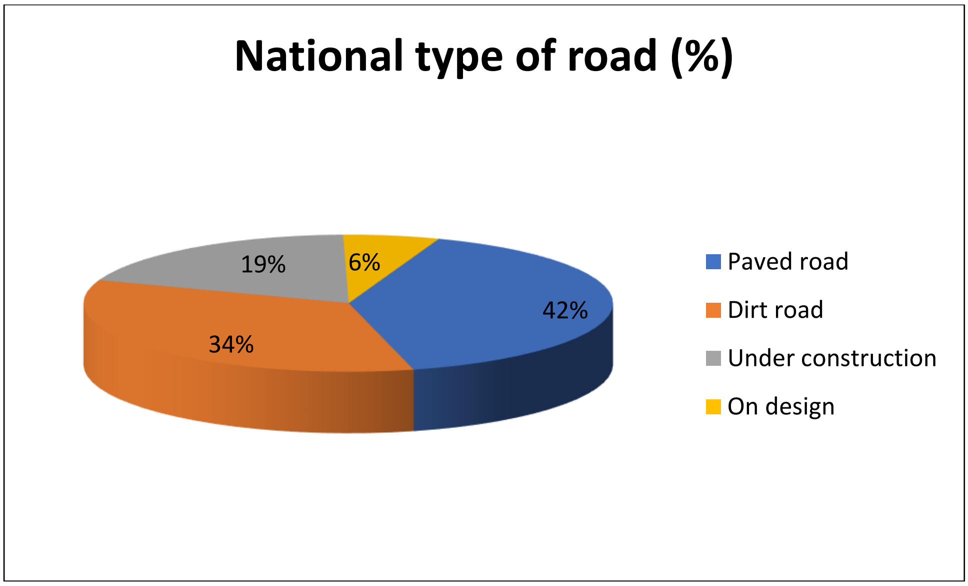

Figure 3 Percentage of roads by type of road

Currently, more than 50% of the roads are not paved, but there was a substantial increase in paved roads in the last years. The department with most paved roads is Santa Cruz followed by Oruro and Potosi. A steady increase on road construction has taken place during the past years, especially since 2014. This offers a great opportunity to incorporate road water harvesting not only in on-going programs but also in guidelines, contracts and environmental and social safeguards.

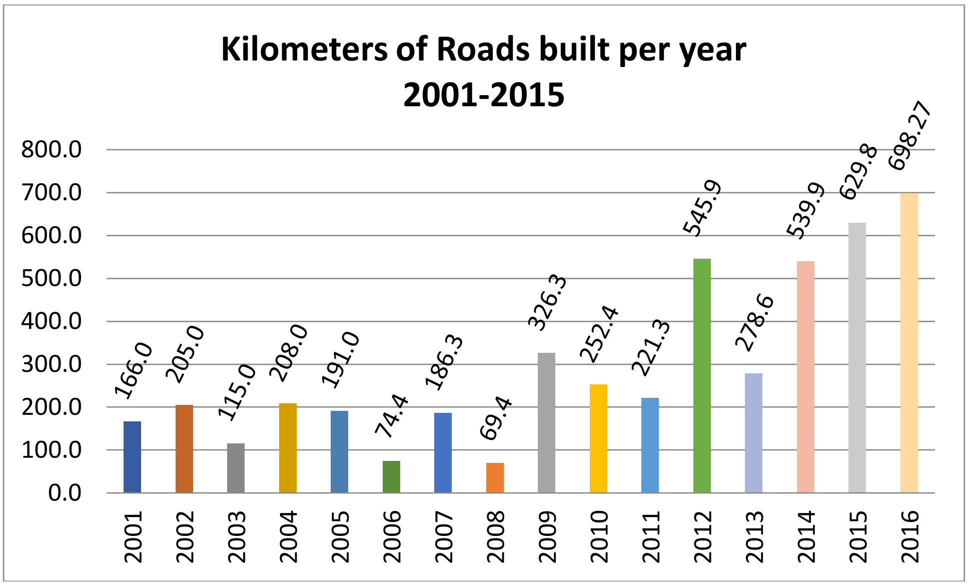

Figure 4 Kilometers of roads built per year from 2001 to 2015 (Source: own elaboration based on ABC data)

2.1 Maintenance of the Main Road Network (Red Vial Fundamental)

To maintain the MRN, the ABC created the Road Conservation Program with Microenterprises (PROVIAL). To date this program serves 13,602.96 km of the MRN, with road maintenance activities making intensive use of the local workforce. The microenterprises are dedicated to the conservation activities of the drainage system (ditches, sewers, ditches, culverts and channels), conservation of the road, patching, horizontal and vertical signalling, construction of dry walls, vegetation control in the right of way, as well as administrative activities (track monitoring, vehicle counting and accident registration). The investment in road reconstruction and conservation has increased gradually since 2010, when it was 50 million USD for the MRN. Since 2012, the maintenance budget has doubled, the graph below (Figure 5) shows the budget for investment that now reaches almost 150 million USD per year.

We argue that part of these investments could be also used to build road water harvesting structures to create a triple win, better road maintenance, reduce environmental damage and water for productive use. The microenterprises under PROVIAL can also build and maintain road water harvesting technologies such as mitre-drains, trenches and small water harvesting ponds in communal land.

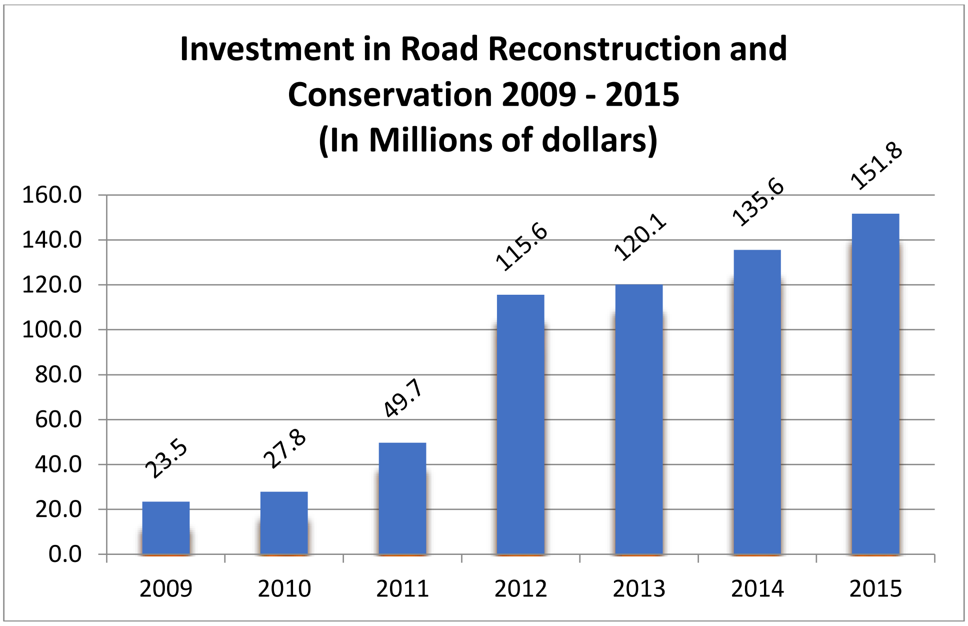

Figure 5 Investment in road reconstruction and conservation 2009 – 2015 Source: ABC Budgetary Execution of Public Investment Conservation - Construction - Studies As of January 31, 2017 (In Millions of Bolivians)

3. Water related challenges and climate change

Bolivia has a very diverse territory in terms of climate and topography, with high and low lands, as well as dry and wet weather. In the low lands, most of the rivers are part of the Amazon River basin and are prone to seasonal flooding (See Figure 6), These floods are reported to becoming more extreme every year. In 2014, the floods in Beni and other areas of the Bolivian Amazonia have been the largest since meteorological records are registered. The impact of these floods caused the loss of 31 million USD to the livestock sector (Bolivia informa, 2018). One of the main causes for these phenomena is climate change that will most likely increase the amount of rain during the rainy season. Another cause is the extended deforestation in sensitive areas such as Yungas, Chapare and the northern part of Santa Cruz (Hoffmann, 2018).

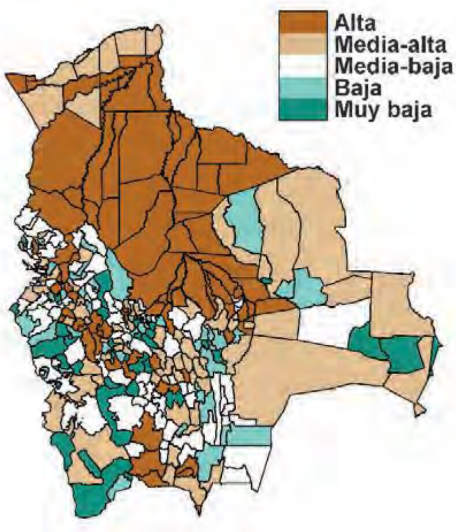

Figure 6 Flood hazard Regions (UDAPE, 2015)

On the other hand, some parts of the highlands such as the Altiplano and Valleys have serious problems with long dry periods (See Figure 7). Is in these areas where road water harvesting will be most relevant. In 2015, the lake Poopo (See Figure 8) located in Oruro (Altiplano region) and considered the second largest lake in Bolivia, suffered a long period of drought, which resulted in the disappearance of the lake and more than 200 species of birds, fish, mammals, reptiles and plants. What used to be a lake of 2,337 Km^2, nowadays is an area of a few small wetlands (See *Figure 8*). The causes for the drought are complex and related to climate change, global warming, inappropriate water resource management, mining and El Niño (BBC, 2018).

