Studies regarding the irrigation to the hilly and terraced surfaces

B. Lepadatescu, A.-E. Dumitrascu, and A. Nedelcu

***Abstract*—** In the paper is shown a solution to use irrigation for hilly and small terraced surfaces of upland areas, where the water is not available and the electricity grid is missing. The condition to use this solution of irrigation is to have a water source available. This water source can be a spring, an artesian well or a stream that must be near the surfaces on the hillside that need the water. Usually, the level of the water source must be above the site location of the homestead's water needs. If the location of household, garden, or livestock water supply is higher that the water source is necessary to use a solution to pump the water to this location. To pump the water without use electricity in hilly areas it is used a ram pump system which needs a minimum fall of the water. The paper presents a solution to irrigate hilly surfaces where the water source has not a fall to make working properly the ram pump.

***Keywords*—** irrigation, ram pump, sustainable solution, hilly surfaces, zero pollution, renewable source.

I. Introduction

On the hilly and terraced surfaces due to topographical constraints, an irrigation system is very difficult to make and unavailable because the costs are very high. It is possible to find a solution to irrigate such lands the productivity of crops can increase by 2 times or higher. Most of the people have to depend on rain water due to the unavailability of irrigation facilities that decreases the productivity for the horticultural crops such as fruits, vegetables, flowers, tuber and rhizomatous crops and species. If they use water pump with electricity or fossil fuel the cost is high and the people from those lands cannot afford to pay and they cannot cultivate their primary means of food in time.

The solution that is proposed in the paper is to utilize kinetic energy of the flowing river to pump water uphill without using any other external sources of energy such as fuel or electricity. The proposed solution consists of a water wheel which raises the water from a river at a height of 4-10 m and from there the water is conducted to a ram pump that will send some amount of water to a higher height uphill, from where it can be used for various crops and households for drinking water purpose.

To irrigate such hilly and terraced areas without the use of any outside source of energy which can supply homestead' water needs, or garden, orchard, was necessary to find a solution with simple construction, easy to install, which does not consume petrol, diesel or electricity, which can operate for 24 hours per day and maintenance free. This solution use the energy of a large amount of water falling a small height to lift a small amount of the water to a much greater height from where it can be used to a village or irrigation scheme on the hillside. When is obtained a fall of water, the ramp pump lift this water with a comparatively cheap and reliable means to a considerable heights.

The solution presented in the paper to use water from a river for the hilly and terraced surfaces is shown in Fig.1. To work the system is necessary to have a pump head or fall h needed to start the ram pump function. Because on the plain surfaces where the river is situated, to obtain this pump head is necessary to use a water wheel 1 which lifts the water from the river level to the height h that can be around 4-7 m. These values of pump head ensure a delivery head or elevation H till 7-10 times more than pump head h.

The diagram in Fig.1 shows the main components of a system which irrigate hilly and terraced surfaces. Water is taken from a river 10 with a water wheel 1 that transfers the water to a drive tank or intake tank 2 which ensure constant flow water to the ram pump 4, through the drive pipe 3. The ram pump lifts part of the water coming through the drive pipe to the delivery tank 7 on a higher level through the delivery pipe 6. The ram pump is protected by a pump house from accidental damage. From the delivery tank the water is conducted to the distribution system which consists for example of drinking water for the people 9 or for horticultural crops 9. Waste water is delivered out from pump house through the drain tile 5.

The main advantages of using this system of irrigation are:

- Use of a renewable energy source;
- Has a little environment impact by pumping only a small proportion of the available flow;
- Low maintenance requirement by his simplicity and reliability;

B. Lepadatescu is associate professor at Department of Manufacturing Engineering, Faculty of Technological Engineering and Industrial Management, "Transilvania" University of Brasov, 29 Eroilor Street, 500036 Brasov, Romania (corresponding author: 40-268421318; fax: 40-268421318; e-mail: lepadatescu@ unitbv.ro).

A.-E. Dumitrascu is lecturer at Department of Manufacturing Engineering, Faculty of Technological Engineering and Industrial Management, "Transilvania" University of Brasov, 29 Eroilor Street, 500036 Brasov, Romania (e-mail: dumitrascu_a@ unitbv.ro).

