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**RESEARCH ARTICLE**

# Climate change impact assessment under data scarcity by hydrological and hydrodynamic modeling in Izmit Bay/Turkey

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## ABSTRACT

To assess climate change impact on the hydrology of Izmit Bay, a coupled model chain using the results of four combinations of Global Climate Models (GCMs) and Regional Climate Models (RCMs) and consisting two hydrological models (mGROWA and PROMET) and one hydrodynamic model (MIKE 3HD) was established. Climate model data of the 4 GCM-RCM combinations were applied to both hydrological models. The resulting 8 streamflow data of the hydrological models were then applied to the MIKE 3HD to assess possible hydrodynamic situations in Izmit Bay. Related model results indicate a range of possible future streamflow regimes suitable for the analysis of climate change impact on Izmit Bay. In order to evaluate the effects of the hydrological changes only on the bay, the bay was considered as closed in terms of hydrodynamics. There is a clear indication that the climate change induced impacts on streamflow may influence the sea level in the Bay to a minor extent. However, climate change induced water exchange processes in the Bay may have a much bigger influence. Hence, it is suggested that further simulations should be run once the hydrologic regime of the Marmara Sea has been assessed in a broader macro-scale study.

***Keywords:*** River discharge; PROMET; m-GROWA; MIKE 3HD

## 1. INTRODUCTION

The gradual increase in world's population and industrial activities go hand in hand with the needs of the population to jeopardize natural resources. Water is the most important natural resource, as it is essential for human survival and important to many sectors of the economy. Pressures on water resources induced by human activities, e.g. population growth and field irrigation, are aggravated by climate change. According to the Intergovernmental Panel on Climate Change (IPCC), the global average temperature has increased since 1951, while regional precipitation patterns have changed considerably in the last century [1]. Recently, the number of publications and research on climate change impact on hydrological cycle and surface/sub-surface water resources has increased significantly [2-6], indicating that the effects of the climate change vary from one region to another.

Due to the high population density, the concentration of economic activities and the sensitive aquatic ecosystems, coastal regions are most vulnerable to climate change. Izmit Bay, located in the province of Kocaeli in the eastern part of the Marmara Sea in Turkey is not an exception in this regard. Kocaeli has a population of 1.78 million [7] and accommodates the most important petrochemical and automotive industries of Turkey. Therefore, forecasting the impact of climate change on water resources in Izmit Bay and its catchment is important to reveal a situation that might be encountered in the future and in order to derive necessary precaution measures in due time.

Despite the fact that the number of hydrologic models had already grown until the 1990s as indicated in a survey by Singh [8], the application of hydrological models in Turkey is relatively new [9-11]. Only one study considering hydrological modeling was

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conducted in the study site so far [12]. The general reason for limited environmental modeling studies in Turkey could be attributed to limited data availability. With regard to assessing climate change phenomena however, modeling studies in Turkey are as common as in other parts of the world [13-16].

General Circulation Models (GCM) are used to forecast climate development on earth using also information on processes in the atmosphere, oceans, vegetation etc. [17]. As the spatial resolution of the GCMs is limited to approx. 110 x 110 km at present, Regional Climate Models (RCMs) are used for regional downscaling of GCMs under consideration of information on regional site conditions, e.g. topography. Whereas so called dynamical RCMs disaggregate the results of GCM down to ca. 7 x 7 km, so called statistical RCMs forecast the impact for meteorological stations. Consequently, even in case the same IPCC emission scenario (SRES, A1B) is used as input, the results of different RCMs display considerable differences for the areas applied, simply because certain processes and feedbacks are modeled differently. In order to reduce the uncertainty of different RCMs in the prediction of possible future hydrologic conditions the application of an ensemble of RCMs is suggested as input in hydrologic models in order to account for different emission scenarios and initial conditions [18].

In this study, the effects of climate changes on Izmit Bay were evaluated using two different hydrological models, namely PROMET [19] and mGROWA [20-22]. Both models were applied for Izmit Bay in order to determine streamflow data for the reference period (REF) 1971-2000 and the future period (FUT) 2041-2070 using the results of the regional climate models applied (ECH-RCA, ECH-REM, ECH-RMO, HCH-RCA) as input. In order to further analyze the effects of climate change induced streamflow variations on sea level variations in the coastal area, Izmit Bay was modeled hydrodynamically using MIKE 3HD model developed by Danish Hydraulic Institute [23]. For this purpose, Izmit Bay was assumed as a closed system in the hydrodynamic model set-up, i.e. without an exchange of water to the open sea, so that the changes in Izmit Bay determined with MIKE 3HD were attributed to changes in the streamflow data exclusively. The related MIKE 3HD simulations should be repeated once the hydrologic regime of the catchments of the Black Sea and the Aegean Sea and the processes in the Sea have been assessed in a broader macro-scale study.

## 2. MATERIALS AND METHOD

### *2.1. Study site: The Izmit Bay*

The Izmit Bay is located at the eastern part of the Marmara Sea in the Province of Kocaeli of Marmara Region in Turkey (Fig 1). The Bay is about 45 km in length, 1.8 to 9 km in width and has a surface of 261 km$^2$. The catchment area of Izmit Bay comprises 2255 km$^2$ and is very heterogeneous in terms of soil cover and topography. It comprises a high portion of arable land in the lowland area of the eastern part and a high portion of forests in the northern and southern part, where the elevation rises up to approximately 1500 m above sea level.

There are about forty rivers and streams having a wide range of discharge values in the basin. Among them, regular flow measurement is carried out only in 5 streams with high discharge values. These are the Tavşanlı stream, Çınarlı stream, Ketenci stream, Kirazdere stream and Yalakdere stream respectively. As it can be seen from Fig 1 Ketenci stream has 3 discharge gauging stations while the others have 1 discharge gauging station. The Kirazdere stream has the highest mean annual flow value, which is about 4.5 m/s.

Formations bearing the groundwater in the basin are alluvials in the coastal lowlands and Triassic limestones. Triassic limestone rock unit mostly outcrop in the North and East sides of the Tavşanlı stream (Fig 1). The discharge of groundwater in the lowland areas is usually into the bay, whereas the discharge from the Triassic limestones is into the springs and rivers. Since all the lowland areas are connected to the coastal line of the Izmit bay, seawater intrusion into the wells is an important problem in the region. High quantity water withdrawal from the wells used by industrial facilities in the northern part of the basin cause this problem to be accelerated. The bay can be divided into three sub-sections due to its narrow openings. Detailed information about sub-sections can be found in Table 1 [24].

Since the 1960s thousands of small manufacturing facilities as well as four-hundred large industrial plants, including the most important petrochemical industries, have been built around the Bay. At present, these facilities constitute 13% of Turkey's industrial production [25]. Izmit Bay has a great importance for the transportation of raw materials and products. As it is also the sink for treated industrial wastewaters, water quality of Izmit Bay has been assessed frequently in some studies [26-29]. In contrast, the hydrology of Izmit Bay has only been determined by Karpuzcu et al. [30] with respect to the mean long-term runoff conditions. In the EU 7$^{th}$ Framework Program project CLIMB, Izmit Bay and its catchment have been chosen as a case study area to analyze the possible impact of climate change on the hydrology of the catchment and the bay.

### *2.2. Data availability*

All the input data needed to run the hydrologic models (see Table 2) was provided by state organizations or derived by satellite images. Meteorological data was provided by Turkish State Meteorological Service. Since the meteorological data in the study area were available for the years 1971-2000, this period was chosen as a reference. Discharge data and information about gauging stations were provided by General Directorate of the State Hydraulic Works. Most of the digital maps (Soil, DEM, Geological boundaries etc.) were provided from the Ministry of Forestry and Water Works, formerly known as the Ministry of Environment and Forestry. Pre-processing and parametrization of these maps for hydrologic modeling was carried out by Karpuzcu et al. [30].

**Table 1.** Physical properties (characteristics) of Izmit Bay's sub-sections

| Section | Length (km) | Width (km) | Max. depth (m) | Surface area ($km^2$) |
|---|---|---|---|---|
| East | 16 | 2-5 | 35 | 44 |
| Middle | 20 | 3-10 | 180 | 166 |
| West | 17 | 3-5.5 | 1000 | 100 |

**Table 2.** Input data needed to run the hydrologic models PROMET and mGROWA

| | Data basis | Data source |
|---|---|---|
| **Hydrology** | Catchment areas, rivers and lakes, hydrographs | General Directorate of state Hydraulic Works (DSI) |
| **Climatic data** | Hourly/daily/monthly series of precipitation, temperature, sunshine duration, solar radiation, wind speed, relative humidity, daily precipitation, minimum & maximum temperature as minimum | Turkish State Meteorological Service |
| **Soil data** | Available field capacity, field capacity, bulk density, root depth, capillary rise rates, depth to groundwater, influence of perching water soil type and texture as minimum | Derived from soil map of Turkey |
| **Land cover** | Land use categories and percentage imperviousness | Derived from Landsat TM satellite images |
| **Hydrogeology** | Hydraulic conductivity | Derived from geological map of Turkey |
| **Topography** | Hill slope and aspect | SRTM (NASA), (30 m) |
| **Geology** | Geology of covering layers | Geological map of Turkey |

