WINTER RIVER DISCHARGE TIMING AND LOW-FLOW FREQUENCY UNDER CHANGING CLIMATE CONDITIONS IN THE TAGLIAMENTO RIVER BASIN IN ITALY

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1. INTRODUCTION

The mountain glaciers and snow cover depletion is one of the most obvious evidence of the changing climate. In the Alps, climates have undergone significant change over the past century. Especially, annual average temperatures have risen by up to 2°C in many parts of Alps between 1901 and 2000. Consequently, from 1850 to 1980, glaciers in the European Alps lost approximately one third of their area and one half of their mass. However, the Tagliamento River in Italy, which is considered the last morphologically intact river in the Alps, has not suffered drastic modifications. As changes in the future climate are projected to be more intense, many concerns have been raised regarding the potential burden that may be imposed on hydrological processes in the Tagliamento valley. Thus, the objective of this study is to evaluate the potential climate change effects on water resources in the Tagliamento River.

2. STUDY AREAS AND DATA COLLECTIONS

The Tagliamento River flows from the Italian Alps to the Adriatic Sea (**Fig. 1**). The area of interest covers 1935 km^2 for the Venzone water discharge measuring station, with elevations ranging from 370 m to 2600 m. The study area includes 11 meteorological stations with daily observations covering the past 31 years. The one-hour river discharges averaged daily from January 2008 to September 2009 were used for the analysis.

The temperature decreased with elevation at an average rate of 4.0°C/1000m. The mean daily temperature remained below 0°C for an average of 21 days/year near the catchment outlet, and for 36 days/year upstream of the catchment. The daily average winter (Dec-Feb) temperature was close to the melting point (2.1 and 1.0°C near the catchment outlet and at Forni Avoltri station, respectively), which may adversely affect snow cover changes under a changing climate.

The rate of increasing precipitation with elevation is unclear due to the topography effect in mountainous climates. The annual precipitation at all stations is increasing (0-24 mm/year), and snow precipitation trends follow the temperature change. As a result, the number of frost days during 1980-2010 decreased by 10-13 days for each 1°C of winter warming.

3. METHODOLOGY

Gunawardhana & Kazama (2011) developed a tank model for discharge simulations in the Tagliamento catchment and obtained a good match between the observed and simulated water discharge with the determination coefficient (R^2) equals to 0.84. In this study, we used the same model to simulate the river discharge under changing climate conditions. The precipitation was assumed to be snowfall when surface air temperature is less than 2°C. The snowmelt was estimated by the degree-day method.

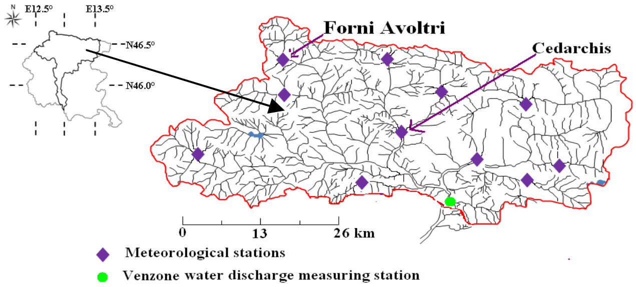

Fig. 1 study area

The temporal and spatial variations of the glacier- and snow-covered areas in the basin were determined using Landsat TM and ETM+ images obtained from 2001-2003. The band combination method was used to extract the snow and glacier areas. To distinguish glacier and snow from similarly bright rocks and clouds, the normalized difference snow index was also applied. Altogether, 7 elevation bands with a maximum elevation difference of 300 m were identified.

For the future predictions, the results of 10 climate scenarios were used. The stochastic weather generator was used to link GCM model parameters with observations at the local scale (Semenov and Stratonovitch 2010). Observed daily weather data for 1980-2010 were used in the WG model to def probability distributions. A wet day is defined as a day with precipitation > 0.0 mm.

The 7Q10 low-flow index, which is defines as the lowest 7-day average discharge that occurs once every 10 years, was used to determine climate change impacts on river discharge. The probability distribution of the low-flow time series is approximated by the Log-Pearson type III distribution function. Here, we developed low-flow statistics using the 1991-2010 period (baseline) and the short-term climate, mid-term climate and long-term climate time series.

4. RESULTS AND DISCUSSION

The results reveal that on average, approximately 46% of the basin is covered with snow and glacier from December to February, which decreases to less than 5% for July to September. The snow cover change follows the trend of temperature variation in the catchment. Once the air temperature passes the 0°C threshold, the snow cover area begins to be depleted at a rate of 125 km^2/°C, which is almost constant until the end of May. The substantial melting rate of winter snowpack during this period contributes to a sustained period of high river flows during the spring and early summer.

