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Department of Hydro science, Institute of Urban and Industrial Water Management, Professorship Urban Water Management

INTERNSHIP REPORT

Dimensioning of a Tyrolean Weir and a small Scale SWMM for a
Construction of a Piping of the Arroyo Morteritos Valle de Sol,
Mendoza.

Auditor:

B.Sc. Christian Marx; Master Wasserwirtschaft

Matriculation Number: 3798616

Mentor:

Ing. Carlos Sansoni

Ing. Carlos Paoletti

Responsible Professor:

Mgr. Ing. Alejandro Cantú,

Prof. Dr.-Ing. habil. Peter-Wolfgang Gräber

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LIST OF ABBREVIATIONS

DoI	Department of Irrigation
INA CRA	Instituto Nacional de Agua Centro Regional Andino
SWMM	Storm Water Management Model

ABSTRACT

This study contains a Storm Water Management Model (SWMM) for the Arroyo Morteritos in the province of Mendoza; the creek will be intubated for the irrigation of the village Las Vegas. The model supports the calculation done by the Department of Irrigation of Mendoza and examines a comparison of alternatives. For verification of the model, a field campaign and a small calibration of the model was executed. During the field campaign the cross sections and a base flow of the Arroyo Morteritos has been measured. For that reason, a tracer test, a Parshall flume, and a levelling off were piloted. The average discharge of the Arroyo Morteritos is $0.077 \text{ m}^3/\text{s}$, the average, maximum and minimum velocity amounted 0.51, 0.72, 0.28 m/s for the observed period. The calculated dimensions, based on the measuring campaign, of the planned Tyrolean weir results into a suggested rack length of 0.5 m, by a rack width of 0.5 m, with a rack porosity of 0.5 to 0.33, or a rack length of 0.5 m with a width of 1 or 2 m and a rack porosity of 0.5 or 0.33 to discharge the base flow and not to damage the tube by high pressured, therefore the tube should have a diameter of 0.4 m. Additionally, the Tyrolean weir should be constructed at the former confluence between the Arroyo Morteritos and Alumbre, where the Parshall flume was located.

1 DEPARTAMENT OF IRRIGATION

The Department of Irrigation (DoI) (org.: *Departamento General de Irrigación*) is a public and decentralized organization, which manages the distribution of the resource water in the province of Mendoza. It is created by the constitution of Mendoza and independent of the executive forces. The department is an autarkic institution, which cares for the control of the water usage in the region. Due its autarkic characteristics, the DoI designs projects, sanction of misbehaviour, and execute their own budget, this includes the collection of taxes. Furthermore, the DoI takes care for the distribution of the water for public and private usage, by (artificial and natural) ditches, canals and rivers. The area of responsibilities of the DoI contains the monitoring of the discharges of the rivers and the groundwater, the planning and construction and monitoring of the irrigation system and other building sites (DoI, n. y., a).

The origin of the department was formed out of various organizations during the time of colonization. With the “Ley General de Aguas” (General Water Law) in 1884, the Department General de Aguas was formed, the predecessor organization of the Department of Irrigation, which was founded ten years later (DoI, n. y., a). The DoI is divided into the five different departments, which are based on the oasis and watersheds in Mendoza. These are managed by different sub-delegations. Those are: “Sede Central”, “Río Mendoza”, “Río Tunuyán Superior”, “Río Tunuyán Inferior” “Río Atuel”, “Río Diamante”, the area of irrigation of Malergüe (DoI, n. y., b).

Without irrigation there would be no agriculture possible in Mendoza. Therefore, a good distribution of the water from the different sources is important. As it can be seen in Table 1-1 Water usage in Mendoza the water usage of the agriculture for irrigation is quite high in comparison to the other water usages. The main water sources for the irrigation are the superficial sources like rivers, reservoirs and the groundwater.

Table 1-1 Water usage in Mendoza (Duek & Fasciolo, 2013)

watershed	Water usage [hm ³ /y]			Total *
	Irrigation	Potable water	Other	
North	2902.0	233.0	34.6	3169.6
Centre	793.0	15.0	0.1	808.1
South	1203.0	36.8	7.3	1247.0
Total				
Mendoza	4898.0	284.8	41.9	5224.7

* without industry, because of lack of data

2 OBJECTIVE

The objective of this paper is to set up and investigation of a Storm Water Management Model (SWMM) for the construction of a Tyrolean weir and piping in Valle de Sol, Mendoza. In the region, the Department of Irrigation wants to improve the irrigation of the village Las Vegas. An embankment of gravel and rocks separate the Arroyo Morteritos with the Arroyo Alumbre and relocate the confluence ca. 2 km downstream, to ensure a good water quality for the irrigation. This is necessary, because the quality and turbidity of the Arroyo Alumbre is not sufficient and as good as the water from Arroyo Morteritos. A Tyrolean weir will be constructed for draining the Arroyo Morteritos into the tube. For protecting the tube of flood events, it will be covered by a relocated earth embankment. Latter is planned as a discharge of the flood over the dyke, directly into the Arroyo Alumbre.

For the dimensioning of the Tyrolean weir a 20-year storm was set up as the base for the construction. To verify the calculations for the dimensioning of the dyke and piping, made by the Department of Irrigation, a model of the region was developed. The model includes the watersheds, the future weir and piping.

3 INVESTIGATION AREA

3.1 MENDOZA

The area of investigation is situated in the province of Mendoza in the west of Argentina, in the region of Cuyo (Illustration 3-1). The city of Mendoza was founded by Pedro del Castillo in 1561, nowadays the area of the province is 150.839 km² and contains 450.000 ha of cultivated land in 4 oasis regions (Geras, 2004). The climate is continental semiarid, dry and sunny. Winters are relatively cold, but the summers are warm (the classification of Köppen-Geiger is BWk) (Merkel, n. y.), the annual precipitation is around 236 mm (Geras, 2004). One of the most important industries in the Province of Mendoza is the agriculture, like wine production, but also vegetables and fruits. For the dry climate, with less precipitation it is essential to irrigate the area. The most important river in the region is the *Rio Mendoza*. Other rivers are Tunuyán, Atuel, Diamante and Malargüe. The main part of the river Mendoza stream is used for the irrigation and for producing potable water. Therefore, exists several dykes, which dam up the river for a water reservoir. The most important to name are *Potrerosillos* and *Cipolletti* in the west of Mendoza capital. The water of the *Rio Mendoza* arises the Cordillera in the west of Mendoza, at the *Punta de Vacas*, the annual mean flow is 50 m³/s but is bound by high fluctuations during the year and over the different years. The discharge of the Rio Mendoza depends on the snowfall during the winter month in its watershed.



Illustration 3-1 Location of the Mendoza Province (Hogward, 2015)

3.2 VALLE DE SOL

One inflow source of the Rio Mendoza is the Creek (Arroyo) Morteritos, which is situated in the Valle de Sol, ca. 55 km south-east of Mendoza city, and 17 km south of the dyke Potrerillos. Arroyo Morteritos join with Arroyo Alumbre to the Creek “Las Mulas”, which discharges into the Arroyo Blanco. The last one flows into the reservoir of Potrerillos. In the Illustration 3-2 the location of the Valle de sol in the Province of Mendoza can be seen. The source of the creek is the mountain Cerro Negro (5365 m), and confluent with the Arroyo Alumbre in front of the village of Las Vegas (altitude: ≈ 2000 m). The watershed of Morteritos (Illustration 3-3) amounts originally about 11.1 million m^2 . These watersheds can be divided into

three smaller parts, with 2.2 (Area 1), 7.9 (Area 2) and 1 (Area 3) million m^2 . The altitude of the area is between 2500 m and 5300 m above sea level. It is a high mountainous area, with snow-fall during winter. The orientation of the valley is West to East and therefore the duration of the sunshine is quite high, which influences the temperature and the snow melt. Probably the snow is the main source of water for the Arroyo Morteritos. This may have a high influence in the monthly and seasonal flow. The slope of the area is around 35-40 %. Because of the size of the area, the high slope it is an area where flash floods may occur. The vegetation is small grass, caused by the dry climate and the high altitude; there is no high developed vegetation.

Las Vegas itself is a touristic village with just a small number of inhabitants. The principal usage of the irrigation in this area is during the weekend days, when tourists and house owners visit the village. Close to the town is a small water reservoir, which is filled by the Arroyo Alumbre and Morteritos, but mainly by Morteritos due its better water quality.



Illustration 3-2 Location of the Valle de Sol in Mendoza (shadowxfox, 2013)

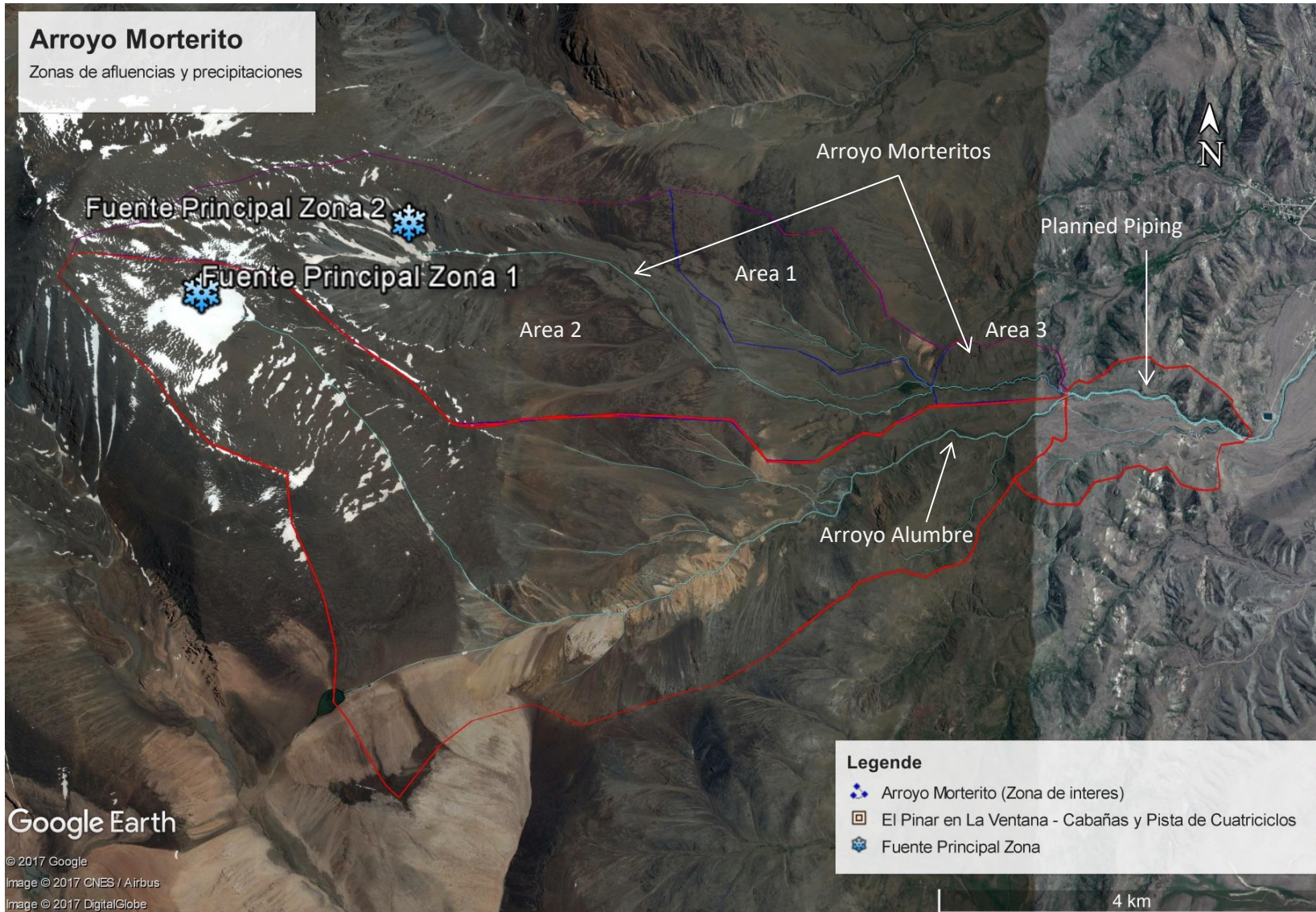


Illustration 3-3 Area of Investigation, Valle de Sol with the Creeks Morteritos and Alumbre and the planned piping of the Creek Morteritos

4 SWMM

4.1 GENERAL

SWMM is a modelling software developed by the United States Environmental Protection Agency (EPA) and is used in the version 5.1.012 for this simulation. It is designed for calculations of storm water runoffs, sanitary sewers and drainage system in urban and non-urban areas.

The program is a hydrology-hydraulic water quality model. Furthermore, it is an open-source, free program; for this reason it fits for the following study.

The hydrologic capabilities of SWMM are inter alia time-varying rainfall, evaporation of standing surface water, the melting and accumulation of snow, infiltration into (un-) saturated soil layers, nonlinear routing of overland flow (EPA, n. y.).

4.2 CONCEPTUAL MODEL

The conceptual model of the Arroyo Morteritos consists of three parts. The first is the piping itself and the natural river section, three areas of precipitation, and furthermore the planned weir. This is represented in the Illustration 4-1. The watersheds of both creeks are marked with a red border, whereby the watershed of Arroyo Alumbre is not considered in the model. It contains all essential system components to describe the system.

Boundary Conditions

The outer-watershed can be seen as a no-flow boundary (red line), and is therefore a Neumann boundary. These lines mark the area of modelling too.

The source of the baseflow is a Neumann (or second-type) boundary condition for their know and constant stream-flow.

The runoff, the infiltration and the precipitation can be seen as a Cauchy (or third type)–boundary condition, because it is a source of discharge. This includes all three areas of precipitation; those areas are marked with a blue line in the Illustration 4-1.

4.3 NUMERICAL MODEL

The numerical model consists of the components, which are summarized in Table 4-1. Two rain gages are used for two different kinds of 20-year storms. These data can be seen in the Illustration 4-4. The data for the sub catchments (the areas of precipitation) can be reviewed in Table 4-3. For the simulation are two outfalls essential, one behind the weir, where the flood is drained into the Arroyo Alumbre, and the other, where the piping is connected to the existing reservoir. Snow packs are not considered, because of missing data and unknown snowfall during the winter month.

Table 4-2 summarizes the settings for the simulation. The time for the simulation is between the 01/01/2017 00:00 and 01/01/2017 16:00 which is sufficient for the storm, which occurs at 6:00 to 7:00 for one hour. The time steps have been chosen for 1 min each, greater time steps cause irregularities in the runoff and flow of the rainfall event due its fast-responding time. It is a non-stationary modelling of the runoff process. Additionally, smaller variable time steps and 20 maximum iterations are permitted for a better convergence of the results. The force main equation of Hazan is used in this model, because it is the standard equation in Argentina.

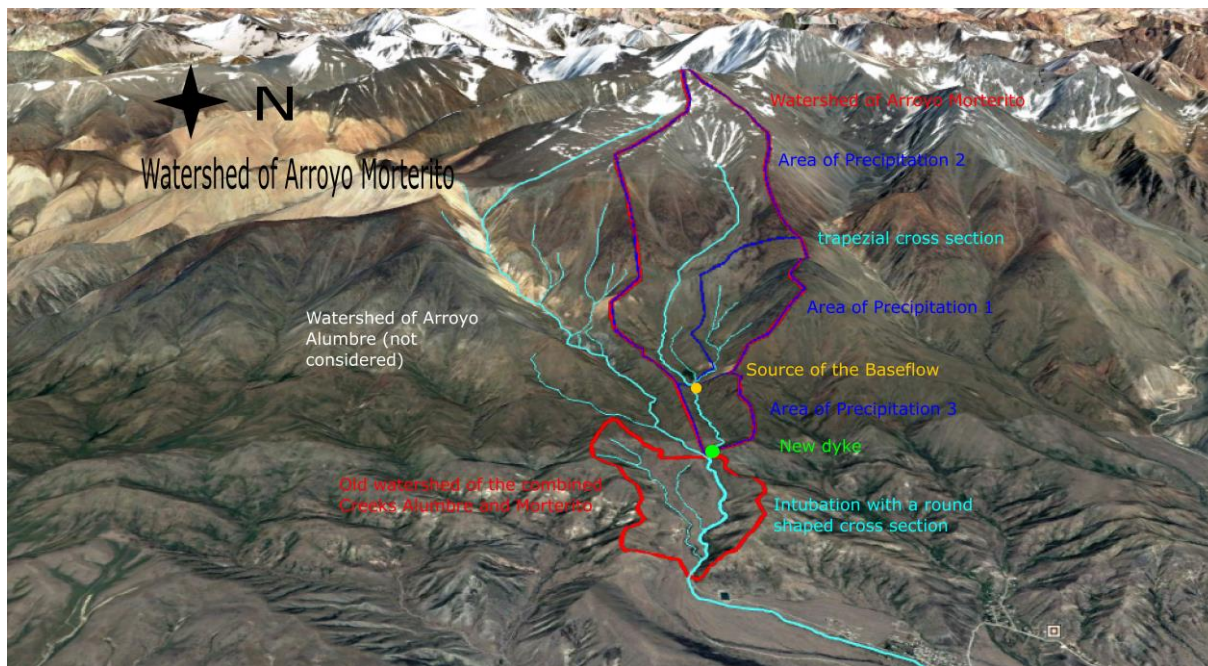


Illustration 4-1 Conceptual model of the area of investigation and the modelled area, marked by the red border

Table 4-1 Project Summary of the physical elements in the numerical model

Project Summary	
components	amount
Rain gages	2
Sub catchments	3
Aquifers	0
Snow packs	0
RDII Hydrographs	0
Infiltration Model	Horton
Junction Nodes	67
Outfall Nodes	2
Storage Nodes	1
Conduit Links	68

Table 4-2 Simulation Summary of the numerical elements of the model

Simulation		
General		
Rainfall/Runoff	Yes	
Infiltration Model	Horton	
Flow Routing	Yes	
Numerical Precision		
Precipitation	2	Decimals
Depth	2	Decimals
Flow	2	Decimals

Routing Model:	Dynamic Wave	
Inertial Terms	Dampen	
Normal Flow Criterion	Slope & Froude	
Force main Equation	Hazan-Williams	
Variable Time Steps	Yes	
Minimum Variable Time Step	0.5	sec
Maximum Iteration	20	
Head Convergence Tolerance	0.0015	m
Time Steps		
Time Steps	1	min
Runoff Dry Weather	1	min
Runoff Wet Weather	1	min
Routing	30	sec
Units		
Flow	L/s	
Time	min	
Precipitation intensity	mm/h	
Head	m	

Both outfall nodes have been defined as free.