A. Nedelcu is professor at Department of Manufacturing Engineering, Faculty of Technological Engineering and Industrial Management, "Transilvania" University of Brasov, 29 Eroilor Street, 500036 Brasov, Romania (e-mail: a.nedelcu@ unitbv.ro).

- Can be manufactured in the rural villages.

The main limitations of using this system of irrigation are:

- It is limited in hilly areas with a year-round water sources;
- It is pumped only a small fraction of the available flow and therefore require source flows larger than actual water delivered;
- Are limited to small-scale applications.

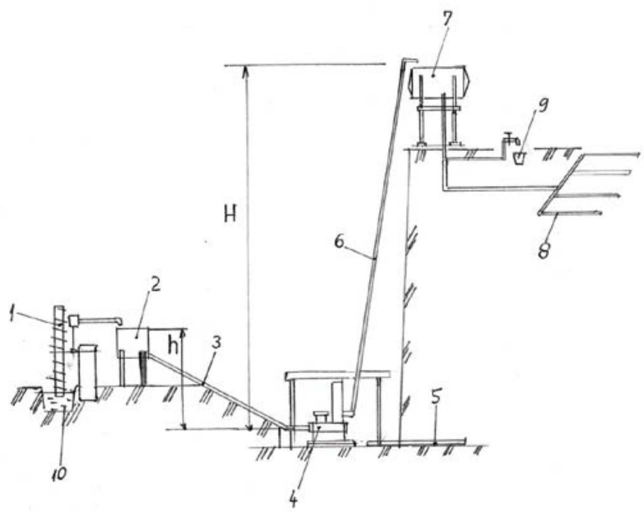

Fig. 1 Layout of the system to irrigate hilly and terraced areas

II. The Main Component of the irrigation System

a. The water wheel

The water wheel 1 from Fig.1 is the first component of this system of irrigation. His role is to lift the water taken from the river to a considerable height *h* that is necessary to start the ram pump to work.

In Fig.2 is shown a constructive solution of a water mill used to take the water from a river and to send further to a reservoir from where is conducted to the ram pump by drive pipe. The main elements of this water mill are (Fig.2): the primary reservoir (1), the pipe (2) from where the water is conducted to the main reservoir; the rotor axis (3); the screws (4) that permit setting of the water mill in a vertical plan; the counterweight (5); the concrete pillar (6) that supports all the construction; 24 collecting tubes (7); the rotor ring (8) where are mounted the collecting tubes.

