# Streamflow analysis for the Yana basin in eastern Siberia

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**Abstract** We analyse Yana River streamflow and climate data in order to understand climate change and its impact on basin hydrology. Basin temperature and precipitation records show little change during 1977–1999. Discharge data near the basin mouth suggest changes (increase and decrease) over the summer months. Basin precipitation has a positive correlation with discharge during June, July and August. The relationship between snow water equivalent and discharge follows an inverse relation; maximum snow water equivalent and discharge have a linear relation, with inconsistencies in some years. Further examination is needed to improve this relationship. The results of this study are useful for a better understanding of the hydrological regime and changes over the northern regions.

**Key words** Yana River, Siberia; discharge; snow cover

## INTRODUCTION

Arctic climate and hydrology have changed significantly in the past decades. Recently we have studied hydrological regimes and changes over the Kolyma and Lena basins in order to quantify and understand human impact and climatic effects on regional hydrological changes (Yang *et al.*, 2003; Ye *et al.,* 2003; Majhi *et al.,* 2008). The Yana basin lies in eastern Siberia and drains into the Mesozoic continental collisional/accretionary zone of very complex geology. This region has a mountainous topography with the Verkhoyansk Range reaching 2000 m. The Yana River is an average sized basin along the coast of the Arctic Ocean. It has a drainage area of 238 000 km$^2$ (Fig. 1), a length of 1073 km (Huh *et al*., 1998), and annual discharge of 34 km$^3$/year. There are no dams in the basin, which has a low population density. It thus provides ideal conditions to examine the effect of climatic variation on streamflow changes. The objective of this study is to better understand factors affecting discharge and its changes. We examine streamflow change and its relation with climatic variables, such as precipitation, temperature and snow cover. The results of this analysis will improve our understanding of hydrological response to climate change in the northern regions.

## DATA AND METHODOLOGY

The Russian Federal Service for Hydrometeorology and Environment (Roshydromet) has monitored discharge of Russian rivers since the early part of this century. The discharge data for this study were obtained from the University of New Hampshire (www.r-arcticnet.sr.unh.edu). Stage height readings were made daily and cross-channel measurements of discharge were made 25–30 times for a rating curve. Estimates of daily discharge from the rating curves were accurate to ±5% (Shiklomanov, 2000). Discharge data are available over various parts of the basins; this analysis focuses on the basin scale. We use monthly and daily flow data collected near the mouth of the river during 1972–1999.

Passive microwave remote sensing in recent years has provided the ability to monitor various features of the Earth's atmosphere and surface, including snowpack properties. A previous study was done on snow covered area for the Lena basin (Yang *et al.,* 2003). A special sensor microwave imager (SSM/I) on the US Defense Meteorological Satellite Program (DMSP) has a daily temporal and good spatial coverage for most areas, which is an important feature for snow pack monitoring. The SSM/I data are from a seven channel microwave radiometer, which has dual polarized channels at 19, 37 and 85 GHz, and a vertically polarized channel at 22 GHz (Hilburn *et al*., 2010). The daily SWE data were compiled by the University of New Hampshire from 1987 to

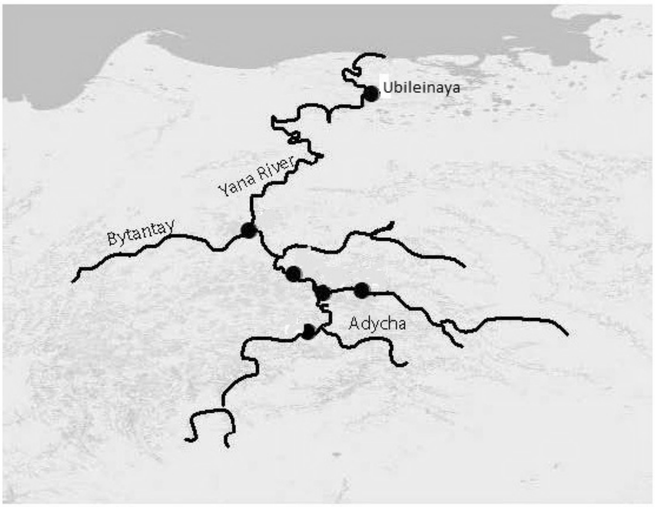


**Fig. 1** Yana basin with all the stations listed from downstream to upstream.

2003, and are available through their website (www.r-arcticnet.sr.unh.edu). We use these data for snow analysis in this study.