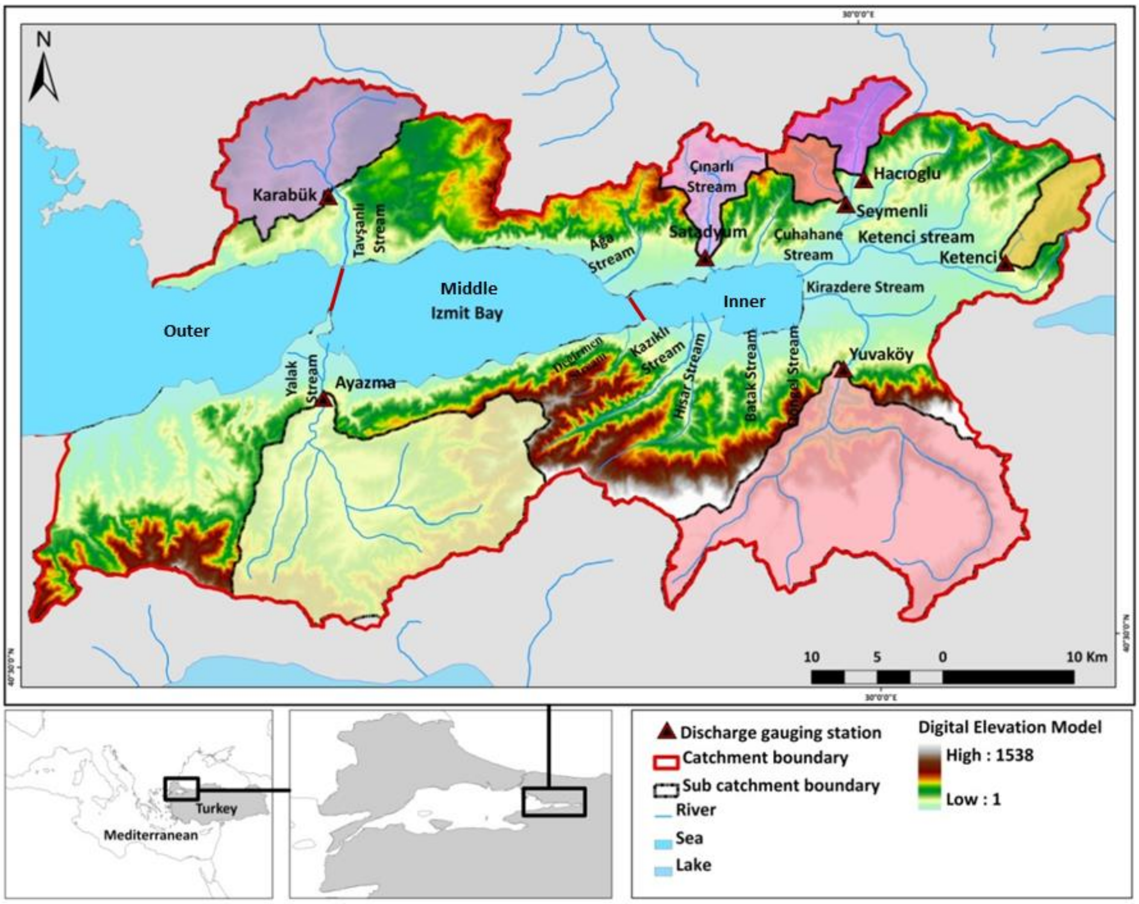


**Fig 1.** Overview of the sub-catchments in the Izmit Bay catchment and the available gauge stations

For the representation of land use change in the modeling of the Izmit Bay catchment, two land use maps were derived from two Landsat TM satellite images from June 25, 2000 and July 31, 2010. The satellite images have been processed with a VISTA intern software package, including radiometric and atmospheric corrections [31]. The satellite images have been classified with a maximum likelihood approach in 9 classes (estate, industry, rainfall and irrigated cropland, deciduous and coniferous forest, bare areas, mosaic cropland/natural vegetation and water bodies). The land use map derived from the year 2000 acquisition was used for modeling the REF period 1971-2000 whereas the land use map from 2010 was used for the modeling of the FUT period 2041-2070.

One of the important inputs for the hydrodynamic model is the bathymetry of the bay. The bathymetry map was derived by digitization of an analog bathymetry map which was prepared by the Office of Navigation, Hydrography and Oceanography. The bathymetry data of the Bay can be seen in Fig 2. The location of sea level monitoring station (Yalova Mareographic Station) is also presented in Fig 2. The dimensions were selected to be 2D and UTM coordinate system for the map coordinate system. As it can be seen from the bathymetry map the deeper parts of the Bay are below 1120 m.

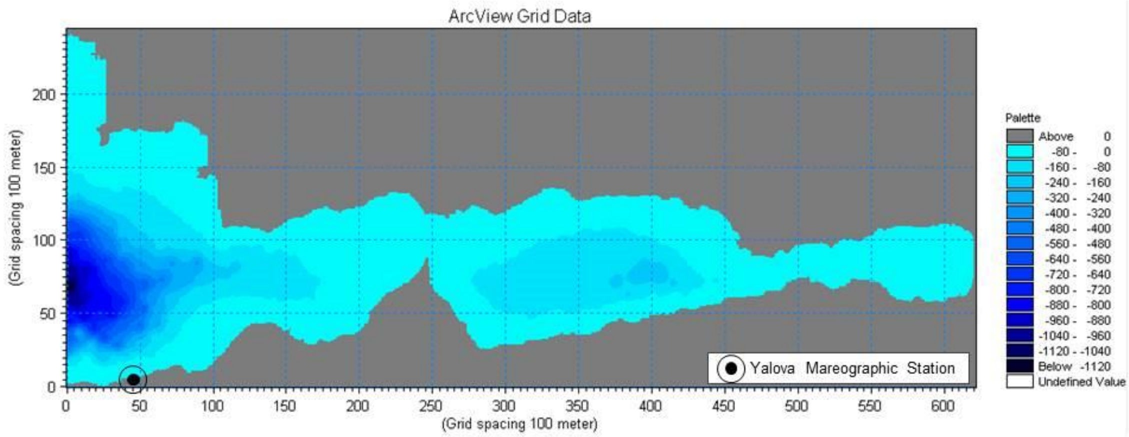


**Fig 2.** Bathymetry map of the Izmit Bay

### *2.3. Izmit Bay model chain*

To assess the climate change impact on the hydrodynamics of the Izmit Bay, a coupled model chain consisting of four combinations of global (GCM) and regional (RCM) climate models, two hydrological models (HM) and a hydrodynamic model (HDM) are established (Fig 3).

By using a complex auditing method, four combinations of the GCM – RCM models, namely ECH-RCA, ECH-REM, ECH-RMO and HCM-RCA (see Table 3) were selected by Deidda et al. [17] and these models fitted best for the data set. Two periods were selected to be used within the model chain, starting with the years 1971-2000 as the REF period and the years 2041-2070 as the FUT period for climate change impact assessment. The climate data for both periods were bias-corrected and downscaled to a spatial resolution of 1 x 1 km. A detailed description of the auditing, the bias-correction and the downscaling of the climate model outputs can be found in Deidda et al. [17].

The downscaled climate data were then used as input for the two hydrological models, namely PROMET (Mauser and Bach, 2009) and mGROWA [21]. Consequently, an ensemble of 8 GCM-RCM-HM combinations was considered in order to assess climate change impact on Izmit Bay. In this way, 40 simulated streamflow hydrographs at the outlet of the 5 major rivers discharging into the Izmit Bay for the two periods were simulated. The streamflow simulations were carried out with monthly time step. From the ensemble of 8 streamflow model results for the FUT period, the 4 best performing GCM/RCM couples of the hydrological models were selected as inflow boundary conditions to the hydrodynamic model.

In the following sections, the terrestrial part of the model chain is introduced, starting with a description of the hydrological models PROMET and mGROWA.

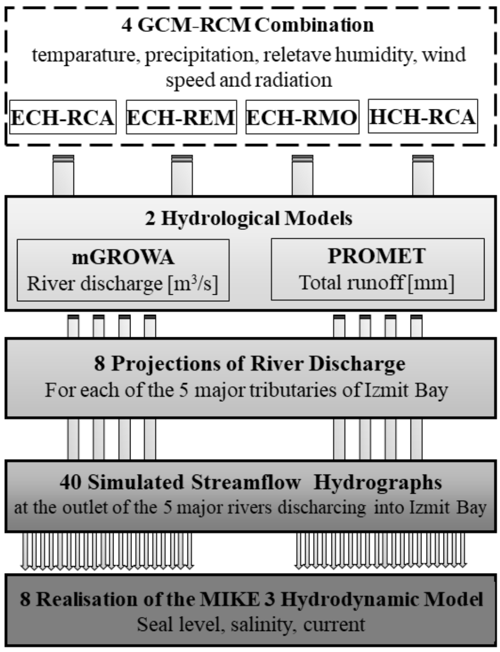


**Fig 3.** Model chain applied in order to assess the impact of climate change on the hydrodynamics of the Izmit Bay

**Table 3.** Climate models that have provided climate forcing

| Scale | Acronym | Climatological center and model |
|---|---|---|
| GCM | ECH | Max Planck Institute for Meteorology, Germany, ECHAM5/MPI OM |
| GCM | HCH | Hadley Centre for Climate Prediction, Met Office, UK, HadCM3 Model (high sensitivity) |
| RCM | REM | Max Planck Institute for Meteorology, Hamburg, Germany, REMO Model |
| RCM | RMO | Royal Netherlands Meteorological Institute (KNMI), Netherlands, RACMO2 Model |
| RCM | RCA | Swedish Meteorological and Hydrological Institute (SMHI), Sweden, RCA Model |

### *2.4. PROMET model description*

The fully distributed, physically based hydrological model PROMET (Processes of Radiation, Mass and Energy Transfer) was developed to study the impact of climate change on the water cycle of large scale, complex watersheds [19]. PROMET was built and tested within the integrative research project GLOWA-Danube [32-33], and has been applied in a variety of studies at different scales from pixel [34] over single fields [35] and smaller regions (100 $km^2$) to a mesoscale catchment (100,000 $km^2$) as well as for numerous locations and climatic conditions in a variety of studies [31, 36-37].

The architecture of PROMET as shown in Fig 4 consists of eight components: meteorology, land surface energy and mass balance, vegetation, snow and ice, soil hydraulic and soil temperature, ground water, channel flow, man-made hydraulic structures.

PROMET strictly follows the principle of conserving mass and energy, using spatial input of topography, land use, soil texture and meteorology for each grid cell. PROMET is not calibrated using historical runoff data to preserve its predictive power. The usual calibration procedures using measured streamflow, simplified process representations, lumped model parameters and the fact that the simultaneous conservation of mass and energy is not guaranteed, makes it difficult and potentially risky to use these approaches to predict future states of regional hydrologic systems under changing boundary conditions with respect to climate. Physical consistency and predictive power should not be diminished or lost in the model calibration process. Therefore, the values of the model parameters of PROMET are not calibrated using measured discharge. Instead, the literature sources and/or measurements (both in the field and from remote sensing sources) were used. Concerning the channel flow component, each modeled grid cell is hydraulically connected to its hydraulic neighbour within a channel network using a digital elevation model. Flow velocities are considered by the Maskincum-Cunge method [38] modified by Todini [39]. A detailed description of the components of PROMET is given in [19].

The model environment was set up for the Izmit Bay catchment using spatial data derived with remote sensing methods [31]. These data include land use maps for the years 2000 and 2010 derived from LANDSAT imagery, a SRTM DEM and vegetation parameters like LAI and albedo for all land use classes using a look up table inversion of the model SLC [40]. PROMET requires meteorological information on precipitation, air temperature, wind speed, humidity and radiation/cloud cover. This data as well as runoff data for validation purposes were provided from the Turkish state agencies [30]. PROMET was set up for the Izmit Bay with a spatial resolution of 300 x 300 m and a temporal resolution of one hour. A series of tests revealed that there is no significant loss of accuracy in the results when reducing the resolution from 100 m to 300 m, but an enormous increase (9 times) of modeling speed was achieved.

