Yuvacik Dam: Improvements to dam operation utilizing an integrated atmospheric-hydrological model

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SYNOPSIS. The paper describes the methodology employed to control water levels within Yuvacık Dam near Izmit, Turkey. It also provides details of a current study, results of which are expected to improve the operational control of this water supply and flood retention dam. The study includes the application of a hydrological model coupled with atmospheric forecast data; the project is currently active and being carried out by Thames Water International in conjunction with Middle East Technical University and Anadolu University. The study proposes to use of semi-distributed hydrologic modelling coupled with numerical weather prediction and GIS technology. The predicted precipitation and temperature values obtained by the numerical weather prediction model will be used as input to the hydrological model for near-real time runoff estimation to the Yuvacık dam reservoir for better and efficient operation.

INTRODUCTION

Turkey Thames Water, working with local partners, was awarded the first build, operate and transfer water supply project in Turkey in 1995. The Thames led project to supply water to Kocaeli Province in Turkey is the largest privately-financed water project in the world. Opened on 18th January 1999, the Izmit scheme provides high quality water to over 1.2 million people along with the rapidly growing industrial sector in the province. The project involved construction of a 101m high earth fill dam (Yuvacık Reservoir), a water treatment plant and a trunk main system of 146 kilometers including branch lines in Izmit, to the northeast of the city of Istanbul. The reservoir has a capacity of 60.6 million m^3 and an estimated annual yield of over 142 million m^3. The treatment plant has a designed production capacity of 480 million litres per day and the pipeline feeds 38 service reservoirs and includes 6 pumping stations.

Thames Water will operate and maintain the new system for 8 years before handing it over to the Izmit Greater Municipality free of charge with all the assets. Until the handover on 18th January 2014, Thames Water is committed to transfer knowledge of the best skills and technology between the projects and to the local community. In August 1999 the area was hit by a massive earthquake, measuring 7.4 on the Richter scale and devastating the local community. The dam, pipeline and treatment works withstood the shock and remained undamaged.

Water control managers who regulate projects need access to timely and accurate information on which to base sound decisions. During a flood event, decisions sometimes have to be made within minutes or hours from the onset of rising river stages. During a drought, decisions can affect water availability for months into the future. Water control managers need continuous real-time data observations from field sites, as well as reliable watershed modelling tools, to provide appropriate responses to changing hydrologic conditions. Accurate real-time forecasts of natural inflows to reservoirs are of particular interest for operation and scheduling. A variety of methods have been proposed for this purpose including conceptual (physical) and empirical (statistical) models (WMO, 1994). As a result, TW identified a pressing need to develop a uniform water management system integrating communication networks, centrally developed and supported software, and state-of-the-art hydrological and hydraulic models.

The semi-distributed hydrological model is applied on near-real time basis with the integration of one day ahead forecast data from a regional atmospheric circulation model to provide an improved decision support system for the operation and management of Yuvacık reservoir. Using this methodology streamflow data contributing to the reservoir is estimated, the extreme flood events are managed and the storage is maximised for water supply during the uncertain periods in the spring months of each year. Data from the existing and newly established network of rain gauging stations could be used for this purpose in accordance with the outputs of atmospheric circulation model.

COMPONENTS OF THE SYSTEM

The solutions to manage a strategy plan for these kinds of problems are the followings: Rainfall-runoff modelling approach based on physical principals, near-real time model application using near-real time data obtained from the data management system network. The project software package can be regarded as a puzzle consisting of five interlocking pieces, as shown in Figure 1 (Fritz et al., 2002). The four pieces around the perimeter all deal with some aspect of data management. The key middle component, which interacts with all of the data management activities, is watershed modelling. It allows water control managers to use observed real-time data and National Weather Service (NWS) forecast precipitation to simulate future conditions.