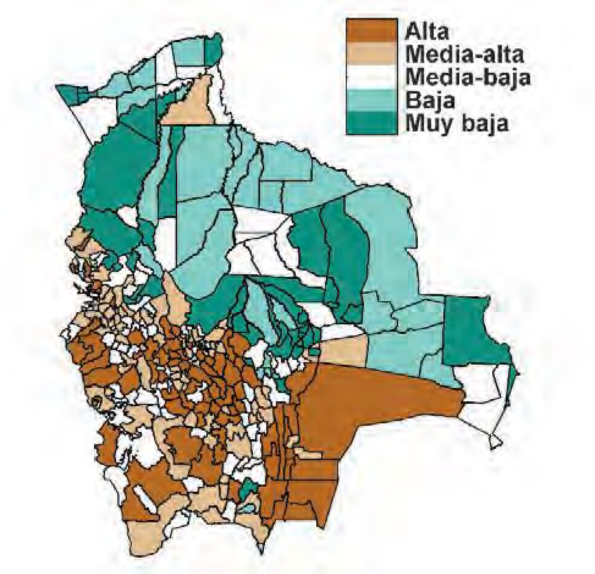

Figure 7 Drought hazard Regions (UDAPE, 2015)

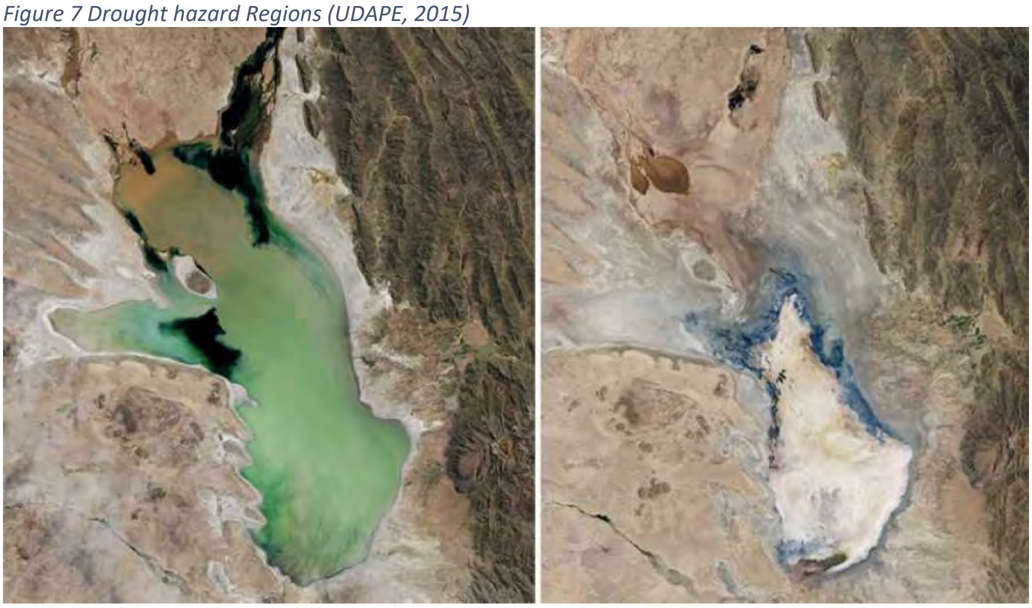

Figure 8 Lake Poopo loss, on the left a picture from April 2013 and on the right an image of January 2016 (EL Pais, 2018)

Regarding vulnerability and preparedness to climate change, the ND-GAIM Country Index from the University of Notre Dame (USA), considers Bolivia as the second most vulnerable country in South America and the fifth least prepared to mitigate the damages of climate change (University of Notre Dame, 2018). Moreover, in 2014, the United Nations World Food

Program (WFP) considered Bolivia as a vulnerable country to climate change, disaster risk and food insecurity. According to the map in *Figure 9*, 148 municipalities in Bolivia are under the category "Severe Vulnerability" and 32 under "Very High Vulnerability" (See Figure 9) (WFP, 2018).

Recently – between 2015 and 2016 – Bolivia went through its worst water crisis in 25 years. The crisis was considered a "National Emergency" involving eight out of the nine departments (Regions) of Bolivia, 173 municipalities (51% of the 339 municipalities), affecting more than 177,000 families, 600,000 Ha of crops and 600,000 heads of cattle (El Diario, 2018). The most affected city was La Paz, where almost 100 neighborhoods were rationing water for more than two months with water supply for 12 hours every three days. According to specialists, the water crisis had five main causes (BBC, 2018 b):

- Climate change and natural phenomena, which include global warming and El Niño
- Lack of planning for new sources of water;
- Poor management of the water companies, there were no emergency plans for water scarcity;
- Energy, mining and oil projects are taking enormous amounts of water for their activities;
- Lack environmental awareness among citizens.

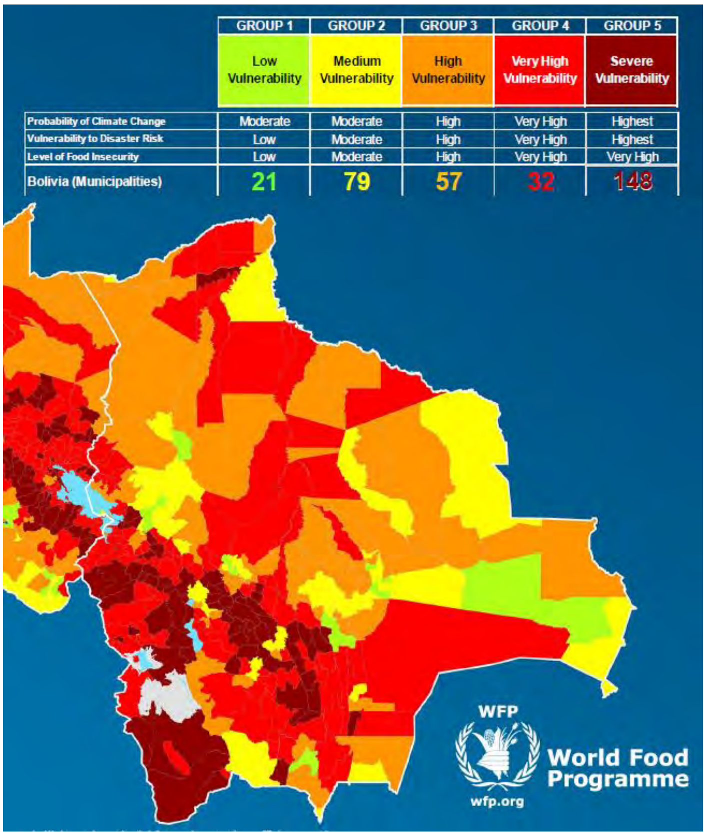

Figure 9 Atlas of Food Security, Disasters and Climate Change in Bolivia (WFP, 2014)

The recurrent droughts and floods show the tremendous importance of increasing water supply for agriculture and other uses by harvesting water from roads. Section 4 focuses on methods for water harvesting in the dry areas of the country such as the Altiplano, el Chaco and Tarija, whereas Section 5 details measures for improved water management around roads in high rainfall areas.

4. Managing droughts and erosion with road water harvesting

The drier areas of Bolivia are characterised by low rainfall volumes, scattered distribution and high intensity events. This translates in spates of surface runoff concentrated in few events. It is dry for most of the year, but suddenly high peaks of rainfall and consequent runoff occur. Runoff brings water out of the system and at the same time it also carves the land, uproots plants, undermines bridge pillars and floods houses in the valley. Yet, only after few weeks, the land is thirsty again and water scarcity hits people.

From a road engineer point of view, rainfall falling on roads and upslope of roads is a risk and a hindrance: run-off must quickly be drained to avoid damage to roads and traffic disruptions. Where water is disposed is not a concern: the key is to dispose water quickly. Alternatively, taking a water manager perspective, roads can also be seen as incomplete water harvesting systems. The surface to generate runoff is already present, commonly together with some form of drainage system. What is missing most of the time is an appropriate storage infrastructure and a channelling system adapted to divert water into it. Roads offer an immense opportunity to be developed into water harvesting systems for multiple uses.

The case of roads to better manage runoff water in dry environments is built on the very same logic that makes road water management a challenge. Roads need to drain high runoff volumes quickly and safely to maintain structural integrity and functionality while at the same time communities need more water for their wellbeing and economic development. Road water harvesting is a double step in the right direction. Water is taken off from the road drainage system to feed a multitude of small water harvesting systems that provide water for agricultural production of a big swath of land. Thus, if the road at first acted as a concentrator of water, at this point is used to redistribute water to multiple end users.