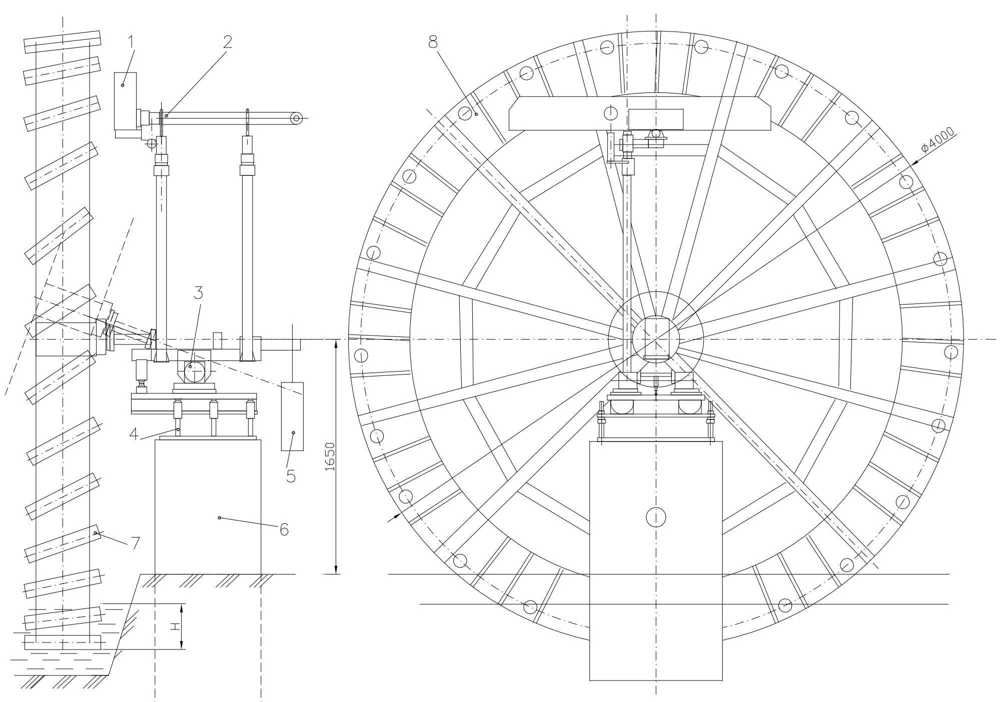

Fig. 2 The components of the water wheel

Water mill has a diameter of 4000 mm which allows lifting water from the river at a height of 3500 mm, where it is stored in a primary reservoir 1. From the primary tank (1), water is passed through the pipe 2 to the drive tank located at a distance of 2 m from the concrete pillar (6). Rotor ring (8) is made of two rings of steel sheet of thickness 0.5 mm and is connected to the main shaft (3) by means of profiled spokes. On the two rings of the rotor are fixed 24 tube collectors, made by polypropylene, with a length of 500 mm and diameter of 75 mm. The impeller is submerged in river water at a depth of 200 mm. This allows complete filling tube collector with water from the river. Turbine construction allows adjustment of horizontal and vertical plan to a range of 150 mm which allows being adapted at specific conditions of the installation in the site near to the river.

In the period between harvest crops and starting a new season in agriculture, the turbine is decommissioned by tilting it 20 degrees. In this mode extends the life of the plant and reduce costs maintenance. Keeping the turbine in this inclined position is realized by a lock system.

Turbine works without interruption throughout the period between the start of the season in farming and till harvesting period ends. During this time water is stored in the drive tank, and then distributed through the drive pipe to the ram pump and further to the delivery tank from where water is used.

To calculate the turbine parameters it is used Fig.3. This figure shows schematically the position of the collector tube fixed on the rotor in the time when its upper end comes out from the water.

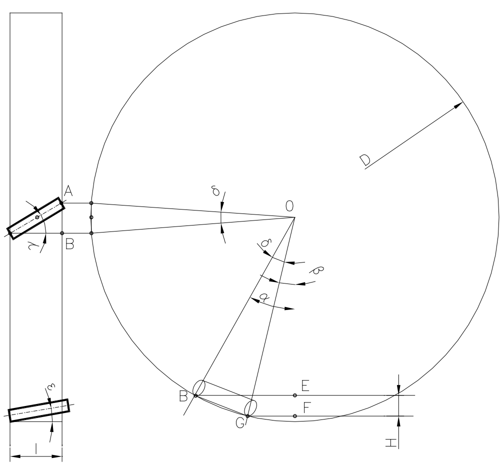

Fig. 3 Sketch used to calculate the water wheel parameters

b. *The components calculus*

At this point the collector tube is almost full with water and continue lifting movement once the rotation of the rotor. Water collection tube is mounted on the rotor's circumference at an angle γ. Using triangle VAB we can calculate the connection between the angle of tube collector and rotor construction elements:

So the angle δ is given by:

$$\delta = 2\arcsin\frac{l\cdot\sin\gamma}{2}. \quad (1)$$

Equation 1 shows the relationship between the tube collector mounting angle and rotor construction elements.

Using ODE triangle is calculated the relationship between the constructive elements of the rotor and the exit angle of the tube collector from the water.So:

$$\alpha = \arccos\left(1-\frac{2H}{D}\right). \quad (2)$$

After some calculations we have:

$$EF = \frac{D}{2}[\cos(\alpha-\delta)-1]+H. \quad (3)$$

Due to tube collector mounting angle, water can never fill its entire cavity. To calculate the amount of water that is transported by one collector tube it is used Fig.4.