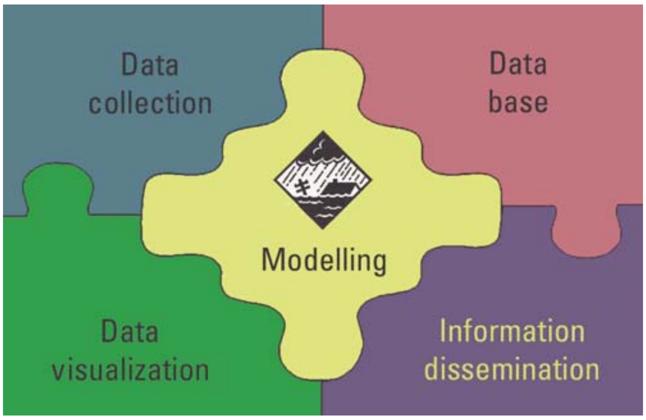


Figure 1: Components of the system (Fritz et al., 2002)

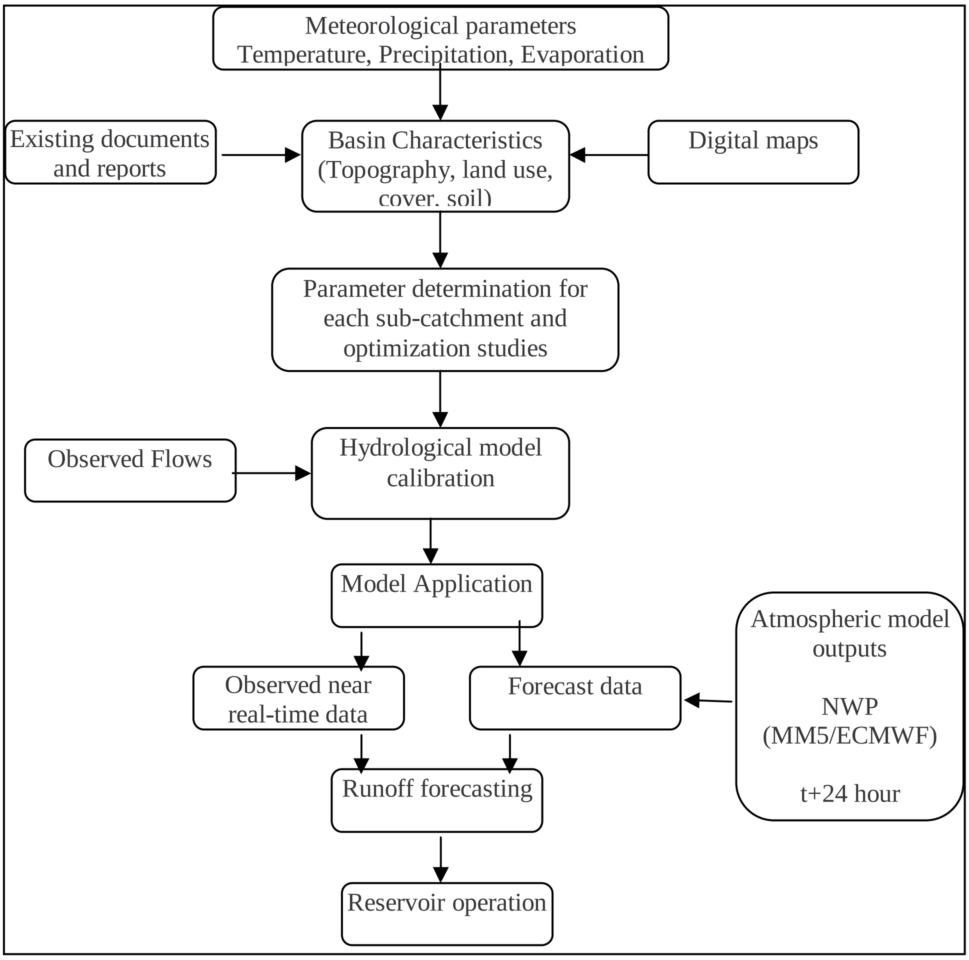


Figure 2: The general structure of the atmospheric-hydrologic model integration and hydro-meteorological components

IMPROVEMENTS IN RESERVOIRS

Steps to be followed for the defined work include; Data retrieval from the existing gauging network archive and their preprocessing, selection of new instruments and establishment of the new network, installation and data transferring through fixed and mobile stations, snow data collection (snow depth data) and manual snow water equivalent data collection with ground observations at the selected sites, selection of hydrological models calibration of selected model, model verification, the development of interface programs and the integration of a regional atmospheric model with the selected hydrological model and model application (Figure 2).

