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THE DEVELOPMENT OF A FLOOD FORECASTING SYSTEM FOR THE SISTAN PLAIN IN IRAN

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Abstract

The Sistan plain is located in Sistan-Baluchistan in the south-east of Iran, bordering Afghanistan. The plain is home to approximately 350,000 people and supports 230,000 ha of irrigated agriculture fed by distributaries of the Hirmand River. The Hirmand River drains a 178,000 km² catchment that is primarily located in Afghanistan. The Sistan plain is regularly affected by devastating flood events that usually result from the sudden melting of snow covering the Kuh-i-Baba mountains in Afghanistan several hundred kilometres away from the Sistan Plain. There is often little warning of these floods in Iran because they usually occur under “blue sky” conditions. A number of mitigation measures have been implemented by the Iranian Government to reduce the damage to infrastructure and the risk to life from major floods. This paper describes these measures including a prototype flood forecasting system for the Sistan plain based on the use of a weather forecasting model and the estimated snow cover on the Kuh-i-Baba mountains in Afghanistan.

INTRODUCTION

The Sistan province is located in the middle of the eastern Iranian borderlands with Afghanistan, shown in Figure 1. The Sistan plain supports a population of some 350,000. The plain is flat and consists of sediment from the Hirmand River. These sediments make the Sistan plain one of the most fertile parts of Iran.

Owing to the politically sensitive nature and agricultural fertility of the Sistan plain the Iranian Government has invested heavily in new infrastructure in the area. In the early 1970s the Iranian government sponsored extensive irrigation works in the Sistan plain. These irrigation schemes cover approximately 230,000 ha and are fed

by offtake structures located on distributaries of the Hirmand River.

Hydraulic features of the Sistan plain

Ground levels in the Sistan plain range between 475 m above mean sea level to 500 m above mean sea level. The mean gradients of the rivers in the Sistan plain hydraulic system are relatively shallow and range between 1 in 2,500 and 1 in 3,500.

The Sistan plain is fed by distributaries of the Hirmand River, as well as other rivers such as the Farah Rud and Kash Rud. The Hirmand catchment, shown in Figure 1 drains an area of approximately 178,000 km² the majority of which is located in Afghanistan. The Hirmand River rises in

the Kuh-i-Baba mountains about 40 km west of Kabul and flows in a south-westerly direction. It is joined by its major tributary the Arghandab River, near Qale Bist, leaving the mountains to enter a wide alluvial plain. From Qale Bist the Hirmand River flows south and then west in a bed sharply cut into the alluvial plain, after which it turns north to the Hirmand Fork where it on reaching Iran it bifurcates into the Sistan and Common Parian rivers.

The Sistan plain is essentially an inland delta with the major watercourses draining to a series of lakes. The Common Parian forms the Iran-Afghanistan border and discharges to the Puzak Lake in Afghanistan. The Sistan River flows in a north-westerly direction for some 50 km before bifurcating, at a point known as the Sistan Fork, into two branches known as the Adimi and Afzalabad Rivers, shown in Figures 2 and 3. These discharge to the

Hirmand Lake. There are three major barrages located on the Sistan River. The Kohak, Zahak and Sistan Barrages assist controlling flows into the major irrigation canals.

Background to flooding in the Sistan plain

In the past 50 years there have been a number of large flood events. Major flood events have occurred in the Sistan plain in 1957, 1982, 1989, 1991 and 1998 that not only destroyed several thousand hectares of irrigable land but also inundated the towns of Zabol and Zahak shown in Figure 2. During 1991 three separate flood events occurred: one in February and two in March. It is estimated that during the February 1991 flood between 800 M.m³ and 1200 M.m³ of water flooded into agricultural areas.