To prevent flooding of the canal nodes, a surcharge depth of 100000 m was chosen.

Additional elements of the model are the usage of a storage element, to simulate the space in front of the weir, to simulate retention. Furthermore, the piping is modelled by a round

shape tube. The Arroyo Morteritos is simulated by a simple trapezoidal cross section.

For the watershed of Arroyo Morteritos, no data is available. The area was calculated by polygons in Google Earth, based on the highest points, which describe the border of the watershed of the three main parts of the Arroyo Alumbre.

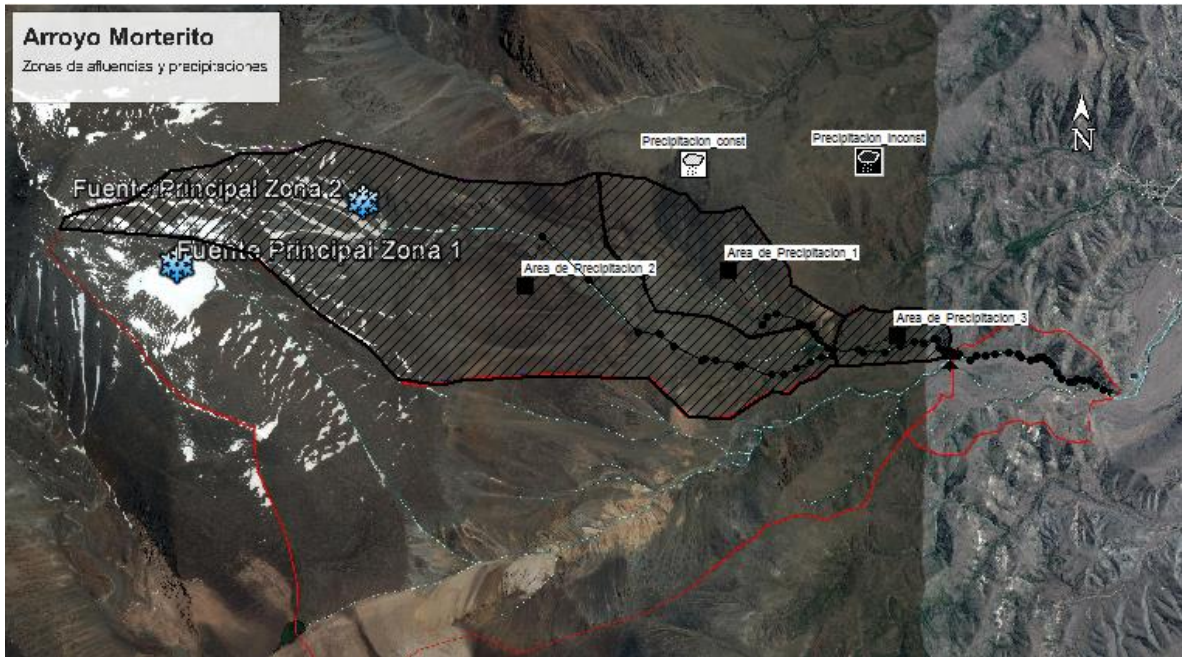


Illustration 4-2 The whole numerical model

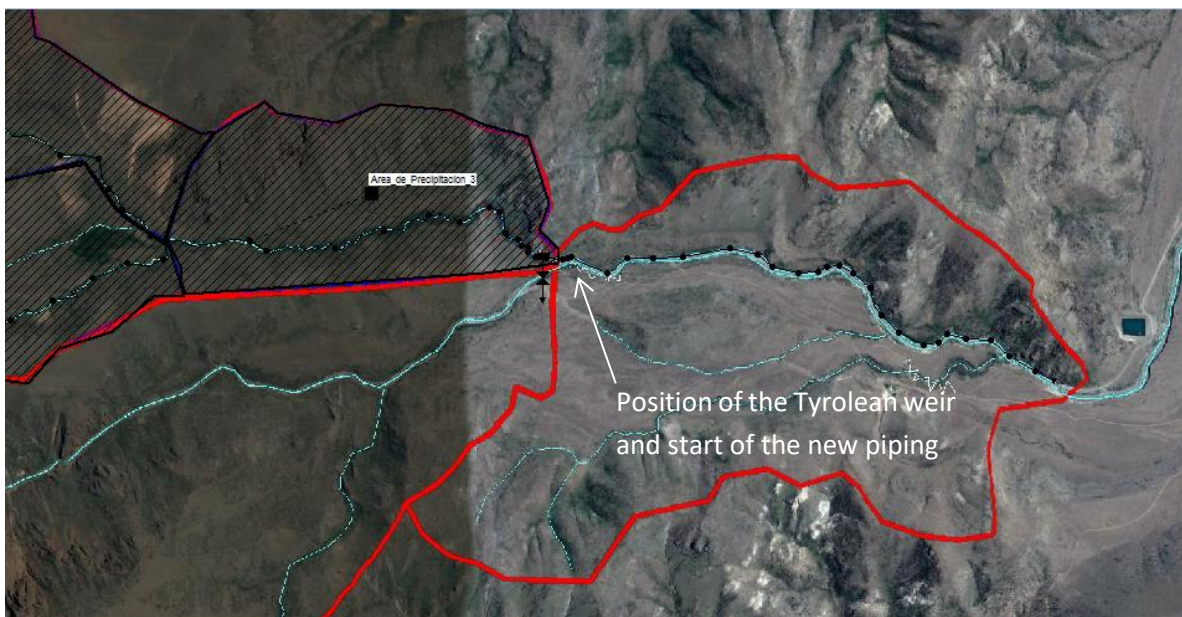


Illustration 4-3 Detailed view of the piping

4.4 IMPLEMENTATION OF THE PARAMETERS IN SWMM

4.4.1 Areas of Precipitation

As mentioned before, three areas of precipitation have been defined. These areas are sub catchments of the watershed of Arroyo Morteritos until the new piping begins. The areas one and two are the springs and the main source of the baseflow, whereby the Area 2 up to the top of the mountain goes, with a high snow impact during winter, and snow melting in the summer. The intensity of the occurring flood, caused by the rainfall, is highly dependent on the used parameters of the precipitation area, which are unknown. To get a clue of the values, the slope, width and area was calculated by the usage of Google Earth. The most important parameters are shown in the Table 4-3. The area is important for the total rainfall volume; the width describes the flow over the area, until it reaches the first Node. The width and the slope are important for the responding time of the area for the rainfall event. The impervious area describes how much of the total area will cause the runoff to the creek. In difference to normal runoff models in urban areas, this value is unknown and was guessed. Theoretically the value is zero, but for a flash flood region, the direct runoff of the area is significant, because there is almost no infiltration possible, besides it is a rocky ground, so a great part of the rainfall will runoff directly. These 30% impervious area will cause a fast responding, and high intensity flood, which can be expected in the region. To portray the forming of small puddles on the area, the depression of the (im-) pervious area was set to 0.5 mm. First, these depression storages must be filled, until a runoff occurs and second, this water wont runoff, just (not examined) evaporation could empty them.

Table 4-3 Values for the Areas of Precipitation in SWMM

Parameter:	Area 1	Area 2	Area 3	Unit
Area	215	796	95	ha
Width	1333	1900	347	m
Slope	39	36	37	%
Impervious Area	30	30	30	%
Depression Storage	0.5	0.5	0.5	mm

4.4.2 Precipitation

A 20 year-storm was assumed, for the storm calculation in SWMM. Therefore, data from *Instituto Nacional de Agua Centro Regional Andino* (INA CRA) was provided and used. In the region of Mendoza a 20-year, one hour heavy summer storm has intensity about 66 mm/h. This causes a medium intensity of 5.5 mm/h, or adapted by the histogram provided by the INA CRA, 2008, a distribution with a maximum intensity of 9.24 mm/5 min. In the model two scenarios, one of a constant and another of a distributed rainfall are implemented. The curves can be taken out of Illustration 4-4.

The rain curve rises fast, after 20 min the maximum precipitation of 9.4 mm is reached and ca. 40 % of the total rainfall volume. The maximum precipitation is for 10 min, the drop of the precipitation is more slowly. The cumulated rain volume of the inconstant rainfall in the first 15 min is almost the same as the constant rainfall, later the volume of the inconstant rainfall is higher. This typical curve of a heavy summer storm can cause flash floods in the region because of its intensity, especially if it is considered, that the slope of a mountainous region is high and so is the responding time of the areas fast.

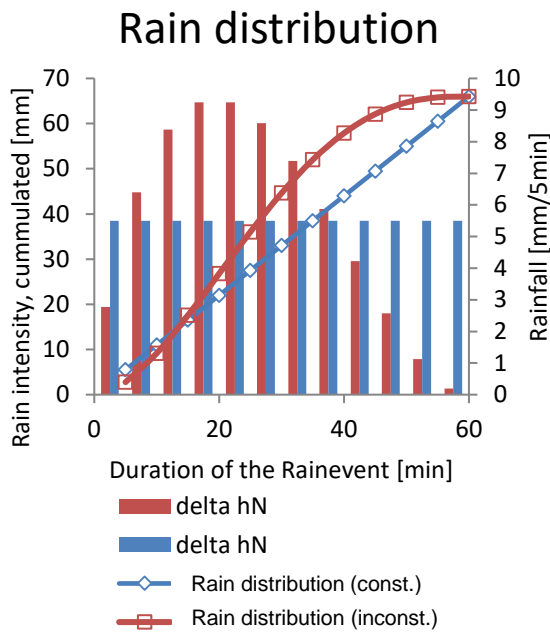


Illustration 4-4 Rain Distribution of a 20-year Storm in the andine region, adapted (INA CRA, 2008).

4.4.3 Weir

Dykes in SWMM are implemented as a weir link and a storage link. A conceptual sketch can be taken out of the Illustration 4-5. The important parameters for the model are the inlet offset and the height, and the discharge coefficient. The inlet offset influences the maximum storage height, all water levels about the inlet offset will overflow the weir.

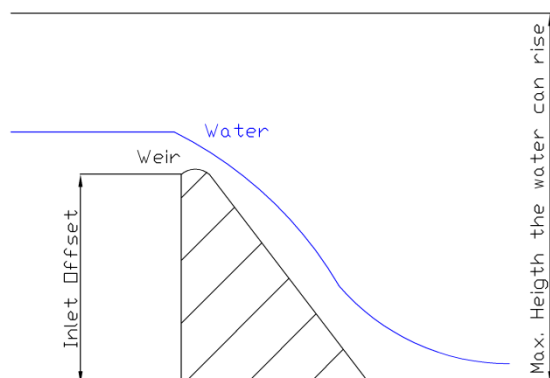


Illustration 4-5 Sketch of a transversal dyke in SWMM

The connection between the storage and the piping is done by an offset of it. This causes an

inflow, into the tube, until the maximum level of water reaches the top of the tube. Higher flow rates will cause a rise of the storage level, until the Inlet Offset of the weir is reached. The maximum height (of the weir) describes the maximum water level which is allowed in the model. It has to be imagined, like a roof of the weir. The properties for the weir are following:

The maximum height was set to 20 m, the length to 2 m, the inlet offset of 0.4 m and the weir cannot surcharge and has no flap gate, which pretend of a backflow.

The discharge coefficient is used different than usually, therefore some calculations have to be done.

According to Stamm, (2011) the discharge coefficient for the equation of Poleni is for a round shaped weir between 0.7 and 0.75.

Equation of Poleni:

$$Q = \frac{2}{3} \times C_D \times \sqrt{2g} \times b \times h_0^{3/2}$$

Discharge Equation in SWMM (Perin, 2016):

$$Q = C_W \times b \times h_0^{3/2}$$

Therefore, the discharge coefficient must be transformed by:

$$C_W = \frac{2}{3} \times C_D \times \sqrt{2g}$$

Whereby Q is the discharge [m^3/s], b is the width of the weir [m], h_0 is the water level [m], C_D and C_W are the discharge coefficients in Poleni and SWMM [-] and g is the gravity acceleration [m/s^2]. Using a C_D of 0.7 results into a C_W of 2.06, which can be used in SWMM.

In situ it is planned to construct a Tyrolean weir (Illustration 4-6, Illustration 4-7), which cannot be implemented as such in SWMM. A Tyrolean weir was chosen, due its several advantages

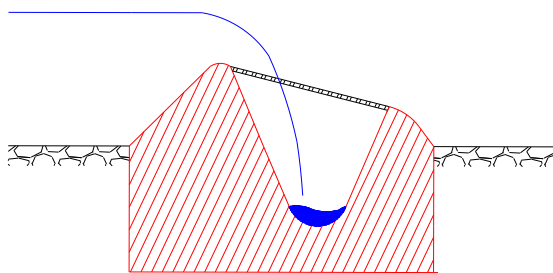
and for its ability to drain water out of creeks without a usage of a pump or manpower.

The advantages of these type of weirs are:

- + An easy construction in the mountains.
- + Reliable
- + Easy extraction of water.

The disadvantage is:

- could get problems in winter with snow and ice.



Legend

Tyrolean Weir

Rack bar

Illustration 4-6 Sketch of a Tyrolean Weir, which shall be constructed.

Due the characteristics of a Tyrolean weir to divide the discharge, it was planned to add a Divider Node additionally to a normal weir link. These should drain the water into the planned piping, in dependence of a given discharge table (Illustration 6-11, Table 12-3, Table 12-4). The divider node just works with a kinematic flow equation. But this caused problems by flooding nodes in the case of the closed tube where no flooding can occur. The kinematic equation cannot handle pressured flow.

Furthermore, it was not possible to simulate the weir by using a pump link, because SWMM just offers Pump curves, based on the water level and not on the flow in the creek, additionally this caused problems in the simulation. To simulate the weir and avoid the named problems, it was chosen to set the maximum capacity of the first tube with the maximum discharge capacity of the weir by a flood of $7 \text{ m}^3/\text{s}$.



Illustration 4-7 Tyrolean Weir (Studio G, 2013)

4.4.4 Storage

A possible backwater effect, caused by the weir is not considered, because of the fact it would be too small, and for proper storage curve more detailed information about the cross section would be needed. This assumption can be made by the fact that the storage is always filled due the constant inflow in dry weather days and a lack of another way of discharge.

4.4.5 Cross Sections

The mediated cross sections have been simplified as following: Bottom: 1 m, Slope: 0.22, with a maximum height of 4 m to avoid flooding.

The cross section of the piping is a round shaped, standard tube. The diameter is all the way constant, depending on the scenario, 0.3 or 0.4 m.

5 METHODS

5.1 MEASURING CAMP

Because of the distance and the amount of measurements, a measuring camp in the valley was erected. This has to be done, especially for the calculation of the daily discharge, to get a proper mean during the melting period. The time of the campaign was three days from 01/11/2017 – 03/11/2017. The permanent residents of the camp were B.Sc. Anna Uhlig (student of Hydrology) and B.Sc. Christian Marx (student of Water Resources Management).



Illustration 5-1 Measuring camp in Valle de Sol, with equipment for the tracer test and levelling of

5.2 FLOW MEASUREMENT

5.2.1 Tracer Test

For the validation of the stream measurement a Tracer test was done. A tracer is a substance, which is observed to follow a chemical or biological reaction, or flow ways and their velocity. There are different kind of tracers, for example invisible like fluorescents, radioactive or special chemical substances, and visible like colour and turbidity or floating material. Because of environmental aspects, a simple salt tracer was used. The advantages of a salt tracer are: they are cheap and easy to buy, almost no environmental impact and no chemical reaction, additionally they are easy to store and easy to

measure with a conductivity meter (Ross & Gerner, 2008).

For the dosage of the salt (NaCl) for a tracer test there is following rule of thumb (Ross & Gerner, 2008):

5 g NaCl per 1 l/s discharge; a more accurate description can be found in Table 12-1 in the appendix.

Conductivity > 500 $\mu\text{S}/\text{cm}$: > 5 g per l/s

Conductivity < 100 $\mu\text{S}/\text{cm}$ < 5 g per l/s

Execution of a tracer tests (Ross & Gerner, 2008):

Before the tracer test starts, there should be a calibration of the water samples and a defined salt water solution.

The feed of the tracer should be direct and like an impulse, if possible the whole volume of the salt water in a short period of time.

