Optimizing water supply and distribution with simple technologies for small gravity fed systems:

Distribution boxes without stop valves & partitioned reservoirs

Damien du Portal – January 2015

This practical guide is about collective drinking water supply systems for low-revenue populations in rural areas, and more specifically about the design of *piped networks that are gravity-fed by spring catchments.*

1. Introduction and reminders:

The proper distribution of water is often an important issue when it comes to gravity-fed systems supplied by springs. Since the water flow of spring catchments is often limited, especially during the dry season, its equitable distribution remains crucial to use efficiently the resources, and to avoid conflicts among water-points users supplied by the same network and/or the same reservoir.

Inter Aide teams have developed and tested simple technologies, enabling the optimisation of water distribution, without the use of stop valves (which are fragile elements, that are often expensive and difficult to find in rural contexts).

These technologies include ***distribution boxes****;* ***partitioned reservoirs*** *and* ***free-flow tap stands****, described in the 3 chapters following the introductory part.*

1.1. What category of flow at the water point?

During the construction of gravity systems fed by spring catchments, two options are possible in terms of collective water points: ***taps-stands or free-flow water points.***

The choice depends on several factors: the flow of the spring, the number of people being supplied, local water uses, the local availability of taps, the location of water points, etc.

- **Water points fitted with taps**: these are supplied by an upstream storage in a buffer reservoir (as it is often the case in the areas where Inter Aide is intervening in Madagascar). Taps must be maintained and regularly replaced.
- **Free-flow water points:** when possible, priority is given to this option[1] – for example in Ethiopia – since no tap means easier maintenance. These systems also enable an easy supply of water for cattle troughs downstream.

Many people think that these free-flow water points ''waste water'', but this is not the case regarding gravity-fed systems: ***The explanatory note in part 4 of this document explains and answers questions and « preconceived ideas » on free-flow water points.***

[1] For example conditions are that the flow rate of the spring must be sufficient (one uses a minimum reference of 0.2 l/sec. per water point), it requires as well that the downstream drainage of the future water-point must be well designed and easy and/or there should be a demand and a use of the overflow downstream (cattle trough, agricultural irrigation...)

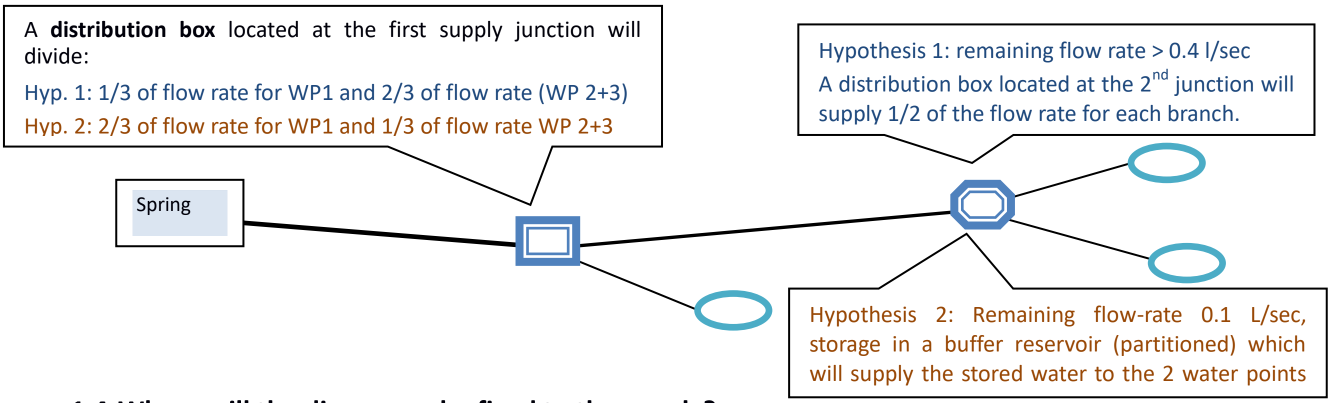
1.2. What is the minimum quantity of water to distribute (when the flow is limited)? :

For the water systems built by Inter Aide in rural areas, **the flow of the spring at low level (dry season)**[2] is a determining factor to be able to establish the maximum number of collective water points that can be supplied by the spring[3].
In general, apportion choices are made using the criterion of a minimum flow rate (dry season) per water point. Inter Aide uses as a reference (for water points suppling approximately 200 users) the objective of ***0.2 l/sec per free-flow water point***[4] and of **0.05 l/sec per water point fitted with taps** (this flow rate supplying a storage within a buffer reservoir functioning upstream, the flow rate of the tap being, of course, far superior: approximately 0.3 l/sec).

1.3. Distribution example:

Let us take for example a two branchs network supplying 3 water-points with 2 different flow-rate hypotheses to compare:

- ✓ Hypothesis 1: The flow rate of the spring in dry season is over 0.6 l/sec and therefore enables the supply of 3 free-flowing water points (WP).
- ✓ Hypothesis 2: The flow-rate in dry season is of 0.3 l/sec, we shall distribute 0.2 l/sec to the first water point which will be free-flowing and we shall build a buffer reservoir (semi-partitioned), to store the remaining flow rate of the 2 other water points which will be fitted with taps.



1.4. Where will the dispensers be fixed to the supply?

It is generally preferable to distribute water as close as possible to water points (thus saving pipes, facilitates maintenance, etc.).But installing a distribution box (or a reservoir) requires a way to vent accumulated air: like for a ''break pressure'', the piezometric profile of the supply is restored to atmospheric pressure at this level, although a sufficient load is necessary to supply the sections downstream. In case of a low slope, the choice of the location for the distribution box can sometimes be tricky and requires technical solutions such as a distribution box located on a higher level (for example see Page 7).

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[2] It is important to base calculations on the flow rates measured during the dry season as flow rates can vary substantially for certain springs between rainy and dry seasons.

[3] Warning: one must not conclude, when an important flow is available, that a maximum number of water points can be constructed! Multiplying water points on a gravity systems can affect it for several reasons (the more water points there are, the more complex the distribution, meaning it needs more maintenance and there is a risk of waste and conflicts. See the note (in French) on the question of determination of the number of water points www.interaide.org/pratiques/sites/default/files/notes_techniques_complementaires_sur_le_captage_de_source_09-05-12.pdf

[4] This 0.2 l/sec flow rate (or 12 litres/min) makes it possible to fill a 20-litre jerrycan in less than 2 minutes and practically reduces waiting time at water points. Daily theoretical needs (approximately 15 l/day in such situations) for a 200-people population are fulfilled in less than 5-hours of fetching. In such water scarcity cases, one can go down as 0.15 l/sec (low water flow rate).