EXISTING DATA AND PREPROCESSING

The digital and the analog maps are required for the physically based modelling studies. Geographical Information System (GIS) tools are also used to carry out analysis and enhance graphical displays. Aerial photography, digital maps and other GIS data allow the geo-referencing of critical features in the watershed. The maps basically include digital elevation model (DEM), land use and land cover, soil types and geological maps. DEM (Figure 3) of the basin is basically used to evaluate the performance of the existing rain gauge network which has been upgraded with new equipment. In addition, DEM is essentially used for the watershed delineation and formation of sub-basins. The slope and aspect maps are also derived to emphasize the basin characteristic of the region. Land use/land cover and soil/geological maps are used in the cross quarry analysis that will be required later in the study for the optimization of infiltration parameters of hydrologic models. All these maps form the geospatial background of the hydrological modelling.

Thames Water (TW) data can be classified as either real-time data or static information. Real-time data include time-series observations, such as river stages (3), precipitation (6) and reservoir elevations (2). Gauges are provided at key locations and they record observed conditions such as river stages and precipitation. Typically, gauges are equipped with telemetry units which record data in 5 minutes time-steps and transmit the information. The data are then downloaded to TW computer servers in the water control management center (DMS). DMS has a comprehensive system incorporating the acquisition, transformation, storage, display of information to support TW real-time water control mission. The incoming real-time data include hydrological information (river stage, reservoir elevation), meteorological information (observed and forecast precipitation), and other hydro-meteorological information (such as water quality data). Observed data, shown in Table 1 and Table 2, are used to view the current status of the watershed. Watershed modelling programs are used to forecast runoff, reservoir response and operations. A number of future precipitation and reservoir operation scenarios can be evaluated.

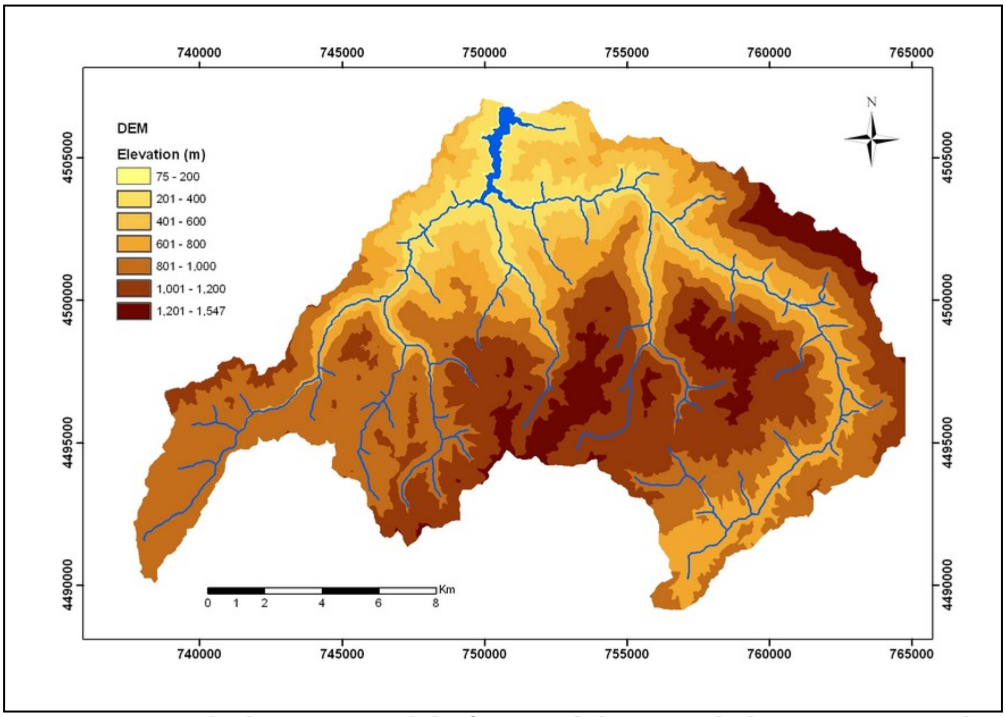


Figure 3: Digital Elevation Model of Yuvacık basin with dam reservoir and river network

Table 1: Available meteorological records for the project

Meteorological Records				
Organization	**Station**	**Data Type**	**Data Interval**	**Elevation**
State Meteorological Org. (DMI)	Kocaeli (2000-2005)	Precipitation Snow Depth Temperature	Daily Daily Daily	76 m
State Hydraulic Works (DSI)	Hacıosman (2000-2004)	Precipitation Snow Description	Daily Daily	900 m
State Hydraulic Works (DSI)	Kurtköy (1987, 1989, 1991)	Precipitation	Daily	40 m
Thames Water (TW)	DMS (2001-2005)	Precipitation	5 Minutes	320 m 170 m