Some parts of Bolivia are highly affected by erosion. In parts of el Chaco, high soil loss amounts are likely caused by high rainfall amounts in combination with erodible soils that contain high amounts of silt and clay. Soil erosion in Tarija can also be very high (Bastian and Gräfe, 1989), while water scarcity is also of great concern. This makes it a suitable area for systematically implementing road water harvesting to reduce erosion and increase water availability.

Table 2. Areas affected by erosion by department

Department	Area affected by erosion (Km2)*	Percentage**
Cochabamba	24.365	96%
Chuquisaca	47.179	92%
Potosi	84.021	71%
La Paz	26.410	62%
Oruro	30.787	57%
Tarija	16.199	43%
Santa Cruz (Chaco)	46.583	38%

* Severe and very severe **In relation to the area under desertification
Source: MDSMA 1996 (Former Ministry of Rural Development and Environment)

During the reconnaissance visit, the team has identified numerous opportunities and needs to introduce road water harvesting to buffer water availability variations and simultaneously put a check on soil erosion. The observations are summarized in the table below:

Issue	Observations and recommendations
Road challenges	• Many crossings with seasonal rivers • Erosion on the road sides, sometimes threatening road infrastructure • Soft and highly erodible soils, especially around El Chaco
Water and environment challenges	• Erosion at the outlet of culverts and roadside drainge • Low water availability for livestock and households • Low availability for road construction and maintenance, which may lead to conflicts with communities
Resilient roads	• Adequate drainage system • Protection of drainage outlets to halt erosion • Bio-engineering
Resilient road environments and communities	• Water harvesting ponds, reusing borrow pits and water spreading from culverts and roadside drainage • Sand dams • Multifunctional small-dams for irrigation water management and water harvesting

4.1 Current issues and practices around road water harvesting in Bolivia

In Bolivia road water harvesting and erosion control is beneficial to all regions, but its benefits are more evident in the drier areas where water need is higher. The Chaco, Tarija as well as the drier parts of the Altiplano all can benefit from additional water resources and decreased runoff erosion.

Using water harvesting ponds to collect road water

During the field visit some good road water harvesting practices were observed. For instance, in the area immediately to the south of Tarija, grape production is the main cash crop for the majority of the farming community, which mostly relies on reservoirs like San Jacinto for irrigation water. Yet, water distribution does not satisfy the ever-growing demand. High erosion rates are also decreasing the overall capacity of the dam. Some farmers along roads are successfully experimenting with road water harvesting (Figure 100). There are many forms of storing road water, one of the most common is the use of water harvesting ponds. When speaking of water harvesting ponds (also referred as *atajados* – the local name), we refer to small reservoirs easily constructed and managed by individuals or rural communities. In this document, when the dimensions are not otherwise provided, with water harvesting pond and *atajado* we refer to small reservoirs between 200 and 3000 cubic metres in volume. These structures can be built with the lowest level of mechanisation and do not require complex structural engineering materials and layouts. Furthermore, roads as source of water, is in nature a better fit for small structures. Big dams are expensive and will not fill with water from road drainage alone.

An example of road water harvesting comes from the San Jacinto Dam. The piped water - running along the road - is distributed at long and irregular intervals. The atajados helped in buffering water and redistribute it. At first the small farm ponds were built as night storage infrastructures with the intent of storing water during irrigation turns. This gives farmers the freedom of applying water to their field at the most convenient times. With a growing demand and dwindling water supply, the atajados assumed a double role. While storing water from the piped water system, they also started to be recipient of road runoff to compensate the intermittent water supply. The same type of dual purpose atajados were observed along the Rio Camacho piped irrigation system (Figure 11).

Figure 10: Double purpose atajado in Tarija province (Source: Francesco Sambalino – MetaMeta Research)

Figure 11: Double purpose atajado, tapping water from the Camacho river and from the road drainage system (Source: Francesco Sambalino – MetaMeta Research)

Road water harvesting in arid areas also reduces erosion and land degradation. In the watershed upstream of the San Jacinto dam, there are vast areas of highly eroded land. These areas are mostly unused or at best in use as poor grazing grounds. The high rainfall intensity during the occasional rain events together with highly erodible soils pose a great threat to both roads and water infrastructures. The road is threatened by erosion, especially when it crosses seasonal streams with steep and erodible embankments (Figure 12). Severe roadside erosion was also observed in parts of el Chaco.

Figure 12 Road embankment erosion in Tarija (left) and El Chaco (right) (Source: Francesco Sambalino – MetaMeta Research)

Moreover, the sediment laden runoff goes on to clog downstream reservoirs. All water storage infrastructures on the watershed flow lines are disturbed, even the bigger dam of San Jacinto. It is estimated that about 736.022 m^3 of sediments reach San Jacinto every year with every square kilometre of catchment generating 2385 tons of sediments (equals 23,85 tons $ha^{-1}yr^{-1}$) (Benitez, 2006). This is considered to be a high amount of erosion, with the sustainable amount being at 5 tons per hectare per year (Morgan, 1986).

To oppose this trend, a concerted effort is required. The treatment of the upper watershed slopes with soil and water conservation methods, aiming at decreasing slope length and disrupting the runoff generation process, can be easily integrated with small water harvesting structures. These structures, placed at the exits from culverts and drains, can be easily accessed and maintained. This type of effort would help to avoid sedimentation in San Jacinto while providing a distributed access to water to the community further upstream. Some excellent examples already exist in the area, thus proofing the technical viability of these measures. Small atajados are in place in several locations already (Figure13).

At the same time, it is of foremost importance to dimension the road drainage system to avoid water reaching erosive speed, in particular for unpaved roads. Lead off drains, rolling dips (explained in section 4.2) can be both used for this purpose, without having to invest in more expensive concrete or masonry structures.

Figure 13: Atajado capturing water from a culvert in the catchment area of the San Jacinto dam (Source: Francesco Sambalino – MetaMeta Research)

In the Chaco region, some farmers are also spontaneously making use of road water harvesting for productive uses. Farmers along the highway 9 divert water to farm ponds in their land. Culvert water is tapped and brought to ponds through neatly kept, grassed earthen channels. The diverted water permits ranchers to considerably cut costs in watering their livestock. The alternative would be to pay steep fees to run diesel powered-wells year-round. Thus, the opportunity cost of the ponds is predominately positive against its alternatives. The interviewed farmer in the area explained that his reservoir often last through the year (Figure 14). Once in three years the reservoir dries, thus permitting the farmer to clean it from accumulated silt.

Figure 14: Water harvesting pond for livestock watering (Source: Francesco Sambalino – MetaMeta Research)

These efforts are positive and show both need and feasibility for such small systems. Nevertheless, all measures witnessed were not part of a synchronized effort between land users and the road authorities.

The history of rainwater harvesting for productive use in the Chaco region is long. Despite the traditional small pond found throughout Bolivia, the first improved ponds arrived in the Bolivian Chaco in the 60s', introduced by migrants from Argentina that started to produce irrigated tomatoes. At the end of the 70s' several initiatives started to build bigger ponds with heavier machinery at first in the Chaco of Chuiquisaca (project CoDeCha) and in the province of Tarija (PERTT project). Afterwards a multitude of organizations and government offices started to introduce atajados. The German Cooperation Agency (GIZ) started to support water harvesting ponds in the PGRSAP (Proyecto Gestion de Riesgo y Seguridad Alimentaria en la Cuenca del Rio San Pedro) project between 2002 and 2006. The effort continued with the program PROAGRO (Programa de Desarollo Agropecuario Sustentable) through the project "Cosecha de Agua". Between 2002 and 2010 GIZ supported the construction of 550 atajados. In parallel and at times in cooperation with non-governmental entities, the local government is also implementing atajados at scale. A good example is the program in the Anzaldo municipality in Cochabamba department (Romero, 2015).

The local government have promoted improved water harvesting in farm ponds (not necessarily linked to road) with mixed success. For instance, geomembrane was not always available, thus making the structures not effective in retaining water. In both Yacuiba, Tarija and Villamontes the local government have promoted and stimulated the adoption of atajados. In Yacuiba, with the use of a squadron of 5 heavy tractors with implements it has been possible to build 2-3 water harvesting ponds in a week (0.5 hectares areal extension, undefined depth and volume).

During the field visits the highlands were only marginally touched. Nevertheless, many efforts took place and are worth considering. Ancient water management practices have survived to these days and in some cases, are being adapted to make use of road water. Some of these practices are shown in section 4.4.

In Bolivia multiple programs have focused on the promotion of water harvesting ponds for rural development. Between 1998 and 2000 the Bolivian and the German government have constructed over 600 atajados as a response to the earthquake that hit Aiquile (Cochabamba) (Bastiaan et al, 2000). The program successfully tested a simple and solid design, that incorporated modern components to the traditional atajados used on the Bolivian highlands (Q'otañas o vigiñas). The resulting manual is a useful reference document to these days.