2. Distribution boxes with no stop valve

In a gravity fed system supplying several water points (*free-flowing water points, or water points fitted with taps and requiring the installation of upstream reservoirs*), it is necessary **to distribute water equitably among the different branches, at any time, even when the flow rate varies.**

The system of distribution box described hereafter enables a more accurate distribution of small flow rates (ranging from 0.1 l/sec. to 10 l/sec.) without requiring stop valves.
This system enables a stable distribution in the same proportion, whatever the variations of flow rate, and is simple and easily understand by users.

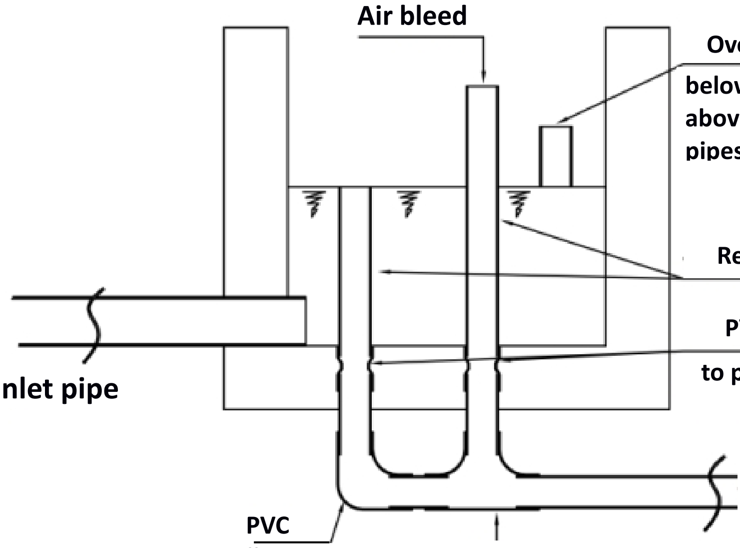
2.1. What are the simple ways to get an accurate distribution ?

The use of stop valves in a distribution box is not recommended, because these:

- deteriorate quite rapidly, and thus disrupt the functioning of the supply
- are complicated to adjust even for a given flow rate (and easy to disrupt !)
- require new adjustments in case of variation of the upstream flow rate (no automatic variation of the distribution).

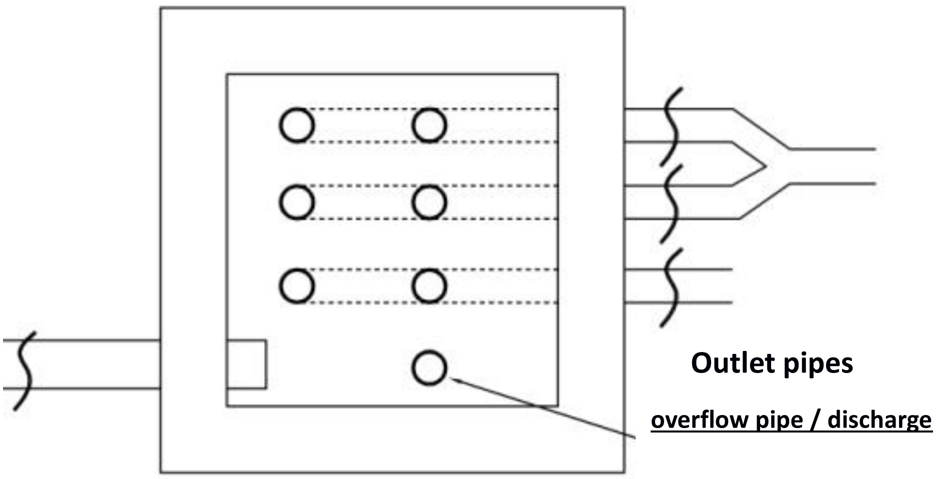
The distribution system which we have progressively implemented in Ethiopia (following different tests[5]) uses a principle of distribution within a series of PVC pipes placed vertically (at the same level) in a concrete box. This system includes air intakes in order to avoid flowing disruptions linked with the downstream section.

Cross section of a distribution box



[5] *System progressively implemented by Akalu Kassa (Ethiopian program manager) and his field team.*

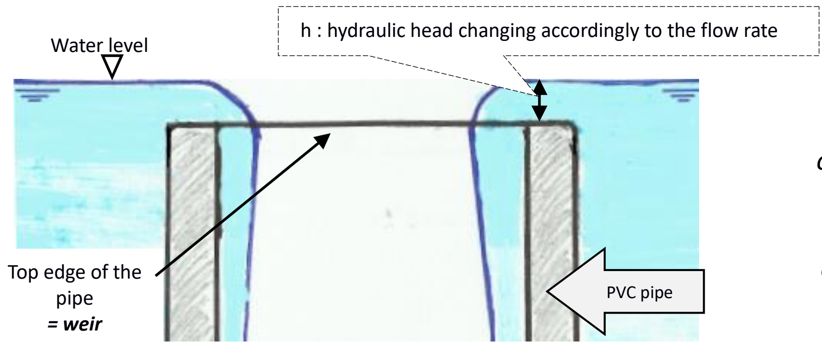
Top view of a distribution box: **repartition 2/3 – 1/3 of the inlet flow with 3 PVC pipes of the same diameter**



Detail: unions sealed in the bottom slab to plug the vertical pipes. The bottom slab must be as horizontal as possible and the union as vertical as possible.

(Drawings made by Fy Tsiriarison, programme manager in Madagascar)

2.2. Explanations of the distribution by overflow in vertical pipes



The water overflows in the pipes vertically fitted in the distribution box

- Water level inside the box (hydraulic head at the edge of the pipe) varies in accordance with the spring flow, water overflowing according to a principle of a thin-walled weir[6].
- The top of the different intake pipes in series is adjusted at the same vertical level (the fact that pipes are removable makes possible a precise adjustment).
- The Flow rate **Q**, overflowing through each pipe, is thus depending of :
  - the hydraulic head on the summit (**h** : depending of the water level inside the box, being itself linked with the flow of the upstream source). But since the vertical pipes are set at the same level, distribution will remain proportional, no matter the variations of **h** are.
  - The perimeter of the pipe (length of the overflow) : **π x D** (unless pipes are submerged !).