The measuring distance should be 20 – 50 times greater than the width of the creek.

The measuring will be done with a conductivity meter, to observe the increase and decrease of the conductivity curve. With the peak time and the distance, the medium velocity can be calculated. The increase and decrease describe the dispersion by ponding and other influences, and also the maximum and minimum velocity.

The discharge of the creek can be calculated by following equation:

$$Q = \frac{m[\text{NaCl}]}{\alpha \times \int_{t_1}^{t_n} \sigma(t) dt}$$

Where Q is the discharge [m^3/s], m is the mass of the salt (NaCl) [g], α is the calibration coefficient [$\frac{g[NaCl]/m^3}{\mu S/cm}$], t is the time [s], and σ is the electrical conductivity [$\mu S/cm$].

Tracer test offers advantage for the calibration of the model. While a simple flow measurement just produces a value, the curve of a tracer, with their peak and incline (dispersion) can be used for a calibration of the numerical model, especially by adjusting the Manning Value, and possible different flow ways, and ponding.

Because of the lack of a conductivity meter with data logging, and the fast-responding signals, the results have been filmed by a camera, to get every second value. This turned out quite well, by the fact the fast rising and falling of the curve.

5.2.2 Venturi Device

The Venturi Device (or flume) is usually used for a flow measurement in the sewer, because it can be easily constructed. The measurement principle is based on the principle of Venturi and Bernoulli.

With a limitation of a cross-section a reduction of the water level is factitious. With the help of the equation of Bernoulli and the relation of continuity the flow can be calculated. In the narrow section a hydraulic drop should appear, furthermore a change of the flow regime from free discharge to a streaming one is necessary. If this occurs, the discharge can be calculated directly from the upstream head. The condition for this is a backwater free flow (Martin & Pohl, 2014).

The equation for calculating the discharge of a Venturi flume can be derived by the Bernoulli equation.

$$Q = b \times \frac{2}{3} h_E \times \sqrt{2g \times (h_E - \frac{2}{3}h_E)}$$

Where Q is the discharge [m^3/s], b is the width of the narrowed cross section [m], h_E is the energy level [m], and g is the gravity acceleration [m/s^2]. The energy level should be the water level in front of the narrowed cross section (Martin & Pohl, 2014).

For the measurement of the discharge of the Arroyo Morteritos, the adapted Venturi Flume of Parshall was used. The relation between the discharge Q [m^3/s] and the water level h [m] of this specific flume can be taken from Illustration 5-2. This curve can be described by following equation:

$$Q = 0.7746h^2 + 0.0406h ; R^2 = 0.9998$$

Discharge Parshall - Flume

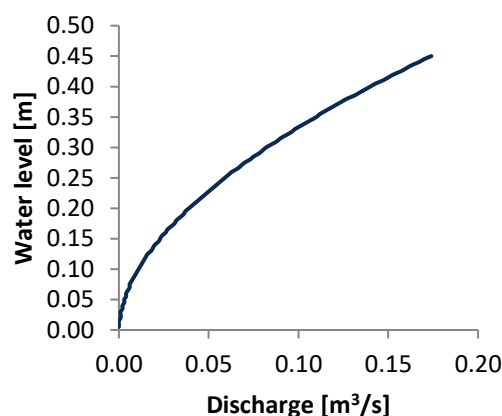


Illustration 5-2 Relation between the discharge and the water level of the used Parshall/Venturi flume for a free flow

The advantage of this measuring method is that it can be placed in the creek for a while, to get constant measuring conditions. Additionally, in combination with a Tracer test, the Parshall flume is a good location for measuring the conductivity, due its narrow opening the whole tracer must pass the Parshall flume in a small section.

5.2.3 Thompson weir

As an alternatively method, a flow measurement with a Thompson weir (Illustration 5-3) has been considered. The weir is typically installed in small rivers or creeks for a calculation of the stream flow. The principle is (related to Bernoulli) that the discharge is directly related to the water depth h above the crotch of the V – shaped opening (LMNO, 2014).

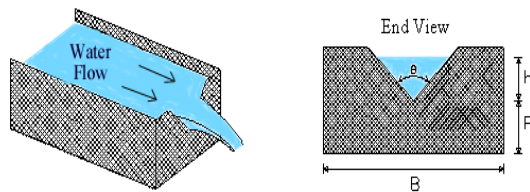


Illustration 5-3 Sketch of a Thompson Weir (LMNO, 2014)

The ASTM D5242 (1993), and the ISO 1438/1- (1980) suggest using the equation of Kindsvater-shen. Whereby Q [cfs] is the discharge, C is the discharge coefficient, α is notch angle (usually 90°), k is the head correction Factor [ft], h is the head over the crotch (LMNO, 2014).

Kindsvater - Shen equation:

$$Q = 4.28 \times C \times \tan\left(\frac{\alpha}{2}\right) \times (h + k)^{5/2}$$

If the angle is 90° , the term $\tan(\alpha/2)$ will be 1, which is equal to the standard Thompson weir.

For calculating k and C , depending the notch angle, following Illustration 5-4 is used.

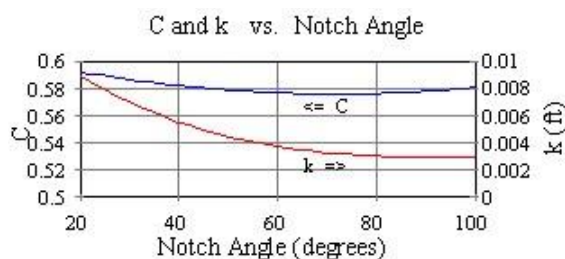


Illustration 5-4 C and k vs. Notch Angle (LMNO, 2014)

5.3 TECHNICAL DESIGN OF A TYROLEAN WEIR

For the technical design no DIN or ASTM standard exists, therefore the results of CİHAN MARAŞ, 2014 were used. In the thesis some calculation was described to calculate the length of the rack bar and the discharge into the flume. A Tyrolean weir consists out of an opening for the water intake, covered by a rack bar and followed by a channel to discharge the water.

The rack maximum length L_2 (compare Illustration 5-6 , page 14) highly depends on the critical head H_c [m], the discharge coefficient C_d [-] and ω the rack porosity [-] which describes the ratio of the spacing between the rack bars and the main flume width (Maraş, 2014).

$$C_d \times \omega \times \frac{L_2}{H_c} = 0.83$$

Rounded and flat rack bars differ by the discharge coefficient.

Round shaped rack bar:

$$C_D = 0.53 + 0.4 \times \log\left(\frac{D}{e}\right) - 0.61 \tan \theta$$

Flat shaped rack bar:

$$C_D = 0.1296 \times \frac{t}{e} + 0.4284 (\tan \theta)^2 + 0.1764$$

Where D [m] is the diameter of a round, t [m] is the thickness of a flat shaped rack bar, e [m] is the spacing between the bars and θ [°] is the angle of the rack bar (Maraş, 2014).

It is assumed, that the energy grade line behaves constant. This is in case of an impoundment of Arroyo Morteritos. To calculate, iterative approaches were used (Maraş, 2014).

In case of an impoundment of the stream, it can be assumed the energy grade line is horizontal (Illustration 5-7). To calculate the unit discharge over the rack q_i [m²/s], the approach of energy equation is needed, with a section x_i [m] of length L_2 , the depth h_i [m] and the energy head H_i [m]. Furthermore, the angle θ [°] of the rack must be considered (Maraş, 2014).

$$q_i = h_i \times \sqrt{2g (H_i - h_i \cos \theta)}$$

To solve the energy head H_i the elevation difference must be added to the energy head H_0 following (Maraş, 2014):

$$H_i = x_i \sin \theta$$

The depth h_i is unknown and must be iterated, therefore a value must be assumed first. The discharge into the flume $q_{w,i}$, that passed through Δx_i , which is an orifice flow can be calculated by the average depth h of the section by following equation (Maraş, 2014):

$$q_{w,i} = \lambda \times \sqrt{h} \times \Delta x_i$$

To calculate the unit discharge of q_{i+1} , $q_{w,i}$ which passes the rack can be subtracted from the former q_i .

Whereby the factor λ is calculated by:

$$\lambda = \mu \times \psi \sqrt{2g \times \cos \theta}$$

$$\psi = \frac{e}{a}$$

e [m] is, as mentioned before the distance between the single rack bars and a [m] the distance between the middle of the rack bars (Illustration 5-5).

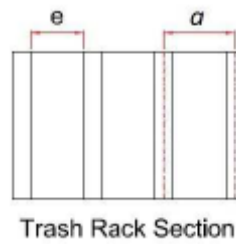


Illustration 5-5 Sketch for e and a (Maraş, 2014)

μ is a contraction coefficient, which distinguishes on the type of the trash rack but can be calculated as follows:

$$\mu = 0.66\psi^{-0.16} \times \frac{a^{0.13}}{h}$$

Each water surface profile and discharge distribution over the trash rack must be iterated for each interval of Δx_i .

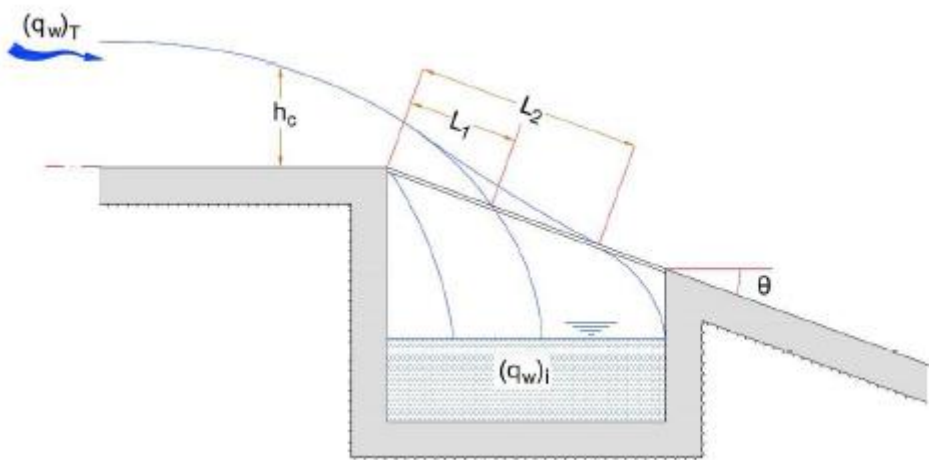


Illustration 5-6 Sketch for the calculation of the rack length. L_2 is the length, where the total discharge went into the flume (Maraş, 2014)

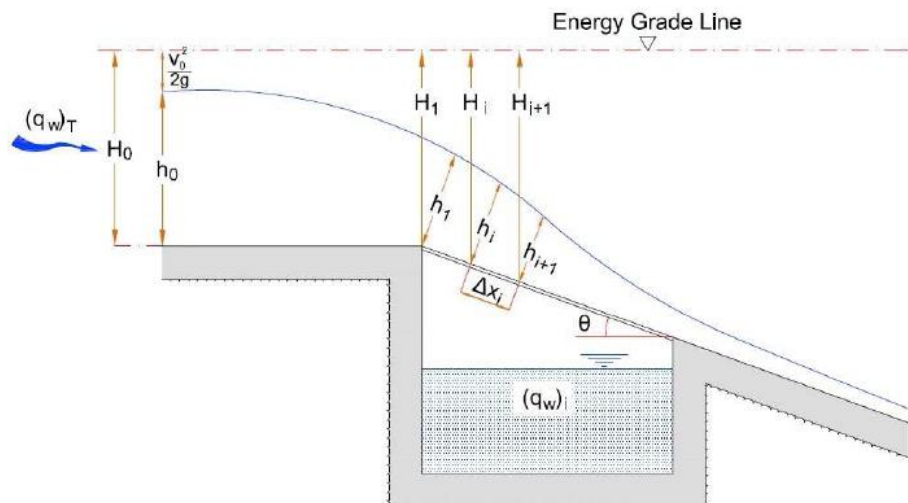


Illustration 5-7 Skeme of a Tyrolean Weir with a horizontal Energy Grade Line (Maraş, 2014)

5.4 LEVELLING OFF

5.4.1 Slope of the River Bed

The mediation of the slope of the river bed is done by a levelling off, for the length of the Arroyo Morteritos. An example can be seen in Illustration 5-8.

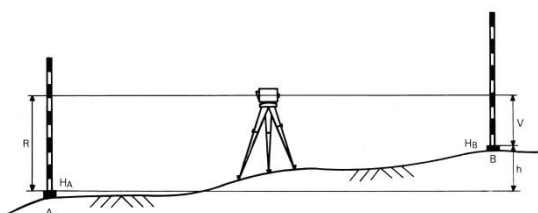


Illustration 5-8 Levelling off (Kern & Co. AG Aarau, n. y.)

5.4.2 Cross Sections

The cross sections have been mediated in two ways. First was done with a measuring tape and stick, later by two measuring tapes. Both have advantages and disadvantages. First is probably more exact, but needs more time and has problems with the rocks in the river bed. The second is done more rapidly, but with a great water velocity of the creek, the measuring tape buckles, which causes inaccuracies.

6 RESULTS

6.1 RESULTS OF THE FIELD TEST

Illustration 6-4 shows the main measuring area, with the position of the Parshall flume, and the region where the tracer test was realized.

6.1.1 Slope and Cross Sections

The area of investigation is marked by a moderate and high slope (5 – 25%) and a manmade creek beds, below the Parshall flume.

Upstream the Parshall flume the creek flushed a small canyon out, with some larger dry areas in the curves. But in general, the creek bed is not wider than 1 m; an average depth could not be measured because of the rapid change between ponding area and waterfalls, which would make the results irrespective. An area 50 m above the Parshall flume has been investigated, because there the Tyrolean weir shall be constructed. The average slope is about 10.12 % for the reach of the tracer Test.

The part downstream the Parshall flume has a longitude of 53 m by an altitude difference of 5 m, this results in a slope between 5 - 15 % (compare Illustration 12-1).

In total three cross sections have been measured. The Illustration 12-3 in the Appendix represent the cross sections for the construction area (and tracer input, cross section (1)) upstream the Parshall flume, and the tracer input (cross section (2)) and mediation (cross section (3)) downstream. The last two positions can be seen in Illustration 6-4.

6.1.2 Flow

The discharge of the Arroyo Morteritos has been measured by the Parshall-flume, the average water level has been 19-21 cm, this results in a discharge about 39 L/s (0.039 m³/s) (compare Illustration 6-1). The Parshall flume has been deployed at the beginning of the existing earth deposit, ca. 2 m behind a small waterfall to get a plain area to place it. Furthermore, big rocks have been removed and used to stabilize the flume.

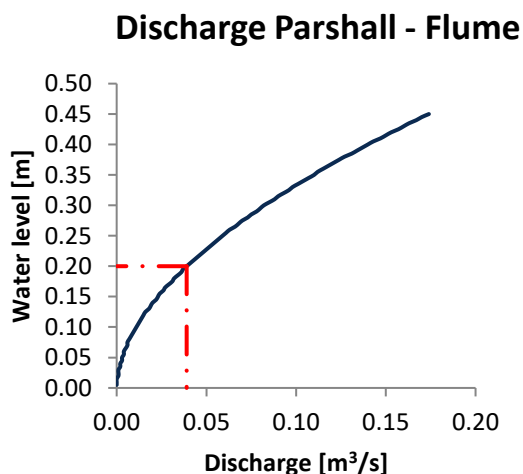


Illustration 6-1 Results of the Parshall flume

These results differ quite a lot from the tracer tests. This can be explained by the fact that the flume could not be sealed completely. Some

water with an unknown discharge was flowing beside and under the flume.



Illustration 6-2 Parshall flume

Illustration 6-2 display the applied Parshall flume in the Arroyo Morteritos. As it can be seen, a measuring stick was used to mediate the water level. The measuring stick is quite thin, to avoid problems in the stream and for an improved reading. The discharge of the Parshall flume was free, and a good stream could be reached, as it can be seen in Illustration 6-3. Furthermore, it was tried to seal the sides of the Parshall flume by two wooden doors, which worked quite well. But it was almost impossible to seal it completely, because of the high porosity of the used stones and gravel. Filling the gaps with sand, and smaller sized gravel worked at the beginning, but after a while those barriers washed out.