The results of the analysis can be briefly summarized in three parts. First we define the climatic regime and change, using monthly precipitation and data. In the second section, we quantify the discharge regime and change at monthly and annual timescales over the basin. Finally, we compare the snow water equivalent and discharge data at various time scales, in order to examine their compatibility and the effect of SWE change on discharge.

## RESULT AND DISCUSSION

### Basin climatology

We analysed temperature and precipitation data for the Yana basin during 1972 to 1999 – a common data period for this study. The mean annual temperature ranged from –14°C to –18°C. The cold temperature is characteristic of regions with continuous permafrost. The basin has a long cold season of eight months, with temperatures ranging from 0°C in September to around –1°C in May. The coldest month is January, with a mean monthly temperature of –45°C. The brief warm season has a temperature range of 9°C in June to 8°C in August; July is the warmest month with a mean temperature of 12°C. Both the seasonal variation and the linear trend have low values.

Mean annual precipitation over the basin ranged from 171 mm to 300 mm, with an average of 217 mm. Trend analysis of the precipitation data showed no significant change for any month; the highest change was for July, about 4 mm during 1972–1999. The rest of the months had very low trend. The month with the most significant trend was April, with an α value of 0.03. It is interesting to note that the precipitation changes are mostly during the winter months, except for August. We compared the relationship between precipitation and temperature during 1972–1999, and found that they were strongly correlated, and significant at an α value of ±0.05 for a few months. The winter months (October to April) showed positive correlations, implying warmer temperatures associated with higher precipitation.

### Basin hydrology

The Ubileinaya station, situated on the main river valley, (70.77°N, 136.08°E) (Fig. 1), is the closest station to the basin outlet. It has a drainage area of 224 000 km$^2$, with a mean annual flow of 1020 m$^3$/s from 1972 to 1999. The highest discharge takes place in June (4300 m$^3$/s), followed

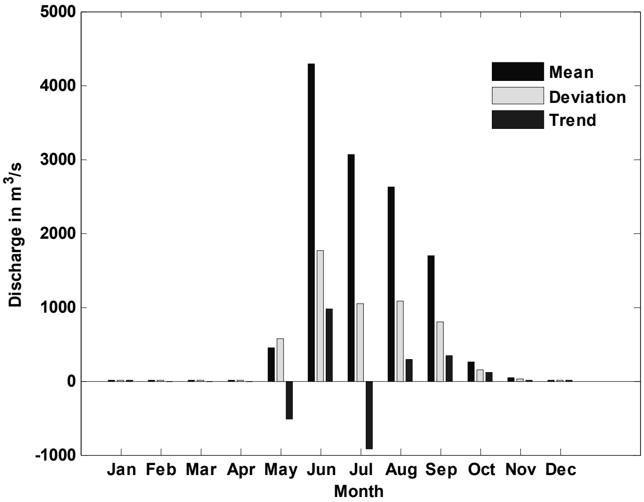


**Fig. 2** Ubileinaya mean discharge, trend and standard deviation from 1972 to 1999.

by July (3055 $m^3$/s), August (2615 $m^3$/s), and September (808 $m^3$/s). Low flows were from December (12 $m^3$/s) to April (0.1 $m^3$/s). Seasonal flow fluctuations showed a high standard deviation for the months with high flows, i.e. June (1771 $m^3$/s), July (1051 $m^3$/s), August (1075 $m^3$/s), and September (805 $m^3$/s). Flow records showed a decrease of 500 $m^3$/s in May, and an increase in June by approximately 1000 $m^3$/s. The increase in June was compensated by July, which had a decrease of 1000 $m^3$/s. Flows in August, September and October also increased by 100 $m^3$/s (Fig. 2).