To carry out distribution combinations, it is possible:

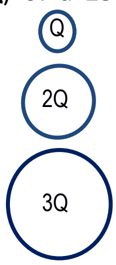
- ➢ **Either to multiply pipes of the same diameter in parallel that will be linked just downstream** (according to different combinations - e.g. 2/3 & 1/3 – as illustrated in the previous diagram)**.**
- ➢ **Or use water pipes of different diameters** set at the same level inside pipes of a superior section): this is important in the case of very different flow distribution between several lines (important networks). *More details hereafter on the choice of pipes with this distribution mode.*

[6] Calculations regarding thin-walled weir on www.suezwaterhandbook.com/formulas-and-tools/formulary/hydraulics/weirs (or on http://infoterre.brgm.fr/rapports/RR-38193-FR.pdf in French!)

It should be noted that the distribution system using pipes of the same diameter, placed in parallel, has generally the advantage of being more understandable by local users, who can thus have a better interpretation of the different proportions distributed.

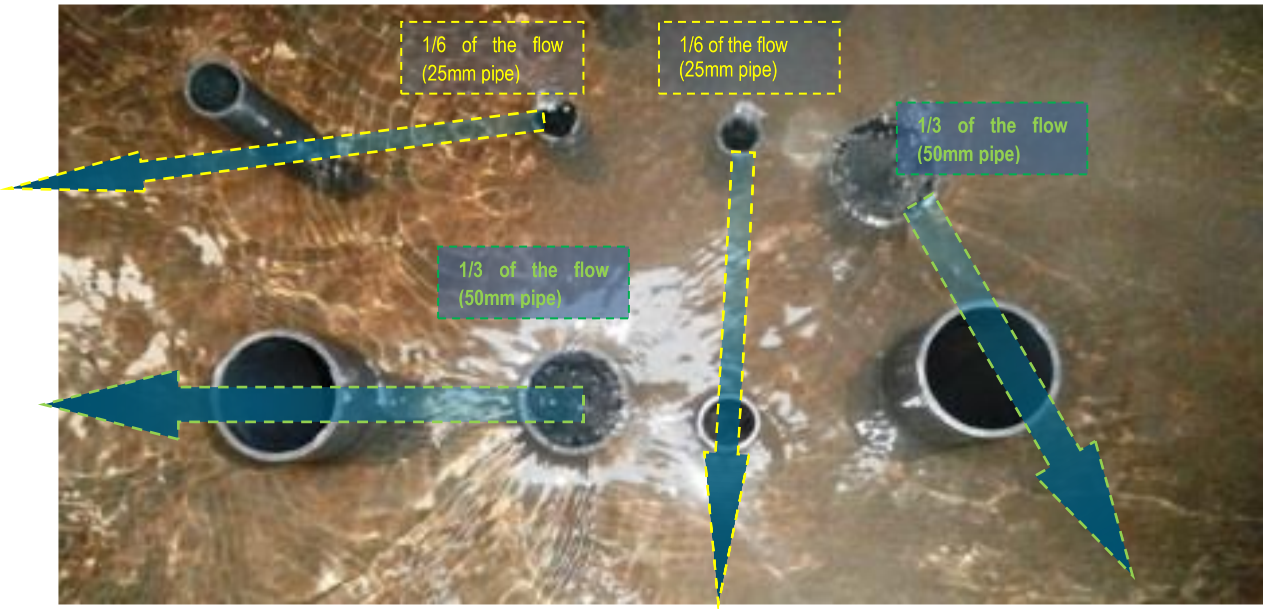
<u>Three important points :</u>

- A turbulent water inlet flow (overflowing by the top inside the distribution box) can disrupt this distribution mechanism (ripples on the surface…), therefore, **the inlet pipe must be fixed in such a way that it comes at the bottom of the box** (cf. cross-section diagram) so that water goes up inside without disrupting the surface.
- **If the pipes are submerged, it will not work** (e.g. the case of an important upstream flow overflowing in a small number of pipes) the functioning could then be different, especially if distribution is done through pipes of different diameters : it is better to over-dimension the vertical vent pipes when important distribution flow have to be distributed.
- If the option is to apportion through pipes of different diameters, things are not what they seem when choosing pipes, since it is not the section, but the perimeter which regulates the flow : a 50-diameter pipe will ''only'' enables the overflow of a double flow (**Q**) of a 25-diameter pipe (and a 75-diameter pipe only triple the flow) since :



  - L= Length of the edge of an overflow pipe of 25-mm (π x D) : 78.5 mm
  - 2L= Length of the edge of an overflow pipe of 50-mm (πx D) : 157 mm
  - 3 L= Length of the edge of an overflow pipe of 75-mm (πx D) : 235.5 mm

Example of a distribution 1/3 - 1/3 - 1/6 - 1/6.



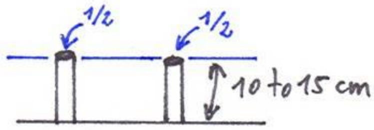
<u>Precisions on the air bleed system aimed at avoiding flow disruption due to the downstream flow.</u>

This overflow distribution system will work correctly (distribution in the same proportion whatever the flowing variations are) only if the flowing problems due to the downstream part are avoided: vortex effect or disruption/blockage due to creation of air bubbles. Hence, it becomes necessary to fix an **air bleed just after the inlet pipe,** it can be vertical pipes placed at a superior level from the inlet pipes.

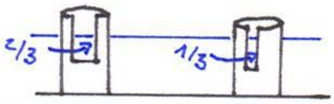
A combination of Tees and PVC unions is a simple way to realize that, while the box itself is built (although, in the case of several connections, the number of combinations will require a good general overview to assemble it properly!). However, this system of air bleed does not necessarily solve the problems of flow further downstream on the supply system (air block at high level points...).