Illustration 6-3 Parshall flume outflow

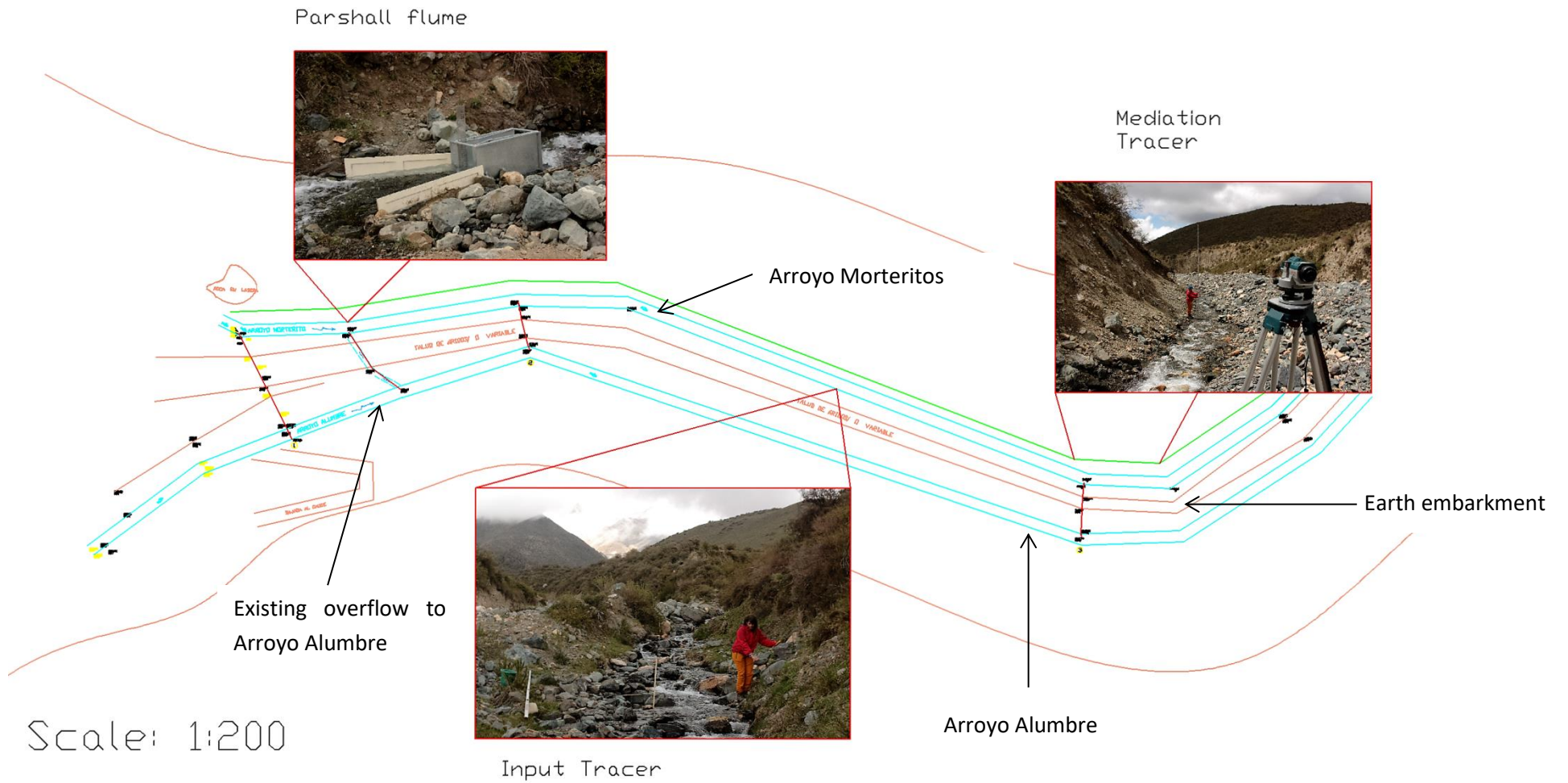


Illustration 6-4 Layout of the measuring field

To assume the discharge beside and down of the Parshall flume, two measurement distances for the tracer test have been chosen, one in front of the Parshall flume, one behind.

The difference between the measuring distances is, the first one has a higher slope and includes the future construction place for the Tyrolean weir, but as a disadvantage it has a lot of small waterfalls, so the tracer could get lost. Because of this problem, the measuring distance was quite short, 29.75 m. In fact, of the waterfalls in the creek, the high slope of 10.12 % and the high velocity, just one tracer test out of three turned out well, the rest was without results. For the tracer test 500 g NaCl in 3 l water have been used, this distinguished of the Table 12-1 from the Appendix, but it turned out quite well. A smaller solution was not useful, because the packages of salt have been 500 g and 1 kg, and there was no way to weight smaller portions during the campaign.

For the measurement area in upstream of the Parshall flume following results have been gained. As it can be seen in the Illustration 6-5, the Tracer reached the conductivity meter after 22 seconds, this results in a maximum velocity of 1.35 m/s, the peak has been reached after 36 seconds, so the mean velocity is 0.83 m/s. After 117 seconds the background conductivity was reached, therefore the minimum velocity in this part is about 0.25 m/s. The discharge has been calculated by 69 L/s (0.069 m³/s).

For the measuring area downstream the Parshall flume, four successful measurements have been done. The distance has been 53 m. The results can be reviewed in the Table 6-1, and the corresponding illustrations at page 18.

Tracer Test 03/11/2017 (2)

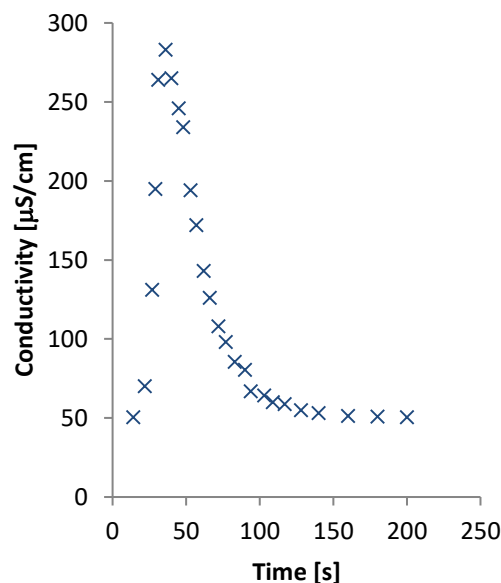


Illustration 6-5 Tracer test 03/11/2017 (2), in front of the Parshall flume, 29.75m

Considering all measurements downstream the Parshall flume, the average values for this period are:

- Maximum velocity: 0.72 m/s
- Mean velocity: 0.51 m/s
- Minimum velocity: 0.28 m/s
- Discharge: 0.077 m³/s

As mentioned before, the discharge between the Parshall flume and the tracer test are different, more reliable are the results of the tracer test, but to get a fast overview and to guess the discharge the flume is useful. Especially to roughly estimate the discharge, to get the calculation of the salt concentration for the tracer test the Parshall flume is very useful.

6.1.3 Additional Observations

During the mediation campaign an alternative position for the weir was found. It should be considered to place the weir at the same position as the Parshall flume.

Table 6-1 Results of the Tracer Tests

Tracer Test							
Date:	02/11/2017	02/11/2017	03/11/2017	03/11/2017	03/11/2017		
Test-Number	1	2	1	2	3		
Place	Behind Parshall Flume	Behind Parshall Flume	Behind Parshall Flume	In front of the Parshall Flume	Behind Parshall Flume		
Reach length	53	53	53	29.75	53	m	
Slope	9.8	9.8	9.8	10.12	9.8	%	
Velocity	max:	0.75	0.73	0.71	1.35	0.70	m/s
	mean:	0.55	0.53	0.46	0.83	0.50	m/s
	min:	0.27	0.3	0.27	0.25	0.29	m/s
Discharge	0.077	0.069	0.083	0.069	0.078	m ³ /s	
Graph	Illustration 6-6	Illustration 6-7	Illustration 6-8	Illustration 6-5	Illustration 6-9		

**Tracer Test
02/11/2017 (1)**

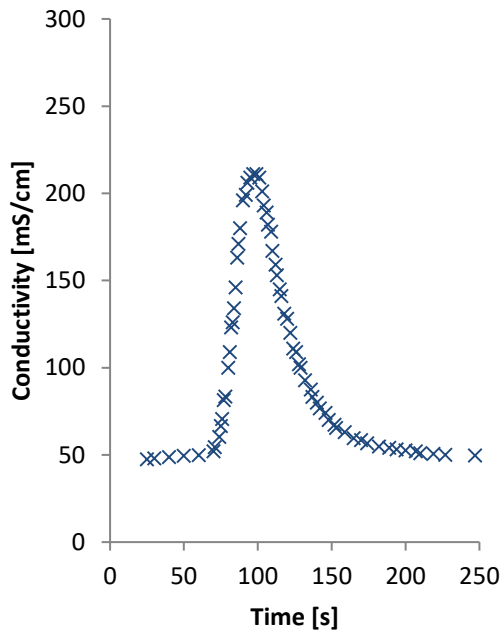


Illustration 6-6 Tracer test 02/11/2017 (1), downstream the Parshall flume, 53 m; $Q = 77$ L/s

**Tracer Test
03/11/2017 (1)**

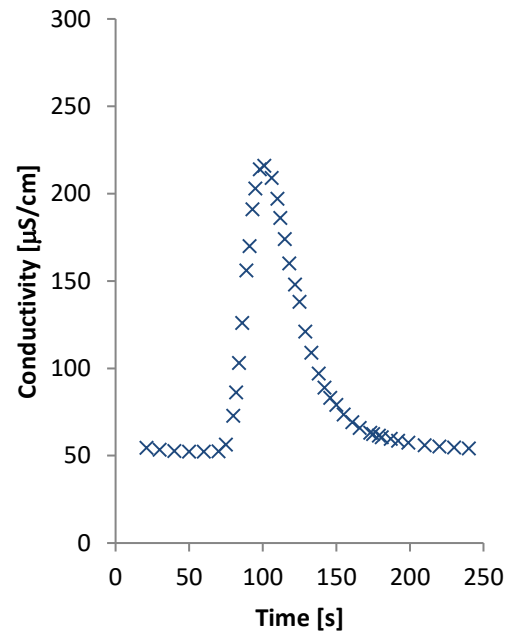


Illustration 6-8 Tracer test 03/11/2017 (1), downstream the Parshall flume, 53 m; $Q = 83$ L/s

**Tracer Test
02/11/2017 (2)**

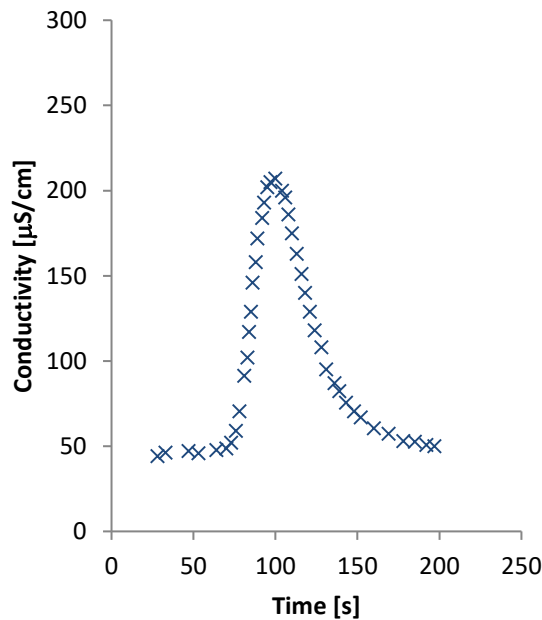


Illustration 6-7 Tracer test 02/11/2017 (2), downstream the Parshall flume, 53 m; $Q = 69$ L/s

**Tracer Test
03/11/2017 (3)**

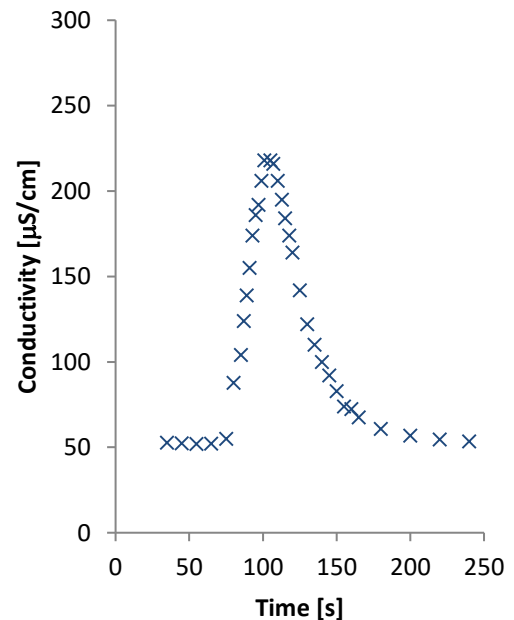


Illustration 6-9 Tracer test 03/11/2017 (3), downstream the Parshall flume, 53 m; $Q = 78$ L/s

6.2 TECHNICAL DESIGN OF THE TYROLEAN WEIR

For the Tyrolean weir two different principle designs will be examined.

First: the weir will dam Arroyo Morteritos, up to the foreland of the creek, related to the cross section 1 in the Illustration 12-3. The height will be about 0.5 m and the width about 2.3 m, whereby the rack should not be over the total width of the Tyrolean weir.

Second: the weir will be constructed plane into the ground analogue to the slope, with a width about 1 m.

Both types could be constructed with a rack over the total width or just partially, as it can be seen in Illustration 12-2 for the first type of weir.

Different dimensioning of the Tyrolean weir can be taken from the Table 12-2, whereby the calculated discharge the maximum discharge is without, a loss into the river bed, this means the whole stream goes into the tube. Greater floods will increase the discharge into the piping, but will also cause a discharge over the weir. For the calculation it is the Usage of flat rack bars is assumed, with a diameter of 0.02 m and a spacing of 0.02 or 0.01 m (rack porosity: 0.5 or 1/3). Furthermore, the maximum velocity of 1.35 m/s has been used for dimensioning. An example of a rack bar for a Tyrolean weir can be seen in Illustration 6-10.

Illustration 6-11, Table 12-3 and Table 12-4 shows the discharge over the Tyrolean weir with an angle of 20°. For the calculation it was assumed, that in a case of a flood just the water level rises but the velocity remains constant 1.35 m/s. This assumption must be made because of the lack of a Discharge – Water level

relation in the creek. This is a conservative way of calculation, because the rise of the discharge into the Tyrolean weir will drop with a higher velocity in case of a flood. This drop is significant by a greater discharge, because the velocity has a square impact on the base energy line.



Illustration 6-10 Rack bar of a Tyrolean weir (HZI, n. y.)

A Tyrolean weir with a width of the rack bar of 0.5 m cannot discharge completely the base flow of 0.08 m³/s, without a loss into the riverbed (compare Table 12-3). It is recommended and planned to use the whole base flow for discharging into the Tyrolean weir and later for the irrigation. However, the advantage lies in the flood discharge. The small racks do not intake more than 0.2 m³/s, in contrast to the large weirs, which can have an intake of up to 1.2 m³/s. A compromise between a good flood dynamic and a wide rack bar is the version of a 2 m rack bar and 1/3 rack porosity (1 cm gap between the bars with a diameter of 2 cm). A small rack porosity has the disadvantage of coating the rack bar with ice during winter, but offers a good protection of rocks and a smaller water intake during flood events. To avoid the problem of the freeze over the rack bar, the dimension of the distance between the single racks and the diameter can be changed, as long the ratio of 0.5 or 1/3 is the same as calculated.

6.3 SCENARIOS

In the following SWMM simulation, the impact of the discharge of the piping during a flood will be modelled. For the piping several alternative scenarios have been chosen.

Principally it can be distinguished between the position of the Tyrolean weir (at the Parshall flume or upstream) and the used diameter of the tube (0.3 or 0.4 m), furthermore about the maximum inflow (by a discharge of 7 m³/s during a storm event (compare 6.5.1 Precipitation)) of the Tyrolean weir, which depends on the dimensioning. The respective maximum discharges into the tube are:

1. **0.25 m³/s** (Width = 0.5 m, rack porosity = 0.5, length = 0.5 m),
2. **0.50 m³/s** (width = 2 m, rack porosity = 1/3, length = 0.5 m; and width = 1 m, rack porosity 0.5, length = 0.5 m)

3. **0.75 m³/s** (width = 2 m, Rack porosity = 0.5, length = 0.5 m)
4. **1.00 m³/s** (Width = 1m, Rack porosity = 0.5 m, length = 1m)

For different scenarios of the precipitation has been relinquish, because the available data is quite insecure and a proper climate model for the micro climate in this area does not exist, furthermore it is no flood risk management model, so the importance of the exact discharge data is quite low. Therefore, just the inconstant rain distribution (Illustration 4-4) was used, due its greater maximum precipitation. This event will cause a maximum discharge into the creek, and offers a worst-case scenario. Besides another scenario for the precipitation will not change to much of the outcome, due it would be the same 20-year storm event, just with an unrealistically approach without the rain distribtion and a smaller runoff peak.

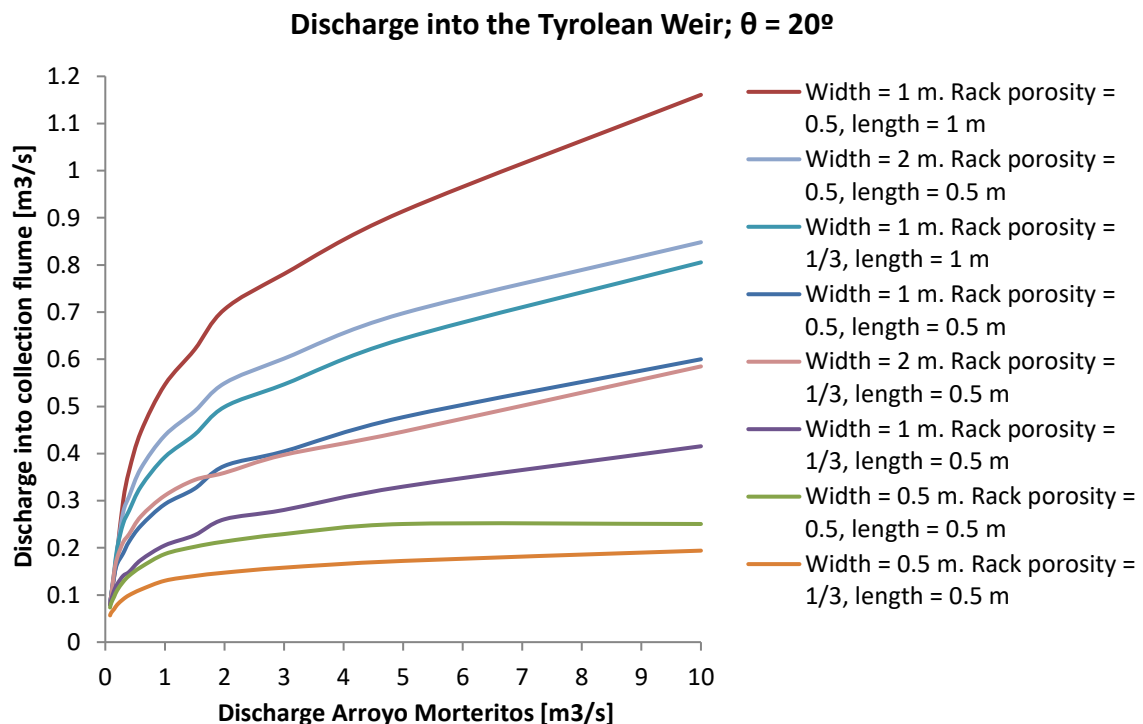


Illustration 6-11 Discharge of different designs of the Tyrolean weir

6.4 CALIBRATION OF THE MODEL

A calibration of the model with the help of the tracer test was not possible, because the length of the mediated distance was too short to simulate properly with a tracer, but the simulated velocities are similar to the measured velocities. The runoff data during a storm could not be verified, but the values seem to be realistic for mountainous area.