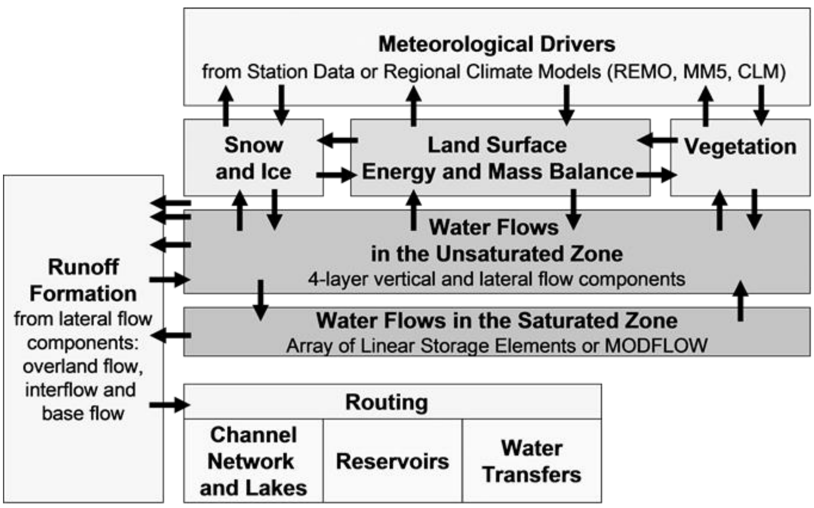


**Fig 4.** Schematic diagram of the components of PROMET and the interfaces between them. Boxes indicate components and arrows indicate interfaces, through which data is exchanged [19]

### 2.5. mGROWA model description

The mGROWA model [21] was developed for determining water balance and runoff of large areas (river basins, Federal States etc.). Soil moisture dynamics, capillary rise from groundwater to the root zone, actual evapotranspiration and total runoff generation are calculated in daily steps. Although groundwater recharge and direct runoff (drainage runoff, interflow) are determined in daily steps as well, model results are presented in monthly time steps, as groundwater management is usually based on this temporal aggregation level. For the simulations, a 100x100 m grid was selected. By doing so, the Izmit Bay catchment was sub-divided into 187,972 grid cells for which soil water balance and runoff were determined individually. However, as the individual grid cells are not linked together, lateral flow processes are not considered in mGROWA.

Fig 5 shows the data basis needed to run the mGROWA model and the water balance quantities calculated in two general modeling steps. Precipitation and grass-reference evapotranspiration have to be regionalized (pre-processed) prior to the modeling from the available climatic data sources, i.e. data from climate monitoring stations, weather radars or climate projections. For this purpose, regionalization procedures adapted to the available data sources are selected, according to Kunkel et al., [41] and Marke et al., [42]. The data bases of the Izmit Bay catchment were made available by the Turkish state agencies (State Hydraulic Works and State Meteorological Service). Pre-processing and parametrization of these maps for hydrologic modeling was carried out and described comprehensively in [30].

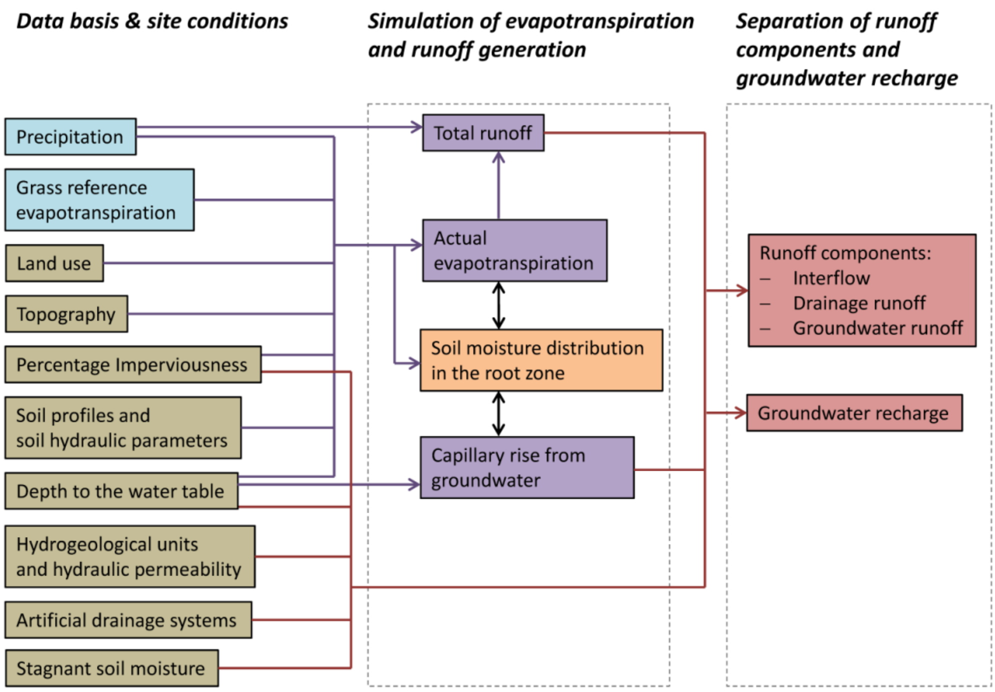


**Fig 5.** Data basis and general modeling scheme of mGROWA [21]

The spatially and temporally highly distributed simulation of vertical soil moisture dynamics in each grid cell of the study area is the essential part of the first mGROWA simulation step, i.e. for determining actual evapotranspiration and runoff generation. This includes the explicit consideration of the plant available water stored in the root zone which is increased by capillary rise from groundwater in areas where shallow groundwater occurs. The water balance equation and its climatic, runoff and storage terms are the basis for this simulation step (Eq. 1).

$$\frac{\mathrm{ds}}{\mathrm{dt}} = \mathrm{p} + \mathrm{q_{cr}} - \mathrm{et_a} - \mathrm{q_t} \qquad (1)$$

In eq. 1 $p$ represents the precipitation level (mm d$^{-1}$), $q_{cr}$ the capillary rise from groundwater (mm d$^{-1}$), $et_a$ the actual evapotranspiration (mm d$^{-1}$), $q_t$ the generated total runoff (mm d$^{-1}$), sthe amount of water stored in a grid cell (mm) and $t$ the time (d). At sites covered with vegetation $s$ corresponds to the soil water content θ. In urban areas $s$ represents the water stored on impervious surfaces.

In the mGROWA model, special attention has been paid to the calculation of actual evapotranspiration and the associated storage functions (Eq. 2). Grass reference evapotranspiration $et_0$ (mm d$^{-1}$) is determined based on the Penman-Monteith-equation [43]; $k_{LN}$ is a land use specific evapotranspiration factor (crop coefficient); $f(\beta,\gamma)$ represents a topography function in order to correct actual evapotranspiration according to hill slope and exposition [44] and $f(s)$ is a storage function which takes the water available for the evapotranspiration processes into account.

$$\mathrm{et_a} = \mathrm{et_0} \cdot \mathrm{k_{LN}} \cdot \mathrm{f}(\beta,\gamma) \cdot \mathrm{f(s)} \qquad (2)$$

The storage function is defined differently for different site conditions. For land surfaces covered with vegetation, the function values of $f(s)$ originate from a multi-layer soil water balance model [21,45]. This sub-model simulates the water fluxes in the root zone with respect to the continuity equation but ignores the dependency of percolation on unsaturated hydraulic conductivity. For impervious surfaces in urban areas and free water surfaces, specific storage functions have been implemented in mGROWA, respectively [21].

The mGROWA model has been developed in order to determine runoff generation as well as percolation and groundwater recharge rates respectively for large areas temporally and spatially highly distributed. Same as PROMET, mGROWA is not calibrated using historical runoff data to preserve its predictive power. However, mGROWA does not take into account the simulation of streamflow as PROMET does. In order to benefit from the main features of both models, mGROWA and PROMET have been merged in the model chain. In this way, the total runoff generation in the grid cells calculated with mGROWA was fitted to the time patterns of the hydrographs simulated with PROMET. The main advantage of this procedure was that the balanced total runoff simulated with two different hydrological model concepts could serve as boundary condition for the subsequent model element of the chain. The resulting 8 realizations of streamflow were subsequently used as boundary conditions for the simulation of the hydrodynamics in the Izmit Bay based on the MIKE 3HD model.

### 2.6. MIKE 3HD model description

MIKE 3HD [23], is a modeling program which uses hydrological and hydrodynamic properties of water bodies in order to determine a variety of different characteristics of surface water; such as coastal, lake and reservoir hydrodynamics (circulation, water levels, flow rates etc.), coastal and inland flooding, water quality and sediment structure.

The MIKE 3HD module solves a number of different equations including conservation of mass and momentum, salinity and temperature variations. Mass conservation in the two/three dimensional system was expressed using the Reynolds-Average-Navier-Stokes equations, considering the assumptions of Boussinesq and of hydrostatic pressure.

In addition, the system is closed by a turbulence closure scheme. In order to characterize the eddy viscosity different turbulence models (Smagorinsky model, k model, k-ε model, mixed Smagorinsky / k-ε model and a constant eddy viscosity model) are included in the model.

The needed databases given in process chart (Fig 6) can be divided as basic parameters for identifying the system and hydrodynamic parameters.