A variant :

Distribution can also be carried out with a system of rectangular cuts made on the edge of the pipe.
(Cf. scheme on the right)



Without regulation, 1/2 of the yield goes in each pipe



With Regulation
The width of the cut is 1x for the right pipe and 2x for the left pipe

2/3 of the yield goes in the left pipe
1/3 goes in the right pipe

Accurate alignment of the level of the PVC inlet pipes

Once the box is built, accurate adjustment of the level of vertical pipes must be carried out. Before connecting the branches, the distribution will be checked by measuring the flow at the outlet of the pipes, just downstream the box. Indeed, the verticality of the inlet unions and the precision of the cutting of the pipes are never perfect. As the pipes are removable (it can plug on the unions with a good impermeability) it allows a quite easy adjustment.
This system also enables the modification of the distribution in the future (a set of Tee + elbows can even be added to double the outlet).

2.3. Other illustrations and variants

A 2-lines distribution box with large diameter air intakes and overflow-discharge (the choice of large diameter has been made because the network is on a high slope, but this is not in theory necessary).



Outlet pipes of different diameters (air bleeds of small sizes) but in this box, the inlet of water by a supply on top disrupts the overflow which is not laminar.
⇨ give priority to inlet supply by the bottom of the box in order to reduce turbulent effects.

Small distribution box without air bleed: this simple system works correctly for small repartition between short supply lines and of low slope (limited risk of downstream vortex phenomenon).

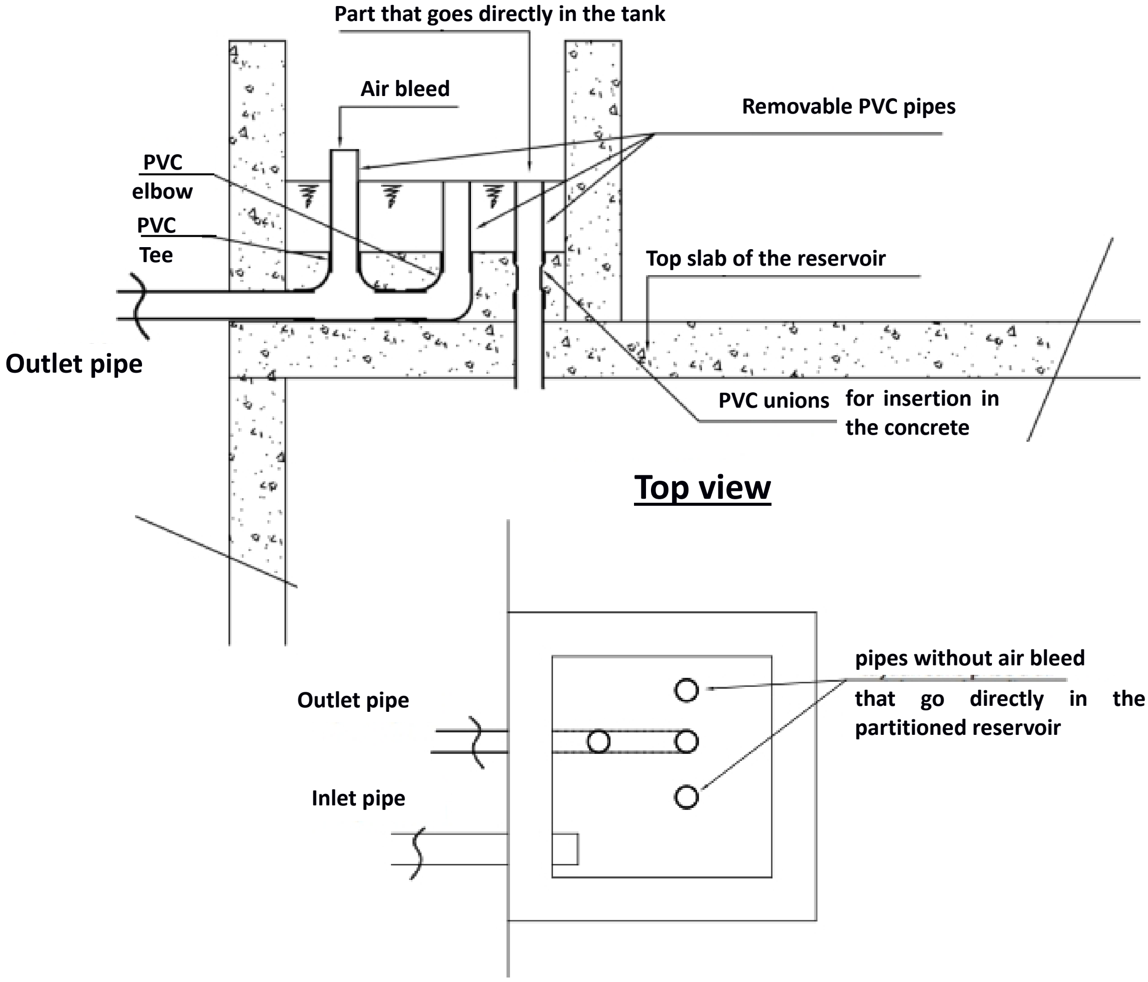
Two distribution box variants :

a. Distribution box located directly above reservoir

(Innovation of Fy Randriantsitovana Tsiriarison-Programme Manager - Madagascar):

This distribution system is interesting when the distribution implies the construction of several reservoirs in series at different locations on the same line (e.g. extended villages or network supplying several hamlets).

Cross section



b. Elevated distribution box :

(Innovation of Terefe Simion – Programme Manager Ethiopia).

The objective of this construction is to keep enough head (pressure) to distribute water between water points located in plain area with no elevation.

The spring is located far upstream (higher elevation), only one supply pipe is reaching the distribution box located as close as possible to the water points, the distribution pipes go out through the central pillar.

3. Semi-partitioned reservoirs (or buffer tanks) for the supply of community water points

3.1. Introduction and issue :

For several gravity-fed systems supplied by springs catchments, **it is necessary to store water produced by the source[7] in buffer reservoirs[8]** : *these reservoirs generally allow users to store water meant for the supply of several water-points fitted with taps.*

Water storage in a reservoir implies dependency between water-points located downstream:

When different groups of users depend on the same reservoir, **the bad behaviour of only one group can penalize all the users of the other water-points.**

Indeed, if the users of a water point (among several water points fed by only one reservoir) :

- Poorly control the access and the use of the water point, do not close their tap properly, or do not replace it if it is leaky (bad management and maintenance of the water point), they will then consume an excessive volume of water leading to a shortage for all users.
- Do not repair quickly a broken tap or a leak on the line between the tank and the water point; this waste of water can then totally empty the tank, thus penalizing all the other related water points.