6.5 RESULTS OF THE MODEL

6.5.1 Precipitation

During the simulation of the distributed rainfall of a 20-year storm, a flash flood occurs. The three areas of precipitation have different runoff properties, depending of their average slope, their retention and their area. As expected, the run off from the biggest area causes the highest peak and the highest discharged volume, but occurs a few min later than the others. While the Area of Precipitation 2 causes a maximum discharge of 5 m³/s, the smaller areas discharge about 2 or 0.8 m³/s in their peak period. The period of discharge is different to the precipitation period; it occurs later (about 20 min) and lasts longer (up to 4 hours), depending on the properties of the area (Illustration 6-12).

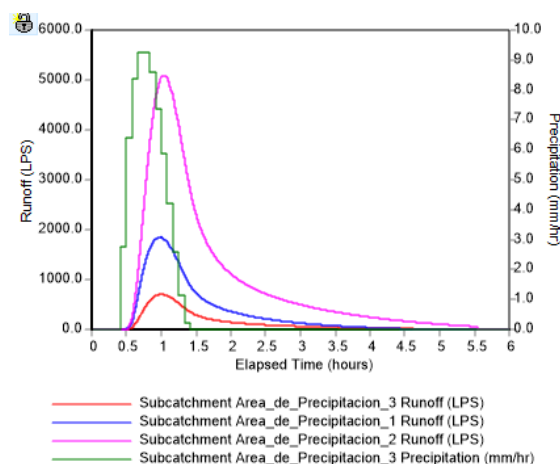


Illustration 6-12 Runoff the Areas of Precipitation

The flash flood has a peak about 7.3 m³/s. As it can be seen in Illustration 6-13, the flash flood reaches the weir after 25 min (Illustration 6-14), the peak 52 min (Illustration 6-15) after the beginning of the rain event. The decline of the flood needs much more time. After 11 hours the discharge has reached almost the base flow level again.

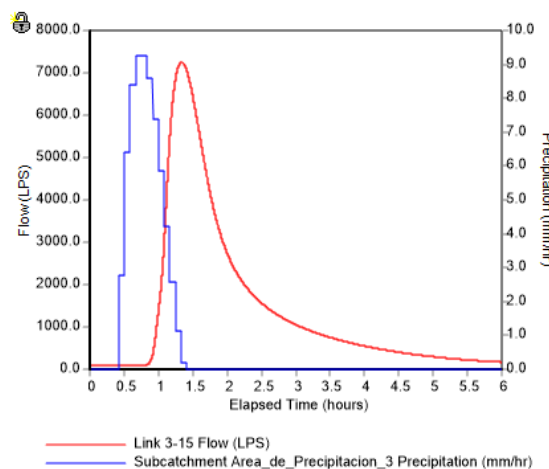


Illustration 6-13 Time course of the flash flood

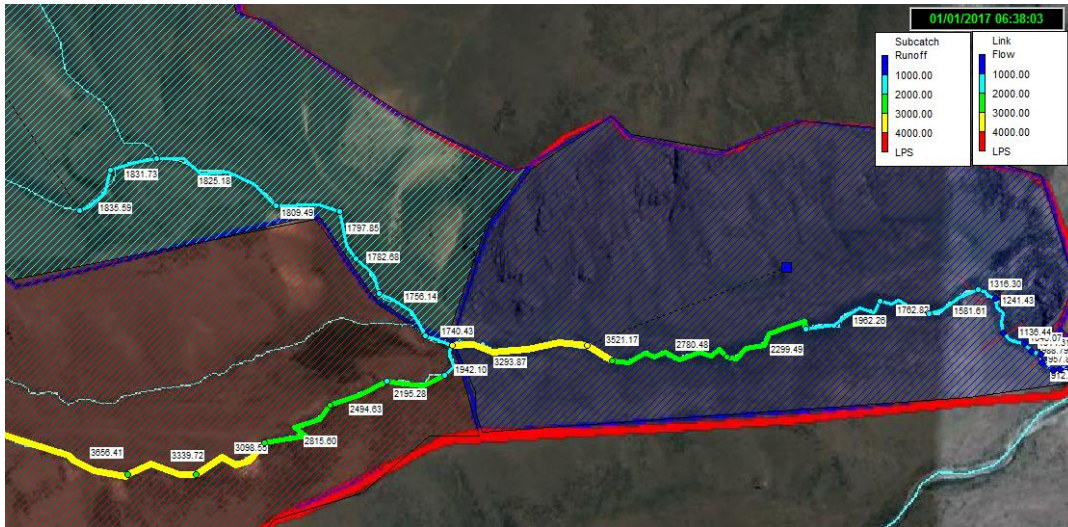


Illustration 6-14 Rising Runoff and Discharge of Arroyo Morteritos [L/s], Flood reaches weir after 25 min

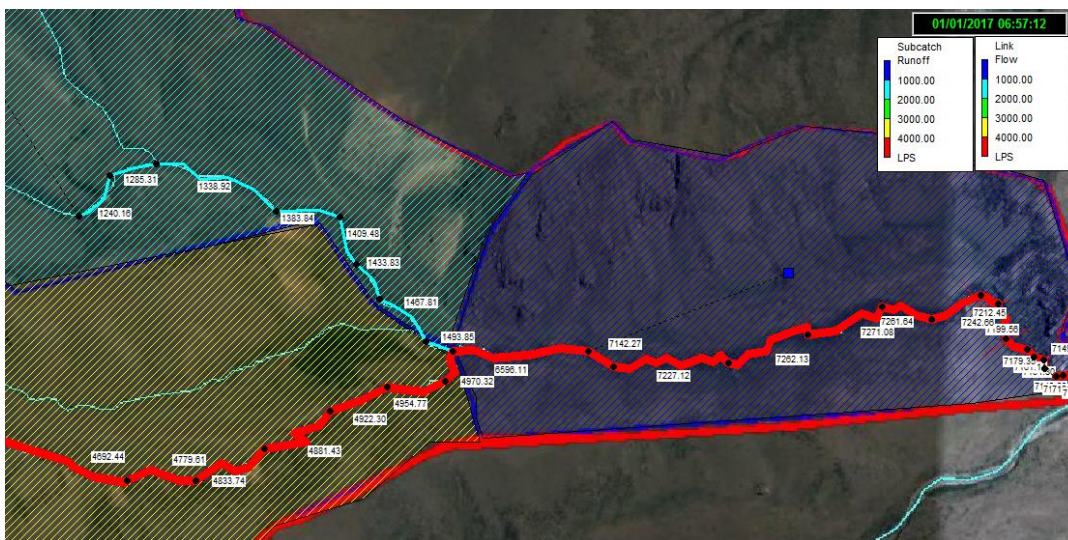


Illustration 6-15 Peak Runoff and Discharge of Arroyo Morteritos, Peak reaches weir after 52 min [L/s]

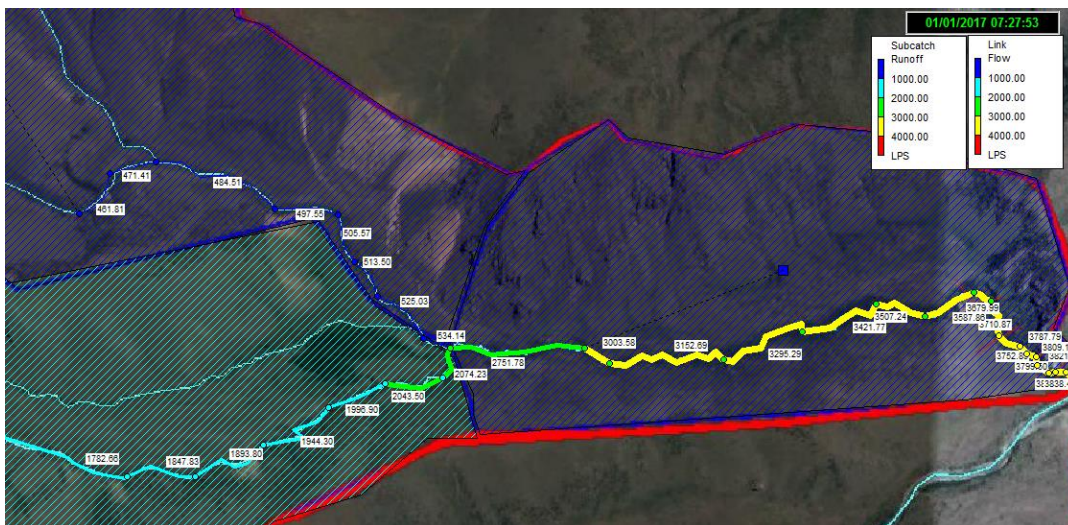


Illustration 6-16 Declining Runoff and Discharge of Arroyo Morteritos [L/s]



Illustration 6-17 Names for nodes of the tube

6.5.2 Discharge and Pressure in the Piping

The position of the single nodes can be taken out of Illustration 6-17. For the first scenario, where the piping begins upstream of the Parshall flume the first node with the tube is node 3 – 18; in the second scenario the first one is node 3. The difference is the slope of the first part of the piping, this result in different velocities and pressures in case of a change of the slope. Furthermore, the discharge in the tube can be influenced by backflow. As critical pressure, which is allowed in the tube 2 m are assumed. Pressure over this value will cause a total failure of the planned system.

6.5.2.1 Scenario: Diameter 0.3 m; Upstream Parshall flume

The scenario with a maximum discharge of 0.25 m³/s by a 0.3 m diameter, does not reach the maximum capacity of the tube (Illustration 6-18), therefore no part of the tube has a higher water level as the diameter (Illustration 6-19) and the calculated maximum capacity of

the Tyrolean weir can be discharged pressure free.

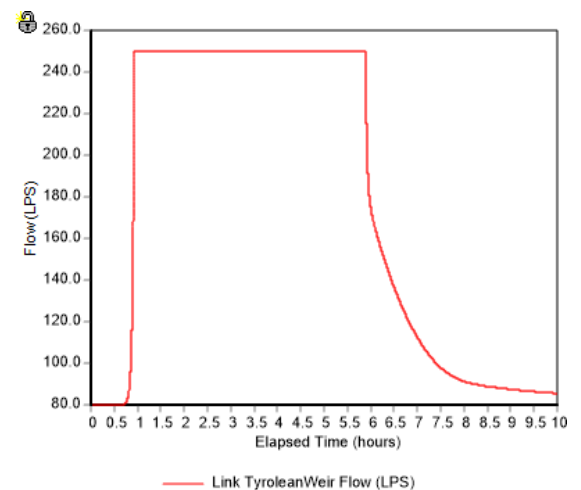


Illustration 6-18 Discharge into the tube; Scenario: Max. discharge: 0.25 m³/s; Upstream Parshall Flume, 0.3 m diameter

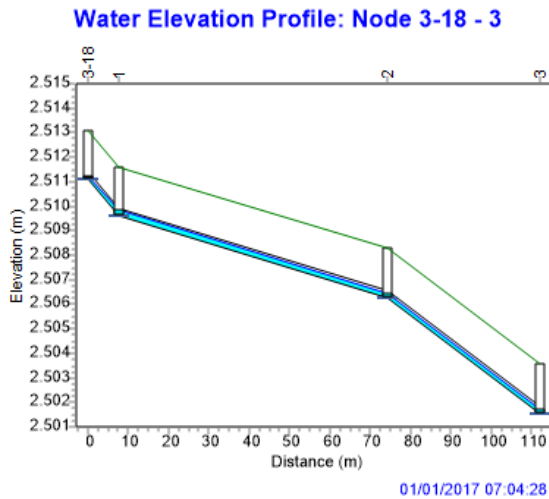


Illustration 6-19 Water level, Scenario: Max. discharge: 0.25 m³/s; Upstream Parshall Flume, 0.3 m diameter

The maximum discharge of 0.5 m³/s by a bigger dimensioning cannot be reached (Illustration 6-20), because the water level (or pressure in the tube) rises up to 2.5 m in the first part of the tube (Node 3-18), and 3.4 m in Node 1 (Illustration 6-21), this prevents a higher discharge than 0.371 m³/s by the tube. A high discharge of 0.35 m³/s exists, until the discharge of the Arroyo Morteritos falls and the pressure in the tube declines. Not until the water level in the tube declines, and a free discharge occurs, the discharge will drop significantly.

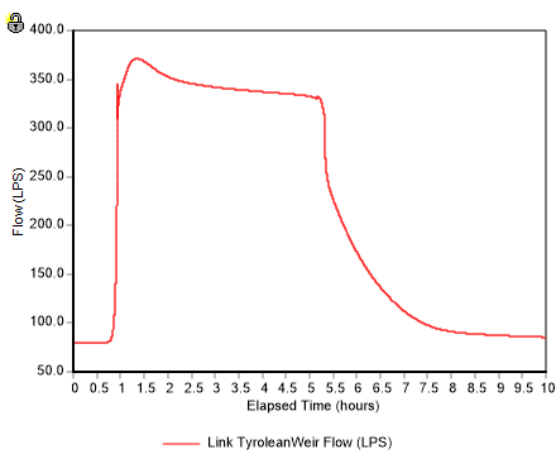


Illustration 6-20 Discharge into the tube; Scenario: Max. discharge: 0.5 m³/s; Upstream Parshall Flume, 0.3 m diameter

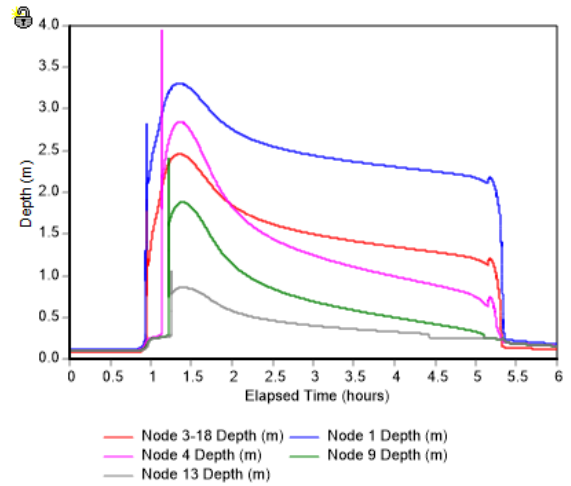


Illustration 6-21 Critical water level in the nodes; Scenario: max. discharge: 0.5 m³/s; Upstream Parshall flume, 0.3 m diameter

This scenario was not further examined because the maximum discharge of the tube was smaller than the capacity of the simulated Tyrolean weir, and the pressure in the tube was greater than the critical level of 2 m.

6.5.2.2 Scenario: Diameter: 0.4 m; Upstream Parshall flume

If a greater diameter is used, the results do not distinguish in the case of a maximum capacity of 0.25 m³/s (Illustration 6-22), over the total piping exists a free discharge.

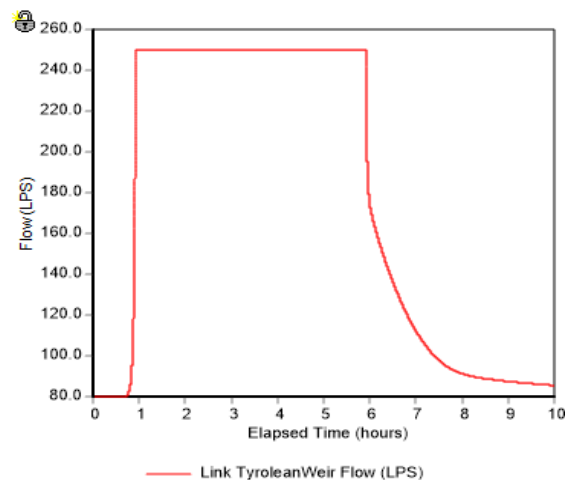


Illustration 6-22 Discharge into the tube; Scenario: Max. discharge: 0.25 m³/s; Upstream Parshall flume, 0.4 m diameter

A further capacity increment of 0.5 m³/s can be discharged completely without causing a pressured discharge in the tube (Illustration 6-23 and Illustration 6-24) The maximum water level of 0.25 m is in Node 1, which is smaller than the diameter of 0.4 m.