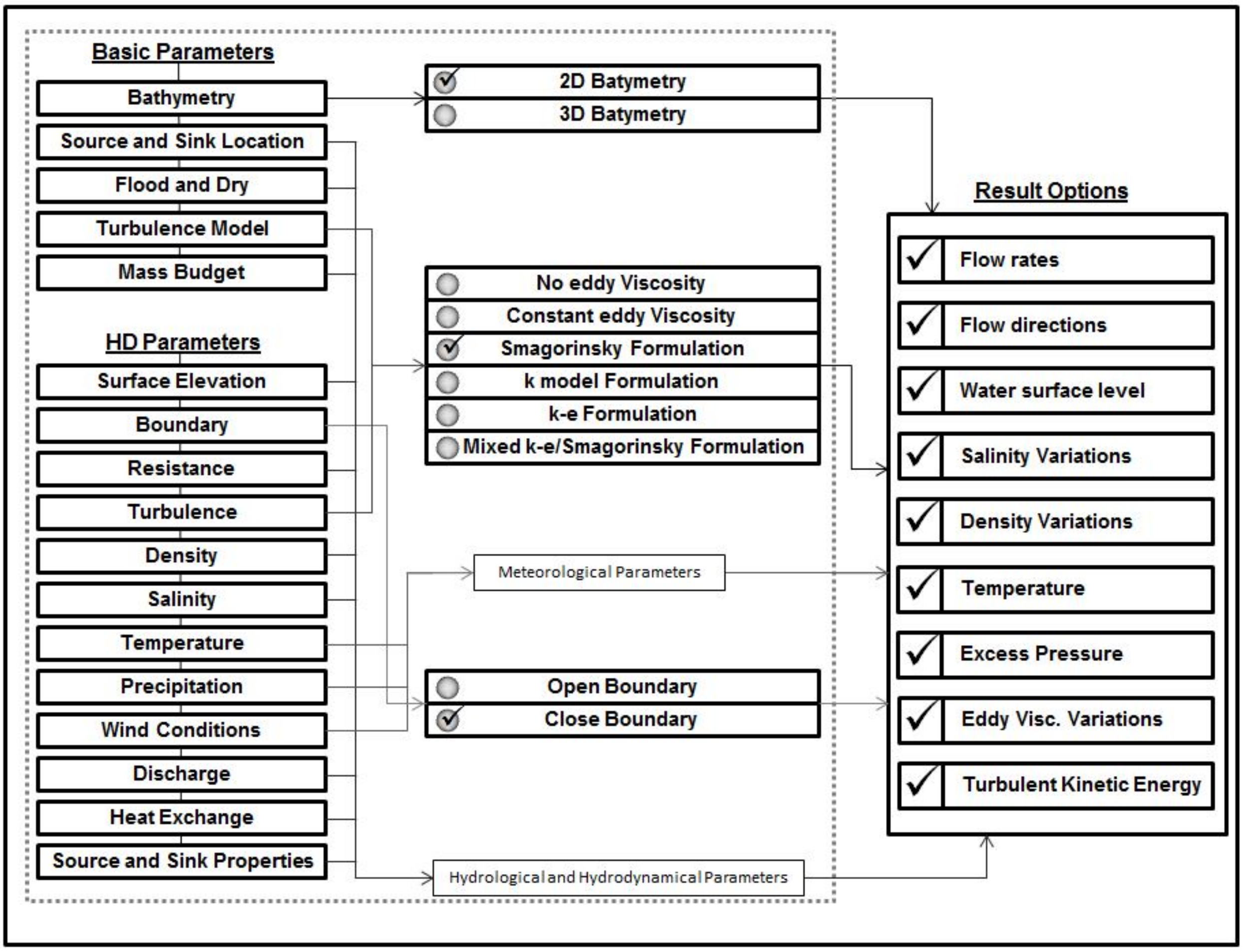


**Fig 6.** Preferences made during model installation (MIKE 3HD)

Fig 6 shows preferences made during model installation. Accordingly, the model is run in 2D. In the production of the numerical bathymetry map, an analog map provided from the map general command has been used. The resolution of the digital bathymetry map is 100m. The Smagorinsky model was chosen for turbulence calculations, as this model is commonly used.

The bay was considered hydrodynamically closed. However, in terms of meteorological variables, the model is operated as an open system. The results of the climate models (precipitation, temperature) and the data of stations belonging to the meteorological administration (wind speed) were used as meteorological data. In the same way, the model results for the two hydrologic models are used as discharge data and the data of the stations belonging to the state water works are used for the other rivers which are not considered in the hydrological modeling.

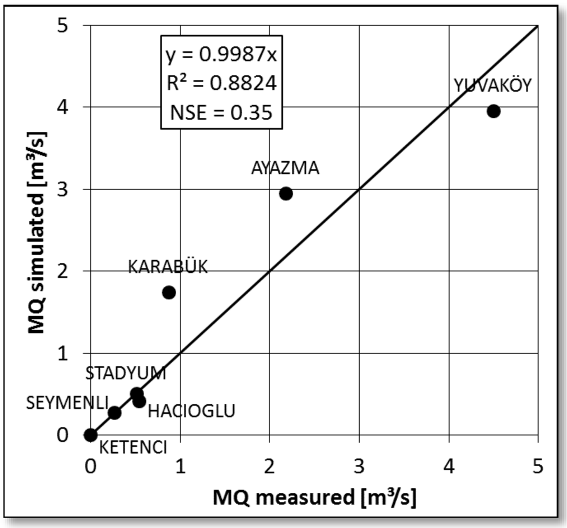


**Fig 7.** Comparison of measured and PROMET simulated MQ for all discharge stations in the Kocaeli catchment

## 3. RESULTS & DISCUSSION

### *3.1. Model results of the hydrologic models PROMET and mGROWA*

The hydrologic models were validated using the available gauging station runoff data for the years 1975-2009 showing good results in both cases. As an example Fig 7 shows the comparison of measured and modeled mean streamflow (MQ) for PROMET for the available discharge stations, revealing a $R^2$ of 0.8824. Looking on the comparison of measured and modeled MQ for the three discharge station with the highest runoff values, a slight overestimation of streamflow for Karabük and Ayazma as well as a slight underestimation for Yuvaköy can be seen. The mean Nash-Sutcliffe model efficiency coefficient calculated from daily measured and modelled discharge data for all stations was found to be 0.35 and indicates a sufficient model performance. The relevant output of the model within the model chain is streamflow into the bay from five outlets.

After validation, PROMET was run for both periods (REF and FUT) with the climate data from the four GCM-RCM combinations to assess the climate change impact on the hydrology of the Izmit Bay catchment. Exemplary results from the PROMET model are shown in Tables 4 and 5.

Table 4 gives an overview on the mean annual values of some important hydrological parameters derived by the PROMET model driven by the four different climate model scenarios. Displayed are the absolute values for both periods REF and FUT.

Table 5 shows the relative changes from REF to FUT with regard to the mean annual values, again for all four climate model combinations. The Tables 4 and 5 show that HCH-RCA, in comparison to the other climate models, predicts the driest conditions for the future with a decrease of 106 mm (-13.1%) in mean annual precipitation and an increase of mean annual temperatures of 3 °C (+23.3%). This leads to a decrease in percolation of water from the lowest modeled soil layer, which indicates a decrease of ground water recharge.

**Table 4.** Absolute values for the REF and FUT periods for several water balance variables (annual mean) and for all 4 climate models (modeled with PROMET)

| **PROMET results** | ECH-RCA | | ECH-REM | | ECH-RMO | | HCH-RCA | |
|---|---|---|---|---|---|---|---|---|
| | REF | FUT | REF | FUT | REF | FUT | REF | FUT |
| Temperature (°C) | 13.1 | 15.1 | 13.0 | 15.0 | 13.1 | 14.9 | 12.9 | 15.9 |
| ET pot (mm) | 980.0 | 1028.5 | 920.5 | 980.3 | 908.5 | 954.4 | 961.0 | 1067.2 |
| ET act (mm) | 384.1 | 350.4 | 397.6 | 358.7 | 367.0 | 342.2 | 379.5 | 334.5 |
| Percolation (mm) | 214.7 | 206.8 | 209.4 | 192.2 | 219.1 | 227.0 | 215.3 | 168.7 |
| Precipitation (mm) | 811.5 | 788.0 | 816.5 | 766.5 | 799.1 | 811.1 | 808.4 | 702.1 |
| Runoff (mm) | 434.0 | 441.2 | 424.4 | 412.8 | 438.6 | 476.4 | 432.5 | 371.8 |
| Water budget (mm) | 427.3 | 437.6 | 418.9 | 407.9 | 432.2 | 468.9 | 428.9 | 367.6 |

**Table 5.** Absolute increase of mean annual temperatures and relative difference from REF to FUT for several water balance variables (annual mean) as well as for all 4 climate models (modeled with PROMET)

| **PROMET results** | ECH-RCA | ECH-REM | ECH-RMO | HCH-RCA |
|---|---|---|---|---|
| Temperature (°C) | +2.0 | +2.0 | +1.8 | +3.0 |
| ET pot | +4.9% | +6.5% | +5.1% | +11.1% |
| ET act | -8.8% | -9.8% | -6.7% | -11.9% |
| Percolation | -3.7% | -8.2% | +3.6% | -21.6% |
| Precipitation | -2.9% | -6.1% | +1.5% | -13.1% |
| Runoff | +1.6% | -2.7% | +8.6% | -14.0% |
| Water budget | +2.4% | -2.6% | +8.5% | -14.3% |

The moistest future climate conditions were predicted by using climate data from ECH-RMO with a slight increase of mean annual precipitation. All four climate models show an increase of potential evapotranspiration and a decrease of actual evapotranspiration. The runoff (combination of direct runoff, interflow and baseflow) as well as the water budget (precipitation minus actual evapotranspiration) was simulated to increase slightly for ECH-RCA, to decrease slightly for ECH-REM, to increase for ECH-RMO and to decrease for HCH-RCA.

Fig 8 shows the quotient ETi as an example for spatially fully distributed output of PROMET. ETi was calculated by the PROMET modeled monthly mean actual evapotranspiration divided by potential evapotranspiration, as spatial output for the whole Kocaeli catchment for the moistest climate forcing ECH-RMO. ETi can be regarded as an indicator for drought conditions, since the gap between actual and potential evapotranspiration was high during dry periods and low during periods where enough water was available for the transpiration of plants and the evaporation of surfaces. In Fig 8, the green areas stand for moist conditions whereas the red areas indicate dry conditions. It is visible that there is a predicted increase of ETi in the months from November to January using ECH-RMO as climate forcing. In June, the climate model scenario shows a decrease of ETi. Areas which show the most decrease of ETi comparing REF and FUT were the regions around the coastline due to expanding industry, which was included into the modeling by using two different land use maps for the REF and FUT period.

The simulated streamflow into the bay of both hydrological models was linked to the MIKE 3HD hydrodynamic model, i.e. a total of 8 different possible present and 8 future runoff regimes were used as variable boundary conditions of the Izmit Bay model. The mean streamflow (MQ) differs only slightly between both hydrological models but varies more pronounced when different GCM-RCM combinations drive the hydrological models (see Fig 9). The differences of low water streamflow (LQ) are marginal. In fact, all combinations of the ensemble tend to simulate a seasonal running dry at the end of dry summer half-years in the reference and future periods, respectively. The variability of high-water streamflow (HQ) is considerably, on the one hand between the two hydrological models and on the other hand between the four GCM-RCM-combinations. However, as the 20thand 70th percentiles (Q0.2, Q0.7) of the flow duration curves show, the intermediate streamflow varies little between both the hydrological models and the GCM-RCM-combinations.

