Design, Installation of a Snowmelt Lysimeter and Analysis for Energy Mass Balance Model Studies In Turkey

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ABSTRACT

Accuracy of the snowmelt models is assessed based on the capability of reproducing an existing hydrograph. It is clear that considering the entire model parameters and components only in the hydrograph and judging them with it would not be sufficient. Dividing the snowmelt model into two parts, the first being the snowmelt component and the second the river runoff is more logical.

Snowmelt lysimeters collect and measure the melt water that is released from the snow pack. The recorded data are very valuable for formulation of snowmelt module of a snowmelt runoff model provides a more sound physical background for the snowmelt modeling.

Turkey has high mountains with rich snow storage in the eastern region that feed the Euphrates and Tigris Rivers, however the snow studies in this region has been lacking. In this paper the installation of a snowmelt lysimeter, which is invaluable for snowmelt modeling, is explained. The released water from snow pack is evaluated on hourly and daily basis and compared with rain and snow water equivalent values. This work is a part of an operational snowmelt modeling study performed in the region related with the analysis of physically-based snow processes using the energy-mass balance of the snowpack which also includes the design, installation and operation of other related automated recording sensors and meteorological instruments.

Keywords: snowmelt lysimeter, operational snowmelt modeling, Turkey

INTRODUCTION

In most snowmelt runoff models, testing and calibration are performed for the entire model based on the reproducing an existing stream flow hydrograph. It is believed that the careful evaluation of the model components will lead to a stronger physical base for the model under study.

Water release from the base of the snow pack is an attractive observation to use for model evaluation since it serves as the output of the snow routine and the input of the runoff production routine. Snow lysimeters have been used to provide a physical measurement for testing models of snow pack energy balance and/or melt water production (Kattelmann, 2000).

Snow pack outflow and the snowmelt at/or near the snow pack surface are the two concepts that are misunderstood. Snowmelt lysimeters collect and measure the liquid water outflow originating from the bottom of snow pack, thus they are the excellent tools for satisfying the snowmelt timing and volume requirements of snow melt studies.

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Turkey, having high mountains in the eastern part of its country has the enough snow storage for water usage. However snow studies in this region has been delayed for some reason or another. In this paper, the installation of a snowmelt lysimeter that is located within an automated meteorological and snow pillow station and which is a part of an ongoing project related with the snowmelt in the aforementioned area, is explained (Sorman et al., 2002). The melt water released from the snow pack is evaluated for snow model studies.

COMPONENTS OF A SNOWMELT LYSIMETER

The main components if a snowmelt lysimeter are a collector, a flow measuring device and a pipe that links two together. The collector can be surrounded by either a raised rim (unenclosed lysimeter) or by a barrier that completely isolates a column of snow (enclosed lysimeter).

Most of the snow lysimeters have been in the form of unenclosed kind (Figure 1a). Water within the area of the lysimeter percolating below the top of the rim will be captured and measured. Above the top of the rim, water is free to flow into or out of the column of snow directly above the lysimeter. Enclosed lysimeters (Figure 1b) trap all of the water percolating through the snow directly above the collection container. Enclosed lysimeters may have an adjustable barrier height to accommodate the natural development of the snow pack or may be of fixed height and artificially filled with snow (Kattelmann, 1984)

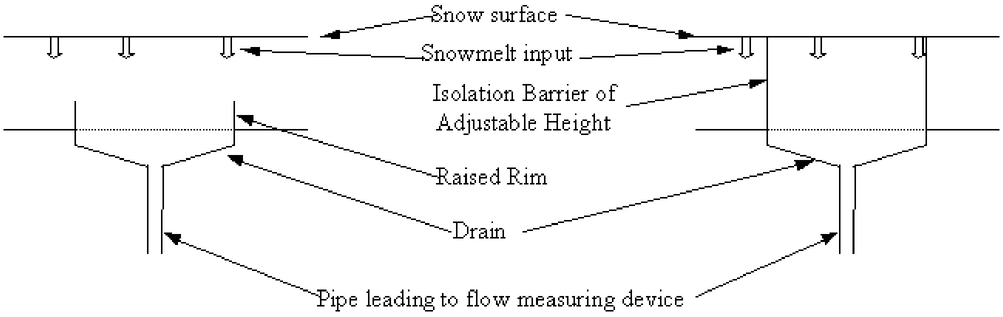

Figure 1a
Unenclosed snowmelt lysimeter

Figure 1b
Enclosed snowmelt lysimeter

SNOWMELT LYSIMETER DESIGN

Before the formation of the snow pack, the collector either enclosed or unenclosed is placed on the ground surface. Impermeable collectors varying from 1m^2 to 100 m^2 in area are the most common. The water amount received by the measuring device may not be the same amount as water input at the snow surface. This is due to the possibility of the lateral inflow and/or outflow that may occur within the snow pack above the collector. The volume of lateral flow is variable within and between the seasons. As the area of the collector is increased, the possibility of balancing the lateral inflow and outflow is increased.

DESIGN CONSIDERATIONS

Designers of new installations should consult available literature and users of snowmelt lysimeters for critical details, but they should also experiment with fresh approaches (Kattelmann, 2000). Although the design considerations are usage specific and site dependent, the general rules which can be found in literature and those that can be thought as rule of thumb will be discussed in the following sections.

Collector area and quantity:

The area of the lysimeter collector must be adequate to obtain a representative sample of melt water flux (Kattelmann, 1984). Male and Gray (1981) proposed that as a rule of thumb for the dimensions of the snow melt lysimeters the area of the lysimeter should be greater than the square of the snow pack depth. In numerous studies it is seen that the above rule holds true for a number of performed studies (Kattelmann, 2000). Rims varying 10 to 15 cm high around the collector/snow interface for the unenclosed lysimeters is essential for accurate monitoring of the flux at the level of the interface (Kattelmann, 1984).