In the municipality of Anzaldo (Cochabamba) more than 300 atajados were constructed to augment farmers resilience to climate vagaries. Despite the conspicuous investment, in 2012 less than 50% of the ponds were functioning, thus the government and its partners started to question, what were the reasons behind this partial success (Oros Martinez et al, 2012). The major findings from this study must be kept in mind in developing projects that involve the construction of atajados:

- In many instances the gross revenue of the family did not show a relevant increase due to the presence of the atajado. In turns low revenues, hardly justify increased expenditures incurred to maintain the structure.
- Often the pond failed in retaining water because the soil had a high permeability and high leakage losses. Mostly because of poor investigations before construction took place. The leakage was documented in 83% of the cases. The leakage in 68% of the cases occurred at the base of the pond, in 22% at the foot of the embankment and in 10% simultaneously at the base of the pond and at the foot of the embankment. On the positive side, the leakage contributed to groundwater recgarge.
- In some cases, communal ponds sparked conflicts, when access rights and duties were not negotiated in advance and included in a formal contract between users.
- On the other hand, in the same study, the remaining household stand out as an example of resilience to climate shocks. The family that managed well their atajados also developed a more flexible agricultural production system that incorporated both complementary and supplementary irrigation in their practice. On average the area irrigated with water harvesting ponds is 2000-2500 square meters.

Ancient water harvesting practices in the altiplano of Bolivia

Water scarcity is not new to the inhabitants of the Bolivian altiplano, who have lived and thrived despite this struggle for millennia. The altiplano consists of a high plateau located between 3.650 and 4.100 meters of altitude. The precipitation decreases towards the south, from 400 mm in the north to 200 mm in the south. The communities of the Bolivian Altiplano have developed during centuries skills and techniques to cope with adverse weather events and challenging climatic conditions. Some of these practices are neglected on under-documented. However, an effort has been made by two Bolivian organizations –Autoridad Plurinacional de la Madre Tierra and Agua Sustentable – to document, study and push the revival of this practices. Below is an overview of the ancient water harvesting and soil and water conservation practices that have been collected on the report "Ancestral sciences as a mechanism for climate change adaptation/Las ciencias ancestrales como mecanismo de adaptación al cambio climático".

Suka kollu

Suka kollu are platforms of cultivable land whose height was increased artificially. They were built to facilitate drainage and modify the local environment to improve the soil conditions, crop growth rates and control the humidity. In the Suka kollu, water channels are placed around the cultivable area. Besides serving for water harvesting, it is believed that the channels were built to improve the microclimate by absorbing heat from solar radiation during the day, releasing heat at night in the surrounding area to prevent damage to crops due to frost. Even though is not a current practice, these structures could be linked to roadside drainage to harvest water from roads.

Q'otañas or vigiñas

Q'*otañas or vigiñas* are rainwater harvesting reservoirs built to provide water for irrigation, livestock drinking and domestic use. They are communal ponds built also to regulate the local temperature and increase the humidity in the nearby areas. The increase on humidity will foster the re-establishment of native pastures.

Figure 26 SUKA KOLLO (Source: Atlantis Bolivia).

Figure 27. *Q'otañas or vigiñas* (Source: Gonzaga Ayala, 2017)

Inka takanas

Inka takanas means "inka terraces" and are very ancient structures sometimes built centuries ago. They are built to slow down runoff, preventing further soil erosion. The base of the terraces is built with stones, which capture solar radiation during the day and warm down the area at night. The stone walls are built along the contour lines and thus allow for water infiltration and shallow ground water recharge. Besides, they also collect sediments brought by runoff from the upper catchment areas and allow the growth of very valuable native fodder species. By slowing down the run off, the terraces also increase infiltration and recharge groundwater.

Figure 29. Inka Takanas (Source: Virreira, D., 2013)

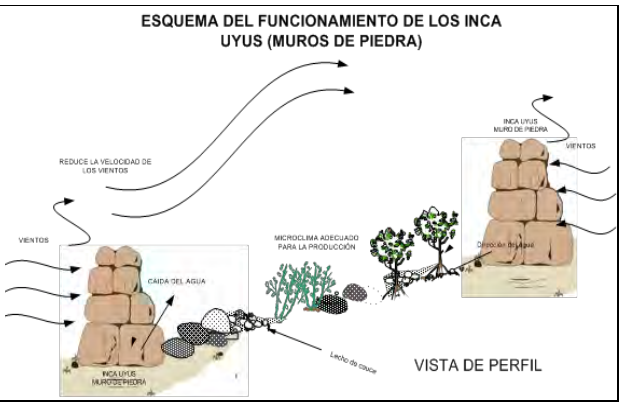

Figure 30. Drawing of Inka Uyus (source: Torrez, E., 2015.)

Inka uyus

Inka uyus are ancient structures built in the lower part of the landscape. They are groups of stone walls built perpendicular to the slope and have different dimensions. They are usually 2-meter-long and 70 to 40 meter wide. They were built to protect crops and pasture from wind and frost by creating a microclimate. They were also built to slow down runoff, preventing erosion and allowing infiltration. The inka uyus have been also built in areas where seeds from native pasture tend to accumulate, which combined with fertile sediment deposition they allow pastures to grow during the rainy season.

All these practices have been successfully implemented over centuries. Although they are known to provide benefits in the surrounding areas, more research on these practices is needed to consolidate designs and maximize the benefits. Once the practices are well understood, they could be scaled up to other dry areas of Bolivia.

4.2 Road water harvesting opportunities

There are several techniques that were not observed during the field visit but have high potential to be implemented in arid areas in Bolivia. They can be implemented in El Chaco, where there is high water scarcity during the dry season and heavy erosion problems and in Tarija, where water scarcity represents a greater challenge throughout the year.

4.2.1 Harvesting directly from road surfaces

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 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.

Asphalt paved roads have a rainwater collection efficiency (RCE, or runoff coefficient) of 0.65 to 0.75 (ERA, 2011). For an unpaved road, the RCE is more variable, ranging from 0.25–0.30 in semi-arid areas up to 0.80 during heavy storms. In humid or sub-humid areas, due to the frequent rain and higher soil moistures, the RCE from unpaved roads is higher. Runoff generated by the road surface can be diverted to recharge areas or storage ponds through the use of drainage techniques.

Areas with heavy traffic should be avoided for direct road water harvesting: the pollution from hydrocarbons and oils may prohibit the reuse of road water for different purposes. These risks do not exist where the road bodies are used to guide run-off in the catchment rather than the road itself serving as the water collection structure.

4.2.1 Rolling dips

Rolling dips are excavated cross-drains at gentle gradients – between 2 and 5 per cent. They collect road surface runoff and divert it away from unpaved road surfaces (Figure 15). They are broadly angled with a cross slope of 4-8%, steep enough to flush away sediments. It is important to maintain slope and velocity of flow to prevent puddling and sedimentation. It can additionally drain water from the upslope drain 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 a preferred technique in dirt roads (Zeedyk, 2006; Sambalino and Neal, 2016). They are important strcutures as they reduce the damage to unpaved roads: this is very important because maintenance of unpaved roads is almost always under-resourced, so anything that reduces damage to such roads contributes importantly to connectivity.

Rolling dips can be easily constructed into existing feeder roads and they are most appropriate on low speed roads (25-50 Km/h). At higher speed, they can become dangerous to drive. The whole rolling dip must be long enough to be comfortably driven on. Usually a length of 15-60 meters is suggested. Rolling speeds are a preferred option on roads with a maximum gradient of 8-10% (From Keller, G., Ketcheson, G., 2015).

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.

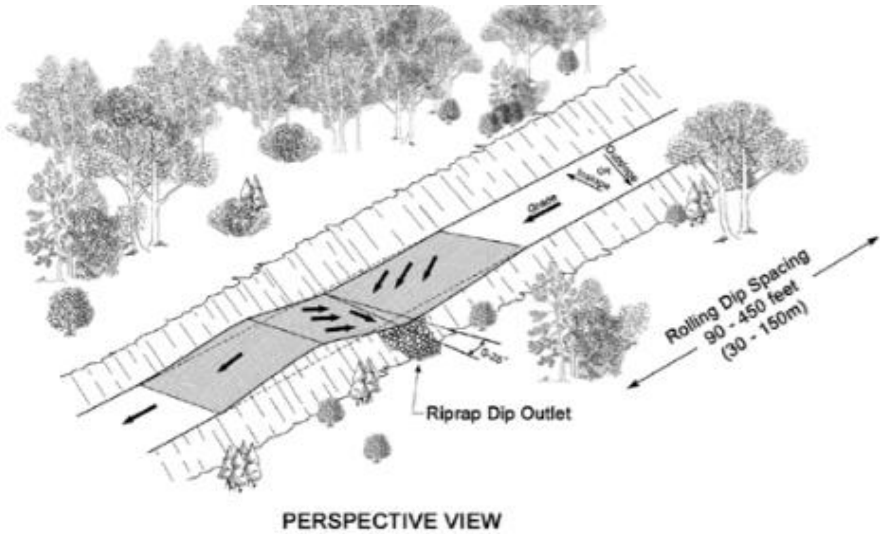

Figure 15: Rolling dip typical layout (Source: Keller, G., Ketcheson, G., 2015)

4.1.3 Water diversion from road side drains

Mitre drains, also called turnouts or lead-off drains are used to divert water from side drains into adjacent land. This is possible when the road is at the same level of the surrounding land. Low runoff volumes and speed should be achieved at each discharge point to minimize erosion. Therefore, to limit erosion, it is important to build lead-off (mitre) drains at short and regular spacing besides implementing erosion prevention measures at the outlet. Mitre drains are serial structures that are repeated at regular interval: as frequent as every 20 meters (MWI, 2015). Mitre drains are needed to reduce the amount of water accumulating in side drains and to unload it safely to the side of the road.