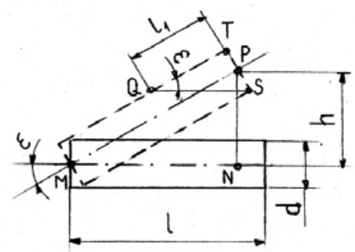

Fig. 4 Calculation of the amount of water carried by the tube collector

Using triangle MNP we have:

$$\varepsilon = \arcsin\frac{EF}{l} = \arcsin\frac{D[\cos(\alpha-\delta)-1]+2H}{2l}. \quad (4)$$

$$V_{tube} = \frac{\pi d^2}{4}l. \quad (5)$$

V_1 = volume of the cylinder with height l_1, $V_1 = \frac{\pi d^2}{4}l_1$.

Using triangle TSQ, we have: $l_1 = \frac{d}{tg\varepsilon}$. But:

$$V_1 = \frac{\pi d^2}{4tg\varepsilon}. \quad (6)$$

V_2 is the volume of the water that is transported by one collector tube and can be calculated with relation $V2 = V_{tube} - \frac{V_1}{2}$. Using relation (5) and (6) we obtain:

$$V_2 = \frac{\pi d^2}{4}\left(l-\frac{d}{2tg\varepsilon}\right). \quad (7)$$

But, $tg\varepsilon = \frac{\sin\varepsilon}{\sqrt{1-\sin^2}}$. Using relation (4) equation (7) becomes:

$$V_2 = \frac{\pi d^2}{4}\left(l-\frac{d\sqrt{4l^2-(D[\cos(\alpha-\delta)-1]+2H)^2}}{2(D[\cos(\alpha-\delta)-1]+2H)}\right). \quad (8)$$

Equation (8) gives the amount of water that is taken from the river by one tube collector. Since the rotor has 12 tube collectors, this value must be multiplied by 12 to determine the amount of water that comes to one rotation of the rotor.

Below is calculation of water volume that is taken from the river for the next elements of the rotor:

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l = 500 mm; D = 3900 mm; H = 200 mm; $\gamma = 45^0$; d = 75 mm.

First we must calculate value of angle α with relation (2):

$$\alpha = arccos\left(1 - \frac{2H}{D}\right) = arccos\left(1 - \frac{2\cdot 200}{3900}\right) = 26^0 10'$$

Next we must calculate value of angle δ with relation (1):

$$\delta = 2arcsin\frac{l sin\gamma}{D} = 2arcsin\frac{500\cdot 0,70711}{3900} = 10^0 20'$$

So, the amount of water that will be transported during one rotation of the rotor will be: $1.57 \cdot 24 = 37.68l$.

An important factor for plant efficiency is the speed of the water of the river. As the speed of the water is higher the amount of water extracted by the rotor will be higher and therefore higher plant efficiency.

Number of revolutions of the rotor in a minute n_{min} is given by:

$$n_{min} = \frac{v_w}{\pi \cdot D}, \quad (9)$$

where v_w is the velocity of river water, and D is the diameter of the tube collector disposed on the circumference of the rotor.

Volume of water extracted from the river in one minute V_{min} is given by:

$$V_{min} = n_{min} \cdot V_2. \quad (10)$$

where V_2 is the volume of water extracted from the river by the rotor in one rotation given by equation (8).

Relation (10) can be written:

$$V_{min} = C \cdot v_w, \quad (11)$$

where C is a coefficient given by: $C = \frac{V_2}{\pi \cdot D}$.

Coefficient C was calculated for the following angles γ of mounting tube collectors on the rotor circumference, and volume of water V_2 extracted from the river water at one rotation (Table 1).

Using C coefficient values (Table 1) we can calculate the volume of water extracted from the river in one minute Vmin, depending on the speed of river v_w for different mounting angles γ of the collector tubes on the rotor circumference (Tables 2-7).

Table 1. Coefficient C depending on the angle γ and the water volume V_2.