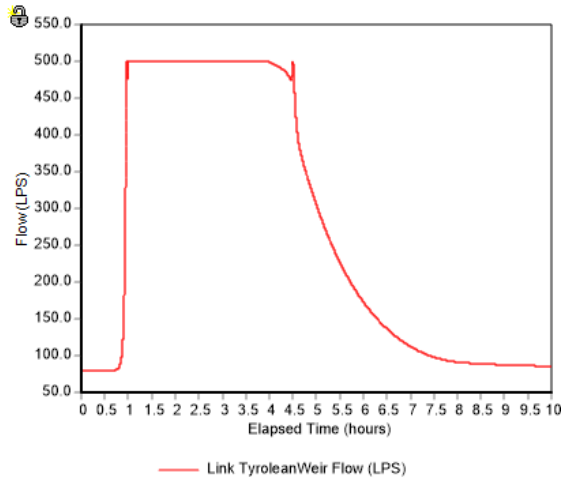


Illustration 6-23 Discharge into the tube; Scenario: Max. discharge: 0.5 m³/s; Upstream Parshall flume, 0.4 m diameter

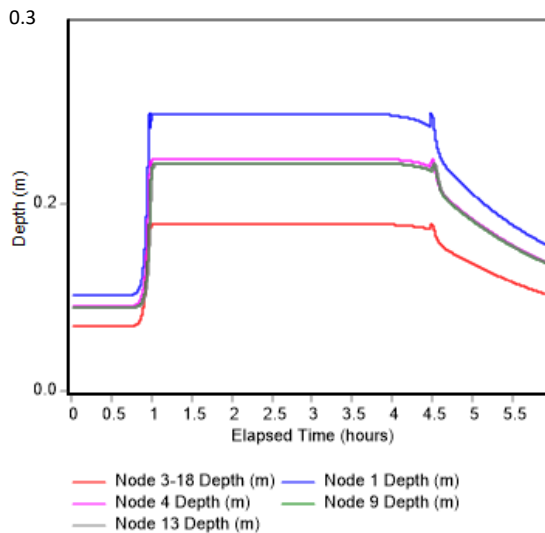


Illustration 6-24 Critical water level in the nodes; Scenario: max. discharge: 0.5 m³/s; Upstream Parshall Flume, 0.4 m diameter

The increment of the maximum inflow of the tube to 0.75 m³/s can be discharged completely (Illustration 6-25), in difference as before, the discharge is not completely free and in the nodes occur water level up to 2.5 m in Node 1

and directly behind the weir the water level is 1.75 m. During the discharge peak the pressure in the tube is almost constant. When the peak passed, the pressure in the tube falls slowly first, then fast when the discharge of the creek is equal to the maximum discharge of the tube.

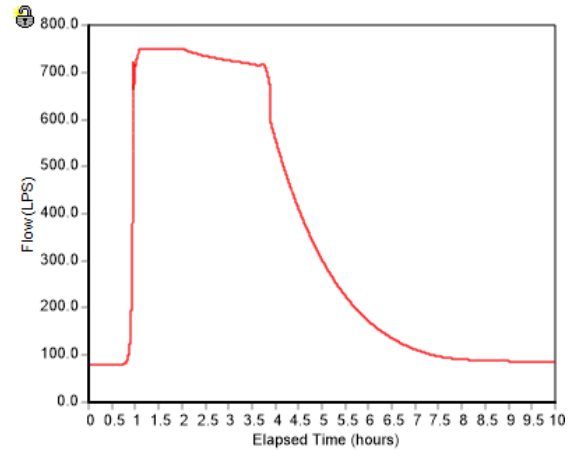


Illustration 6-25 Discharge into the tube; Scenario: Max. discharge: 0.75 m³/s; Upstream Parshall flume, 0.4 m diameter

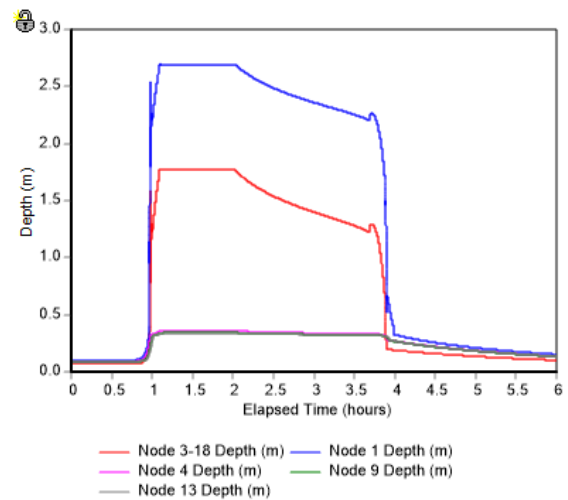


Illustration 6-26 waterlevel in the nodes; Scenario: max. discharge: 0.75 m³/s; Upstream Parshall Flume, 0.4 m diameter

The maximum capacity of 1.0 m³/s of the Tyrolean weir cannot be reached, because of the pressure and backflow in the tube; the maximum discharge is 0.792 m³/s (Illustration 6-27). This discharge causes a high pressure over the total length of the tube. Especially the

nodes 3-18, 1, 4, 9 and 13 have a water level of about 0.8 m to 3.25 m (Illustration 6-28). As it can be seen in the Illustration 6-29 the distance between node 3-18 and 2 the backflow limits the maximum discharge. This is caused by the change of the slope between both nodes. In this part the velocity is not sufficient to drain out.

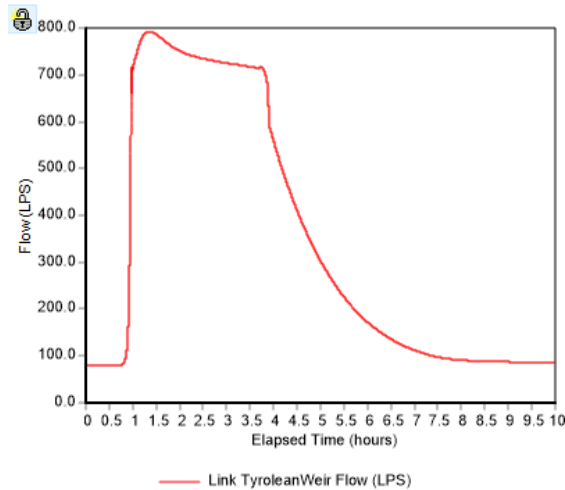


Illustration 6-27 Discharge into the tube; Scenario: Max. discharge: 1.00 m³/s; Upstream Parshall flume, 0.4 m diameter

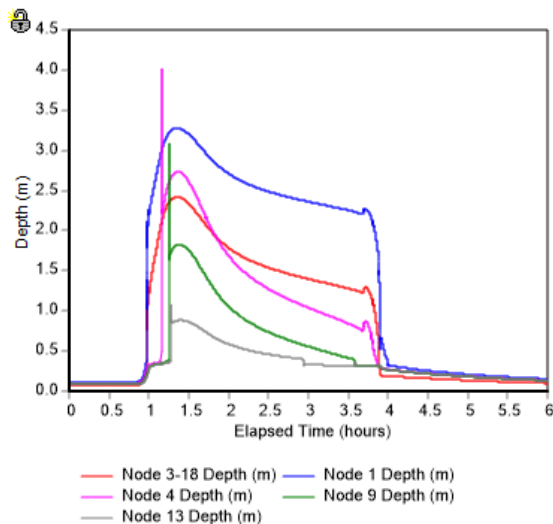


Illustration 6-28 water level in the nodes; Scenario: max. discharge: 1 m³/s; Upstream Parshall flume, 0.4 m diameter

Water Elevation Profile: Node 3-18 - 3

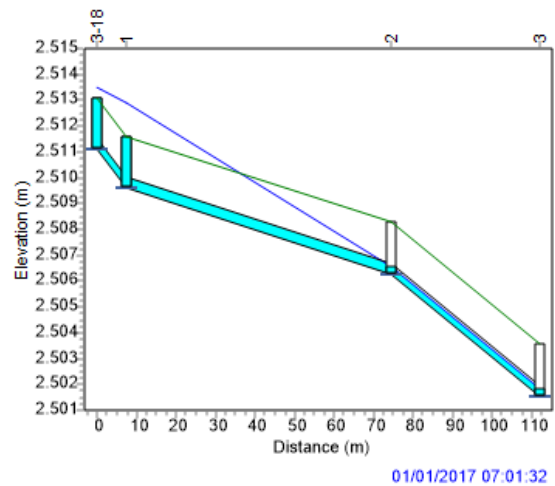


Illustration 6-29 Water Elevation profile, max. discharge: 1 m³/s Upstream Parshall flume, 0.4 m diameter

6.5.2.3 Diameter 0.3 m; At the Parshall flume

With a diameter of 0.3 m a discharge up to 0.25 m³/s works at this position without any problems. In every point of the tube there is a (pressure) free discharge possible.

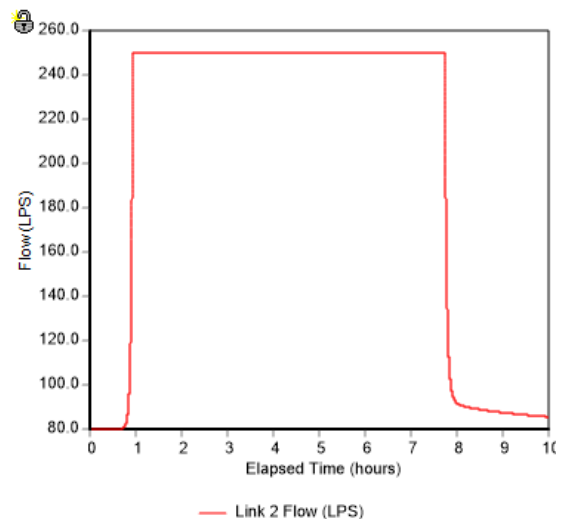


Illustration 6-30 Discharge into the tube; Scenario: Max. discharge: 0.25 m³/s; at the Parshall flume, 0.3 m diameter

With an augmentation of the capacity of the Tyrolean weir up to 0.5 m³/s, a free discharge is not possible anymore (Illustration 6-32). In every point of the tube is a pressure about

2 – 5 m, by a maximum discharge of 0.39 m³/s (Illustration 6-31). A further investigation of this scenario will not be continued, because a capacity augmentation of the Tyrolean weir will further increase the pressure in the tube, with just a small benefit of the discharge.

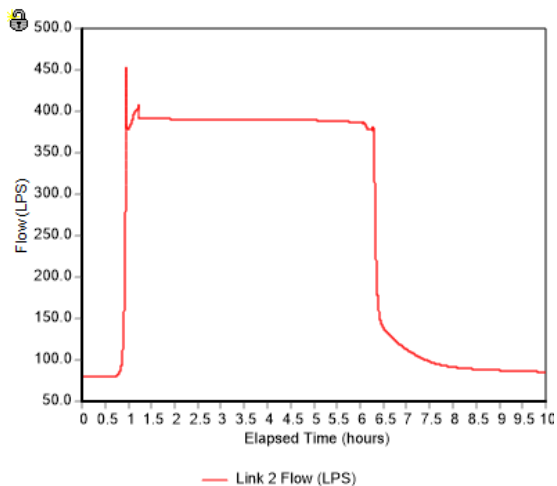


Illustration 6-31 Discharge into the tube; Scenario: Max. discharge: 0.50 m³/s; downstream Parshall flume, 0.3 m diameter

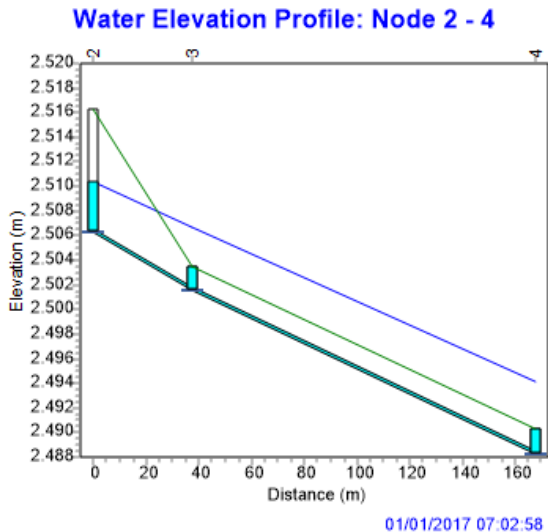


Illustration 6-32 Water Elevation profile, max. discharge: 0.5 m³/s at the Parshall flume, 0.3 m diameter

6.5.2.4 Diameter 0.4 m; At the Parshall flume

A diameter of 0.4 m can discharge 0.25 m³/s without any problems (Illustration 6-33). The water level in the tube is smaller than the

diameter, therefore the discharge is free.

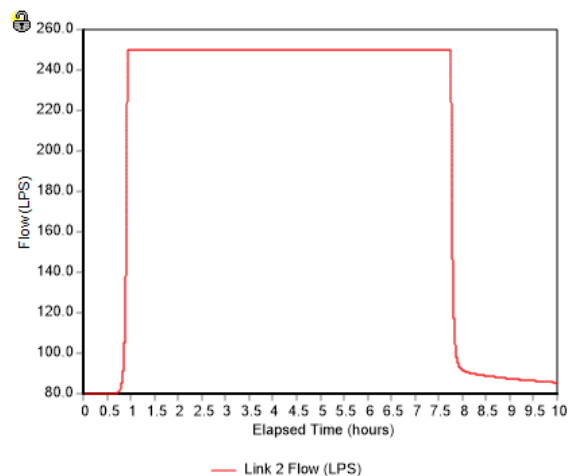


Illustration 6-33 Discharge into the tube; Scenario: Max. discharge: 0.250 m³/s; at the Parshall flume, 0.4 m diameter

An increment of the capacity up to 0.5 m³/s causes no back flow as well and the tube can drain it completely (Illustration 6-34).

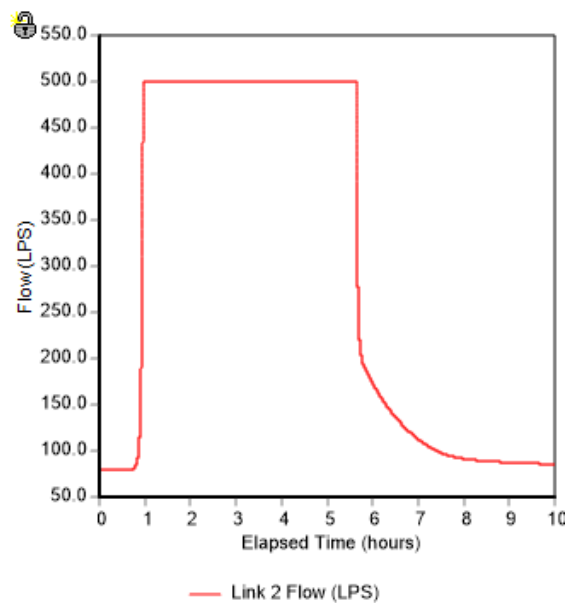


Illustration 6-34 Discharge into the tube; Scenario: Max. discharge: 0.50 m³/s; downstream Parshall flume, 0.4 m diameter

The tube with a diameter of 0.4 m can drain a discharge of 0.75 m³/s too without causing a backflow and pressure in the tube (Illustration 6-35). The water level in the tube is maximum at 0.34 m.

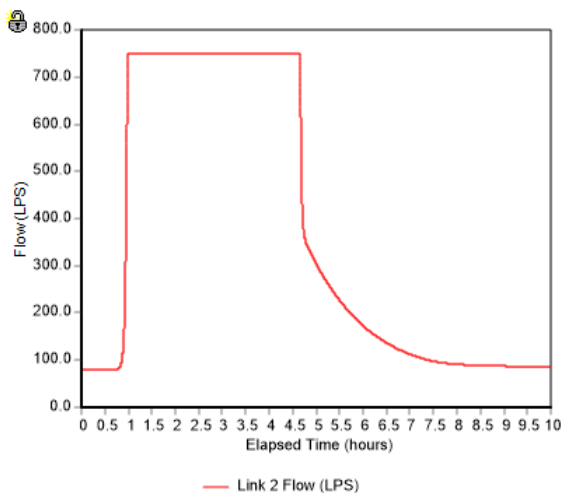


Illustration 6-35 Discharge into the tube; Scenario: Max. discharge: 0.750 m³/s; at the Parshall flume, 0.4 m diameter

A further increment of the Tyrolean weir cannot be discharged completely by the tube. The maximum capacity of the tube is about 0.85 m³/s (Illustration 6-35). This discharge in the tube causes high pressure from two, up to 5 m over the total length of the tube (Illustration 6-37).