Site selection:

Site selection is also closely related to the installation objectives. It is a fact that the smooth, nearly level terrain provides the easiest working conditions. However, a gentle slope may also enable easy drainage of the collector area.

Outflow measurements:

Among the several methods, the simplest is the manual one, which is not a solution for an operational snowmelt modeling. The combination of collection tank, a water level recorder, an automatic drain and/or a siphon are common ways to measure the melt rate. Tipping bucket recorders, either from precipitation gages or custom built, have been used successfully with many lysimeters (Kattelmann, 1984). Lastly but not the least, the reliability of the measuring system is the most important thing to be cared for.

Construction and Installation:

Any impermeable material having the ability to withstand the moisture, cold and pressure can be used as a collector. Low cost of the plastics made them the best candidate for usage in large area collectors. The material used should be able to carry the expected maximum snow load.

During the construction, the drain of the collector should be at the lowest position even loaded with snow. The drain should be free of debris that may prevent the flow. Using large diameter pipes and adequate sloped layout can be a solution to the freezing possibility of the drainage.

Testing:

Checking the lysimeter for the leakage before the usage is very important. Anecdotal information from the installers of the equipment is also useful in apprising new users of the data of the specific limitations of the snowmelt lysimeters (Kattelmann, 2000). In this sense, photographs taken during the construction would be helpful for the new lysimeter designs and for determining problems and repairing the equipment when the lysimeter is under snow.

CASE STUDY FOR DATA ANALYSIS

Based on the discussions above, a snow lysimeter was designed, constructed and built in place in Guzelyayla Automatic Snow Pillow and Weather Station in September of 2002. The Guzelyayla station (latitude: 40^{o} 12’ North, longitude: 41^{o} 28’ East, elevation: 2065m) is located within the Karasu basin. Karasu Basin is located in Eastern part of Turkey and has an area of 10215.7 km^2. The elevation changes between 1125m and 3478m within the basin. The terrain in the study area is rugged and mountainous. Land cover of the basin can be classified as shrub, grass and bare land. Basin includes the Karasu River which is one of the major contributions to Keban Dam on Euphrates River. The 60%~70% of the total annual volume of the Karasu River comes during the snowmelt period (Tekeli, 2000). The location and a general view of Guzelyayla station and the built snow lysimeter are illustrated in Figures 2, 3 and 4 respectively.

The unenclosed snowmelt lysimeter was constructed from a 120 cm x 200 cm galvanized steel sheet having a thickness of 2 mm. A 15cm wide rim was left along the sides of the steel sheet. After leaving 15 cm rims, the net dimensions of the lysimeter are reduced to 90 cm x 170 cm. This yielded an area of 1.53 m^2. The square root of the net area is 124 cm which is larger than the maximum snow depth observed at the site (61 cm for the winter season of 2003), satisfying the rule of thumb described in collector area and quantity section. Although it was designed as an unenclosed one, the lysimeter was placed so that the lateral flows intrusion into the lysimeter will be minimized. As it can be seen from the Figure 4, the three sides of the lysimeter are open and lysimeter is about 50 cm above the ground surface. This definitely will not prevent but it will at least reduce the lateral flows (Tekeli, 2002).

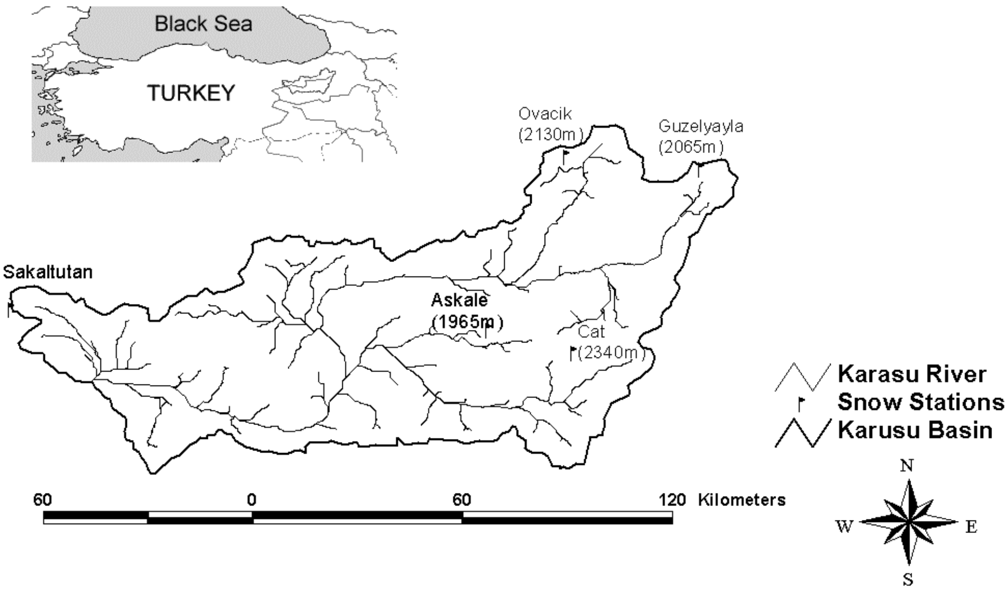

Figure 2: General overview of the Karasu – Upper Euphrates Basin and Location of the Automated Snow Pillows and Meteorological Station.