According to the 10 GCM scenarios, the averaged annual mean warming for the long-term climate is as high as 2.3°C and 2.7°C for the minimum and maximum temperatures, respectively. When 10 scenarios were averaged, for a 2.5°C increase in winter temperature at the Forni Avoltri meteorological station, the number of frost days is likely to decrease by 35 days. In lower elevations, the reduction is expected to increase by more than the amount estimated for higher-elevation areas. For example, the rate of frost day decrease in the lower-elevation area (Cedarchis area, with a 1.32 rate) is 262% higher than that in the higher-elevation area (Forni Avoltri area, with a 0.50 rate). The seasonal change in river discharge is significant for all months in all three future time periods except from winter to early spring (Dec-Mar). The highest reduction will occur in October in 2080-2099 time period, with a value approximately 59% lower than the river discharge in the 1991-2010 climate (**Fig. 2a**).

According to the low-flow analysis results, the magnitude of the 7Q10 discharge will clearly increase for all scenarios (e.g., a 25% increase during the winter season). This behavior contradicts the expected decline in river discharge due to an increase in evapotranspiration demand and a precipitation drop in the future, but can be explained by the relative frequency distribution of daily precipitation in the future. On average, different scenarios indicate an increased frequency of low precipitation events in the future compared to the baseline time period. For example, the relative frequency of daily precipitations less than 15 mm increases from 85% for the baseline time period to 93-95% for the long-term climate. On the other hand, the daily precipitation corresponds to a 99th percentile value decrease from 72.2 mm for the baseline time period to 25.5-30.2 mm for the long-term climate. Therefore, on a broader time scale, we can expect regular low-level river discharge in the future compared to the present climate. For example, the annual low-flow events, on average, will increase by 16 and 15 days during the spring & summer seasons, respectively, in the long-term climate in comparison to the average for the baseline period. Therefore, we can conclude that, even though the magnitude of the minimum river discharge increases under the changing climate, variations in water discharge can increase significantly, leading to a future with regular low-flow events.

The winter-early spring center of volume, which is defined as the Julian Day when half of the total river discharge from January to May has occurred (WSCV), was used to evaluate the river discharge timing. In contrast to the short-term climate, for the mid-term and long-term climates, a significant change in river discharge timing can be expected, which according to the average of all scenarios, may shift the timing of river discharge to occur 6 to 12 days earlier than in the baseline climate. (**Fig. 2b**) This shift in WSCV represents an integrated response of the catchment to the variations in temperature and precipitation in future.

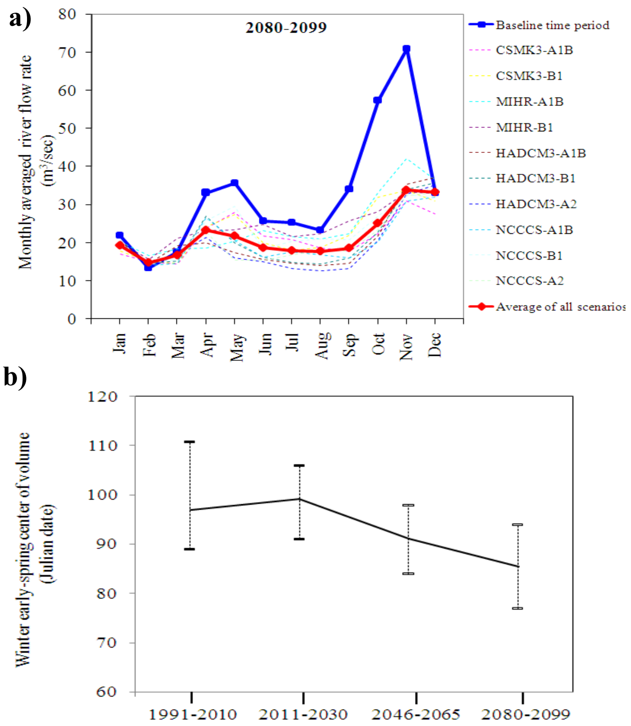

Fig. 2 a) Changes in monthly average river discharge compared to the baseline time period. **b)** Shift in river discharge timing in the future compared to baseline climate conditions. The whiskers represent the interquartile range for the 25th and 75th percentiles.

5. CONCLUSIONS

This study evaluates the hydrological response of the Tagliamento River for probable variations in temperature and precipitation patterns. Results show that the river discharge will remain relatively unchanged for the winter months until the end of the 21st century, but for all other months, it will decrease with the highest predicted reduction as large as 59% in October for the 2080-2099 period compared to the baseline river discharge. The results from Low-flow analysis reveal that variations in river discharge may cause an uneven temporal distribution of the water in downstream areas. Moreover, accumulated effects of climate change would eventually result in river discharge occurring approximately 12 days earlier during the 2080-2099 in comparison to 1991-2010.

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