Figure 1 Location of the Sistan plain and the Hirmand catchment

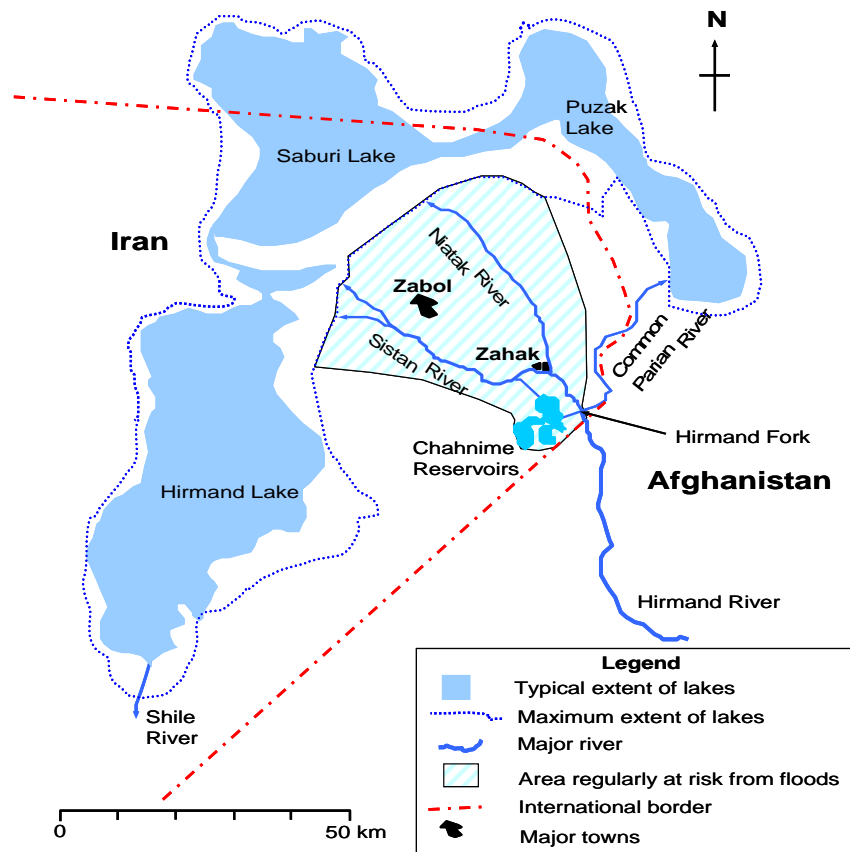


Figure 2 The Sistan plain

Most floods in the Sistan plain occur between February and June. The floods originate from snowmelt in the Kuh-i-Baba mountain range in Afghanistan or from heavy rainfall. Floods resulting from rainfall have different characteristics from those resulting from snowmelt. Rainfall tends to be intense and localised leading to hydrographs with steep rising limbs and relatively small volumes. Floods resulting from snowmelt tend to have hydrographs with a less steep rising limb but a higher peak discharge, longer time base and larger volumes than those resulting from rainfall as shown in Figure 4. As a consequence floods resulting from snowmelt are the ones that generally result in large areas being inundated in the Sistan plain. Owing to the fact that the Kuh-i-Baba Mountains are located several hundred kilometres from the Sistan Plain these floods often occur when there are “blue sky” conditions. As a consequence warning times of flooding are currently minimal.

FLOOD MITIGATION MEASURES

The frequency of devastating floods coupled with the strategic importance of the Sistan plain led the Iranian Government to seek funding for flood mitigation measures. In 1992, funded by a World Bank loan, the Iranian Government commenced implementing a flood mitigation project comprising the following:

- Rehabilitating and upgrading 130 km of dikes along both sides of the Sistan River;
- Construction of the Niatak weir;
- Construction of 30 km of dikes along the Niatak floodway and Niatak River.

The flood control project was designed for a flow of 3,200 m³/s in the Sistan River at the Hirmand Fork shown in Figure 3. This flow is reputed to have a return period of 1 in 100 years. Brief details of the components of the scheme are given below.