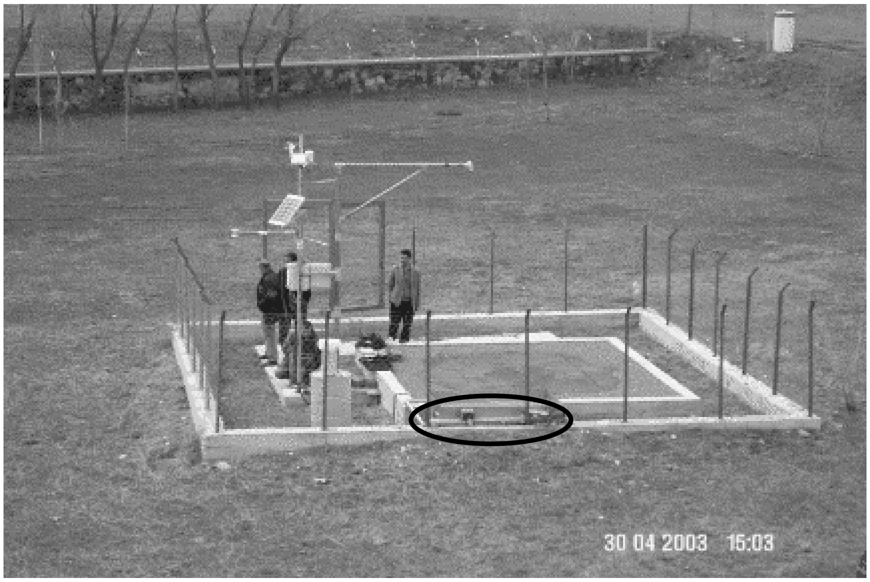

Figure 3: General overview of Guzelyayla Automatic Snow Pillow and Automatic Weather Station (Circle indicates the location of the snowmelt lysimeter).

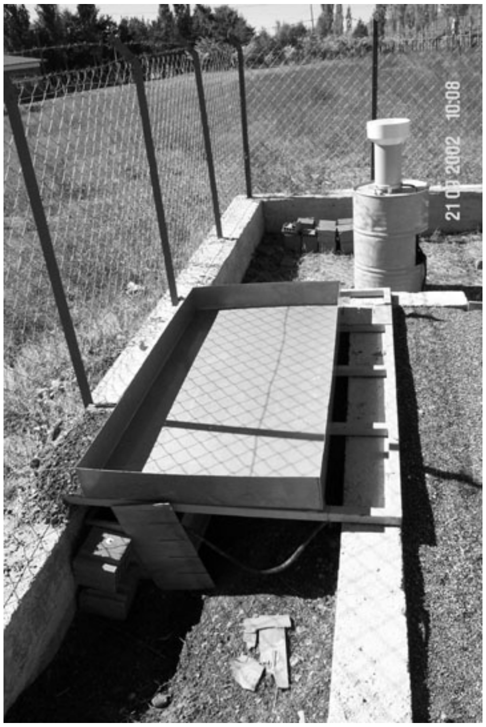

Figure 4: Snowmelt Lysimeter at Guzelyayla Station.

The outflow from the snowmelt lysimeter is measured with a tipping bucket type rain gauge collector placed at the bottom of the lysimeter outlet opening (Figure 5). This hopefully prevents the problematic cases arising from frozen pipes. The output from the tipping bucket is transmitted to the data logger via cable to store the melt of snow as yield. The data stored in the data logger is transferred via satellite to the main office in Ankara.

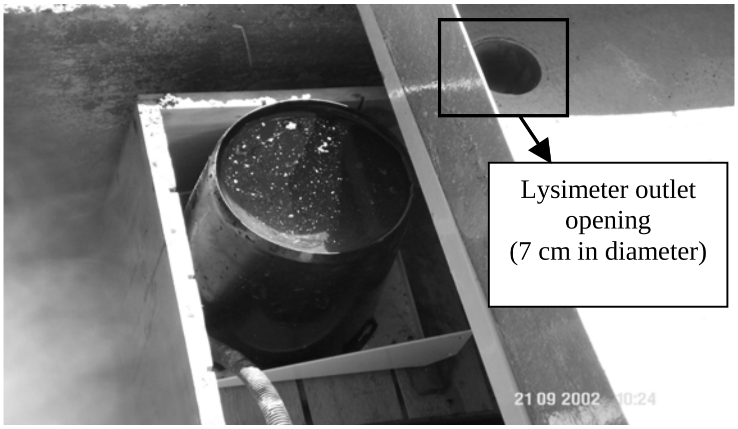

Figure 5: Tipping Bucket Type Rain Gauge Collector to measure snow melt rate.

DISCUSSION OF RESULTS

The results are discussed under three different sub headings as listed below based on the data recorded during the winter period of 2003.

a) Rainy period when there is no snow
b) Rainy and non-rainy period when there is snow at the melting period
c) Melt rate comparisons between event types

a) Rainy period when there is no snow (September and November 2002)

The precipitation is recorded by a tipping bucket type rain gauge at the Guzelyayla station (Figure 6), which is also connected to a data logger, logging precipitation depth and intensity. So, in the absence of snow, the snowmelt lysimeter acts as a classical tipping bucket rain gauge.

Figure 6: Tipping Bucket Rain Gauge.

This behavior was proven with data during the period from September to November 2002. There is a good agreement of rainfall data measured from both of the sensors, lysimeter and the rain gauge (Figure 7).