Users of the other water points – if they do not have the means to force users of the faulty water point to repair it - can then, through a perverse effect, go as far as showing disinterest in the control of their own water point[9] and of the overall system.

When the quantity of water is limited, a system of fee payment of water is not enough to encourage the communities to pay attention to the system:

In rural areas, users of small gravity-fed systems supplying collective water points under community management do not normally pay for water as per volume consumed but as periodic fee contributions.

This way of payment by subscription arises from a certain logic for these small systems supplied by spring catchment, since the cost of "water production" is null (excluding water maintenance) and the system management, exploitation and maintenance[10] costs are not directly linked with the volume of water produced (naturally by the source) or consumed.

- This mode of payment has the advantage of being simple to manage and it is not restricting, because of the price, the poorest households have access to safe drinking water. Its cost is rather low for all users, and it works well when the water committees correctly play their role of delegate manager[11] (and are controlled by the contracting authority).
- However, this mode of payment has the disadvantage[12] of not encouraging users to save water when it should be stored (spring with a small flow). In case of poor management, there is no

[7] Several sources do not have the sufficient flow in dry season to supply free-flow water points (cf. reminder P.1).

[8] A maximum storage corresponding to an overnight source production, a well-dimensioned buffer reservoir must almost empty itself during the peaks of use each day. To dimension a buffer reservoir, the reference is not the flow rate at dry season but rather an average flow in order to avoid a limited access to water outside dry season.

[9] It is unfortunately not rare that rural systems are not working properly because water storage is out of order (empty reservoir) and this due to an leakage not repaired (downstream to the reservoir).

[10] Excluding the marginal wear and tear effect of taps which can be linked to the volume of outflowing water

[11] The Malagasy water law makes the commune responsible of the management of water infrastructures, thus delegation of the commune is made to the water committees.

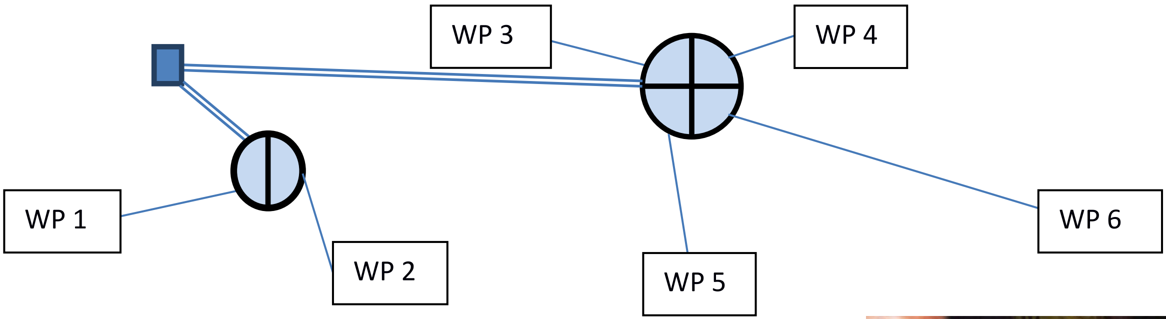
[12] Although, the payment by fee contribution is still well-adapted to small rural gravity-fed systems.

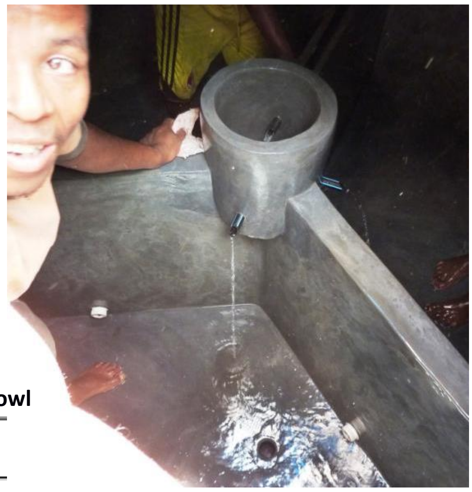
sanction through expenses (since payment is not related to the volume that has been consumed). As long as water is flowing, even with a small flow, the users won't usually anticipate anything specific intervention.

3.2. A simple technical solution reduces these problems :

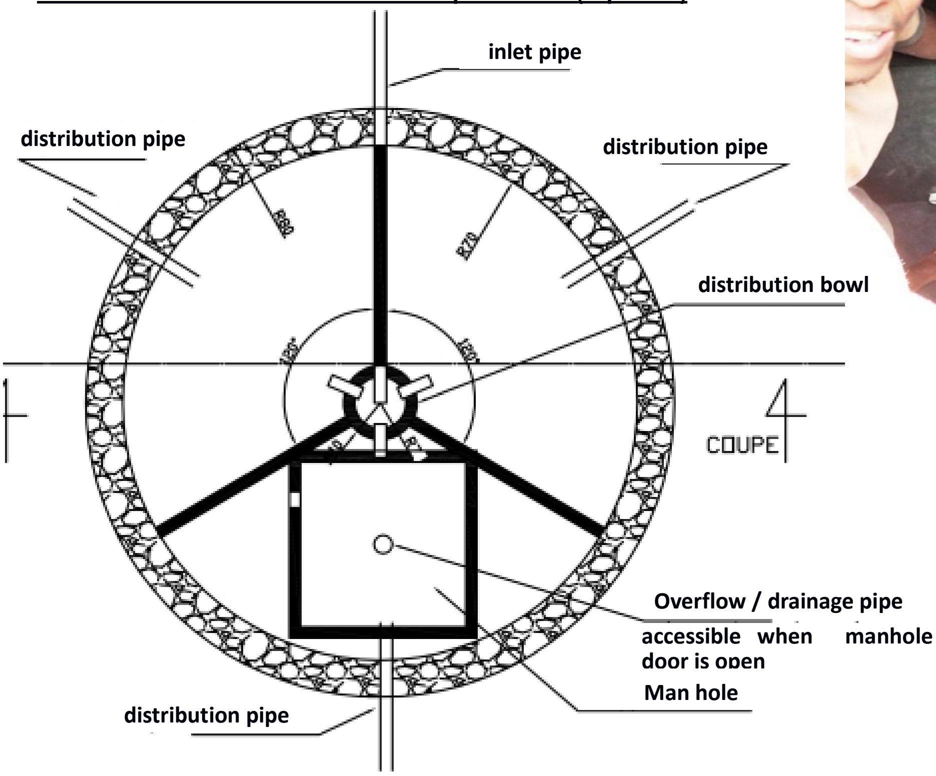
The solution of semi-partitioned reservoir reduces the "collective penalization" effects without disengaging the users on the collective maintenance of their system.
The operation principle of these reservoirs aims at **sharing among members, part of the stored volume (the superior part)** and **reserving the other part to the users of each water point.**