Flow changes in March (–1.5 $m^3$/s) and April (2.2 $m^3$/s) were significant. There is a positive change in the baseflow for the rest of the winter months. Annual discharge increased by 492 $m^3$/s (57%) during 1972 to 1999 (Fig. 2), significant at 83%; this significant change is most likely due to natural causes.

## SWE *vs* runoff

The snow water equivalent (SWE) data used for this work relate to the period 1988–2000. We examine the relationship between SSM/I snow water equivalent and discharge data collected near the basin outlet.

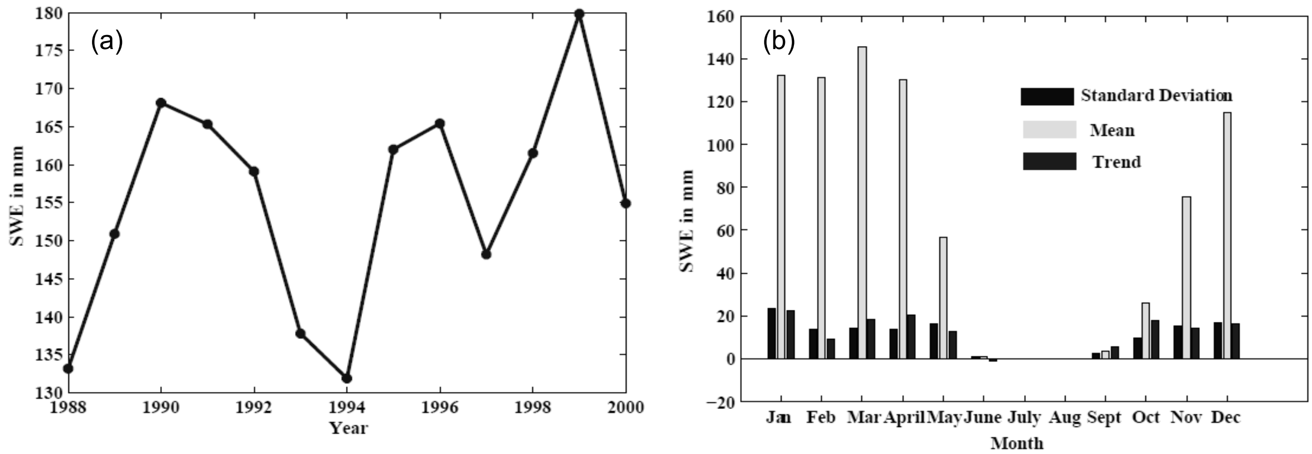


**Fig. 3** (a) Mean March SWE during 1988–2000; (b) monthly mean, STD and trend for SWE for 1988–2000.

Snow starts to accumulate from September (5 mm) and continues to build up through October (26 mm), November (76 mm), December (116 mm), January (130 mm) and February (Fig. 3(b)). The maximum SWE occurs in March, ranging from 133 mm to 180 mm. Max SWE has an increasing trend during 1988 to 1999, with a sudden drop in 2000 (Fig. 3(a)).

Snow ablation starts in April, when SWE reduced from 146 mm in March to 130 mm in April. With the increase in air temperature in May, SWE reduced to 66 mm. There are variations in snowmelt processes among the years. Earlier melt was observed in the springs of 1997, 1998 and 1999, when the snow had gone by Julian day 142. For the other years, snow disappeared around Julian day 150. In spring 2000, snowmelt was complete by day 150.

### SWE *vs* discharge

Discharge and SWE follow an inverse relationship, with the advent of snowmelt at about day 86 (last week of March) and its final disappearance at day 150, around the last week of May. The discharge subsequently peaks on Julian day 160 (Fig. 4). This is typical for the Arctic regions with continuous permafrost. The time series of discharge and snow water equivalent emphasizes the inverse relationship (Fig. 5). A high value of SWE does not always lead to a high peak discharge; this could be due to different ablation rates, which are very variable from year to year. We calculated the ablation rates around mid May to the first week of June, and it varies from as low as 2 mm/d to as high as 16 mm/d at the start of snowmelt. The melt rates change with increase in temperature.