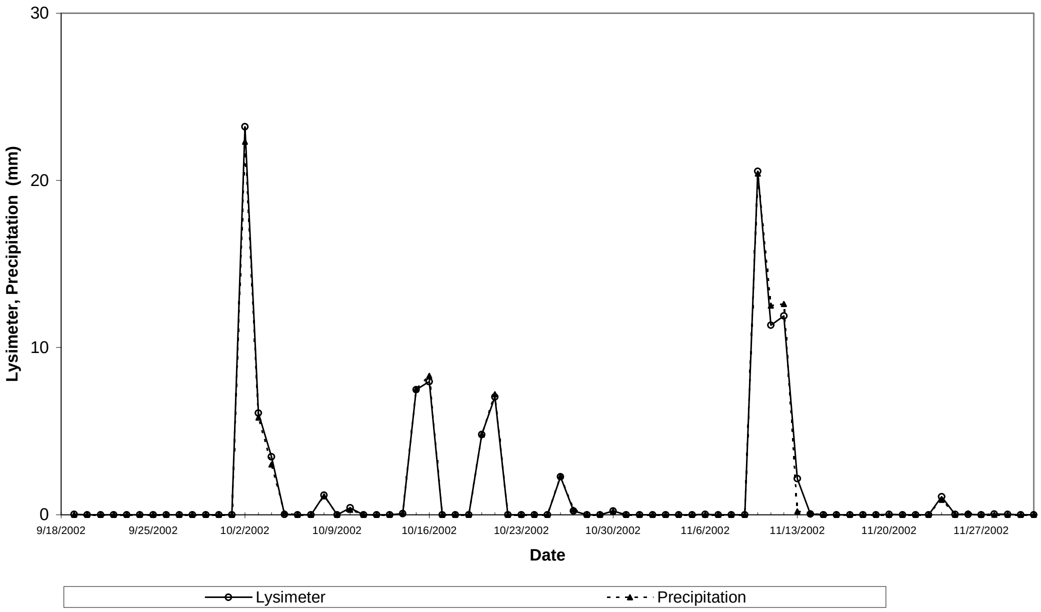

Figure 7: Comparison of Data Recorded by Snowmelt Lysimeter and Rain Gauge at Guzelyayla Station.

The rain amounts collected by both sensors and their differences are given in Table 1. As it can be seen from the table, the differences are at a negligible amount. This proves that both of the sensors are working well before snowfall period of 2003.

Table 1. The Cumulative Rain Depth by Lysimeter and Rain Gauge.

Duration	Lysimeter	Rain Gauge	Difference
	(mm)	(mm)	(mm)
Oct-02	64.44	63.3	1.14
Nov-02	47.22	46.8	0.42

b) Rainy and non-rainy period when there is snow at the melting period (April 2003)

Before describing the analysis of the rainy and non-rainy periods of the snowmelt season, it was surprising to see, and important to note, that the total melt depth recorded by the lysimeter (168 mm) was almost equal to that of the maximum recorded snow water equivalent (177 mm) on the snow pillow as shown in Figure 8.

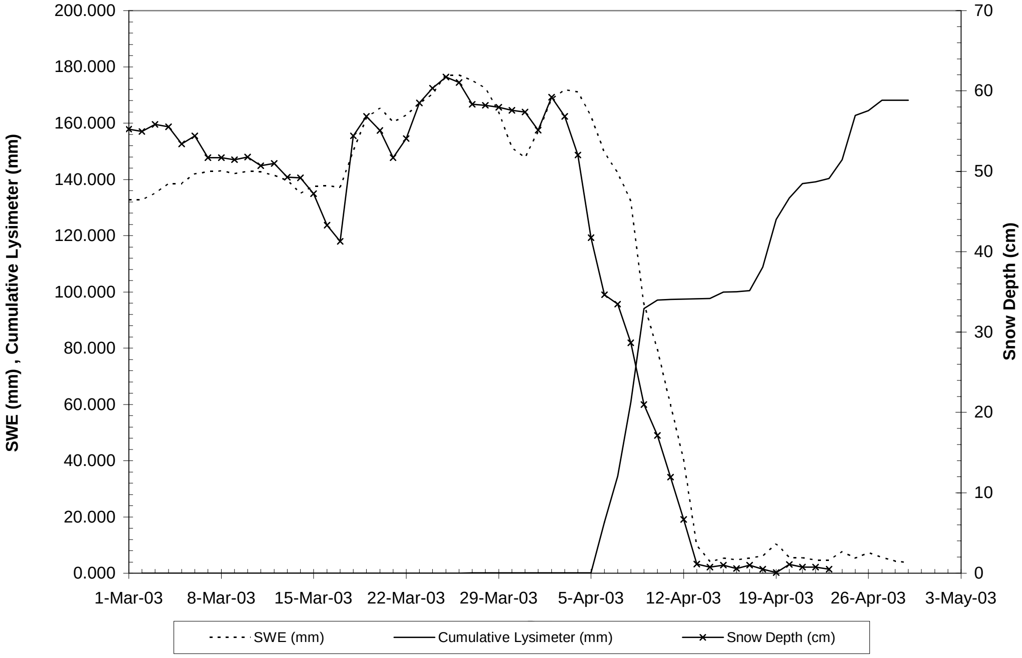

Figure 8: The Change of Snow Water Equivalent and Snow Depth and Cumulative Snowmelt Lysimeter Outflow Data in Guzelyayla Station.

It was more surprising to see the agreement between the lysimeter data and the discharges measured at the basin outlets at both the small and large scales. The small scale discharges were obtained from the discharge measurements performed at Kirkgoze gauging station (243 km^2 area) and those at the large scale were obtained from the discharge measurements coming into reservoir of Keban Dam (67 500 km^2 area). The locations of the discharge measurement stations are shown in Figure 9 and the good correlation in time series between the lysimeter outflows and the measured discharges can be seen in Figure 10. The peak discharges are also marked on lysimeter data records to illustrate the matching trend at the end of each melting stage.