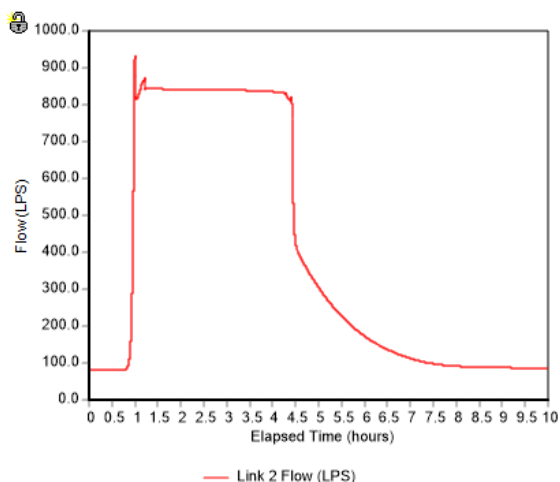


Illustration 6-36 Discharge into the tube; Scenario: Max. discharge: 1.00 m³/s; downstream Parshall flume, 0.4 m diameter

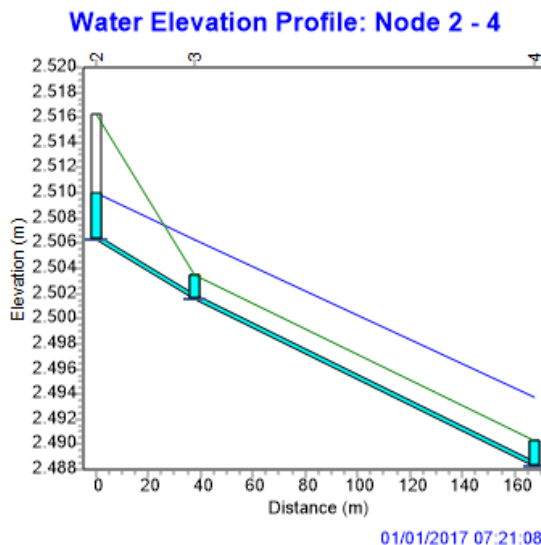


Illustration 6-37 Water Elevation profile, max. discharge: 1 m³/s, Downstream Parshall flume, 0.4 m diameter

7 DISCUSSION AND SUGGESTIONS

7.1 MEDIATION

The results of the discharge mediation are good. Especially the tracer test is an easy and fast experiment to get an overview about the discharge of the Arroyo Morteritos. For future projects it is recommended to prepare one or two of the tracer tests, each time the engineers/inspectors go to the future construction. By several visits it is easy to get different discharges over the year for a proper calculation of the base flow. In the case of the done mediation it can be assumed the “maximum” medium discharge was almost mediated, because in the mountains all snow was already melted, except a small snow cover from the night. Therefore, the base flow of the model was set to 0.08 m³/s instead of the average flow of 0.077 m³/s.

7.2 MODEL

A general problem of the model is, that the dynamic of the Tyrolean weir cannot be simulated directly. The assumption of a direct discharge of the water into the weir is not realistic, the head loss cannot be calculated or assumed. The opening of the weir is at the backside of the weir, this means the flow velocity there during a flood event is greater and the draining into the tube is smaller than simulated. In this model there is just a constant capacity limit, independent of the water level over the weir and the velocity. Therefore, the volume of the discharge into the weir during the flood event is in the simulation greater and could not be considered.

7.3 TYROLEAN WEIR

The small Tyrolean weirs (width = 2 m, rack porosity = 1/3, length = 0.5 m; and width = 1 m, rack porosity 0.5, length = 0.5 m) have the advantage of a controlled discharge during flood events, with a maximum capacity of 0.25 m³/s, during a 7 m³/s flood. No backflow and therefore no pressure in the tube will occur, because of the limited increment of the discharge curve (Illustration 6-11). But the small opening of the rack can hardly intake the complete base flow of 0.08 m³/s. This could cause problems with the filling of the reservoir for the irrigation during the summer. It can be assumed that this dimensioning can resist even greater flood events, because the respective curves (Illustration 6-11) reached already their maximum, furthermore it is assumed, that the whole flood discharges over the rack bar, but in case of the small dimensioning the weir will be just partly covered by the rack bar. The rest of the weir will be concrete and works as a normal weir (Illustration 12-2, right). This lowers the impact on the Tyrolean weir significantly.

A greater maximum capacity for a 0.3 m diameter tube should not be considered, if the Tyrolean weir is constructed upstream, because the pressure in the tube is about 2 m and could cause a total failure.

The usage of a 0.4 m tube allows in both cases a maximum capacity of 0.5 m³/s, without a pressured flow into the tube and with a full intake of the baseflow for a good and secure filling of the reservoir. If the Tyrolean weir is situated at the Parshall flume, the capacity 0.75 m³/s can be drained too, but probably this will cause problems in the reservoir behind the tube, furthermore it is not necessary to intake 0.75 m³/s, or even 1 m³/s during a flood. Therefore, it cannot be suggested to construct a Tyrolean weir with a greater capacity of 0.5 m³/s. These great values have been calculated, because the actual plan is to construct the rack bar over the total length of the weir, this cannot be suggested, as long as no other pressure reduction plants are constructed, which are not necessary if a smaller rack bar is used.

A usage of a 0.4 m diameter tube allows in general high discharges within the tube, without causing a pressured flow. This augmented discharge must be diverted into the Arroyo Alumbre, because the reservoir at the end of the tube cannot intake too much water in the same time. The best place is directly behind the weir, to prevent damages of the tube, maybe by an overflow of a side weir. Useful examples can be seen Illustration 7-1 and Illustration 7-2. The first Rain discharge in the Illustrations has the disadvantage just to work, if pressured flow appears, the remaining flow could be too high for the reservoir too.

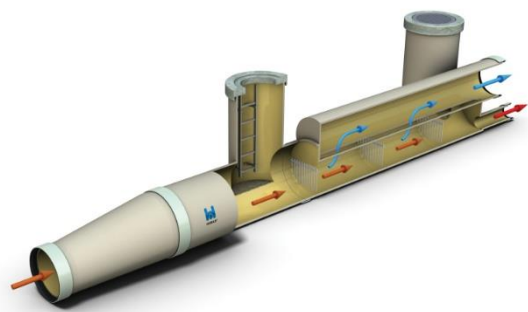


Illustration 7-1 Rain flow over flow tube (Haux & Rohre, 2016)

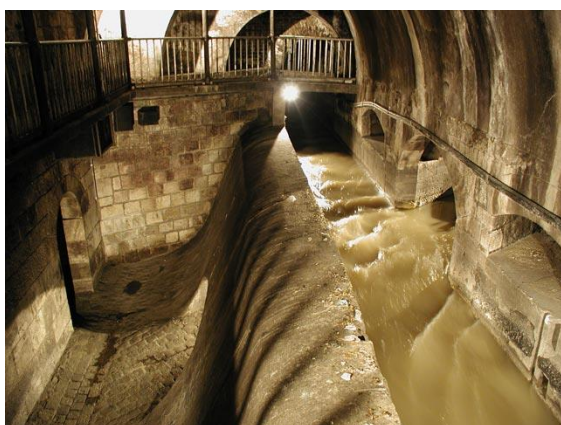


Illustration 7-2 Rain flow overflow weir in a canalisation (Stadt Wien, n. y.)

Table 7-1 Suggestions for the construction

Position	Diameter [m]	Discharge [m ³ /s]	Pressured flow	Suggested
Upstream Parshall Flume	0.3	0.25	×	✓
		0.5	✓	×
	0.4	0.25	×	✓
		0.5	×	✓
		0.75	✓	×
		1	✓	×
At the Parshall flume	0.3	0.25	×	✓
		0.5	✓	×
	0.4	0.25	×	✓
		0.5	×	✓
		0.75	×	×
		1	✓	×

It can be concluded (compare Table 7-1), that a higher capacity than 0.5 m³/s it is not useful but with a diameter of 0.4 m there won't be any troubles to drain this flow independently from

the position of the weir. In case of a flood is the small weir is better, with a 0.4 m diameter tube, and a dimensioning of a width of 2 m, rack porosity of 1/3, length of 0.5 m or 1 m width, 0.5 rack porosity and a length of 0.5 m, because of a small maximum capacity and for security if the weir has a higher capacity than expected. However, the advantages about the construction at the Parshall flume are of other kinds:

Advantages:

- + Floods can be discharged directly into the Arroyo Alumbre
 - ➔ The piping after the weir is better protected, due the earth embarkment
 - ➔ Better hydraulic conditions for the discharge
- + The slope is smaller; therefore, the velocity in the tube is inferior
- + Easier access to the (construction) site
- + Less tubes are needed
- + The place is more exposed to the sun, which helps the snow melting in the spring
- + More space in general for the construction, weir and the tubes

Disadvantages:

- Probably more concrete is needed for the inclined array, and the elevation drop between Arroyo Morteritos and Alumbre
- The earth deposit must be protected from erosion
- A curve for the river bed must be constructed to discharge the flood

- It must be avoided, that the Arroyo Alumbre causes a backflow and floods the weir

Probably a plunge basin must be constructed, because of the high elevation drop between the Arroyo Morteritos and Alumbre.

Furthermore, it can be suggested to construct a sedimentation basin in front of the existing reservoir. This will keep the basin clean, reduces the time of cleaning (because of the smaller area), and the basin must not be drained completely, as well the basin can be filled during the cleaning operation, if a bypass is used. The sedimentation basin should not be constructed behind the Tyrolean weir, the velocity should be sufficient to transport the sand and small gravel downstream. The construction downstream, in front of the reservoir has several reasons: first downstream is an easier access to clean the basin. Second and the most important, if additional water of the Arroyo Alumbre in for the irrigation is used, it can be freed of particles, too. For calculating the length and width of the sedimentation basin, the model must be expanded by the part between the end of the planned tube up to the reservoir by adding a link with the corresponding slope of the existing tube. The calculated velocity from the simulation can be used for the dimensioning with the law of Stokes for a sedimentation basin. An example for a sedimentation basin after a Tyrolean weir in a mountainous area can be seen in Illustration 7-3 and Illustration 7-4. To shorten the length of the basin, a lamella separator could be used, but it is probably not necessary.



Illustration 7-3 Sedimentation basin for a Tyrolean weir in the mountains (HZI, n. y.)



Illustration 7-4 Construction of a sedimentation basin in the mountains (HZI, n. y.)

8 SUMMARY AND CONCLUSION

Arroyo Morteritos shall be intubated for the irrigation of Las Vegas. For this purpose, a Tyrolean weir will be constructed. The measured medium discharge by several tracer tests is $0.077 \text{ m}^3/\text{s}$. For calculating the impact of a 20-year storm in the region of the planned piping a SWMM Model was created. The maximum discharge of this storm is $7.3 \text{ m}^3/\text{s}$. Several dimensions for the Tyrolean weir have been calculated, the best dimensions are with a small rack bar, instead a rack bar over the whole weir. This allows a good flood discharge. Furthermore, the Tyrolean weir should be constructed at the same position, where the Parshall flume was situated during the mediation, inclined to protect the tube and to discharge

future flood events. The tube should be covered with the earth embankment, which divides both creeks.

The mediation of the base flow of creeks is important for dimensioning the tube and the Tyrolean weir. Such mediation is done in less than 30 min and offers a good overview of a discharge of a creek. If the mediation is done regularly, a discharge contribution during a year can be made easily. The usage of a Parshall flume is quite good for getting an overview of the discharge and offers the opportunity to mediate it, without any preparation before.

The Tyrolean weir should be constructed with a maximum capacity of $0.25 - 0.5 \text{ m}^3/\text{s}$, by a 0.4 m diameter of the tube. The rack bar should not cover the whole weir. For an easier access for the construction, and better flood discharge the Tyrolean weir should be placed where the Parshall flume was situated.

In general, the Department of Irrigation should start to mediate their discharges into the flumes, and their usage for the agriculture. Furthermore, the water loss by transpiration and broken flumes should be minimized, to minimize the water usage. The lack of the knowledge where, how much water is used is fatal for the future. Especially in Mendoza where a great part of the agriculture relies on irrigation. Furthermore, advanced irrigation systems should be supported, and the water usage paid by cubic meter, and not by surface area of the used land. This would enhance the will to construct a more developed irrigation. If the stream flow in the flume is known, an automation of the water distribution, depending of the crop (and their water usage) can be planned. This could prevent the salinization of the high aquifer in Mendoza. During my internship at the Department of Irrigation, I was able to learn how to dimension a weir, and what

must be considered during construction. I was able to intensify my knowledge in SWMM, and in freelance work. Thanks, my colleagues I was able to visit many new and done constructions of the irrigation system in Mendoza and Uspalata, which helped me a lot to understand the importance of the distribution of the water, more important, it showed me the problems which occur in Mendoza. Especially the field work, like levelling off with my colleges helped me to intensify my knowledge, which culminated in the three-day measuring camp. The work in the office offered me to train my CAD – skills, for drawing and sketching for the project. In total, I was able to learn quite a lot, especially considered just a small part of my work is represented in this report. During my stay in the Department of Irrigation and at the UN-Cuyo I was able to improve my subject-specific vocabulary in Spanish.

9 OUTLOOK

For the future it should be considered to add a snow model to this calculation, because the base flow is probably highly dependent of the snow zone. This is even more important for a proper use of the water, especially since the climate change will influence the snowfall and melting in the region. With a (general) snow model for each year the water distribution can be better planned for the rest of the year. The investigation area fits quite well for a research of a model. It is a small area, with a high difference in altitude, and easy access. Furthermore, it is an open valley with a spread west – east, so a long sunshine time is secured, which is important for the developing of the air temperature and snowmelt. With the piping it is easy to install measurement units for constant stream mediation. With the constructed weir, and a constantly observed water level gauge even

flood events can be measured quite easy. If one or two weather control station are installed even better results can be made. Best way would be a weather station at the actual parking station, and another in a higher altitude for measuring the snowfall and precipitation. Naturally these results cannot be completely transferred to other valleys, but with the help of these data the developing of the discharge depending of the snow over a year can be assumed, and maybe it can be used for forecasting the future in a climate model. These measurements of the pilot project can be done with the help of the universities in Mendoza, and the climate network in Argentina.

10 ACKNOWLEDGE- MENT

A special credit goes to these persons, who made the time in Argentina possible, first, of course my parents, but also the DAAD, Prof. Gräber of the TU Dresden and Prof. Cantú of the UNCUYO Mendoza.

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And at last, my colleagues in the Department General of Irrigation, I made wonderful experiences with you, and thanks for taking care of me, and supporting my idea of measuring campaign and preparing a simulation for this area. I learned quite much during my time with you, and I really enjoyed every day at work and with an *asado*. Thanks, of all the field trips we made I understand now how the irrigation, the veins and the blood of Mendoza is working. I hope I could teach you at least a bit about modelling and the sense of it, you teached me quite a lot, and not just subject specific topics, even more – how important are good colleagues.

Thank you. I really had a good time with you.



Illustration 10-1 Thank you for carrying for me!
(„¿Are you alive?“)

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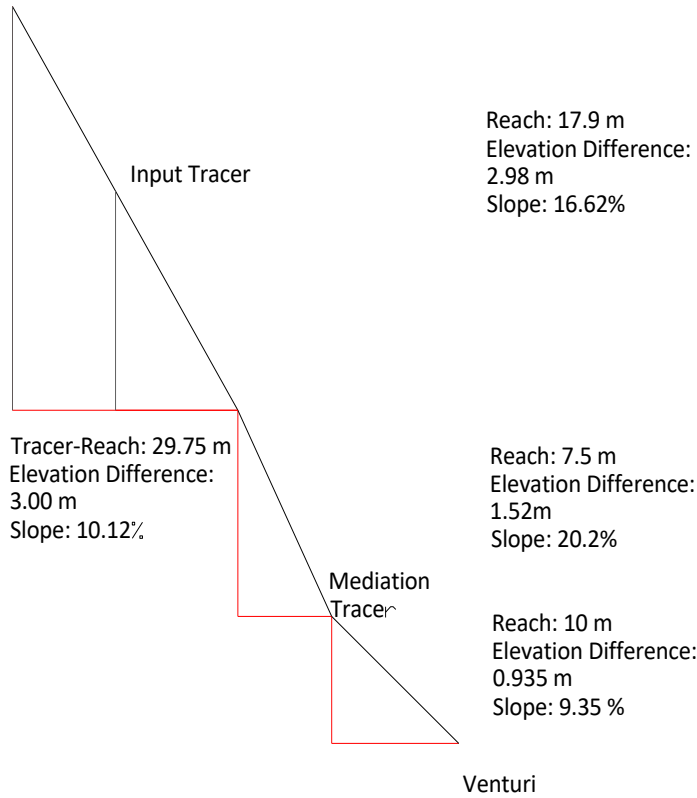
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12 APPENDIX

Table 12-1 Salt and Water demand in function of the estimated discharge (Okunishi, et al., 1992)

Estimated discharge [l/s]	Demand of Salt [kg]	Water Solution [L]
50	0.25	1
100	0.5	1.5
150	0.75	2.5
200	1	3
300	1.25	4
400	1.75	5
500	2	6
600	2.25	7
700	2.75	8
800	3	9
900	3.25	10



Input Tracer

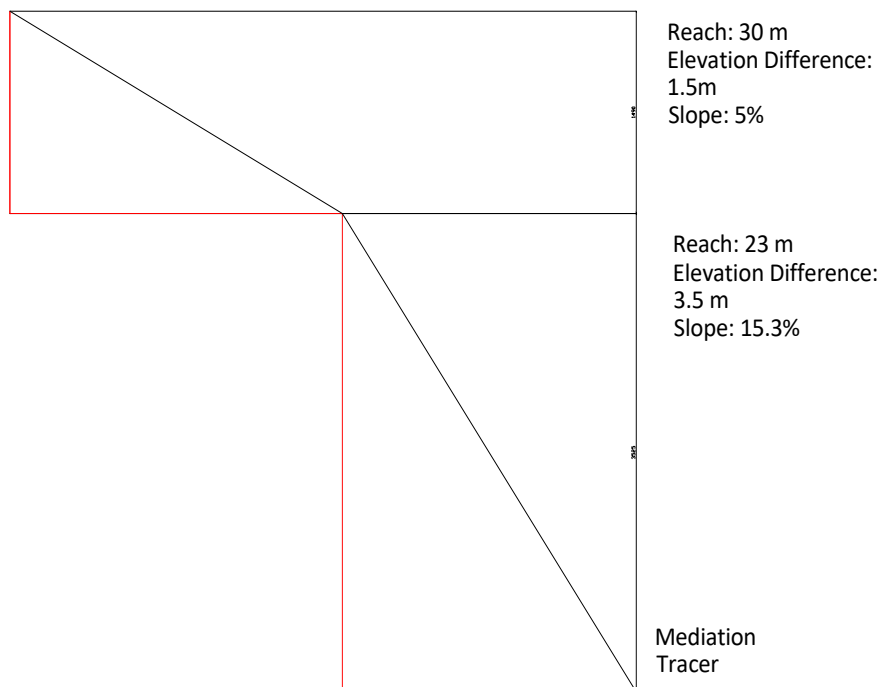


Illustration 12-1 Slope of the route for the tracer test, a top: in front of the Parshall flume (27.9 m), below: behind Parshall flume