The mGROWA-setup driven with observed climate data is validated using measured streamflow data of the 3 observed river gauges for the years 1975-2009, for which time series was almost complete (Fig 9).

As indicated by the performance criteria NSEc = 0.78 and PBIASc = -3.1%, there is a good fit of observed and simulated mean annual total runoff in the selected catchments. Model results presented in Figs 8 for PROMET model are not presented for mGROWA model, because differences in the model results of the two models are insignificant. Instead, direct comparisons of the model results are presented.

Accordingly, Fig 10 shows the comparison of PROMET and mGROWA modeled mean streamflow in ($m^3/s$) of the 5 major rivers in Izmit Bay for the REF period (1971-2000) and the FUT period (2041-2070). Displayed are the MQs of all four used climate model inputs. It is visible that the modeled MQ is very similar between the two hydrological models for all climate scenarios and rivers.

In the reference period the modeled MQs of the different climate scenarios are not scattered very much, which indicates a very stable performance of all GCM-RCMs. In the FUT period differences in the MQ are visible between the different climatic drivers. The scattering of the MQ is relative to the size of the catchments and therefore bigger for the Kirazdere and Yalakdere rivers, which leads to an increased uncertainty of the climate change impact on the hydrology.

ECH-RMO as climate forcing leads to an increase of modeled mean run-off for all rivers, whereas HCH-RCA is the driest scenario with a relatively huge decrease of modeled MQ. For ECH-RCA and ECH-REM it depends on the river if the MQ will increase or decrease. Using ECH-RCA as climate forcing Kirazdere and Yalakdere will show no or a very small change in

MQ, whereas the use of ECH-REM leads to a decrease of MQ. In the case of Ketenci and Tavşanlı ECH-RCA predicts a slight increase of MQ, whereas ECH-REM indicates no or only a small decrease of MQ. For Çınarlı the modeled changes in MQ are very small besides a decrease for the dry HCH-RCA scenario.

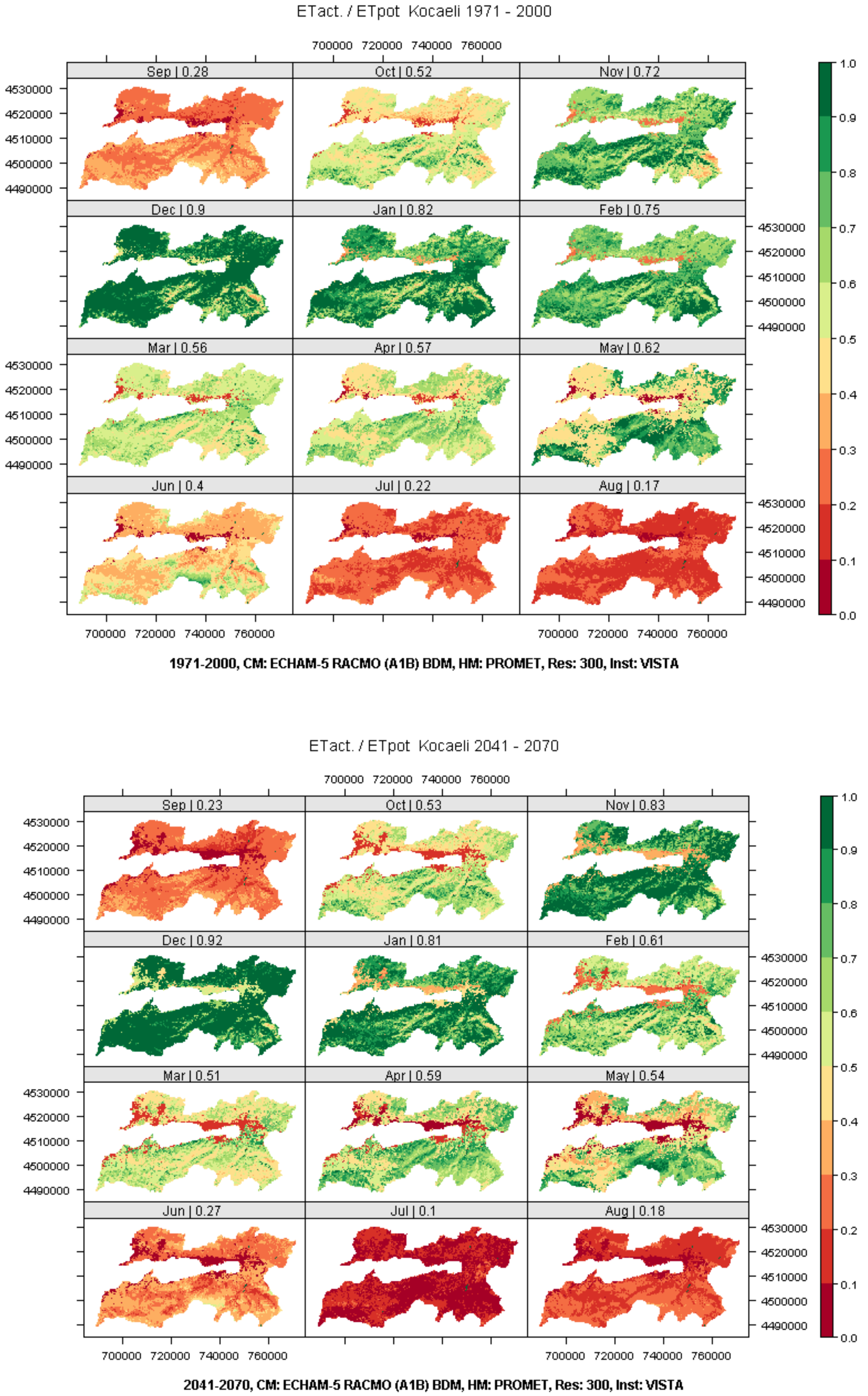


**Fig 8.** PROMET modeled monthly mean actual evapotranspiration divided by potential evapotranspiration as an indicator for drought conditions. REF period from 1971-2000, FUT period from 2041-2070. 300 m spatial resolution. Climate model forcing is ECH-RCA

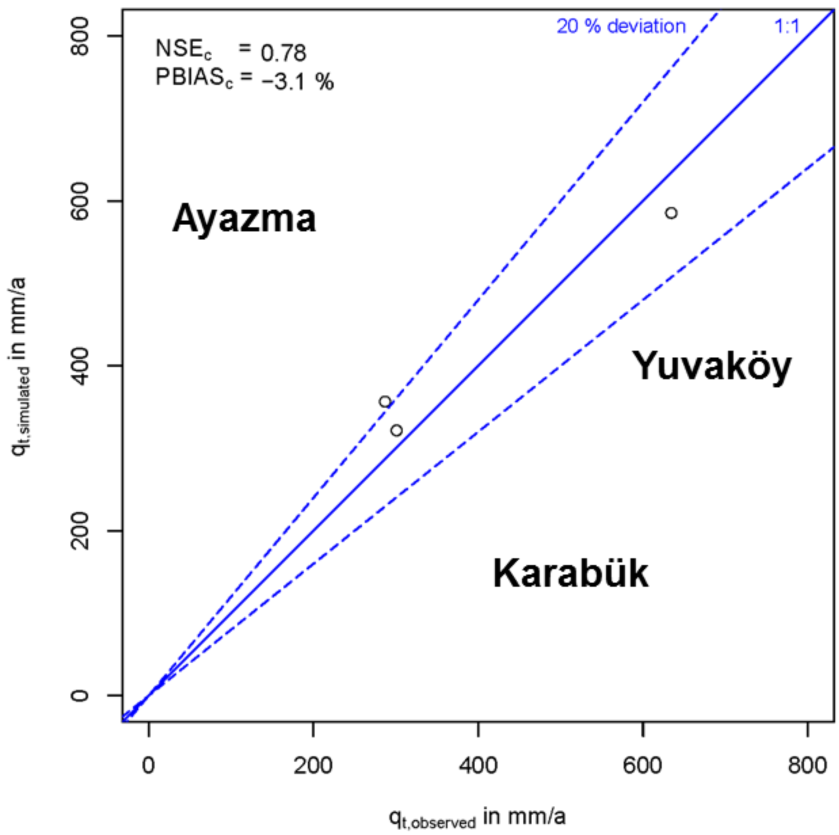


**Fig 9.** Validation results of the 3 observed river gauges for the years 1975-2009 (mGROWA)

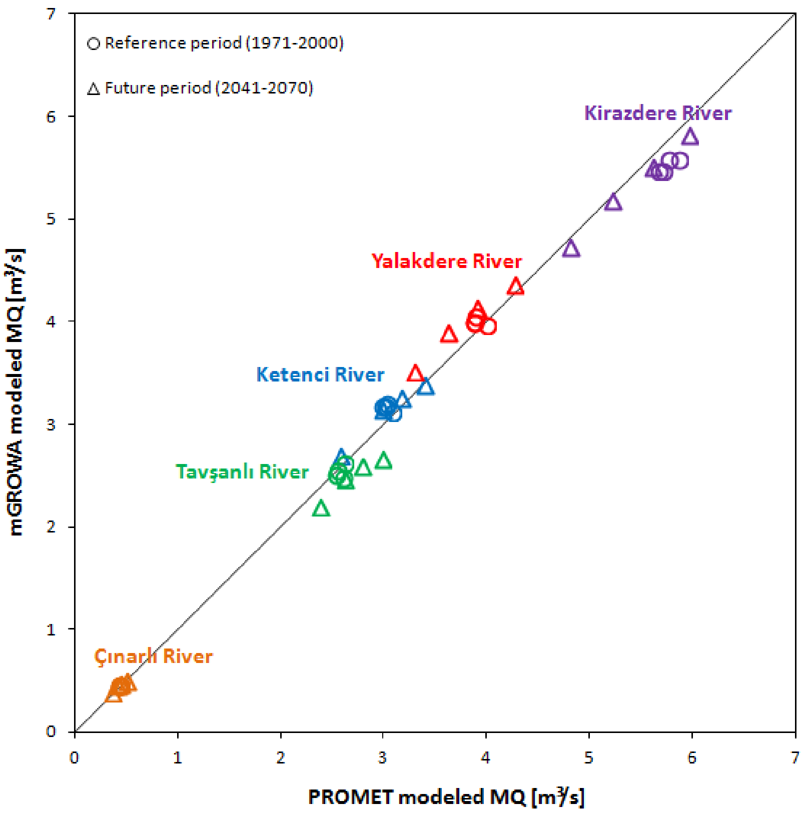


**Fig 10.** PROMET and mGROWA modeled mean streamflow in [$m^3/s$] of the 5 major rivers in Izmit Bay for the reference period (1971-2000) and the future period (2041-2070). Displayed are the MQs of all four used climate model inputs

A selection of raster hydrographs to portray the variety of simulated streamflow in the Kirazdere River is given in Figs 11 to 14. This type of Fig to visualize time-series in a raster form is designed according to suggestions in [46]. The combination ECH-RMO leads to the highest increase of mean streamflow when comparing the REF and FUT periods (Fig 11). In addition, a shift in the frequency and magnitude of the high-water streamflow events is clearly visible. While high-water events are simulated to be relatively equally distributed within the winter half-year of the REF period, in the FUT period, high-water events occur more often and long-lasting from December to February and decrease in March and April. Low-water events seem to stay unchanged. Fig 12 shows the differences of the raster hydrograph in Fig 11 and the corresponding ECH-RMO - mGROWA hydrograph. While the general time-pattern of streamflow is simulated nearly equal with both models (the reasons are already described above), the differences are explained by the amount of water that was balanced as total runoff using different modeling concepts.