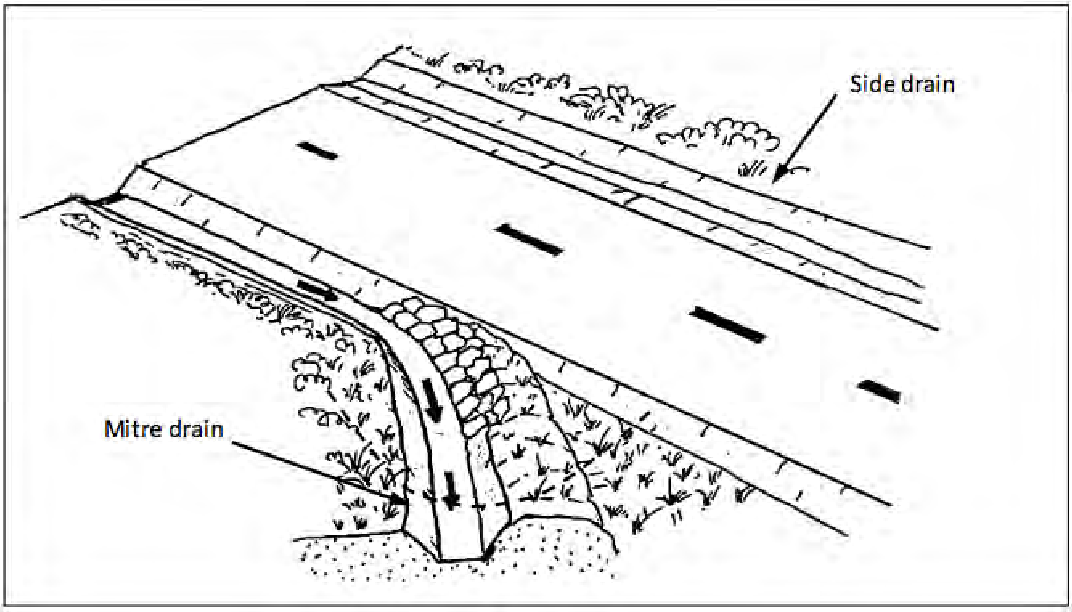

Figure 16: Mitre drain diverting water from main road side drain. This diverts water to a stable area. The water can also be diverted into storage or recharge structures (Source: MWI, 2015).

A barrier is required to ensure that water flows out of the side drain into the mitre drain (Figure 16). The angle between the mitre drain and the side drain should preferably be 30 degrees, but not greater than 45 degrees. The desirable slope of the mitre drains is 2%. The gradient should not exceed 5% otherwise there may be erosion 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 help prevent erosion (Sambalino and Neal, 2016).

Where soils are very erodible such as in certain parts of El Chaco, 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 mitre drains on erodible slopes.

4.1.4 Water from culverts

Culverts are the most common cross road drainage option together with bridges. Culverts offer an excellent opportunity to channel concentrated runoff away from the road and towards a variety of storage, spreading and groundwater recharge measures (example in Figure 17).

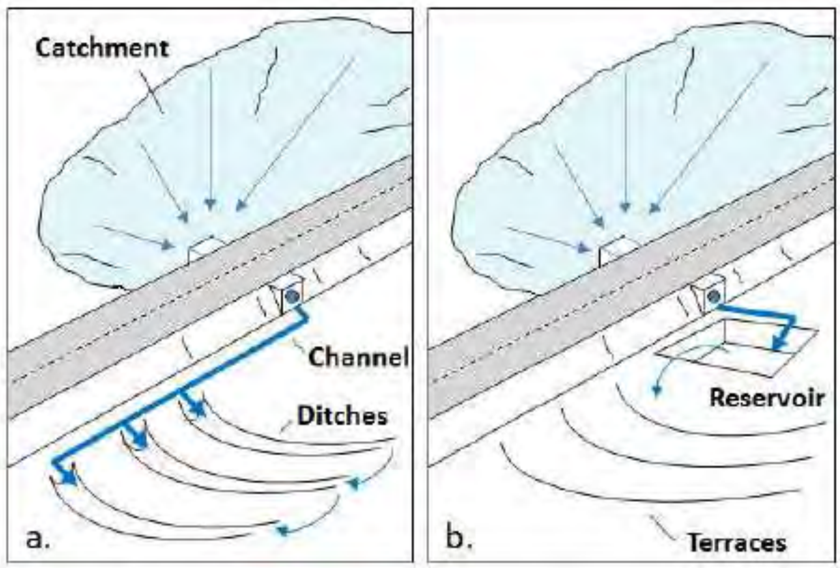

Figure 17: Options for spreading or storing water from culverts

4.2 Solutions: spreading, storage and aquifer recharge

Road water harvesting can be divided in three categories:

1. Runoff harvesting from roadside drains using mitre drains;
2. Runoff harvesting from culverts;
3. Runoff harvesting from road surface using rolling dips.

The harvested water can be used and store in different ways. It all depends on the landscape characteristics and the final water use. Nevertheless, some guiding principles can be drawn (see also *Figure*18):

Road water can be channeled to and used in three different ways:

1. Spread over land to provide additional water for crop/grass/tree production and increase soil moisture. The water can also be directed to planting pits and trenches that are used to grow trees. 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.

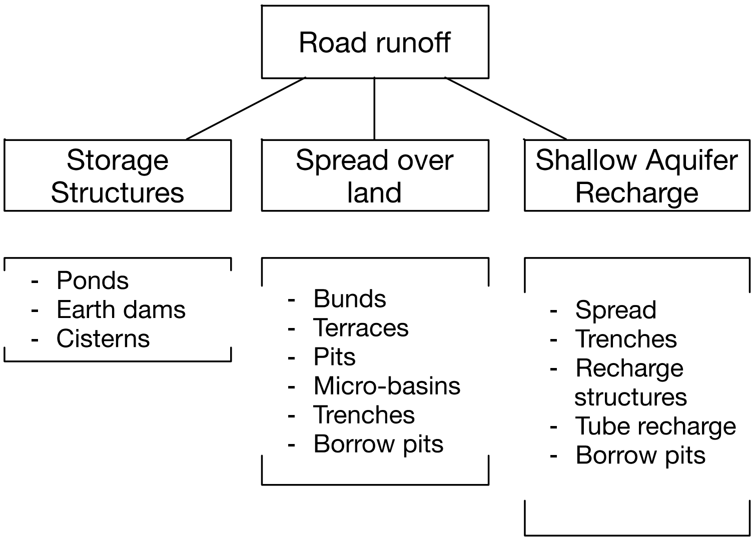

Figure 18: How can road runoff be managed (Sambalino et al, 2016)

4.2.1 Spread water over land

To spread water over land, at first the water is brought to the target area using simple diversion structures from culverts and road side drains (*Figure* 18). The simplest diversion structures are loose stones barrier that slow down the runoff and divert it laterally in direction of the fields. Mitre drain commonly spread water directly over flat or gently sloping land.

Figure 18: Runoff water diverted from a culvert towards farming land

When the field is not directly adjacent to the road water source, water can be directed to the target area with small ditches with a very gentle side slope to avoid erosion.

Three common methods to evenly spread water over an area are:

a. A levelled ditch at the top of the field, homogenously spill water to the downstream field. Nevertheless, the field needs to have a very even and continuous gentle slope to avoid erosion and waterlogging;

b. The field is divided in sub-basins (Figure 19). Water is allowed in the uppermost basin. Once filled its retaining bund is breached to allow water to enter the consequent field downslope.