Diagram : Each water point (WP) has a secured volume stored in semi-partitioned tanks

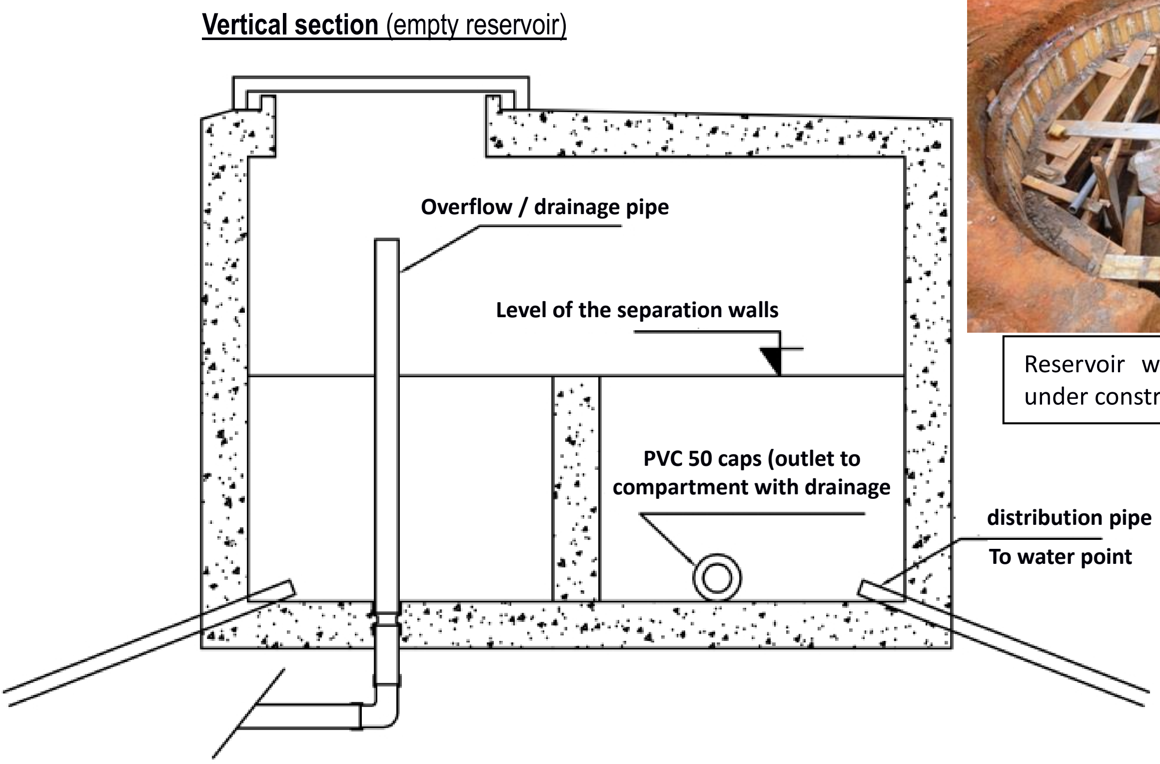




Cross section - reservoir with 3 compartments (top view)

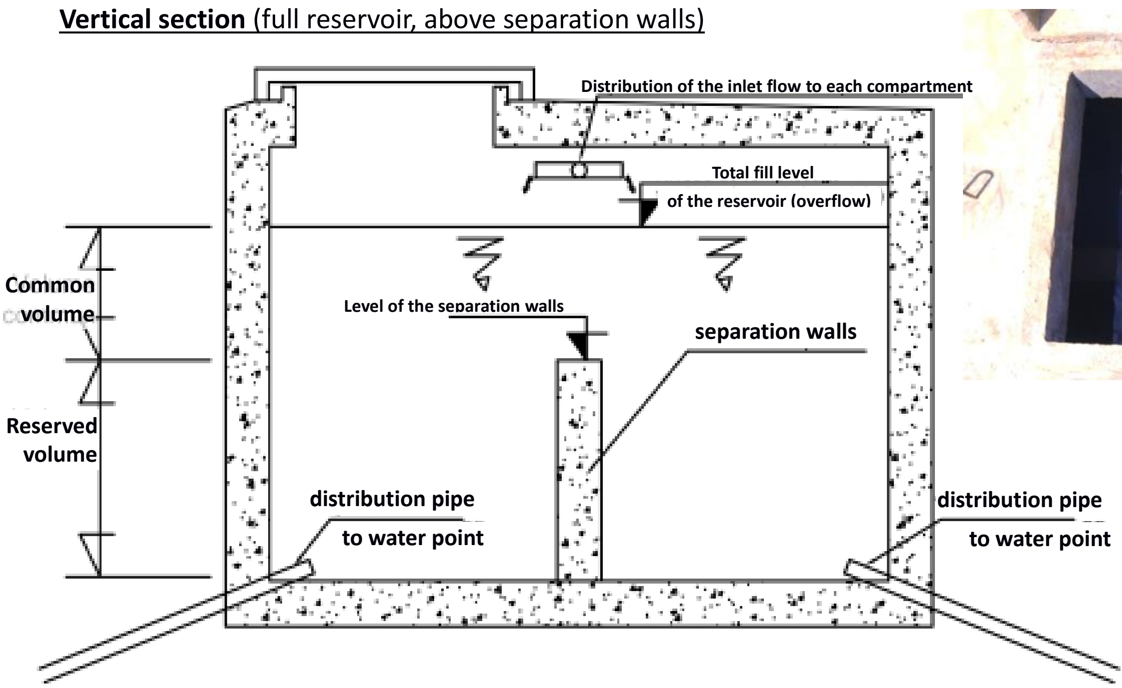


The water flowing from the upper part of the reservoir is shared between the different compartments either through a distribution box located on top of the reservoir, either with a partition made inside (example-picture : a distribution bowl)