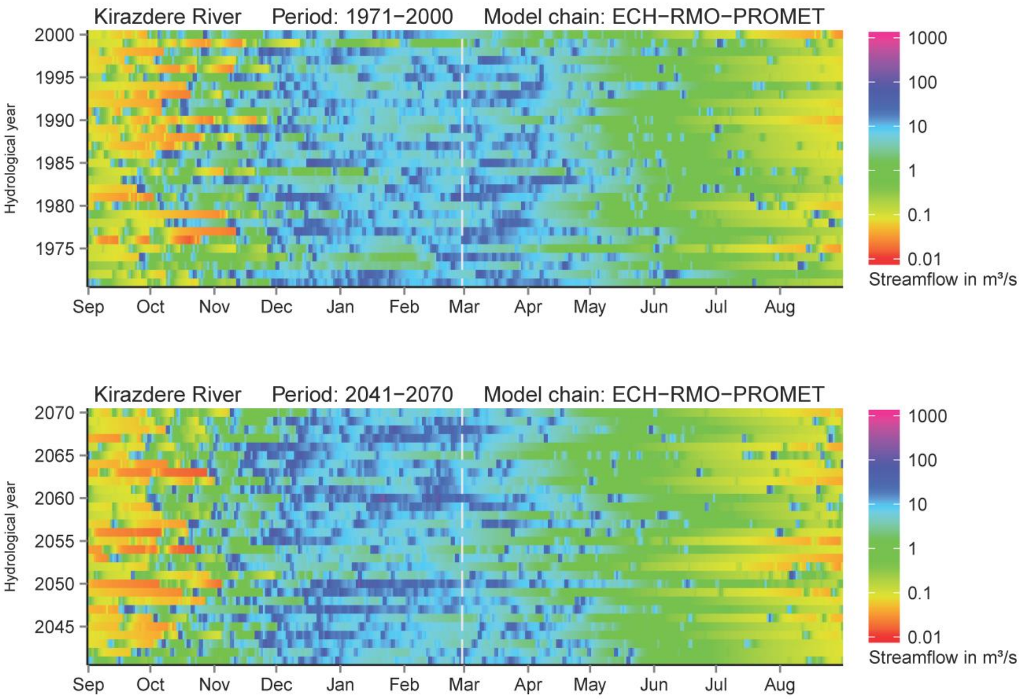


**Fig 11.** Raster hydrograph for the Kirazdere River simulated with the model chain ECH-RMO-PROMET

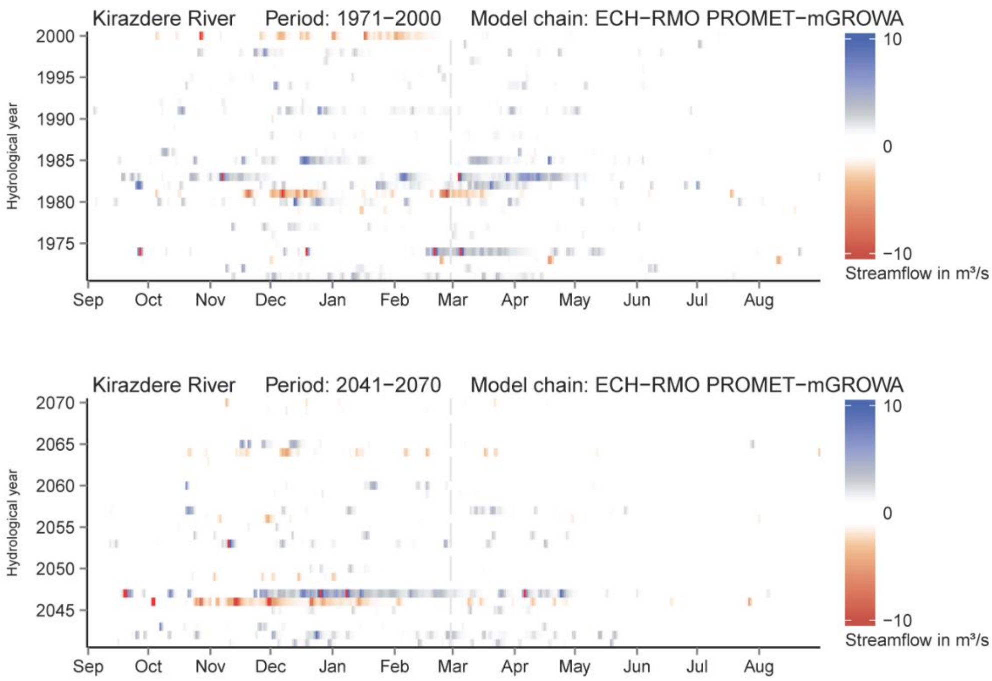


**Fig 12.** Differences in the raster hydrographs for the Kirazdere River (ECH-RMO PROMET-mGROWA)

In contrast to the combination ECH-RMO, HCH-RCA causes a considerable decline of mean streamflow and duration of high-water phases during winter as well as an extension of low-water phases close to running dry of the river during summer when comparing both periods (Fig 13). In the same way, for the combination HCH-RCA, the differences between streamflow balanced with PROMET and mGROWA are shown in Fig 14. The Kirazdere River has a mountainous headwater with elevations up to 1500 m, whereas in the other catchments elevation reaches up to 700 m only. The slight tendency of the mGROWA model to underestimate observed total runoff in relatively wet mountainous regions becomes visible in Fig 13 where streamflow is lower in the reference period compared to PROMET. We assume that this slight underestimation is due to the mGROWA input parameter effective field capacity in the root zone derived by using the tabulated pedo-transfer functions in [47] for the main soil groups of the digital soil map of Kocaeli Province 1/25 000.

Finally, it can be noted that the resulting ensemble of 8 inflow boundary conditions comprise a range of possible future streamflow regimes which is suitable for the analysis of climate change impact on the hydrodynamics of the Izmit Bay.

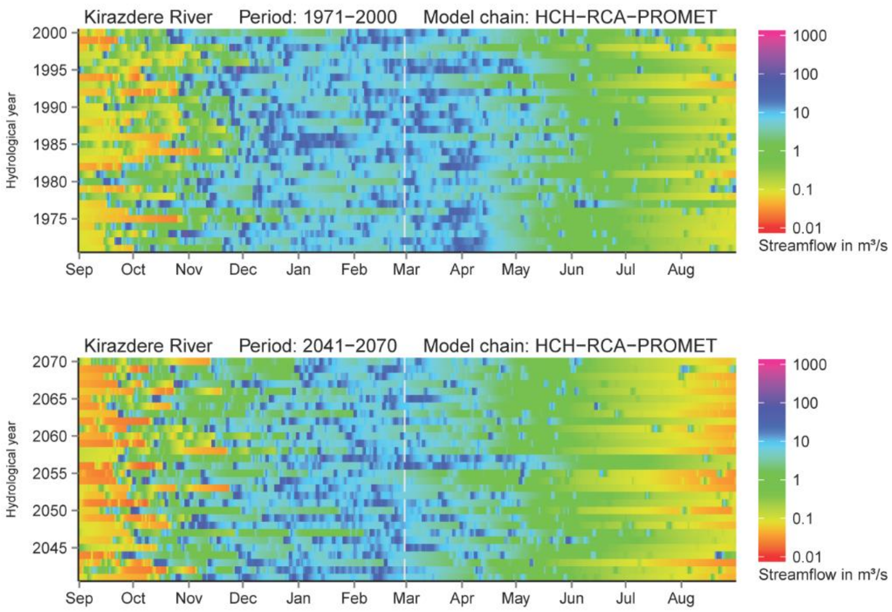


**Fig 13.** Raster hydrograph for the Kirazdere River simulated with the model chain HCH-RCA-PROMET

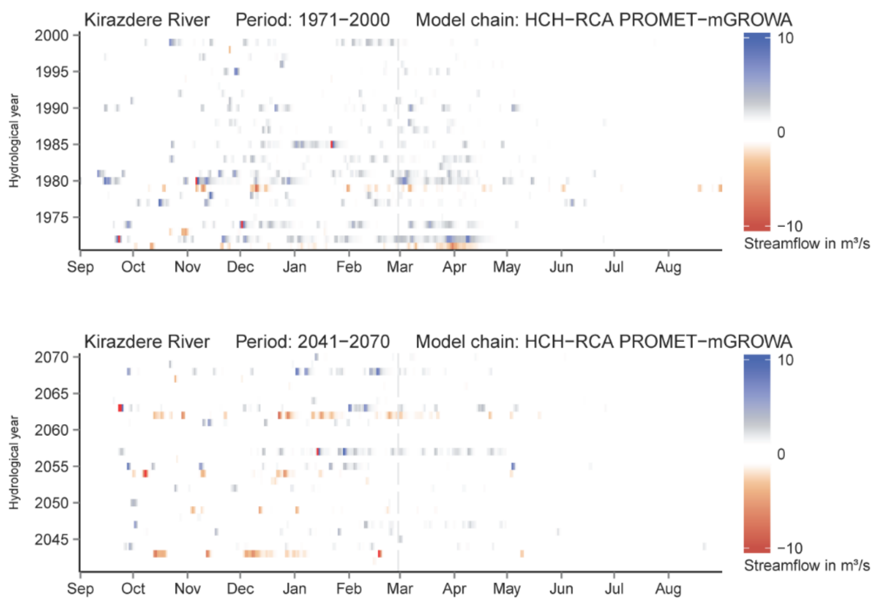


**Fig 14.** Differences in the raster hydrographs for the Kirazdere River (HCH-RCA PROMET-mGROWA)

### 3.2. Preliminary results of MIKE 3HD hydrodynamic model

The model setup procedure for Izmit Bay was carried out in two stages. In the first step, the basic parameters, such as the bathymetrical description (provided by the Naval Forces) were introduced to the model. After digitization, a 250 m grid size was set in the model. As it can be seen from the bathymetry map (Fig 2), the boundary was selected so that deeper parts of the Bay (below 1120 m) were included in the modeling. Therefore, it was intended to reflect the depth effect of the Marmara Sea (the deepest point of 1270 m) into the model. The locations of the sources and sinks were also defined during the model establishment. As a secondary step, all the inputs such as wastewater discharges, streams and rivers entering the water body were identified.