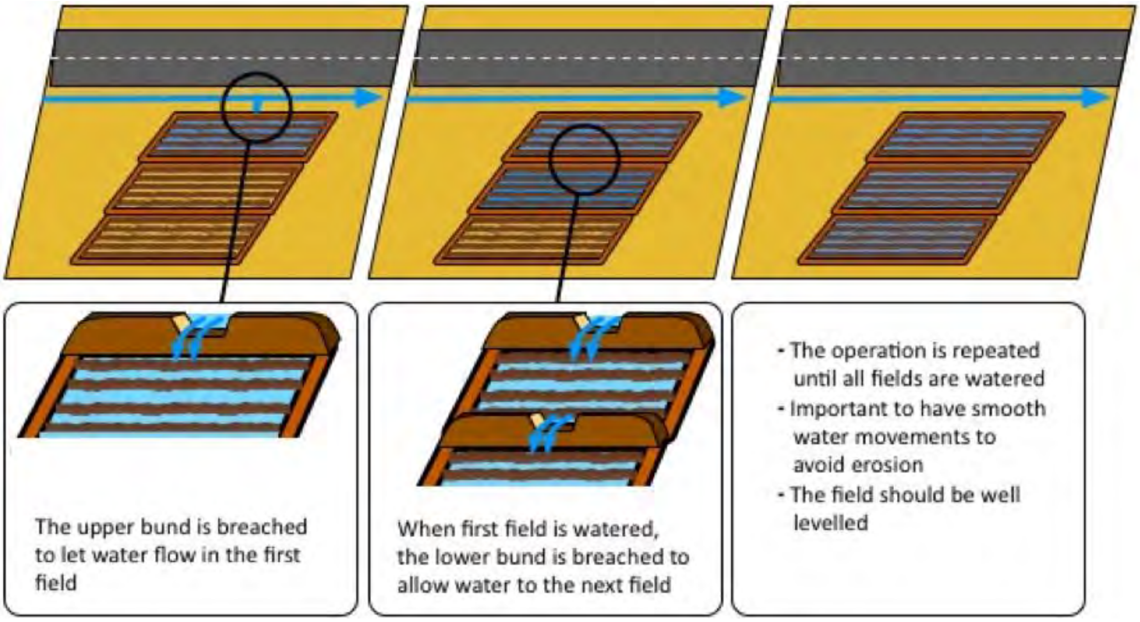

Figure19: Flood irrigation sequence (Sambalino et al 2016)

c. Water is directed to planting pits which are connected to each other by ditches (Figure 20). Once a pit is filled water continuous to the consequent pit. This system is typically used to grow high value trees. In some areas the same principle is applied with long trenches.

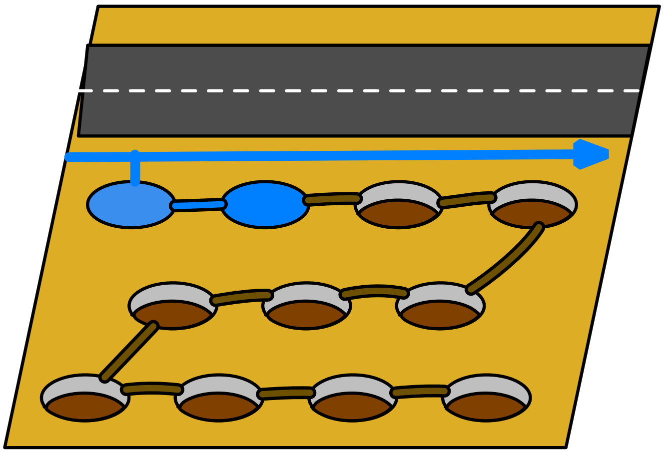

Figure 20: Road runoff is directed to inter-connected soaking pits (Sambalino et al 2016)

4.2.2 Collect water in storage structures

Water diverted from the road drainage system can be guided to water storage systems. This approach is suitable both in the highlands and in the plains. Storage is commonly divided in:

a. Open storage: Ponds/atajados (Figure 21), small dams, armored reservoirs (cement, masonry) and converted borrow pits. When using earthen structures, it might be necessary to line the structure in order to reduce seepage losses.
b. Closed storage (Figure 22): Cisterns of various shapes

Figure 21: Road side runoff diverted into ponds for surface water storage and groundwater recharge.

Figure 22: Closed masonry cistern in Yemen

To be technically feasible and economically sound water harvesting ponds can be built on slopes below 15%. The higher the slope the lower is the amount of water per cubic metre of soil excavated. The ponds are best situated in areas with a high content of clay although not all clays are favourable. Kaolinite and Illite are good clays, but the shrink-and-swell Montmorillonite shall be avoided because of the high instability and initial permeability that characterise it. As a general rule is the best soil for pond construction need to have: 50% sand, <40% silt, >30% clay. It is 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.

Borrow pits are the result of the excavations made to extract materials for road construction. Borrow pits are often left open and located nearby roads, which offers an opportunity for water harvesting. They can be used as storage reservoirs for rainwater by for instance connecting them with culverts and other cross-drainage structures through a canal. However, since their original purpose is not water harvesting, some measures are needed to improve the design, safety and accessibility to transform them into ponds. These measures include technical considerations such as improving the geometry to facilitate access and increase capacity, compress the base and sides to reduce permeability and construction of well for water extraction to allow filtration and improve water quality (AFCAP 2011).

The amount of water that can be harvested from a given road depends on the drainage layout and how it interferes with its watershed. A culvert can have a contributing drainage area varying from few hectares to hundreds. Likewise, when diverting water from side drains, the amount of water that can be harvested depend on the grade of the pavement, the length of the road and the slope.

The harvested water is most of the time used for agriculture, livestock production and in some cases even for domestic use. By summing up agricultural, livestock and domestic needs is thus possible to calculate the amount of water needed and to consequently dimension atajados. These structures are most commonly designed to cover a portion of the year. With rainfall only occurring few months in the year, a very large reservoir would be otherwise needed to provide water year-round.

The cost of a water harvesting pond with a capacity of 1200 m^3 is about 7.385 USD and includes the planning, construction, waterproofing and transaction costs. The agricultural production costs raise from 580 to 1145 $ per hectare, due to the crop diversification, higher inputs and higher plant density. At the same time the annual gross profit increases from 820 to 2210 $. The net profit triplicates from 188$ to 583 $ (PROAGRO, 2013). This was true for PICAs (Proyectos Integrales de "Cosecha de Agua"), which couples improved agricultural production methods with the water harvesting structure.

4.2.3 Enhance recharge

For groundwater recharge two options are available. First it is possible to spread water over flat areas with high infiltration rates. Flow speed, over the areas should be minimal to allow a slow and steady seepage into the ground. To spread the water homogenously is possible to use bunds laid precisely along the contour lines. Water spreading weirs can also be used for this scope.

Alternatively, it is possible to direct road water to recharge structures that help water to pass the superficial impermeable soil layer. Borrow pits, when well planned, can be designed to become recharge structures. Instead of being refilled they can be easily converted to recharge groundwater. Smaller structures such as trenches, recharge pits (Figure 23) and recharge ponds are also a valid alternative when applied at scale

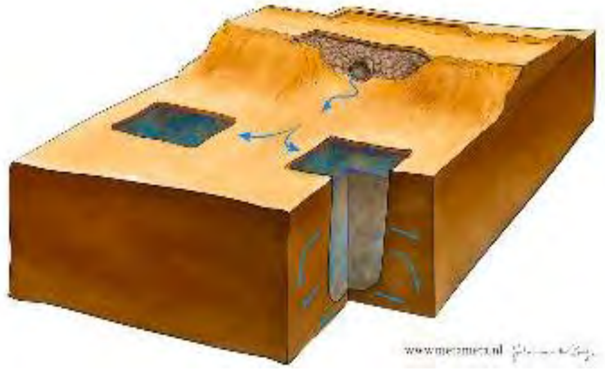

Figure 23: recharge pit (Source: MetaMeta)

4.2.4 Road-river crossings

In Kenya, there are examples of road drifts that have been raised and act as sand dams whilst retaining sufficient capacity to accommodate the peak design flood (Figure 24). River sediment collects behind the drift and water is stored in the sand. This water is protected from evaporation and contamination. An infiltration gallery and shallow well allows this water to be abstracted for domestic and productive purposes. This technology was not observed during the field visit in Bolivia, but the potential for implementation in areas such El Chaco is huge. In El Chaco, soil forming parent materials are unconsolidated sands, and clay or silty sediments, making it an ideal location for sand dams.

Figure 24: Road acting as a sand dam in Kenya (Source: MetaMeta)

Only on smaller roads, with a low daily traffic, drifts or Irish bridges are commonly an option. In bigger roads, a sand dam can be constructed in the sandy river upstream of bridges with a double purpose. It can be used to stabilize the river bed. Secondly it becomes a source of fresh and relatively clean water for the surrounding communities.

Figure 10 Perennial river in El Chaco area where a road crossing/sand dam could be built

In flatter flood plains, water spreading weirs can be combined with road crossings. The weir spreads water (and river sediment) onto the flood plains, recharging the shallow groundwater and allowing flood recession farming on the residual soil moisture (Figure 25). On minor roads, water spreading weirs can be combined with road. Like in the case of sand dams, they have the added advantage of stabilizing the river bed upstream of the crossing. A stable river bed makes the construction of temporary offtake structures or bunds for upstream spate or flood diversion irrigation simpler and more predictable.

Figure 25: Water spreading weirs / spate irrigation, Niger

5. Managing water around roads in high rainfall areas

Bolivia is home to some of the wettest areas in the world that reach over 1.750 mm of annual rainfall (see map below). This high amount of water poses a great challenge for road construction and maintenance and can have very destructive consequences. Bridges, river banks and sometimes even houses are washed away. Some villages (such as Villa Tunari) have been flooded recently due to overflow from the rivers. Landslides are also a recurrent issue. All of this makes the humid areas of Bolivia a very challenging environment, but still there are many solutions that can be put in place.