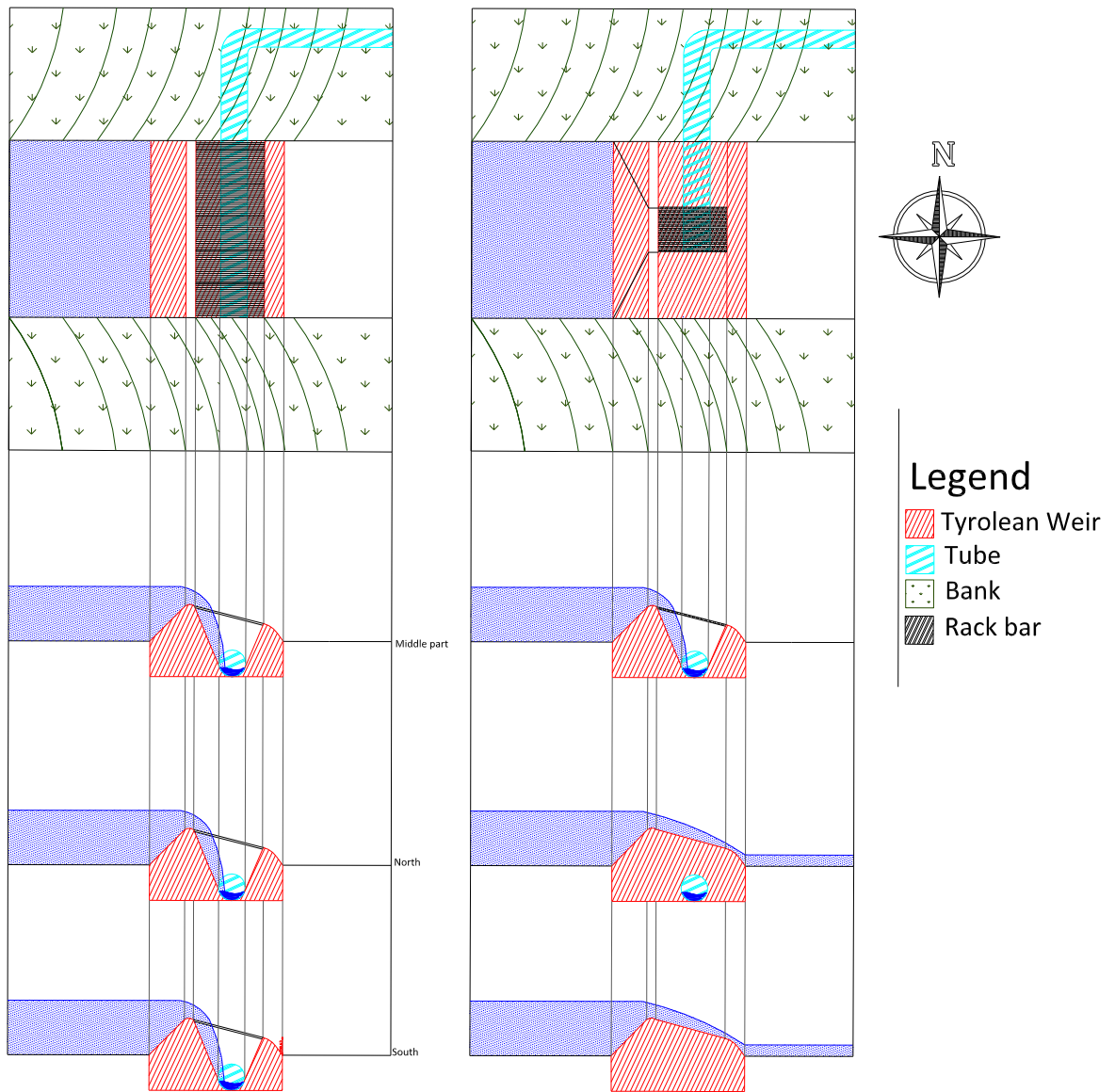
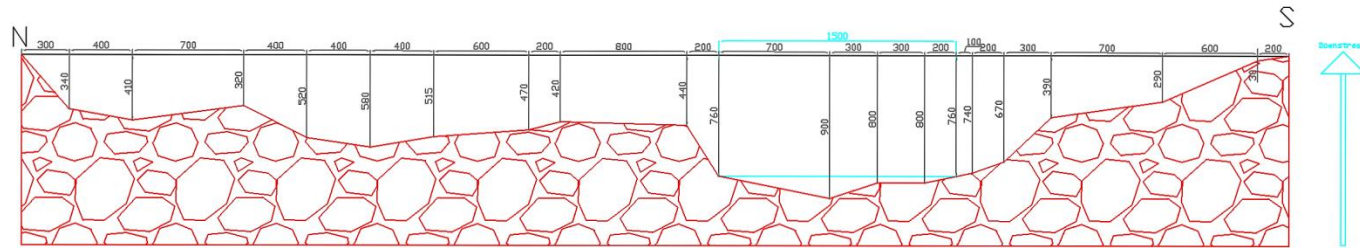


Illustration 12-2 Sketches of the Tyrolean weir, left: the rack bar is covers the whole weir, right: the rack bar covers partially the weir

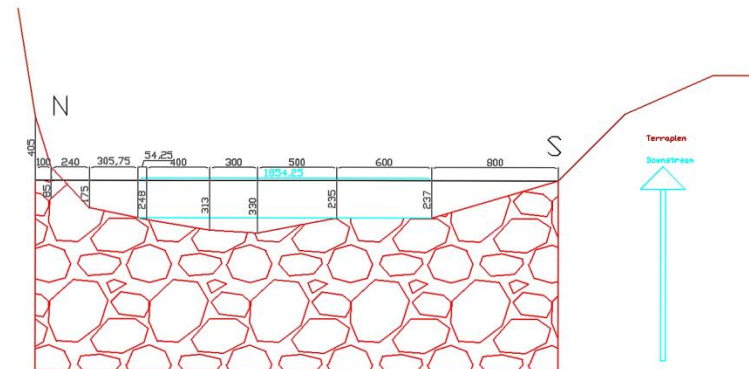
01



02



Input Tracer



03



Mediation Tracer

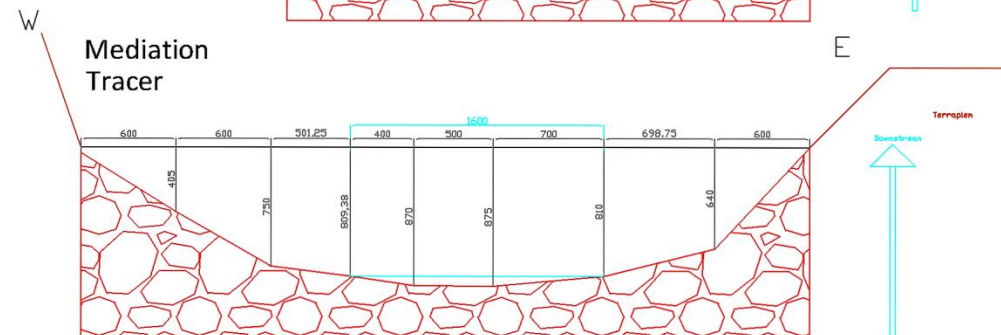


Illustration 12-3 Cross sections of the Arroyo Morteritos, 1) At the planned weir, above the Parshall flume Tracer Input, 2) Tracer input behind the Parshall flume, tracer mediation behind th çe Parshal flume

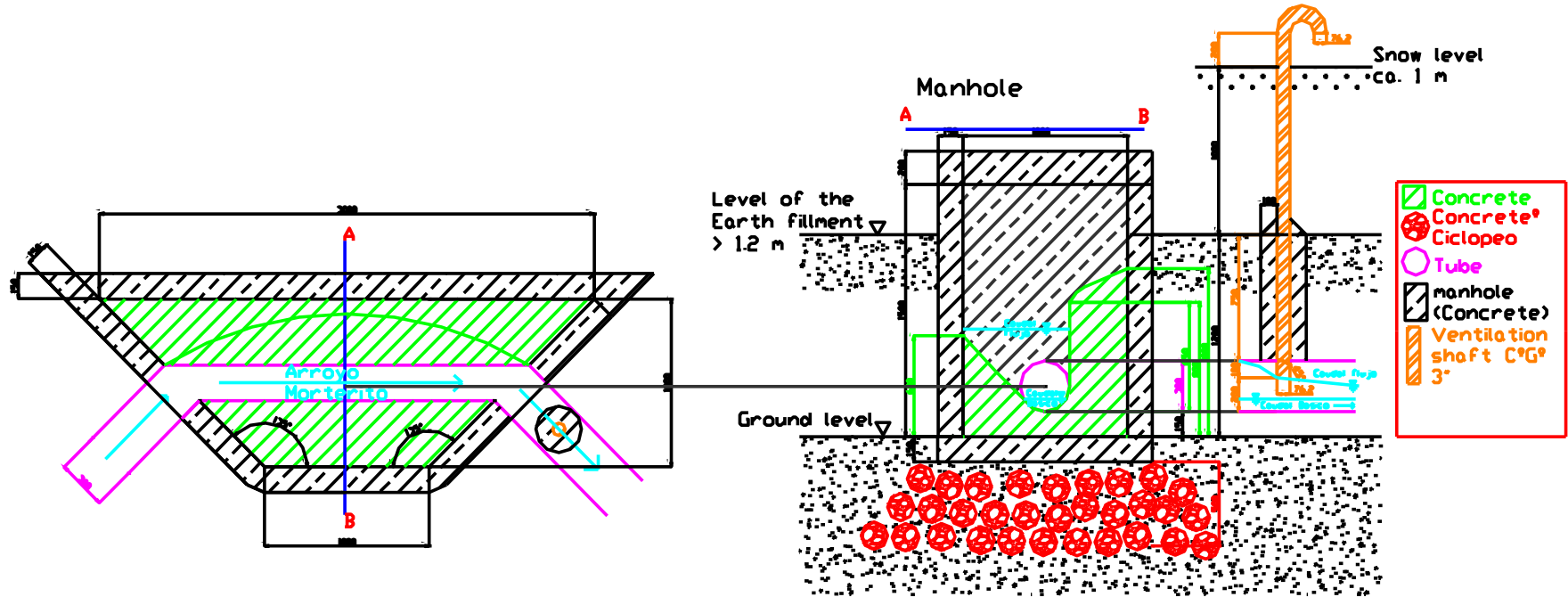


Illustration 12-4 Manhole for the Tube (0.3 m diameter)

Table 12-2 Technical Design of the Tyrolean weir, with the needed length for not discharging any water into the Creek

Tyrolean Weir				
Width = 1 m. Rack porosity = 0.5				
Discharge	0.08	0.1	0.15	0.2 m ³ /s
Length	0.47	0.47	0.6	0.7 m
Area Rack	0.235	0.235	0.3	0.35 m ²
Width = 0.75 m; Rack porosity = 0.5				
Discharge	0.08	0.1	0.15	0.2 m ³ /s
Length	0.5	0.64	0.7	0.87 m
Area Rack	0.1875	0.24	0.2625	0.32625 m ²
Width = 0.5 m; Rack porosity = 0.5				
Discharge	0.08	0.1	0.15	0.2 m ³ /s
Length	0.59	0.7	0.96	1.17 m
Area Rack	0.1475	0.175	0.24	0.2925 m ²
Width = 1 m. Rack porosity = 1/3				
Discharge	0.08	0.1	0.15	0.2 m ³ /s
Length	0.52	0.55	0.75	1 m
Area Rack	0.35	0.37	0.50	0.67 m ²
Width = 0.75 m; Rack porosity = 1/3				
Discharge	0.08	0.1	0.15	0.2 m ³ /s
Length	0.63	0.74	0.7	1.23 m
Area Rack	0.315	0.37	0.35	0.615 m ²
Width = 0.5 m; Rack porosity = 1/3				
Discharge	0.08	0.1	0.15	0.2 m ³ /s
Length	0.84	0.99	1.35	1.66 m
Area Rack	0.28	0.33	0.45	0.55 m ²

Table 12-3 (1) Discharge [m³/s] of Tyrolean weirs with different dimensions, Angle: 20°

Discharge Arroyo Morteritos	Width = 1 m. Rack porosity = 0.5, length = 0.5 m			Width = 1 m. Rack porosity = 0.5, length = 1 m			Width = 0.5 m. Rack porosity = 0.5, length = 0.5 m			Width = 1 m. Rack porosity = 1/3, length = 0.5 m			Width = 1 m. Rack porosity = 1/3, length = 1 m			Width = 0.5 m. Rack porosity = 1/3, length = 0.5 m		
	into the collection flume	passes towards downstream	water level	into the collection flume	passes towards downstream	water level	into the collection flume	passes towards downstream	water level	into the collection flume	passes towards downstream	water level	into the collection flume	passes towards downstream	water level	into the collection flume	passes towards downstream	water level
0.08	0.08	0.00	0.15	0.08	0.00	0.15	0.07	0.01	0.15	0.08	0.00	0.15	0.08	0.00	0.15	0.06	0.02	0.15
0.10	0.10	0.00	0.15	0.10	0.00	0.15	0.08	0.02	0.15	0.09	0.01	0.15	0.10	0.00	0.15	0.06	0.04	0.15
0.15	0.14	0.01	0.15	0.14	0.01	0.15	0.10	0.05	0.30	0.11	0.04	0.15	0.15	0.00	0.15	0.07	0.08	0.30
0.20	0.17	0.03	0.20	0.19	0.01	0.20	0.11	0.09	0.30	0.12	0.08	0.20	0.20	0.00	0.20	0.08	0.12	0.30
0.30	0.19	0.11	0.30	0.30	0.00	0.30	0.13	0.17	0.40	0.14	0.16	0.30	0.25	0.05	0.30	0.09	0.21	0.40
0.40	0.21	0.19	0.50	0.36	0.04	0.50	0.14	0.26	0.50	0.15	0.25	0.50	0.28	0.12	0.50	0.10	0.30	0.50
0.60	0.25	0.35	0.50	0.45	0.15	0.50	0.16	0.44	0.70	0.17	0.42	0.50	0.33	0.27	0.50	0.11	0.49	0.70
1.00	0.29	0.71	0.70	0.55	0.45	0.70	0.19	0.81	1.00	0.21	0.79	0.70	0.39	0.61	0.70	0.13	1.74	1.00
1.50	0.33	1.17	1.00	0.62	0.88	1.00	0.20	1.30	1.50	0.23	1.27	1.00	0.44	1.06	1.00	0.14	1.36	1.50
2.00	0.37	1.63	1.00	0.71	1.29	1.00	0.21	1.79	2.00	0.26	1.74	1.00	0.50	1.50	1.00	0.15	1.85	2.00
3.00	0.40	2.60	1.50	0.78	2.22	1.50	0.23	2.77	3.00	0.28	2.72	1.50	0.55	2.45	1.50	0.16	2.84	3.00
5.00	0.48	4.52	2.00	0.91	4.08	2.00	0.25	4.75	5.00	0.33	4.67	2.00	0.64	4.36	2.00	0.17	4.83	5.00
10.00	0.60	9.40	3.00	1.16	8.84	3.00	0.25	4.75	5.00	0.42	9.58	3.00	0.81	9.20	3.00	0.19	9.81	10.00

Table 12-4 (2) Discharge [m^3/s] of Tyrolean weirs with different dimensions, Angle: 20°

Discharge	Width = 2 m. Rack porosity = 0.5, length = 0.5 m			Width = 2 m. Rack porosity = 1/3, length = 0.5 m		
	Total diverted discharge into the collection flume	Total discharge that passes towards downstream	water level	Total diverted discharge into the collection flume	Total discharge that passes towards downstream	water level
0.08	0.08	0.00	0.15	0.08	0.00	0.15
0.10	0.10	0.00	0.15	0.10	0.00	0.15
0.15	0.15	0.00	0.15	0.15	0.00	0.15
0.20	0.19	0.01	0.20	0.18	0.02	0.20
0.30	0.28	0.02	0.30	0.21	0.09	0.30
0.40	0.31	0.09	0.50	0.23	0.17	0.50
0.60	0.37	0.23	0.50	0.27	0.33	0.50
1.00	0.44	0.56	0.70	0.31	0.69	0.70
1.50	0.49	1.01	1.00	0.34	1.16	1.00
2.00	0.55	1.45	1.00	0.36	1.64	1.50
3.00	0.60	2.40	1.50	0.40	2.60	2.00
5.00	0.70	4.30	2.00	0.45	4.55	3.00
10.00	0.85	9.15	3.00	0.58	9.42	3.00