Table 2: Available hydrological records for the project

Runoff Records				
Organization	**Station**	**No.**	**Data Interval**	**Elevation**
Thames Water (TW) (2001-2005)	Kirazdere	FP1	5 minutes	185 m
	Kazandere	FP2	5 minutes	180 m
	Serindere	FP3	5 minutes	200 m
	Reservoir	FP4	5 minutes	190 m
State Hydraulic Works (DSI) (1963-1992)	Kirazdere	02-06	Daily averages	37 m
State Hydraulic Works (DSI) (1987, 1989, 1991)	Kirazdere	02-06	Instant peak flow discharges	37 m

INSTRUMENTATION

Yuvacık basin has an area of 258 km^2 and an elevation ranging from 75-1547 m, as depicted in Figure 3, with a mid-altitude of around 800 m. The existing network of six rain gauges in Yuvacık basin was not capable of representing the spatial variation of precipitation amount in terms of the whole catchment and its sub-basins (Kirazdere, Kazandere, Serindere). Hence, it was decided to renew and upgrade the existing rain gauge network with new instrumentation. Numerous site trips have been carried out with a Global Positioning System in order select possible locations for the new stations based on certain criteria (location, communication, electricity, accessibility, elevation, aspect, land cover and security). According to the site conditions, four of these locations are chosen as fixed stations whereas the other three are marked as mobile stations. The reason for constructing mobile stations at certain locations instead of fixed ones arose mainly from electricity and communication incapability of the points although the position of the stations would represent valuable precipitation data. In the future, if some of these mobile stations are thought to be important representative points, then stronger measures could be taken to solve the current incapabilities and turn them into fixed stations. The locations of the new stations along with the old precipitation and flow plant (stream gauging) network can be seen in Figure 4. Views from one of the fixed and mobile stations are shown in Figure 5.

In the new stations, besides collecting precipitation data only, other important meteorological and snow measuring sensors (temperature, humidity, snow depth) are also installed in order to collect data about the region. Especially as the new stations are positioned at higher locations, the form of precipitation could be different at these locations (such as snow) as compared to the lower altitudes (rainfall) at certain time periods. This process may have a significant effect on the discharge reaching the dam reservoir when enough energy is present to melt the deposited snow on the higher grounds of the basin. To be able to follow the snowmelt process in the catchment, snow depths as well as air temperature are also monitored at the stations. Also at certain intervals of the winter season, manual snow depth and density measurements are conducted around the fixed stations to the stations to compare with the automatically collected data in the stations.