## CONCLUSION

Yana basin is a pristine and permafrost basin in eastern Siberia. It drains into the Laptev Sea. The basin has a long cold season of eight months, with temperatures ranging from 0°C in September to around −1°C in May. The basin has warmed up over the past three decades. Mean precipitation for the Yana basin ranged from 171 to 300 mm. Precipitation and temperature during 1972–1999 were strongly correlated (significant at α value of ±0.05) for a few months. The winter months (October to April) showed positive correlations, implying warmer temperatures related with high precipitation. Monthly flow increased during the low flow months and decreased in June. These changes are significant and consistent with the slight increase in temperature over the last three decades.

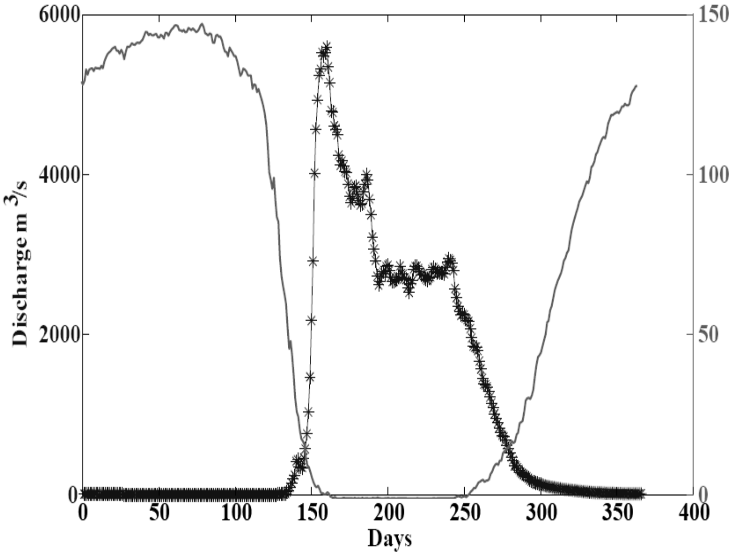


**Fig. 4** Mean daily discharge and SWE for the basin, 1988–2000.

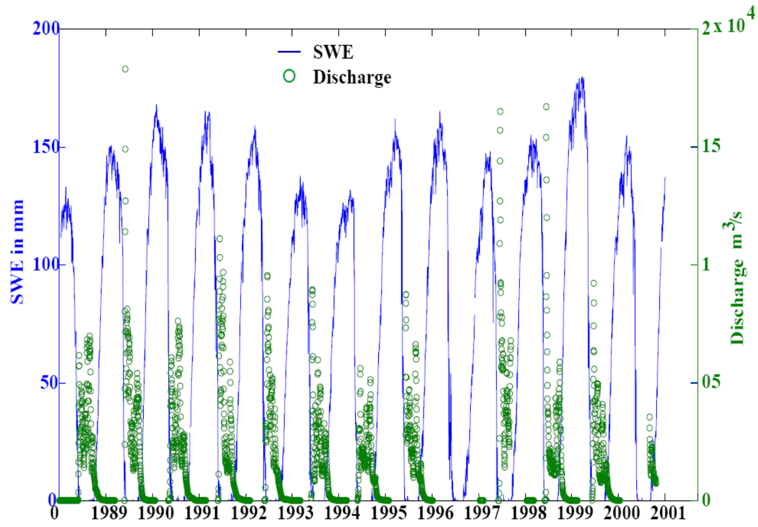


**Fig. 5** Time series of SWE and discharge for the basin, 1988–2000.

The snow water equivalent shows the maximum accumulation in March; the interannual variability in the maximum SWE shows an increasing trend during 1988–2000. The SWE and discharge relationship does not always show consistency, that is, the years with high SWE do not always have peak discharge. Different melt rates could result in this discrepancy. There is a logarithmic relation between daily maximum SWE and discharge. Similar results exist for monthly flow and SWE. It is necessary to continue this research so as to better understand the discharge dynamics and hydrological cycle for the Arctic regions.

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