When considering the overflow and dry conditions, a minimum water level (here 0.001 m) was selected. The turbulence model was determined using the Smagorinsky formulation [23]. The vertical and horizontal borders of the system were entered into the mass budget system. The sea surface level, boundary conditions, friction coefficient, turbulence and temperature changes, precipitation values and wind were the system parameters for the hydrodynamic information. As mentioned in the previous sections, the streamflow rates were taken from the PROMET and mGROWA model results for the modelled 5 major streams. Precipitation data were taken from the results of the RCMs. Because of lack of data, water temperature and salinity parameters were assumed to be constant (temperature value assumed to be constant at 10 $^{o}$C). The Smagorinsky coefficient which was used at the turbulence module, was selected to be Cs = 0.176. The sea level data was taken from the Yalova Mareographic Station, which is the only available sea level change monitoring station within the region. The mean value of September was 0.35 m. This mean value was used as an initial sea level value. Consequently, the sea level change was determined as a function of time in the x and y directions.

MIKE 3 HD simulation runs were performed for the Izmit Bay using streamflow data provided by the models PROMET and mGROWA based on climate data from an ensemble of four general GCM and RCM combinations mentioned before, namely the ECH-RCA, ECH-REM, ECH-RMO and HCM-RCA models. In accordance with the hydrologic simulations, MIKE 3HD simulations were carried out for the reference period (1971-2000) and the future period (2041-2070) in order to assess possible variations in sea level. Both modeling periods start on 1st of September and end on 31st of August.

Fig 15 presents the monthly mean sea level change results of MIKE 3HD using PROMET and mGROWA runoff data. The mean values of the reference period indicate that the variations in sea level are more prominent between September and February compared to the other half of the year. This is due to the fact that most precipitation events occur during this period. The variations between the reference period and the future periods are quite significant between September and February, so that the seasonal pattern of precipitation may sustain in the future. Vice versa, the values between February and August show that sea level change is smoother and the predictions for future periods are close to the reference values.

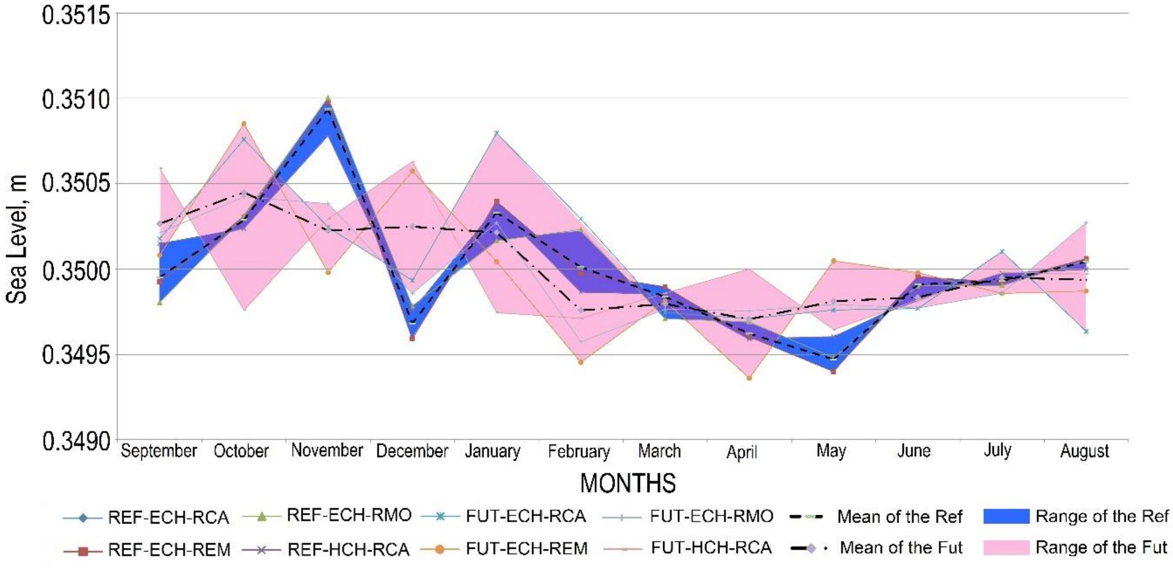


**Fig 15.** Monthly mean sea level change results of MIKE 3 using PROMET and mGROWA runoff data

The monthly mean sea level change values obtained from the MIKE 3HD simulation runs using river discharge data provided by PROMET and mGROWA models can be found in Table 6. As can be seen, both PROMET and mGROWA model results are quite comparable to each other and the differences between the two models are negligible.

**Table 6.** Monthly mean values of the sea level change results using river discharge data provided by the PROMET (VISTA) and mGROWA (FZJ) models

| | PROMET REF (m) | mGROWA REF (m) | PROMET FUT. (m) | mGROWA FUT (m) | Mean of the REF (m) | Mean of the FUT (m) |
|---|---|---|---|---|---|---|
| September | 0.3499 | 0.3500 | 0.3503 | 0.3502 | 0.3500 | 0.3503 |
| October | 0.3502 | 0.3504 | 0.3503 | 0.3506 | 0.3503 | 0.3504 |
| November | 0.3509 | 0.3510 | 0.3501 | 0.3504 | 0.3509 | 0.3502 |
| December | 0.3494 | 0.3500 | 0.3500 | 0.3505 | 0.3497 | 0.3502 |
| January | 0.3503 | 0.3504 | 0.3502 | 0.3502 | 0.3503 | 0.3502 |
| February | 0.3500 | 0.3500 | 0.3498 | 0.3497 | 0.3500 | 0.3498 |
| March | 0.3501 | 0.3496 | 0.3498 | 0.3498 | 0.3498 | 0.3498 |
| April | 0.3501 | 0.3491 | 0.3497 | 0.3497 | 0.3496 | 0.3497 |
| May | 0.3498 | 0.3491 | 0.3499 | 0.3497 | 0.3495 | 0.3498 |
| June | 0.3500 | 0.3498 | 0.3498 | 0.3499 | 0.3499 | 0.3498 |
| July | 0.3500 | 0.3499 | 0.3499 | 0.3500 | 0.3499 | 0.3499 |
| August | 0.3500 | 0.3501 | 0.3499 | 0.3500 | 0.3500 | 0.3499 |

Hence the deviation of the model results from the actual level at the reference sea level gauging station Yalova (0.35m) is negligible. As Izmit Bay is assumed to be a hydro dynamically closed system in the MIKE 3HD model set-up, there is a clear indication that the climate change induced impacts on streamflow may only to a minor extent affect the sea level in the bay. Instead, climate change induced water exchange of the bay with the open sea may probably has a greater influence on sea level changes, if the model domain will be set up as an open system. The related MIKE 3HD simulations should be repeated once the hydrologic regime of the catchments of the Black Sea and the Aegean Sea and the processes in the Sea have been assessed in a broader macro-scale study.

## 4. CONCLUSIONS

An ensemble of 4 global climate model/regional climate model couples has been applied to drive the hydrological models PROMET and mGROWA. Based on these overall 16 simulation setups which comprise two hydrological periods from 1971-2000 (reference period) and 2041-2070 (future period) respectively, a bandwidth of possible future development paths of the regional streamflow was determined. Due to the global warming predicted in the climate models and the resulting shift of rainfall periods with increasing precipitation during the winter months and decreasing precipitation during the summer months, river streamflow is simulated to increase in winter and the rivers will fall dry more often and longer than in present times during drought periods in summer.

On the other hand, it was shown that the impact of streamflows of the reference and the future period on the sea level changes is low. This indicates that the effects of climate change on terrestrial hydrology will be negligible or not likely to be reflected in the bay. From here, it can be concluded that under the global climate change conditions, the Izmit Bay will be more exposed to the effects of Marmara Sea. This in mind, we conclude the related MIKE 3HD simulations should be repeated once the hydrologic regime of the catchments of the Black Sea and the Aegean Sea and the processes in the Sea have been assessed in a broader macro-scale study. The latter however was not part of the work packages of the EU 7th Framework Programme project CLIMB.

In a more general sense it can be concluded that the coupling of Global and Regional Climate Models with the hydrologic models PROMET / mGROWA and MIKE 3HD is technically possible. An application for a small bay (here Izmit Bay) however should include discharge data from all catchments (here the Aegean – Mediterranean – Black Sea system) and the related exchange processes with the open seas.

## ACKNOWLEDGMENT

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## REFERENCES

[1]. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 151.

[2]. S.N. Gosling, R.G. Taylor, N.W. Arnell and M.C. Todd, "A comparative analysis of projected impacts of climate change on river runoff from global and catchment-scale hydrological models," *Hydrology and Earth System Science*, Vol. 15, pp. 279-294, 2011.

[3]. A.J. Lamadrid and K.L. MacClune, Climate and Hydrological Modeling in the Hindu-Kush Himalaya Region. Feasibility Report for a Himalayan Climate Change Impact and Adaptation Assessment. International Centre for

Integrated Mountain Development. Kathmandu, 2010.

[4]. A. Panagopoulos, G. Arampatzis, E. Tziritis and V. Pisinaras, F. Herrmann, R. Kunkel, F. Wendland, "Assessment of climate change impact in the hydrological regime of River Pinios Basin, Central Greece," *Desalination and Water Treatment*, Vol. 57, pp. 2256-2267, 2016.

[5]. S. Praskievicz and H. Chang, "A review of hydrological modeling of basin-scale climate change and urban development impacts," *Progress in Physical Geography*, Vol. 33, pp. 650–671, 2009.

[6]. K.M. Strzepek and A.L. Mccluskey. Modeling the Impact of Climate Change on Global Hydrology and Water Availability - Discussion Paper Number 8, 2010.