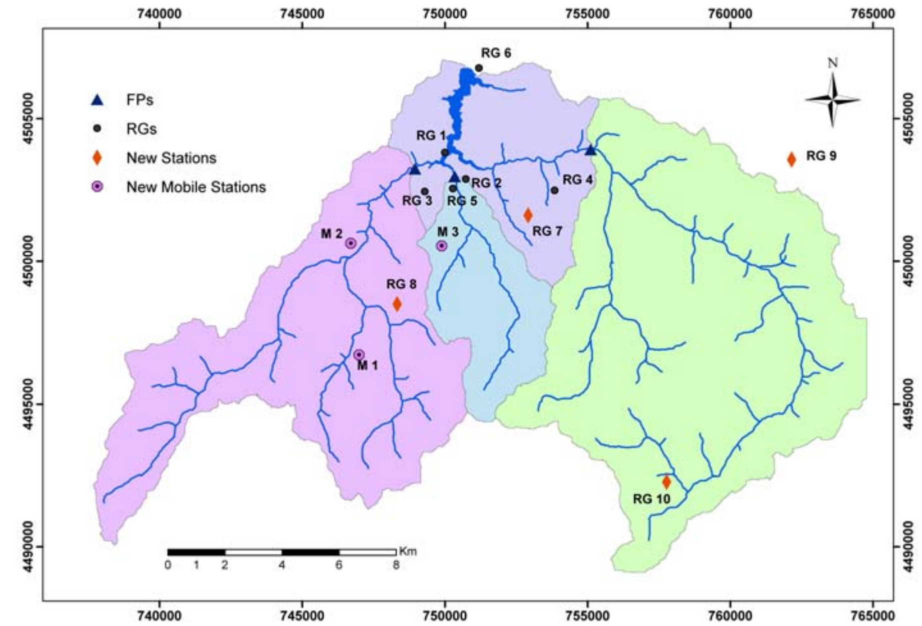


Figure 4: Location of the stations in the basin

Fixed station

Mobile station

Figure 5: Views from a fixed and a mobile station in Yuvacık basin

IMPROVEMENTS IN RESERVOIRS

ANALYSIS OF EVENTS

This analysis forms the main part of any hydrological study, since all types of modelling strategy need both qualitative and quantitative data. TW finds that an enormous amount of time is required in the retrieval and quality control associated with hydrological data collection. At the end of the analysis, there are problems especially for the runoff data set that should be controlled and verified. There are a few events where the three runoff stations collected accurate data simultaneously; therefore the calibration work mainly concentrates on sub-basin terms instead of the whole basin.

This part of the study is especially important since it constitutes the main input of the model calibration step. A query is carried out to derive the basic sub-groups of events from the existing data (September 2001 - June 2005) concerning the double criteria including both total daily precipitation amount (P_T) and the reservoir inflow volumes (R_I). For each event, precipitation (rainfall from all of the stations including DMS, KE and HO and snow depth collected at KE and HO stations) and runoff values (from FP stations) are analyzed in detail. Events are categorized in terms of rainfall/snowmelt – runoff relation.

In some events, there are discontinuities at water stages noticed in the collected data. These mistakes are thought to have occurred from the incorrect measurement of the level (stage) data in the stations. In addition, zero recordings are observed in the stations which cause frequent data jumps in the discharge values. Moreover, in some events although the runoff station seems to work throughout the event, there are missing parts especially in the flood events (peak values). Also sometimes, the radar and ultrasonic flow measurements differ from each other for the same event. Due to the large elevation range of the basin, snow becomes an important factor. In the past very minimal snow data has been collected which makes snowmelt modelling difficult besides rainfall. The HO station operated by DSI is the only snow data source.

HYDROLOGICAL MODEL STUDIES

Thames Water provides an integrated suite of modelling programs which represent the atmospheric conditions and hydrological aspects of the watershed. The installed modelling programs include HEC-HMS (Hydrologic Modelling System, USACE, 2005) interfaces for data inputs. A real-time simulation uses observed data up to the present time and forecast precipitation. The integrated models use those data to forecast the watershed’s response to the anticipated precipitation.

HEC-HMS simulates watershed hydrology using observed and predicted precipitation to compute runoff. Runoff is combined with base flow to generate flow hydrographs at various points within the watershed.

The value of each parameter must be specified to use the model for estimating runoff hydrographs. Some of the models that are included in HEC-HMS have parameters that cannot be estimated by observation or measurement of channel or watershed characteristics. Calibration uses observed hydro-meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. To compare a computed hydrograph to an observed hydrograph, HEC-HMS computes an index of the goodness-of-fit. The key to automated parameter estimation is a searched method for adjusting parameters to minimize the objective function value and find optimal parameter values. In HEC-HMS, one of six objective functions can be used, depending upon the needs of the analysis. The goal of all calibration schemes is to find reasonable parameters that yield the minimum value of the objective function (Table 3).

The total catchment area is divided into four sub-basins and model calibration studies are applied one by one. Precipitation input is entered into HEC-HMS by meteorologic module, which is one of the major components of a project. The meteorologic module has three main components such as precipitation, evapotranspiration, and snowmelt to be used during simulations. Precipitation values are input with gauge weights which are determined by the inverse distance method. The first event set includes hourly hydrographs produced from rainfall events therefore snow data were not used in this part of the study.

After preparing the rainfall input for the hydrologic model, a transformation component for the model must be specified. The synthetic unit hydrographs are derived by State Hydraulic Works (DSI) from historical storms. These unit hydrographs are checked using historical storm events and used in the study.