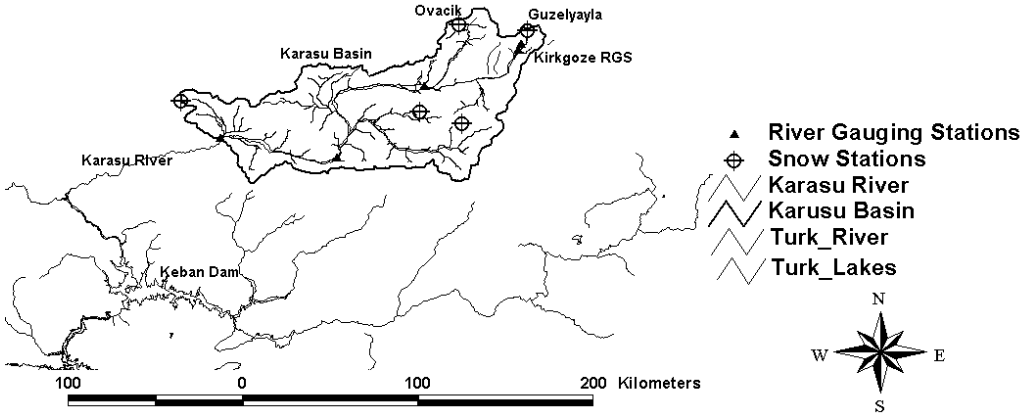

Figure 9: Keban Dam site and runoff stations for small and large basins. Kirkgoze (small) is very near to Guzelyayla Station and Keban Dam (large) is far downstream from the basin.

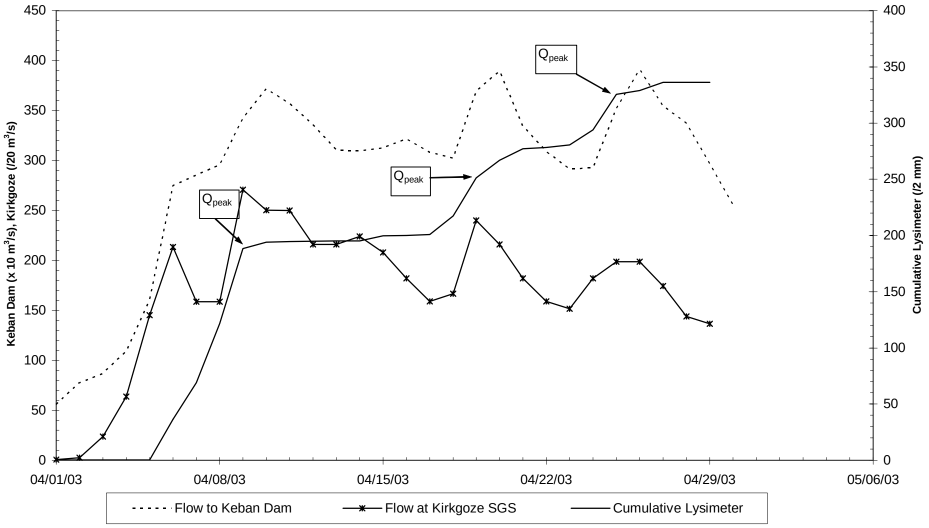

Figure 10: The Relationship Between the Discharge Measurements, Peak Values and the Lysimeter Data.

In snow melt period during April 2003, the volume of snowmelt runoff computed at these two runoff-measuring stations, Kirkgoze (21-01) and the Keban Dam reservoir is 21.7x10^6 m^3 and 7422x10^6 m^3 respectively. During this same period 177 mm of maximum SWE completely melted in Guzelyayla automatic weather and snow pillow station.

Based on meteorological observations, April 2003 can be divided into six events of three major event types; rain on snow (ROS), pure snow melt (SM), and rain (R) as is illustrated in Figure 11

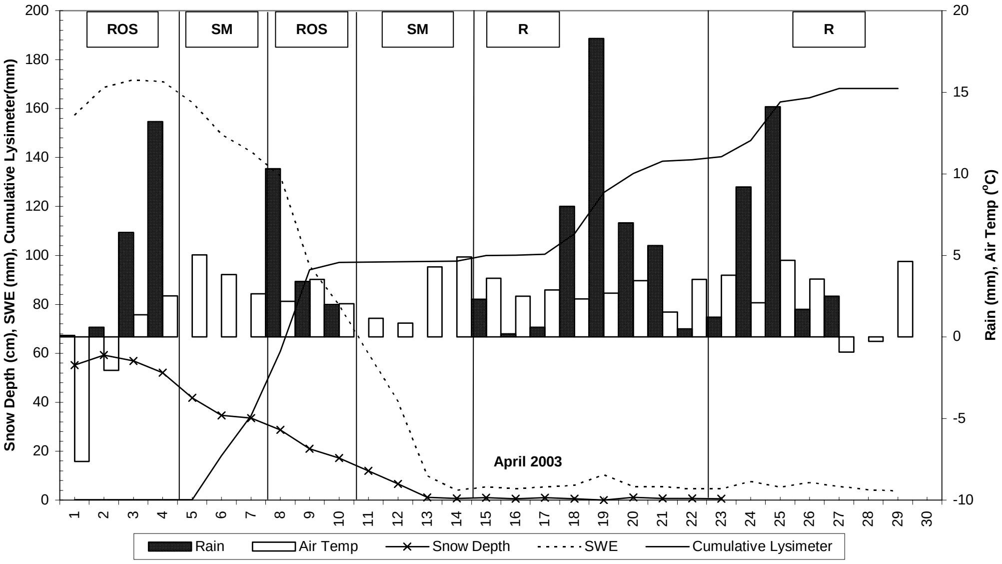

Figure 11: The Change of Snow Depth, SWE, Lysimeter daily summation, temperature and rain at Guzelyayla Station for April 2003.