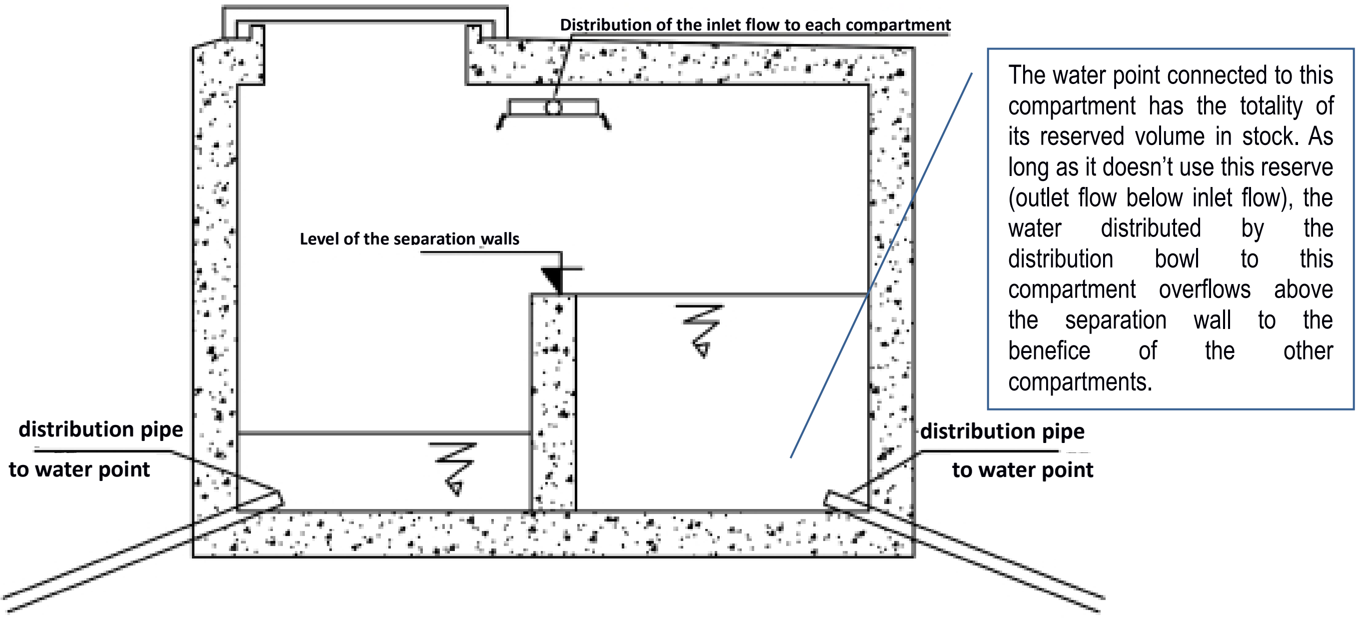
Reservoir with 2 compartments under construction

Partition walls separating each compartment are erected during construction, up to 2/3 of the working height of the tank. These walls are fitted with drain caps in order to drain for cleaning operations.
Volume of water stored above these compartments is a **common volume** which is shared among the water points.

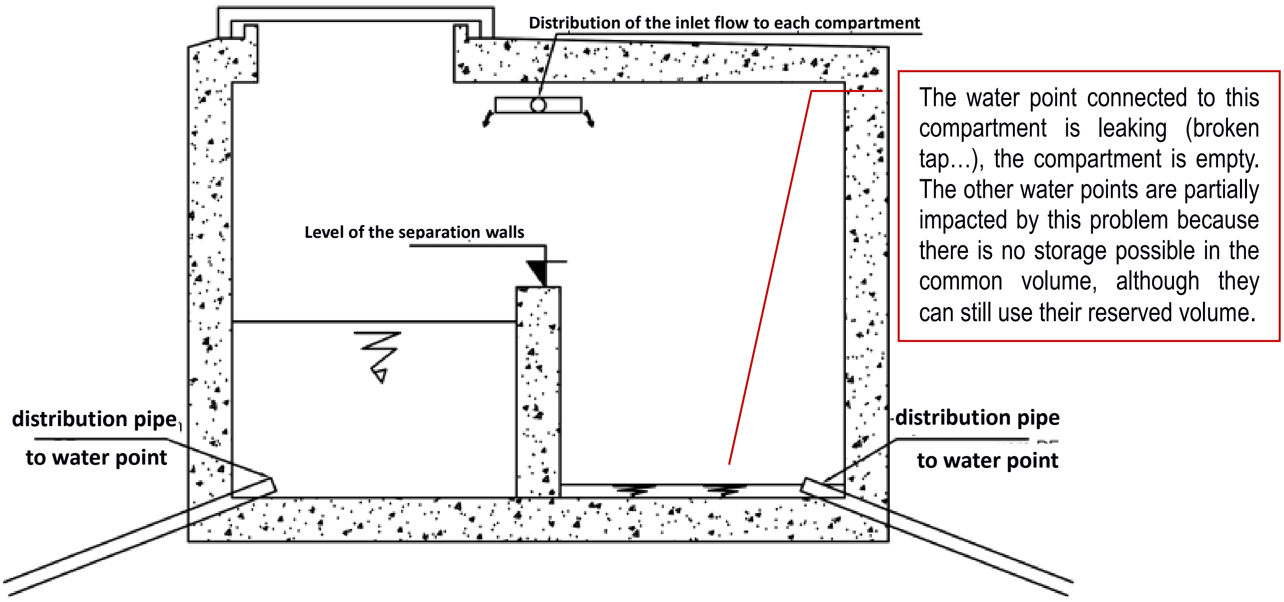


Compared to the option of constructing series of small individual storages per water points, the principle of this reservoir is more economical and it enables optimization of the water storage. Indeed, the sharing out of water stored in the c**ommon volume** is of great interest, since all water points do not necessarily draw the same quantity of water (varying number of users…) simultaneously (usage and/or different needs…). A water point which has already stored its **reserved volume** can thus give back the water overflow for the benefit of other water points. Potential distribution problems between compartments (disruption…) can also be partially compensated by this system.