γ	15^0	20^0	25^0	30^0	45^0	60^0
V_2	14.64	24.20	27.12	36.24	37.68	40.08
C	1.196	1.979	2.215	2.959	3.077	3.273

Table 2. The volume of water extracted from the river for different parameters: $\gamma = 15^0$, C = 1.196

v_w [m/s] (m/min)	0.3 (18)	0.4 (24)	0.5 (30)	0.6 (36)	0.7 (42)	0.8 (48)	0.9 (54)	1.0 (60)
V_{min} [l]	21.53	28.70	35.88	43.06	50.23	57.41	64.59	71.76

Table 3. The volume of water extracted from the river for different parameters: $\gamma = 20^0$, C = 1.979

v_w [m/s] (m/min)	0.3 (18)	0.4 (24)	0,5 (30)	0,.6 (36)	0.7 (42)	0.8 (48)	0.9 (54)	1.0 (60)
V_{min} [l]	35.62	47.50	59.37	71.24	83.12	95.00	106.87	118.74

Table 4. The volume of water extracted from the river for different parameters: $\gamma = 25^0$, C = 2.215

v_w [m/s] (m/min)	0.3 (18)	0.4 (24)	0.5 (30)	0.6 (36)	0.7 (42)	0.8 (48)	0.9 (54)	1.0 (60)
V_{min} [l]	39.88	53.16	66.45	79.74	93.03	106.32	119.61	132.90

Table 5. The volume of water extracted from the river for different parameters: $\gamma = 30^0$, C = 2.959

v_w [m/s] (m/min)	0.3 (18)	0.4 (24)	0.5 (30)	0.6 (36)	0.7 (42)	0.8 (48)	0.9 (54)	1.0 (60)
V_{min} [l]	53.26	71.02	88.77	106.52	124.28	142.03	159.79	177.54

Table 6. The volume of water extracted from the river for different parameters: $\gamma = 45^0$, C = 3.077

v_w [m/s] (m/min)	0.3 (18)	0.4 (24)	0.5 (30)	0.6 (36)	0.7 (42)	0.8 (48)	0.9 (54)	1.0 (60)
V_{min} [l]	55.39	73.85	92.31	110.77	129.23	147.70	166.16	184.62

Table 7. The volume of water extracted from the river for different parameters: $\gamma = 60^0$, C = 3.273

v_w [m/s] (m/min)	0.3 (18)	0.4 (24)	0.5 (30)	0.6 (36)	0.7 (42)	0.8 (48)	0.9 (54)	1.0 (60)
V_{min} [l]	58.91	78.55	98.19	117.83	137.47	157.10	176.74	196.38

III. The Ram Pump

As is shown in Fig.1 [16], the second main component of this irrigation system is the ram pump (Fig.5). Ramp pump is useful where the water source flows constantly and the usable fall from the water source to the pump location is at least 2 m. In our case this distance is 3, 5 m. The operational principle of ram pump is based on water hammer, effect in the ram to transmit water from lower elevation to a much higher elevation. It has only two moving parts that dictates the whole operation. These are waste valve *B* and the check or discharge valve *C*.

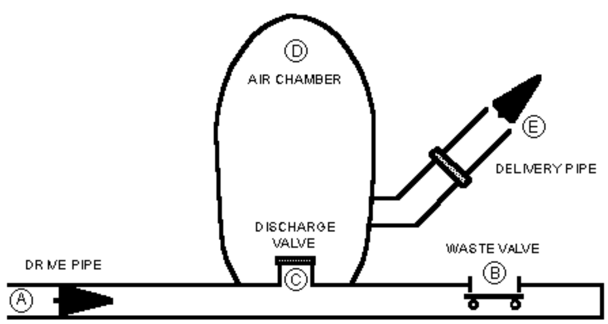

Fig. 5 Schematic illustration of a ram pump

There is an optimum configuration for the ram pump set up. It is a 5 to 1 ratio, where the drive pipe length is five times longer than the vertical fall from the water source to the ram pump. Ideally the drive pipe should have a length of at least 100 times its own diameter. The drive pipe *A* must generally be straight; any bends will not only cause losses of efficiency, but will result in strong fluctuating sideways forces on the pipe which can cause it to break loose. The length of the delivery pipe *E* is not considered in the equation because friction less are normally small due to low flow rates.

The ram pump body requires to be firmly bolted to a concrete foundation, as the beats of its action apply a significant shock load. The ram pump should be located so that the waste valve is always located above flood water level, as device will cease to function if the waste valve becomes submerged.