Two different loss methods are selected in the study; the first one is initial and constant uniform loss method and the second one is exponential loss method. Although the former calibration results show consistent parameter ranges even for events of different seasons, constant loss causes most of the excess rainfall to be lost and hence, the simulated hydrographs do not have an accurate match to the observed measurements. The latter method, specific to HEC models, simulated better fitting results between the observed and calculated hydrographs in the model calibration step. Early summer event data set calibration is given below as an example:

Table 3:
Calibration results of rainfall events with different objective functions

	11-15 Jul 02	9-11 Jun 04	19-21 Jun 04	23-25 Jun 04	31 May-6 Jun 05	4-9 Jul 05
	Sum Squared Residuals	**Percent Error Peak**	**Percent Error Peak**	**Sum Absolute Residuals**	**Percent Error Volume**	**Peak-Weighted RMS Error**
Initial Range (mm)	14.183	16	23.905	21.16	19.589	16.397
Initial Coef. (mm/hr)	0.93891	0.98	0.96341	0.9604	0.93445	0.95593
Exponent	0.96953	0.99	0.98	0.97	0.95922	0.97496
Initial Discharge (m^3/s)	0.37	1.5	1.4	1.37	1.15	0.92
Recession Constant	0.545	0.9	0.8	0.9	0.75	0.3
Ratio / Flow (m^3/s)	1.9	1.6	1.6	1.8	5.6	1.63
Percent Peak Diff.	9.73	-6.67	0.00	-0.41	1.96	-0.80
Percent Volume Diff.	-12.00	-2.54	3.68	3.83	-4.36	-0.99

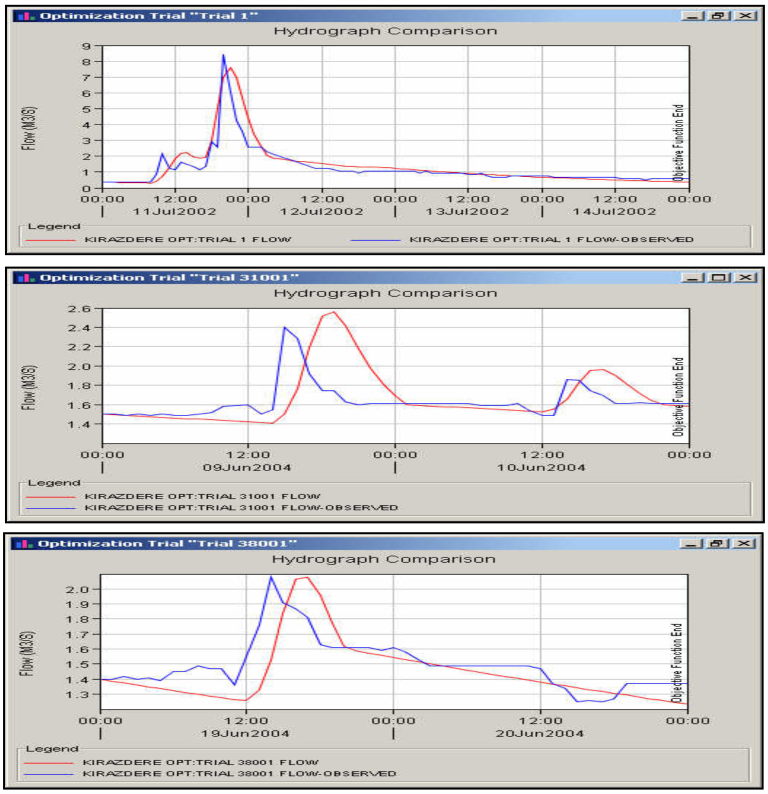
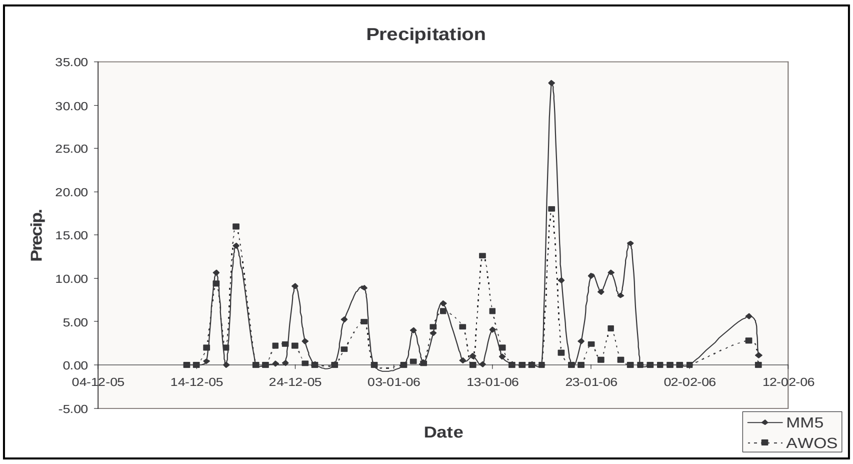