[7]. The Turkish Statistical Institute, TUIK, Available: http://www.tuik.gov.tr, (accessed 06 July 2017).

[8]. V.P. Singh, "Computer models of watershed hydrology," *Water Resources Publications*, Colorado, 1995.

[9]. M. Albek, U. Bakır Ogutveren and E. Albek, "Hydrological modeling of Seydi Suyu watershed (Turkey) with HSPF," *Journal of Hydrology*, Vol. 285, pp. 260–271, 2004.

[10]. H. Apaydin, A.S. Anli and A. Ozturk. "The temporal transferability of calibrated parameters of a hydrological model," *Ecological Modelling*, Vol. 195, pp. 307–317, 2006.

[11]. P. Droogers, W.G.M. Bastiaanssen, M. Beyazgul, Y. Kayam, G.W. Kite and H. Murray Rust, "Distributed agro-hydrological modeling of an irrigation system in western Turkey," *Agricultural Water Management*, Vol. 43, pp. 183-202, 2000.

[12]. F. Keskin, "Hydrological model study in Yuvacik dam basin by using GIS analysis," (Doctoral dissertation). Middle East Technical University, 2007.

[13]. G. Benito, N.G. Macklin, C. Zielhofer and A.F. Jones, M.J. Machado, "Holocene flooding and climate change in the Mediterranean," *Catena*, Vol. 130, pp. 13–33, 2015.

[14]. D. Bozkurt and O.L. Sen, "Climate change impacts in the Euphrates–Tigris Basin based on different model and scenario simulations," *Journal of Hydrology*, Vol. 480, pp. 149–161, 2013.

[15]. A. Erturk, A. Ekdal, M. Gurel, N. Karakaya, C. Guzel and E. Gonenc, "Evaluating the impact of climate change on groundwater resources in a small Mediterranean watershed," *Science of the Total Environment*, Vol. 499, pp. 437–447, 2014.

[16]. Y. Fujihara, K. Tanaka, T. Watanabe and T. Nagano, T. Kojiri, "Assessing the impacts of climate change on the water resources of the Seyhan River Basin in Turkey: Use of dynamically downscaled data for hydrologic simulations," *Journal of Hydrology*, Vol. 353, pp. 33-48, 2008.

[17]. R. Deidda, M. Marrocu, G. Caroletti, G. Pusceddu, A. Langousis, V. Lucarini and A. Speranza, "Regional climate models' performance in representing precipitation and temperature over selected Mediterranean areas," *Hydrology and Earth System Sciences*, Vol. 17, pp. 5041-5059, 2013.

[18]. R. Ludwig, A. Soddu, R. Duttmann, N. Baghdadi, S. Benabdallah, R. Deidda and T. Ammerl, "Climate-Induced Changes on the Hydrology of Mediterranean Basins – A Research Concept to Reduce Uncertainty and Quantify Risk," *Fresenius Environmental Bulletin*, Vol. 19 (10a), pp. 2379 – 2384, 2010.

[19]. W. Mauser and H. Bach, "PROMET - Large scale distributed hydrological modeling to study the impact of climate change on the water flows of mountain watersheds," *Journal of Hydrology*, Vol. 376, pp. 362-377, 2009.

[20]. L. Ehlers, F. Herrmann, M. Blaschek, F. Wendland and R. Duttmann, "Sensitivity of mGROWA-simulated groundwater recharge to changes in soil and land use parameters in a Mediterranean environment and conclusions in view of ensemble-based climate impact simulations," *Science of the Total Environment*, Vol. 543, pp. 937-951, 2015.

[21]. F. Herrmann, L. Keller, R. Kunkel H. Vereecken and F. Wendland, "Determination of spatially differentiated water balance components including groundwater recharge on the Federal State level – A case study using the mGROWA model in North Rhine-Westphalia (Germany)," *Journal of Hydrology: Regional Studies*, Vol. 4, pp. 294-312, 2015.

[22]. P. Kreins, M. Henseler, J. Anter, F. Herrmann and F. Wendland, "Quantification of Climate Change Impact on Regional Agricultural Irrigation and Groundwater Demand," *Water Resources Management*, Vol. 29, pp. 3585-3600, 2015.

[23]. DHI. MIKE 21 MIKE 3 Flow Model FM, Short description of Hydrodynamic Module. DHI Software. Denmark, 2013.

[24]. Kocaeli Mayorship, Kocaeli Environmental Status Report, 2006, Available: http://cdr.cevre.gov.tr/2010_icdrler/kocaeliicd 2010.pdf, (accessed 01 December 2015).

[25]. Kocaeli Govornership, Turkish Government, Available: http://www.kocaeli.gov.tr/sanayi-kenti-kocaeli, (accessed 06 July 2017).

[26]. H.A. Ergül, T. Varol and U. Ay, "Investigation of heavy metal pollutants at various depths in the Gulf of Izmit," *Marine Pollution Bulletin*, Vol. 73, pp. 389–393, 2013.

[27]. E. Morkoç, O.S. Okay, L. Tolun, V. Tufekçi, H. Tufekçi and T. Legoviç, "Towards a clean Izmit Bay," *Environmental International*, Vol. 26, pp. 157–161, 2001.

[28]. L. Tolun, O.S. Okay, A.F. Gaines, M. Tolay, H. Tüfekçi and N. Kıratlı. "The pollution and toxicity of surface sediments in Izmit Bay (Marmara Sea)," Turkey. *Environmental International*, Vol. 26, pp. 163–168, 2001.

[29]. L. Tolun, O.S. Okay, D. Martens and K.W. Schramm, "Polycyclic aromatic hydrocarbon contamination in coastal sediments of the Izmit

Bay (Marmara Sea): Case studies before and after the Izmit Earthquake," *Environment International*, Vol. 32, pp. 758-765, 2006.

[30]. M. Karpuzcu, N. Agiralioglu, N. Alpaslan, G. Engin, H. Gömann, O. Gunduz and F. Wendland. Integrated Modeling of Nutrients in Selected River Basins of Turkey. Schriften des Forschungszentrums. *Jülich, Reihe Energie & Umwelt*, Vol. 17, pp. 183, 2008.

[31]. H. Bach, M. Braun, G. Lampart and W. Mauser, "The use of remote sensing for hydrological parameterisation of Alpine catchments," *Hydrology and Earth System Sciences*, Vol. 7, pp. 862–876, 2003.

[32]. R. Ludwig, W. Mauser, S. Niemeyer, A. Colgan, R. Stolz, H. Escher-Vetter and R. Hennicker, "Web-based modeling of energy, water and matter fluxes to support decision making in mesoscale catchments - the integrative perspective of GLOWA-Danube," *Physics and Chemistry of the Earth*, Vol. 28, pp. 621–634, 2003.

[33]. W. Mauser and R. Ludwig. A research concept to develop integrative techniques, scenarios and strategies regarding global changes of the water cycl.. In: M. Beniston (Ed.), Climatic Change: Implications for the Hydrological Cycle and for Water Management: Advances in Global Change Research GLOWA-DANUBE. Kluwer Academic Publishers, Dordrecht and Boston, pp. 171–188, 2002.

[34]. P. Klug, H. Bach and S. Migdall, Monitoring Soil Infiltration in Semi-Arid Regions with Meteosat and a Coupled Model Approach Using PROMET and SLC. Paper presented at the meeting of ESA Living Planet Symposium, Edinburgh, 2013.

[35]. H. Bach, W. Verhoef, K. Schneider, "Coupling remote sensing observation models and a growth model for improved retrieval of (geo)biophysical information from optical remote sensing data," Remote Sensing for Agriculture, Ecosystems and Hydrology, 4171, 1–11, 2000.

[36]. R. Ludwig and W. Mauser, "Modeling catchment hydrology within a GIS based SWAT-model framework," *Hydrology and Earth System Science*, Vol. 4(2), pp. 239–249, 2000.

[37]. U. Strasser and W. Mauser, "Modeling the spatial and temporal variations of the water balance for the Weser catchment 1965–1994," *Journal of Hydrology*, Vol. 254 (1-4), pp. 199-214, 2001.

[38]. J.A. Cunge, "On the subject of a flood propagation computation method (Muskingum method)," *Journal of Hydraulic Research*, Vol. 7, pp. 205–230, 1969.

[39]. E. Todini, "A mass conservative and water storage consistent variable parameter Muskingum-Cungeapproach," *Hydrolology and Earth System Science*, Vol. 4, pp. 1549–1592, 2007.

[40]. W. Verhoef and H. Bach, "Coupled soil–leaf-canopy and atmosphere radiative transfer modeling to simulate hyperspectral multi-angular surface reflectance and TOA radiance data," *Remote Sensing of Environment*, Vol. 109, pp. 166-182, 2007.

[41]. R. Kunkel, H. Röhm, J. Elbracht and F. Wendland, "Das CLINT Interpolationsmodell zur Regionalisierung von Klimadaten und WETTREG Klimaprojektionen für Analysen zum regionalen Boden-und Grundwasserhaushalt in Niedersachsen und Bremen. GeoBerichte-Landesamt für Bergbau", *Energie und Geologie*, Vol. 20, pp. 6-31, 2012.

[42]. T. Marke, W. Mauser, A. Pfeiffer and G. Zängl, "A pragmatic approach for the downscaling and bias correction of regional climate simulations: evaluation in hydrological modeling," *Geoscientific Model Development*, Vol. 4, pp. 759-770, 2011.

[43]. R.G. Allen, L.S. Pereira, D. Raes and M. Smith, Crop evapotranspiration - Guidelines for computing crop water requirements, 1998.

[44]. R. Kunkel and F. Wendland, "The GROWA98 model for water balance analysis in large river basins - the river Elbe case study," *Journal of Hydrology*, Vol. 259, pp. 152-162, 2002.

[45]. N. Engel, U. Müller and W. Schäfer, "BOWAB - Ein Mehrschicht-Bodenwasserhaushaltsmodell," *GeoBerichte - Landesamt für Bergbau, Energie und Geologie*, Vol. 20, pp. 85-98, 2012.

[46]. E. Strandhagen, W.A. Marcus and J.E. Meacham, "Views of the Rivers: Representing Streamflow of the Greater Yellowstone Ecosystem," *Cartographic Perspectives*, Vol. 55, pp. 54-59, 2006.

[47]. U. Müller and A. Waldeck, Auswertungsmethoden im Bodenschutz. Vol 19: Landesamt für Bergbau, Energie und Geologie Niedersachsen, 2011.