Its operation is based on converting the velocity energy in flowing water into elevation lift. Water flows from the source through the drive pipe which is the drive tank (Fig.1) and escapes through the waste valve until it builds enough pressure to suddenly close the waste valve. Water then surges through the interior check valve inside the pump body into the air chamber *D*, compressing air trapped in the chamber. When the pressurized water reaches equilibrium with the trapped air, it rebounds, causing the check valve to close. Pressurized water then escapes from the air chamber through a check valve and up the delivery pipe *E* to its destination. The closing of the check valve causes a slight vacuum, allowing the waste valve to open again, initiating a new cycle.

The process occurs over and over again until something happens to stop the cycle. Ram pumps can cycle anywhere from 25 to 300 times per minute. The frequency of the cycle is adjustable by changing the length of the stroke of the waste valve. A longer stroke produces a lower frequency. This means more of the supply flows to and through the pump and more is pumped up the delivery pipe. The stroke is adjusted to restrict the amount of water used to the amount available, or if supply is unlimited, to regulate the amount delivered to match the amount needed.

The ram pump utilizes the inertial energy to pump water to a height greater than the source of the water. It runs all the time, requires no fuel, and needs only minor adjustment and cleaning for maintenance after the initial setup. The ram pump uses much more water than it pumps; it uses the energy of a lot of water to move a portion of it, about 10-15%. Because it is somewhat more involved to set up than a powered pump, a ram pump is generally used only where electricity is to expensive or not available.

The cycle repeats between 20 and 100 times per minute, depending upon the flow rate. If properly installed, a ram pump will operate continuously with a minimum of attention as long as the flowing water supply is continuous and excess water is drained away from the pump.

The location of the water source in relation to the desired point of water use determines how the ram pump will be installed. The length of drive pipe should be at least 5 times the vertical fall to ensure proper operation. The length of delivery pipe is not usually considered important because friction losses in the delivery pipe are normally small due to low flow rates. For very long delivery pipes or high flow rates, friction losses will have an impact on the performance of the hydraulic ram pump.

The relationship between vertical fall (F) and length of drive pipe is given in Table 8.

Table 8. Relation between vertical fall and length of drive pipe.

Vertical Fall [m]	Length of drive pipe [m]
0.9-4.5	5.4-27
4.8-7.5	19.2-30
7.8-15	23.4-45

A ram pump system is designed to deliver the desired pumping flow rate for a given elevation lift. The range of available flow rates and elevation lifts is related to the flow quantity and velocity from the water source through the drive pipe. The mathematical relationship for pumping flow rate is based upon the flow rate through the drive pipe, the vertical fall from the source through the drive pipe, and the vertical elevation lift from the pump to the point of use.

To calculate water delivered by ram pump *D* [l/day] to the delivery pipe is used equation (12), [5]:

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$$D = (S \times F \times E)/L \qquad (12)$$

where: S is the quantity of water supplied in liters per minute, F is the vertical fall [m], E is the efficiency of the ram pump installation (usually 0.6), L is the delivery head [m].

More water can be obtained by installing two or more ram pumps in parallel in tandem if is needed. Each ram pump must have its own drive pipe, but all can pump through a common delivery pipe. In Table 9 is shown the delivery liters per day for different working fall and different delivery head [12].

Table 9. Ram pump performance data for a supply of 1 liter/minute.

Working fall[m]	Delivery head (vertical elevation) during one day											
	5	7.5	10	15	20	30	40	50	60	80	100	125
1.0	144	77	65	33	29	19.5	12.5					
1.5		135	96.5	70	54	36	19	15				
2.0		220	156	105	79	53	33	25	19.5	12.5		
2.5		280	200	125100	66	40.5	32.5	24	15.5	12		
3.0			260	180	130	87	65	51	40	27	17.5	12
3.5				215	150	100	75	60	46	31.5	20	14
4.0				255	173	115	86	69	53	36	23	16
5.0				310	236	155	118	94	71.5	50	36	23
6.0					282	185	140	112	93.5	64.5	47.5	34.5
7.0						216	163	130	109	82	60	48
8.0							187	149	125	94	69	55
9.0							212	168	140	105	84	62
10.0							245	187	156	117	93	69
12.0							295	225	187	140	113	83
14.0								265	218	167	132	97
16.0									250	187	150	110
18.0									280	210	169	124
20.0										237	188	140

IV. Conclusions

The present paper is centered towards the development of a hydraulic ram pump that would conveniently alleviate the problem of water supply to the mass populace. Ideally, different combinations of the supply and delivery heads and flows, stroke length and weight of the impulse valve, length to diameter ratio of the drive pipe, volume of the air chamber and size of the snifter valve, were tried to come up with an optimum size of a ram pump presented in the paper.