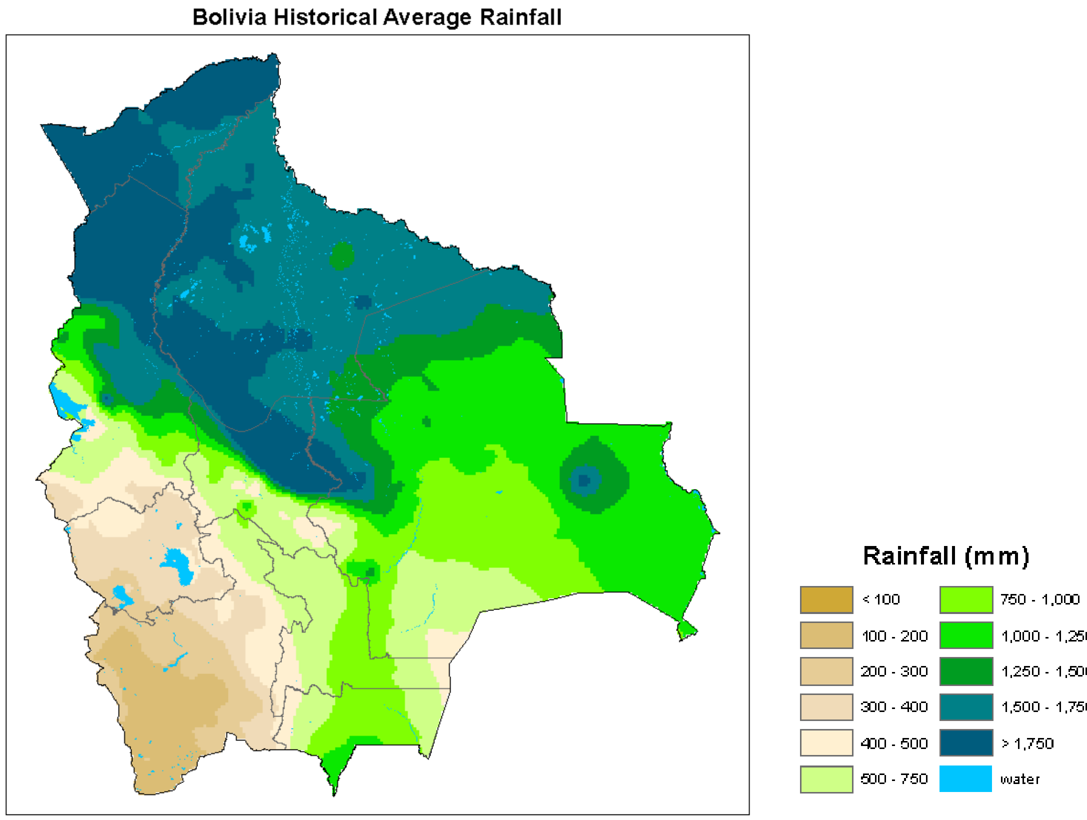

Figure 31. Historical average rainfall in Bolivia (Source: USGD/EROS)

Preventing scouring and collapse of bridges with drop structures and breakwaters

Some of the bridges (Puente Espiritu Santo) in the route visited have collapsed in the past due to the high velocity and volume of water and sediments in big rivers and streams. The bridges are vulnerable to collapse for several reasons, mainly shallow bridge foundations (see figure 32) and bridge scouring. Bridge scour is the removal of streambed material from around bridge abutments or piers caused by moving water. If the foundation embedment into the ground is not good enough to handle the erosion and scour that may occur over the life of the bridge, the bridge is vulnerable to collapse.

One solution to reduce the damage from high speed water on the bridge foundations is the construction of drop structures. Drop structures (Figure 33) upstream of the bridge reduce the kinetic energy of water. There are many types of drop structures, including:

- Sloping Drops:

- Boulder Drops: Boulder drop structures must be anchored into the bank with large boulders and a dip should be constructed in the center to focus the river's energy into the center of the channel
    - Grouted Sloping Boulder Drops: same as above but grouted.
    - Sculpted Concrete Drops: formed or sculpted concrete can be constructed with structural concrete, soil cement, roller compacted concrete, or event glass fibre reinforced concrete. These structures are however labor and material intensive.
- Vertical Hard Basin Drops: in this type of drop a jet of water overflows the crest of a wall into the basin below. The water hits the hard basin and is redirected horizontally. When the water flow is enough a hydraulic jump is initiated. The energy is dissipated through turbulence in the hydraulic jump.

All drop structures should be evaluated after construction. Protection may be needed when erosion and scour around the structures is observed. If the structures are not built properly there is a chance that they will erode on the sides, leading to the collapse of the structures.

Figure 32 Exposed and eroded bridge foundations (Source: Los Tiempos – 11/10/2017)

Figure 33 Erosion in Puente Espiritu Santo (Source: MetaMeta)

Breakwaters are used to protect bridges and river banks from scouring when flow amounts and velocity are too high (Figure 34). They are placed upstream of the bridge and semi-perpendicular to the river flow to break the speed of water and divert the water flow away from the structure to be protected. The breakwaters observed during the field visit were constructed with gabions made with wire mesh filled with stones. Geotextile tubes and bags are also used to construct breakwaters. They are less costly and time-consuming than gabions and are manufactured by sewing multiple sheets of high strength woven polyester or polypropylene fabrics. They can be filled with locally available sand, which makes them a better method for places with less stone availability. The breakwaters should have strong foundations, otherwise water currents or wave turbulence will scour away the sand underneath the foundation and the breakwater will be of no use.

Figure 34. Gabions acting as breakwaters and protecting the road from high peak flows in the river (Source: MetaMeta)

Bioengineering

Bio-engineering measures such as live palisades, fascines, tree and grass plantations will slow down and retain runoff and sediments. They will also reduce erosion and stabilize slopes.

Live palisades are defensive walls of vegetation planted across the slope following the contour (Figure 39). They provide a strong barrier to trap debris and reinforce the slope. The distance between rows of palisades depends on the slope. Vertical interval between rows is about 2 m. The width of the rows is 1m. The tree *Gliricidia sepium* (local name Cuchi verde) can be planted in live palisades because it establishes well on steep slopes (40% gradient). However, it can only grow on altitudes between 0 – 1.600 m, mean annual temperatures of 15-30 °C and mean annual rainfall of 600 – 3500 mm. The leaves of the tree are also a good source of fodder.

Figure 39. Live palisades installed in Nicaragua (Source: Petrone and Preti, 2010)

Fascines (also called wattles) are living branches bundled together to trap sediment and protect against erosion. They are laid horizontally on contours to slow down and retain runoff before it reaches the road. The difference between fascines and live palisades is that in palisades cuttings of trees are planted and will grow to form a live fence, while fascines are living branches bundled together. To install the fascines, trenches need to be excavated into the exposed slope along the contour lines. Afterwards, the fascines should be laid into the trench and the soil backfilled leaving the top of the fascine partially exposed. When more than one fascine bundle is used to fill the length of a trench, a slight overlap of the ends of the bundles should be used.

Grass plantations along contour lines 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 (C*hrysopogon 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°, 1 m - 1.5 m for slope > 30° & < 45°, 1.5 m - 2 m for slope > 45°). The spacing also depends on the root system of the plant to be used.

6. Conclusions and way forward

During the National Workshop on the 13th of December the findings from the assessment were presented. The workshop participants also discussed the way forward and identified the opportunities to systematically introduce beneficial road water management in Bolivia. The main outcomes of the discussion are shown on Annex 3. These are the main conclusions drawn from the Workshop and the field visit:

- There is a strong willingness from all actors to coordinate and work on the implementation of better road water management and water harvesting for climate change resilience
- There is need for better coordination, most actors are developing relevant plans and strategies but there is quite some repetition
- Current road drainage designs do not include road water harvesting, but there is willingness from the Bolivian Road Authority (ABC)
- There is scope for creating a platform on resilient infrastructure bringing together ABC, Ministry of Water and Environment (MMAyA), Ministry of Land and Rural Development Ministerio de Desarrollo Rural y Tierras (MDRyT), Ministry of Defense (VICEDI), Autoridad Plurinacional de la Madre Tierra (APMT), Ministry of Planning and Development (MPyD) and others
- It is crucial to work with municipalities since most interventions are small-scale and very localized
- Road water management can be part of additional works of Fondo Internacional de Inversion Productiva y Social (FPS) and ABC and included in budgets and contracts

Recommendations:

- Create an inter-ministerial platform hosted by Autoridad Plurinacional de la Madre Tierra to coordinate efforts towards climate resilient roads. There is a need to coordinate and unify policies, projects and programs to work towards climate resilient roads
- Awareness raising of opportunities for road water harvesting among main implementers is needed. Opportunities and good practices are there but are often overlooked.
- Working on designs, guidelines, capacity building and piloting innovative designs with ABC within the World Bank "Road Sector Capacity Building Project".
- Work with ABC at Department level to include road water harvesting works in the routine road maintenance works
- Include road water management for resilience approaches in the River Basin Plans developed by the Ministry of Environment and Water. This could be part of the World Bank "Bolivia Climate Resilience - Integrated Basin Management Project".
- Integrate road water harvesting in the World Bank "Community Investment in Rural Areas Project" to implement suitable technologies and include capacity building activities for farmers and experts at municipal level