It is easy to see that the last two events (14-28 April 2003) are purely rain since the change in the lysimeter depth is equal to the rainfall depth in the respective two periods and the snow depth is zero and SWE is nearly zero. This can also be seen in Table 2.

After observing the rainy periods we can concentrate more on the snow melt periods with and without rain.

Snow melting without rain can be seen for the time period defined as SM in Figure 11. At this time, a significant reduction in the snow water equivalent is observed. However, the lysimeter does not indicate any significant yield. This case is in agreement with the discharge measurements at two different locations shown in Figure 10. It is seen in Figure 10 that as the lysimeter reading parallels the time axis, indicating no yield, the discharges begin to recess.

Table 2. The verification of the Pure Rain Events.

	Cumulative Lysimeter (mm)	Daily Lysimeter (mm)	Rain (mm)		**Change In Lysim**	**Total Rain**	**Difference**
04/14/03	97.6		0		**(mm)**	**(mm)**	**(mm)**
04/15/03	99.9	2.2	2.3	**Rain Period 1**	**41.4**	**42.5**	**-1.1**
04/16/03	100.1	0.2	0.2				
04/17/03	100.4	0.4	0.6				
04/18/03	108.7	8.3	8.0				
04/19/03	125.7	16.9	18.3				
04/20/03	133.4	7.7	7.0				
04/21/03	138.5	5.2	5.6				
04/22/03	139.1	0.5	0.5				
04/23/03	140.3	1.2	1.2	**Rain Period 2**	**29.1**	**28.7**	**0.4**
04/24/03	147.0	6.7	9.2				
04/25/03	162.8	15.8	14.1				
04/26/03	164.4	1.6	1.7				
04/27/03	168.1	3.8	2.5				
04/28/03	168.1	0.0	0.0				

This case can be explained by examining the change in daily maximum, minimum and average temperatures shown in Figure 12. The snow pack that melts in the warmer hours of the day causes a reduction in the SWE, while at other times the melt water is trapped in the ice layers within the snow pack and it refreezes in the colder hours during the day. The negative temperatures in Figure 12 (dashed lines with stars) cause stratified ice layers within the snow pack and refreezing of the melt water

The Rain on Snow (ROS) event is the most complex type of melting in snow modeling studies. This event can best be seen in the days of April, 8, 9 and 10 which correspond to Julian dates 98, 99 and 100 respectively. When the two hourly data are examined the combined rain and snow-melting event is better seen. In Table 3 showing a 24 hour period on 8 April 2003, it is clearly seen that the snow melts during the day, mostly between 10:00 and 16:00. As the precipitation is also occurring, the water amount recorded by lysimeter is larger than the amount of measured by the rain gauge. The amount measured by the lysimeter, which is in excess of precipitation, is due to snow melting. This is a typical rain on snow process. Similar cases can also be seen for April 9 and 10, 2003 in Table 4 and Table 5 respectively.

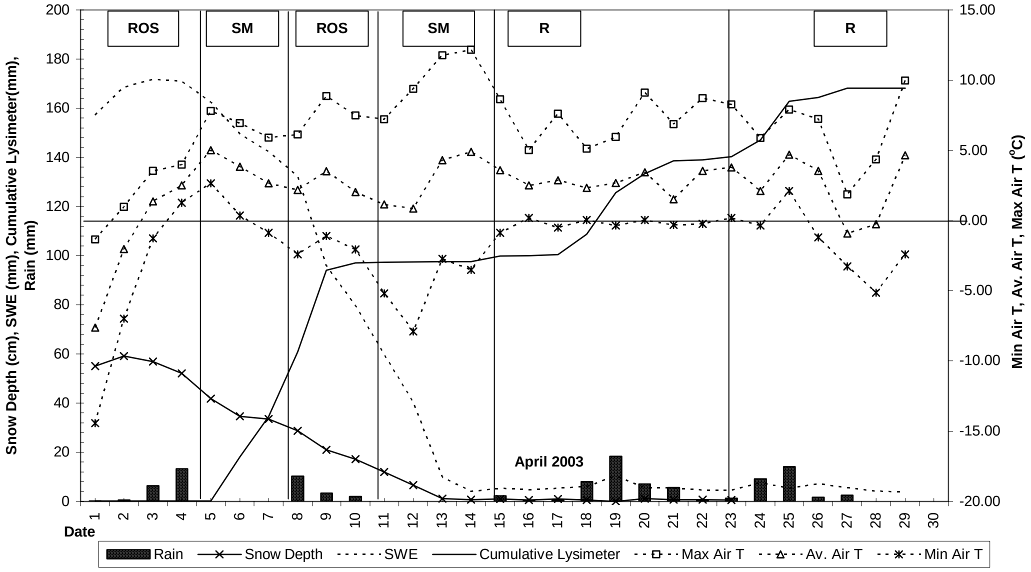

Figure 12: Lysimeter does not indicate any yield even when the SWE reduces. This is attributed to the diurnal variation of temperature.

Table 3. Rain on Snow event on 8 April 2003.