Vertical section (reservoir in use) **:**



Vertical section (reservoir in use, case of a broken tap for a water point) **:**



(Diagrams made by *Fy Tsiriarison, Programme manager Madagascar)*

In case of a problem of leakage on one of the water points, the effects of "collective penalization" are thus restricted to the loss of the common volume in the tank. This partial prejudice draws responsibility from all the users on the collective maintenance of their system (they will always be prompted to carry out the necessary repair). The highest prejudice (total absence of storage) only concerns the broken water point, its repair should be stimulated by the comparison with the normal running of the other water points.

4. Explanatory note concerning free-flowing water points

Some answers to recurrent question on this topic

When the flow of a spring in the dry season is sufficient[13], a gravity-fed supply system can be designed with free-flow water points.

In the contexts where Inter Aide is conducting programmes, priority is given to this option when possible – for example, in the mountains of the southern region of Ethiopia (photos below).


<u>Question1:</u> Why build free-flow water points?

This technical choice makes possible (when dry season flow of the spring allows) :

- Building gravity-fed supply systems which are simple and less expensive than storage-fitted systems (no complicated and costly reservoirs to build)
- Avoiding the installation of all mechanical spare parts (taps, stop valve, etc.). Constantly solicited in the daily use of collective water points, these parts can ruin out quite quickly and are requiring frequent changes. Maintenance of these water points is thus considerably simplified.
- The provision of water to cattle-troughs downstream of the water points, water supply for cattle being an important requirement in certain contexts.



[13] 0.2 l/sec per water point for approximately 200 users = non-restricted flow in accordance with the needs of rural families in the contexts where Inter Aide is developing programmes (Cf. explanation part 1)

In the context of isolated and poor rural areas, the construction of free-flow water points is thus a way to notably increase the sustainability of the hydraulic infrastructure by reducing its maintenance cost for a greater benefit of users.

The only "perverse effect" of this system is that maintenance costs are reduced to such a degree that users tend to forget the necessity of a regular contribution. Leading to the risk that there will be no funds available to carry out the required maintenance for the whole system!

Question 2: ***Is this not a waste? What is the impact on the sustainability of the catchment and its basin? Is the resource unlimited?***

No, it is not a waste, 8 explanatory points:

1. A source is supplied by an aquifer, which itself is recharged by rainfall (and infiltration) at the level of its basin. Flow variations are related to pluviometry regimes (with a more or less important buffer effects depending on the type of aquifers), it is then a renewable (water cycle) and - in theory – a durable resource (excluding climatic change, or deterioration of the basin). Therefore, a source is "unlimited" as long as the pluviometry remains stable over the years, and that the basin is not deeply modified or deteriorated: adequate protection of the basin of a catchment source is thus vital (as opposed to erosion, pollution, etc.).

2. A spring catchment only catches a natural emergence but does not pump directly in the groundwater table : so it only catches water which would anyway flows naturally from the emergence with the same flow rate (and it would supply a stream or a pound downstream the emergence). Tapping a surfacing source does not imply the risk of "emptying the resource" (as opposed to the exploitation of an aquifer through pumping).

3. By catching a spring, the intake area[14] is greatly modified for the benefit of users (men and animals), generally located further downstream (sometimes very far away, in areas where water is rare).

4. During catchment operations, the aim is to reduce the level of the groundwater table at this specific point in order to concentrate the spring at the level of the catchment [15] but these operations do not modify the natural regime of the aquifer nor its general course.

5. Indeed, it is not possible to stop or store water in the aquifer at the source level…(and it is actually to avoid: putting the spring on load would imply the risk of forcing water to find other exits apart from the catchment site and that would be catastrophic for the system).

6. From the catchment box, water is directed in priority towards the supply network and secondly to one or several overflows (according to the flow) : ideally, all the spring water is caught, a part could be directly restored from the overflow at the source level (in case of an important flow, only one part is going to the supply system[16]).

[14] This could have a small ecological impact on the precise spot if all the flow is caught...water from this spring is somehow shifted downstream at the level of the water points level and further down at the overflow of the washing tubs or troughs
[15] Cf. www.interaide.org/pratiques/content/fiche-pratique-le-captage-de-source-exemple-du-captage-par-rabattement-de-nappe-fr-english
[16] Cf. fiche www.interaide.org/pratiques/sites/default/files/133_trop_plein.pdf

7. Concerning water going from the catchment to the supply, 2 options are possible:
   - water is either directed via the supply system towards the water tank (or distribution boxes and tanks) and from the tank towards one /several water points fitted with taps: in this case, there is *an* ***overflow*** *at the tank level* and the "free-flowing process" is done at this level when the reservoir is full : ***having taps does not change the fact that water is flowing continuously somewhere***.
   - or water goes towards the distribution boxes, and from distribution boxes to free-flow water points offering an easy possibility to supply drinking troughs (eventually to irrigate downstream plantations of fruits, kasava, spices or vegetables...)

     ☝ In both cases, water produced by the spring and not used is restored to the environment, and recharges streams and aquifers located downstream via streaming or infiltration.

8. Finally:

   Gravity-fed systems do not require – *by definition* – external energy for pumping. A proper spring catchment does not require treating water (naturally safe for drinking): with this technique water production is not energy-consuming and does not require any supplies or material. The cost of water production does not depend on the flow delivered at the water points, and the free-flowing process (or at overflow levels) does not bring about extra costs nor waste.

To summarize, for gravity systems fed by spring catchment*:*

- ✓ **Having taps or not at the level of water points (free-flowing)**
  - Does not impact the source and its regime
  - Does not impact the sustainability of the spring catchment
  - Does not waste water nor energy.

- ✓ Springs being fed by rainfalls at basin level, **the protection of this basin is thus an important stake** (prevention of risks of pollution, protection against erosion, reforestation and improvement of the stability of the soil by a proper plants-coverage in order to boost rain infiltration...)

Final brief parallel

Within our, current urbanized societies, we forgot that there are still in the countryside, mountains and European villages, several water points, washing tubs or water troughs (of which some are over a hundred-years-old) fed by catchment springs still in use…and which are -very fortunately- not considered as wasting water !

Damien Du Portal, head of sector – January 2015