Figure 6: Calibration results between simulated and observed hydrographs

ATMOSPHERIC MODEL INTEGRATION STUDIES

As the event calibration process is continued as one phase of the study, on the other hand numerical weather prediction data are collected and processed. Numerical weather prediction data, Mesoscale Model 5 (MM5), are processed in the supercomputers of State Meteorological Organization (DMI) each day and uploaded through file transfer protocol. The input prediction data to the hydrological model consist of daily average temperature and total precipitation. To test the accuracy of the numerical weather prediction data, the data collected from the 11 automatic ground weather observation stations (AWOS) in the vicinity of the Yuvacık Basin is plotted against the corresponding MM5 temperature and precipitation grid data. The resulting trends seem to match quite accurately although there can be certain offset adjustments needed due to the underlying topographic map mismatch between the AWOS stations and MM5. Daily average temperature and total precipitation between AWOS measurements and one-day ahead predicted MM5 results are presented in Figure 7.



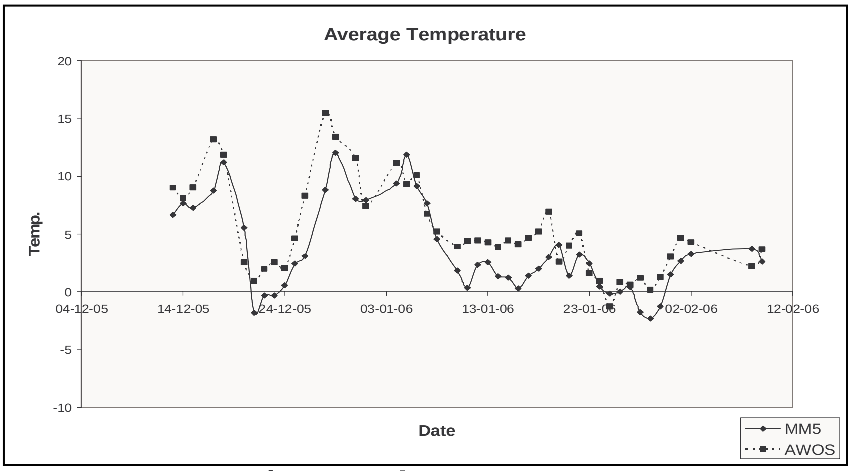


Figure 7: Comparison of MM5 and AWOS average temperature and total precipitation data

DISCUSSION AND RESULTS

The study has been proceeding on schedule (Progress Report I, November 2005). The new instrumentation was placed in time to collect valuable hydro-meteorological data. During the 2006 winter the weather conditions were harsher than average with quite a lot of solid precipitation (snow) being present in the basin. With the construction of snow depth sensors it will be possible to monitor snow data in real-time and hence take precautions especially from high discharges coming from snowmelt.

So far the calibration procedure is being done for rainfall events only and seems to give promising results. As the HEC-HMS program is very recently upgraded to version 3, it also includes snowmelt component using the simpler temperature index method. For those certain selected events that have high discharge values due to snowmelt and rain-on-snow, the next step is to use the new HEC-HMS version 3.1 to calibrate these mixed events in the very near future.

The calibration procedure is to be completed in a few months time (2-3 months) according to the work timeline with the atmospheric-hydrological model integration being the following step. In the end, watershed modelling, when combined with atmospheric forecast data, will allow water control managers to prepare one-day ahead forecasts of hydrological conditions in the watershed. The managers will then use the results to help make reservoir regulation decisions with the knowledge of how those decisions will affect both reservoir operation and the downstream populated and industrial areas of İzmit.

REFERENCES

Fritz J.A., Charley W.J., Davis D.W., Haines J.W. (2002). New water management system begins operation at US projects, *Hydropower and Dams*, Issue 3, United Kingdom.

Progress Report I (2005) Middle East Technical University and Anadolu University, November 2005.

USACE (2005) Hydrological Modelling System, HEC-HMS, User’s Manual, Version 3.0.0, December 2005.

WMO (1994). *Guide to Hydrological Practices*, World Meteorological Organization, WMO-No. 168, Geneva, Switzerland.