Day	Time	Lysimeter (mm)	Rain (mm)	Difference Lys-Rain (mm)	Snow Depth (cm)	SWE (mm)
98	200	0.0	0.0	0.0	33.3	142.5
98	400	0.0	0.0	0.0	33.4	141.8
98	600	0.0	0.0	0.0	33.1	138.6
98	800	0.4	0.0	0.4	32.1	136.2
98	1000	4.8	0.0	4.8	30.9	139.1
98	1200	5.2	1.0	4.2	30.4	137.9
98	1400	3.4	0.5	2.9	29.3	135.0
98	1600	1.5	0.1	1.4	29.9	132.4
98	1800	1.2	0.1	1.1	29.9	131
98	2000	1.5	1.0	0.5	30.2	130.3
98	2200	2.8	2.9	-0.1	29.1	130.3
98	2400	5.6	4.7	0.9	28.5	132.1

Table 4. Rain on Snow event for April 9, 2003.

Day	Time	Lysimeter (mm)	Rain (mm)	Difference Lys-Rain (mm)
99	200	3.1	2.3	0.8
99	400	1.6	1.0	0.6
99	600	0.4	0.1	0.3

Table 5. Rain on Snow event for April 10, 2003.

Day	Time	Lysimeter (mm)	Rain (mm)	Difference Lys-Rain (mm)
100	1000	2.8	0.5	2.3
100	1200	0.1	0.0	0.1

c) Melt rate comparisons between event types

Air temperature and snowmelt lysimeter outflow in the month of April 2003 are shown in Figure 13 and the rain and snowmelt lysimeter outflow comparison are illustrated in Figure 14.

A typical snow melting without rain is seen on 6 April 2003. The lysimeter outflow rate is seen to vary from 1.5 mm/hr to 3.7 mm/hr. The maximum lysimeter outflow rate is recorded as 4.6 mm/hr for the rain on snow in 9 April 2003 at 12:00.

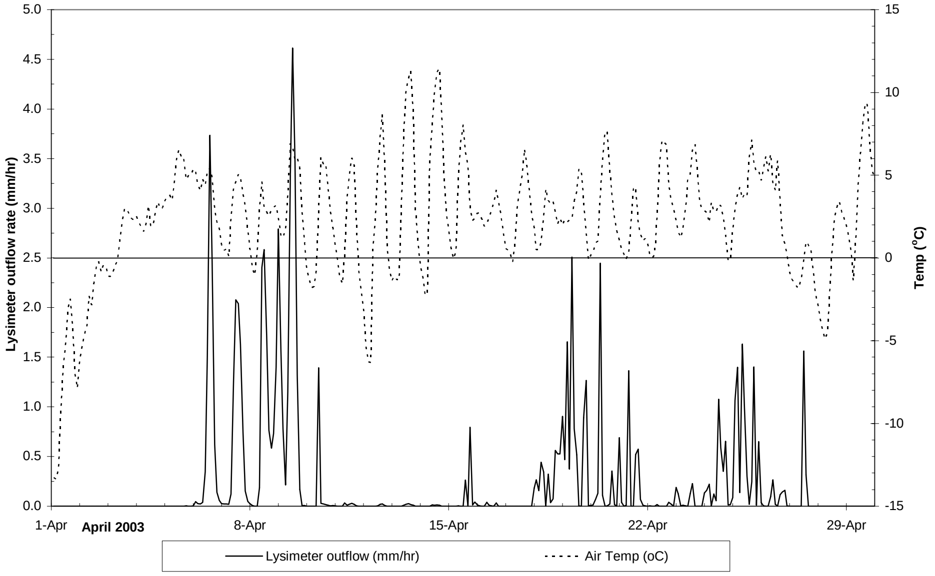

Figure 13: Air temperature and snowmelt lysimeter outflow in April 2003.

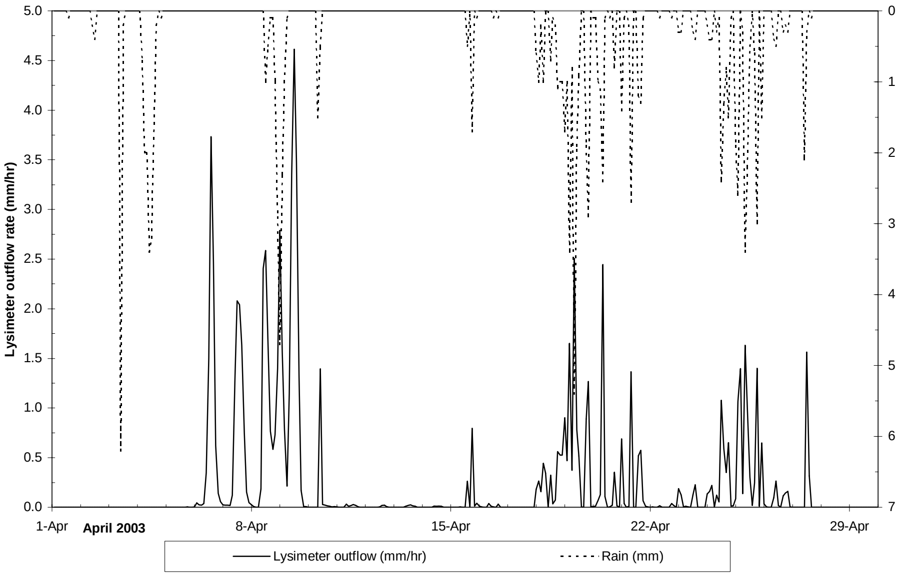

Figure 14: Rain and snowmelt lysimeter outflow in April 2003.