Following the main recommendations, below is an action plan to introduce "Roads for Water" in Bolivia:

Short-term actions (1-6 months)	Medium-term actions (6 – 12 months)
Working with ABC on road drainage designs for water harvesting and piloting	Create a national platform on green infrastructure that includes road water management and harvesting. The platform could be hosted by APMT, they are in charge of climate change adaptation actions
Training ABC, Ministry of Environment and Water (MMAyA), FPS and Ministry of Rural Development on road water harvesting practices	Develop road water harvesting guidelines with ABC including ancient technologies
Research on ancient water harvesting practices and adapting them to "Roads for Water"	Integrate road water harvesting in river basin plans being development by the Ministry of Environment and Water (MMAyA)
Collaborate in the development of the Environmental Manual of ABC	Awareness raising and implementation campaign with communities
Involve local university to create curricula on Road Water Management for Climate Change Resilience	Include road water harvesting in the Plan Plurinacional de Cambio Climatico developed by APMT

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Annex 1. Mission program

Activity	Date	Time	Comentar
Arrival and meeting World Bank office	Monday, 4 december 2017	10h00 – 12h00	Meeting the local team, discussing agenda and preparing logistic arrangements
Field visit	Tuesday to Saturday 5 – 9 december 2017		Field visit to priority areas agreed by ABC and World Bank team.
Meeting Agriculture Specialist at World Bank	Monday 11 december	14h00-15h00	Francisco Obreque
Meeting Water Specialist at World Bank	Monday 11 december	17h00-17h30	Jorge Trevino
Mini-workshop with Ministry of Water and Environment (***MMAyA)***	Tuesday 12 December	15h00 – 17h00	1. Unidad de Estudios Especiales 2. Unidad de Planificación Hídrica y Calidad de Aguas 3. Unidad de Gestión del Riesgo 4. EMAGUA 5. SENASBA 6. Autoridad Binacional del Lago Titicaca
Meeting with ABC	13 December 2017	09h00 – 11h00	• Gerencia socio-ambiental • Gerencia de construcción • Gerencial de conservación vial
Stakeholder workshop to discuss opportunities for implementing road water management for climate change resilience	13 diciembre 2017	14h30 a 18h00	Objetivos del taller: - Presentar evaluación de oportunidades. - Explorar ideas para el Manual de *Roads for Water*
	14 diciembre		*Wrapping-up*

Annex 2. Workshop Program

15:00 – 15:15	Opening by World Bank – Mauricio Navarro
15:15 – 15:30	**Integrating climate change adaptation and water management in the design and construction of roads** Fabricio del Rio Valdivia – MetaMeta
15:30 – 16:00	**The need to combine the design and construction of road with water management in Bolivia** Rodrigo Villegas - ABC
16:00 – 16:15	**Water Harvesting from roads: ancient practices** Gonzaga Ayala and Fany Ramos - Autoridad Plurinacional de la Madre Tierra
16:15 – 17:00	**Resilient roads and resilient communities: presentation of solutions** Marta Agujetas Perez –MetaMeta
17:00 – 18:00	Discussion "**Integrating climate change adaptation and water management in the design and construction of roads**" – Options for implementing in Bolivia

Annex 3. Outcomes of the stakeholder discussion held during the National Workshop

Stakeholder	Subject			
	Opportunities for road water harvesting implementation on current and future projects	**Technical needs that should be included in report and manual**	**Contributions from different institutions on the manual**	**Multisector integration for implementation at different levels (national, regional, local)**
Ministry of Water and Environment	1. Promotion of successful pilot projects on water harvesting ponds, smallholder irrigation and protection of water recharge areas 2. Structural and non-structural actions must be planned territorially under the watershed approach	1. Elaboration of water balance at subnational level 2. Development of risk maps 3. Capacity building at subnational level on water quality issues	1. Watershed national plan 2. GIRH/MIC project guide 3. National water balance 4. Guide for water harvesting ponds 5. Catalogue of water harvesting technologies	1. Creation of interinstitutional platforms
Ministry of Planning	1. The regional authorities should coordinate the road water harvesting efforts	1. Define indicators related to this subject 2. Technical, normative and methodological instruments 3. Incorporate actions, programs and projects in sector and territorial plans with specific methodologies	1. Plan for socioeconomic development (PDES) 2. National policy for urban development 3. Structure of PDES considering action, programs and projects related to the topic 4. Territorial plans for integral development (regional and local) 5. Proposal for National Land Use Plan	1. Law 777 from the State Integral Planning System 2. Articulation of sector plans with territorial plans
FPS National Productive and Social Investment Fund	1. Rainwater catchment through mitre drains and culverts built along roads	1. Mention procedures and local techniques that allow water harvesting and use	1. Share experiences from FPS on water harvesting in different regions	1. The results from this study should be disseminated and allowed to be applied through the main ministries

Ministry of Rural Development	1. Rules to avoid harm to local communities during road construction 2. Include road water management in road maintenance works as a way of risk management 3. Implement road water harvesting combined with small scale irrigation with international cooperation at regional and local level	1. Organise coordination workshops in the topic at regional and local level	1. Interinstitutional coordination among subject-related institutions 2. APMT must protect the environment and indigenous and local communities from harmful activities	1. Include in VIPFE (Vice-Ministry of public investment) manuals the formulation of investment projects with risk management 2. The Ministry of Planning should incorporate the topic and Land Management and Use Plans
Bolivian Road Authority	1. Local communities are becoming aware of the importance of proper water management and should be better organized on this respect 2. Roads in the design stage: a) Open a consultation process to collect local knowledge b) Include recommendations from "Roads for water" 3. Roads in the building or maintenance stage: a) Coordinate implementation of solutions between local stakeholders and institutions 4. Inclusion of transition devices between the road drainage and the local road water management devices implemented by the communities 5. Pilot roads with sand dams and water storage devices	2. Technical specifications for the water harvesting projects to be implemented 3. Collect all experiences and lessons learned on the report and the manual 4. Technical manuals for design, building, operation and maintenance of water devices for water management including costs for road water harvesting 5. Technology implementation manual for erosion control and bio-engineering in watersheds 6. Ancestral infrastructure manual	1. Share experiences from different countries 2. Technical information about rainwater harvesting projects 3. Report on experiences or lessons learned from implemented projects (contribution at mid-term) 4. Local technical manuals: hydrology and sewage of ABC 5. Problem description by regions	1. Workshops for interinstitutional coordination 2. Creation of interinstitutional committees 3. Capacity building for the different institutions 4. Multisector integration needs 5. Development of norms that oblige institutions to contribute 6. ABC designs the road and consults all relevant stakeholders. They identify the watersheds along the road and come up with bio-engineering solutions
Autoridad Plurinacional de la Madre Tierra (APMT)	1. Include in the Plurinational plan for climate change 2. Work within the resilient-infrastructure platform to act as a dialogue and interinstitutional coordination space 3.Economic and Social Development Plans (PDES) in Bolivia that include road planning and building 4.In the complementarity approach is important to join efforts with government and local authorities. Central government: builds roads. Local authorities:	1. APMT is a new and small institution still in process of institutional and financial planning, therefore unable to address all climate-change issues 2. Give relevance to ancestral knowledge on water harvesting 3. Describe clearly the approach of infrastructure-based adaptation (IPCC) adapted to the Bolivian context, considering that climate change intensifies rains, hail and	1. APMT owns publications on water management and ancestral knowledge 2. Interinstitutional and intersectoral coordination. The creation of a Resilient Infrastructure Platform is an important initiative	1. Include in Plurinational plan for CC in order to have specific actions such as development of handbooks for incorporation at all governmental levels 2. Multisector integration a) Consider government and local authorities in the formulation of resilient infrastructure projects (FAM, Autonomy) to establish

	complementary works	droughts		intergovernmental gatherings
Vice-ministry of Civil Defence	1. High current and future investment on roads demanding multisector coordination for integral development 2. Development of coordination and normative mechanisms	1. Standards that include seizing water and mitigate risks in accordance with the ecological tiers	1. Take up some criteria from Law 602 on risk management and Law 300 from "Mother earth"	1. Integration with SPIE system 2. Governmental integral planning system (Law 777) 3. National council on disaster risk reduction (CONARADE Law 602) 4. National system on risk reduction and emergency attention (SISRADE Law 602, national, regional, local)
IFAD	1. Water harvesting important for CC issues, not only road maintenance but also: a) Productivity (income) b) Food security (poor areas) 2. Water harvesting should be done first in places without water	1. Participation of government for policy definition: a) Ministry of Planning b) Ministry of Public Works c) Ministry of Water and Environment d) Ministry of Land and Rural Development All of them together with their dependencies	1. Participation of all sectors 2. The selection of water harvesting measures should be participatory (with Communities) 3. Communal contest as done by IFAD could be replicated	1. Multisector integration 2. AMDES, FAM (Association of Municipalities), etc. 3. Work with territorial entities