This solution presented in the paper can save hours of back-breaking work carrying water and cash where expensive water pumps are replaced. As long as is free water and we have or can create at least two meters drop, the installation is best suited option compared to fuel, wind or solar operated pumps.

The benefits of working with this installation are:

- It puts an end to children and women carrying heavy water jugs to and from the spring;
- Its time saving;
- It improves general health of the villages;
- It males laundry washing near the houses possible;
- Fishponds become possible, as well as vegetable growing, and animal husbandry.

Some of the advantages of installing this system of obtaining water are listed below:

- Zero pollution;
- Operates 24 hours a day, 7 days a week without supervision;
- Pumps 20+ more its own falls with the record of 200 meters up without a motor;
- No fuel or electricity cost;
- Low maintenance and repair cost;
- Repairs are done locally;
- Installation is up to 80% cheaper than other water system models;
- Local manufacturing and training generates employment.

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B. Lepadatescu is associate professor at „Manufacturing Engineering" Department, Faculty of Technological Engineering and Industrial Management, Transilvania University of Brasov. He received a Ph.D. degree in Industrial Engineering from Transilvania University of Brasov in 1999 and a M.Sc. in Quality Engineering, with 40 years experiences in the fields of renewable resources valorization, reliability engineering, industrial project management, manufacturing, quality and environment management system implementation. He published over the 130 papers in prestigious international and national journals, and at international conferences in the field of design and manufacturing engineering, from which 19 papers in the field of renewable energies.

He finished over 40 research contracts with prestigious industrial factories from Romania, as researcher engineer in the field of manufacturing technologies. He is member of the Center for Scientific Research of "Technological Development System" (CCSDeTInfo) of the Transilvania University of Brasov, member of Scientific Research Center "Advanced Technologies and Manufacturing Systems".

From the researche activities in the field of renewable sources of energy we can note some of them as :

- Design and execution of a horizontal axis wind turbine for extracting water from the river Danube ;
- Design and execution of a vertical axis wind turbine 1000 W ;
- Design and execution of an installation to extract water from the river using only the energy of river water, used in irrigation.

Also, he obtained the Winner of Excellences Prize for scientific research and international recognition offered by "Transilvania" University in 2010

A.E. Dumitrascu is currently an senior lecturer and quality management responsible of „Manufacturing Engineering" Department, Faculty of Technological Engineering and Industrial Management. She received a Ph.D. degree in Industrial Engineering from Transilvania University of Brasov in 2005 and a M.Sc. in Quality Engineering, with 14 years experiences in the fields of renewable resources valorization, reliability engineering, industrial probability and statistics, industrial project management, manufacturing, quality and environment management system implementation. Member of the Center for Scientific Research of "Technological Development System" (CCSDeTInfo) of the Transilvania University of Brasov, NURC recognized center, member of Scientific Research Center "Advanced Technologies and Manufacturing Systems". The scientific activities consists of publication as author and coauthor of 146 scientific papers (128 scientific articles, 11 books), 7 research grants - one as project manager, and co-organizer of several international conferences.

A. Nedelcu is Head of Department for Continuing Education, "Transilvania" University of Brasov, Ph.D. supervisor in the domain of Industrial Engineering and Management. Professional experience was performed within the innovative manufacturing engineering, CAD/CAPP/CAM systems, Reverse Engineering. Also is member of Manufacturing Romanian Association and Center for Scientific Research of "Technological Development System" (CCSDeTInfo) of the Transilvania University of Brasov, NURC recognized center, member of Scientific Research Center "Advanced Technologies and Manufacturing Systems". He published over the 200 scientific papers and he participated as project manager or member in international and national grants.