The computed flow rates are in good agreement with the findings of frequency modulated continuous wave radar of Albert et al (1999). In their research, it is found that the average number of flow channels within a snow pack varied from 3 to 5 /m^2 of lysimeter area, and the average flow through each flow finger was found to vary form 0.3 to 0.5 mm/channel/hour. Their findings led to a result as 0.9 mm/hour/m^2 as the minimum and 2.5 mm/hour/m^2 as the maximum lysimeter outflow rate. Since the installed lysimeter in this study has an area of 1.53 m^2, the expected minimum and maximum outflow rates can be computed as 1.38 mm/hr and 3.83 mm/hr respectively. Comparing these with on site observed outflow data, 1.38 mm/hr is less than 1.5 mm/hr. This satisfies the minimum criteria. Where else the maximum melt rate, 4.6 mm/hr that was observed in April 9, 2003 is larger than the 3.83 mm/hr observed by Albert et al. (1999). But the quoted sentence from the same reference clarifies this difference; “Clearly, the amount of water that each finger transports is governed both by micro-structure dynamics and by the amount of melt water available for transport, so this value may change in time, and more can be learned from more intensive testing” (Albert et al, 1999). The values are still in the range indicated by lysimeter studies performed in Central Sierra Snow Laboratory, where the maximum melt rates were found as 15 mm per hour for clear weather melt and 50 mm per hour for rain on snow conditions (Kattelmann, 1984).

CONCLUSIONS AND RECOMMENDATIONS

Based on the experience gained in winter of 2002-2003, a larger size snow lysimeter (Area > 1.53 m^2) is planned to be installed at a higher altitude (2130 m) at the Ovacik station (Figure 2) where similar snow and meteorological records are continuously collected. The larger area of Ovacik lysimeter will help eliminate the variability in the snowmelt outflow rate, since Figure 15 clearly shows the lysimeter area effect on the coefficient of variation of the melt water outflow rate.

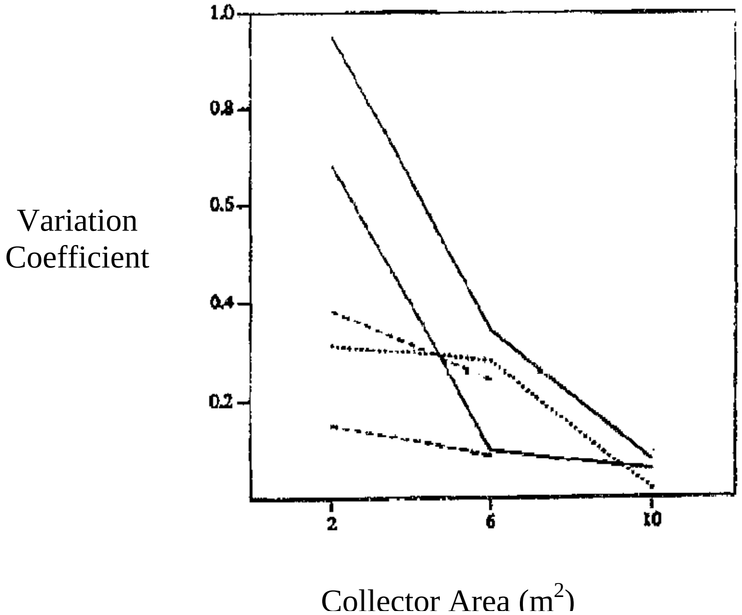

Figure 15: The area effect on the variability of the measure melt water outflow rate (Each line represents a different year, (Kattelmann, 2000)).

Figure 16 shows the SWE graph of the above-mentioned station in comparison with Guzelyayla station (2065 m).

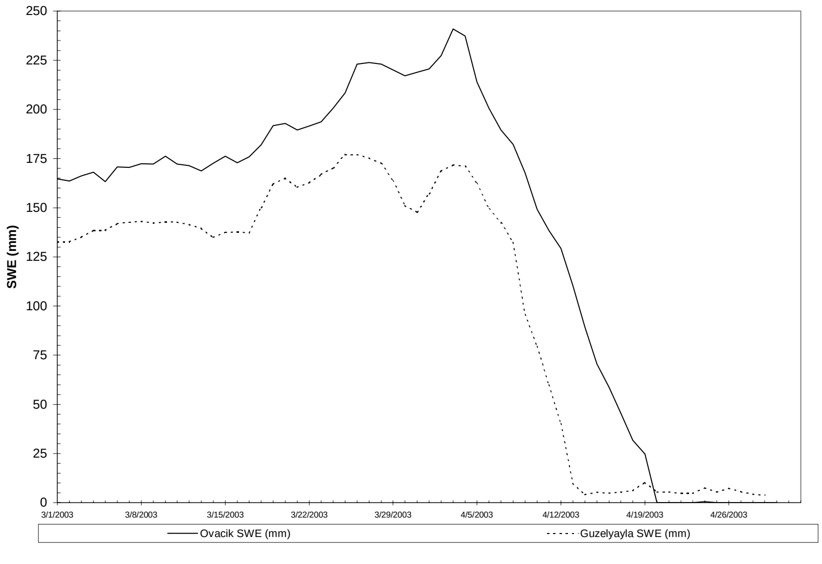

Figure 16: SWE variations in Ovacik and Guzelyayla stations during March-April 2003.

With the all above discussed issues, rain on snow and pure melting processes can be studied further in order to solve the energy mass balance approach and the temperature index methods. The advective heat flux due to rain in addition to net radiation flux (due to temperature and solar radiation) during melting can be solved to determine the positive internal energy within the snow pack that results in snow melting. The outputs of the both modeling approaches, temperature index and energy mass balance, will give runoff as a yield. The model calibration and its verification can be done using the lysimeter records, which provide valuable information as the actual rate of melt and volume in accumulated time increments. The related studies are still in progress which will be ready for publication in later studies.

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