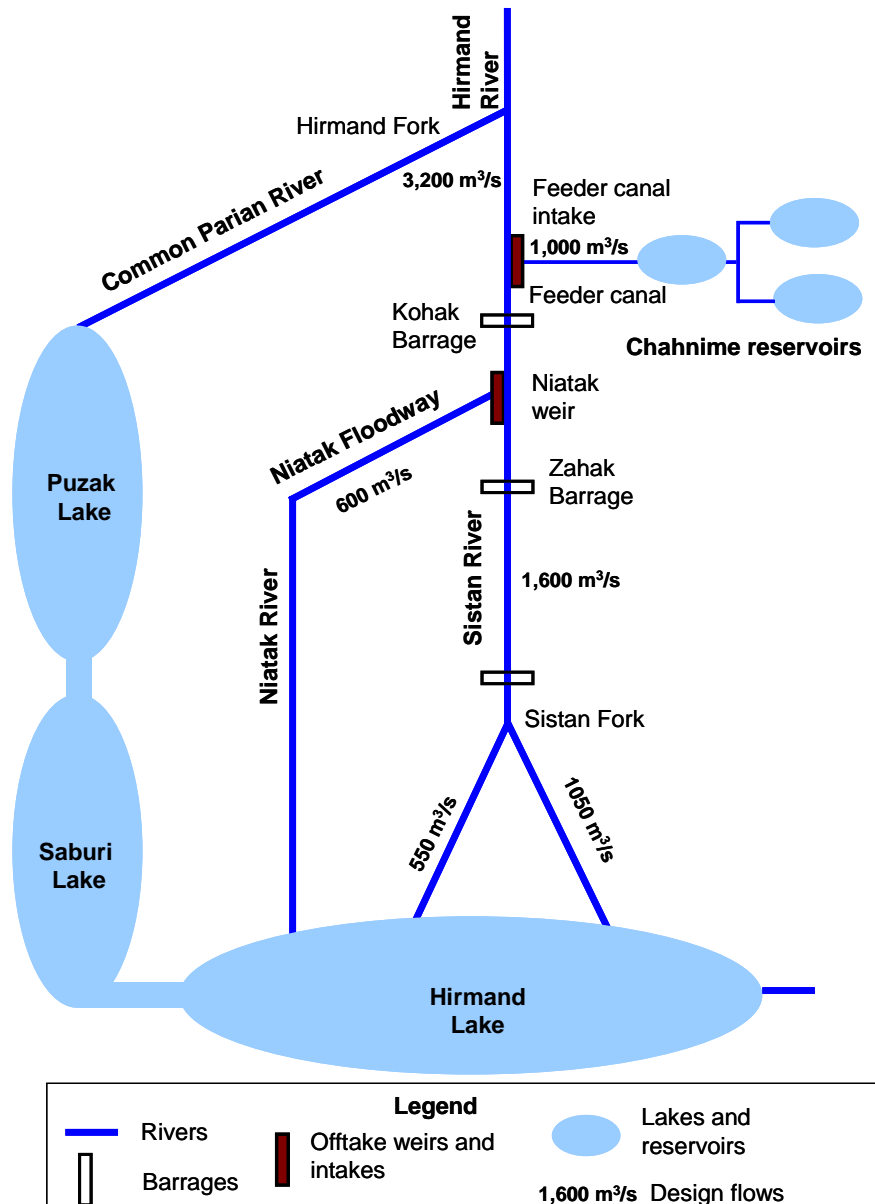


Figure 3 Schematic diagram of the river system within the Sistan plain

The natural capacity of the Sistan River is insufficient to carry the design flood discharges. As a consequence flood control dikes are required to prevent inundation of the Sistan plain. The capacity of the channel formed by the dikes varies between 3,200 m³/s and 550 m³/s as shown in Figure 3. To improve the conveyance efficiency of the Sistan River a number of meander cuts have also been constructed.

The Chahnime reservoirs are a series of natural depressions used primarily to store

water for irrigation. However, they also play an important part in attenuating floods. During periods of high flow, water is diverted to these reservoirs via an intake and canal which has a capacity of up to 1000 m³/s.

The Niatak Weir is located approximately 3 km upstream of the Zahak Barrage on the right bank of the Sistan River and is designed to divert up to 600 m³/s of water into the Niatak Floodway. The Niatak Floodway is a trapezoidal channel

approximately 12 km long that acts as a flood relief channel, connecting the Niatak Weir to the remnants of the Niatak River. To allow a peak flow of $600 \text{ m}^3/\text{s}$ to be safely conveyed by the Niatak River, dikes have been constructed approximately 500 m apart along its left and right banks.

IMPLEMENTATION OF A FLOOD FORECASTING SYSTEM

Background

The implemented infrastructure forms the backbone of the flood mitigation strategy for the Sistan Plain. However, to operate the flood control project effectively a flood forecasting and warning system is required. Upstream of the Hirmand fork the entire river catchment is located in Afghanistan where a very limited amount of hydrological and meteorological monitoring takes place. This poses considerable constraints to setting up a flood forecasting system. The lack of hydrological and meteorological data means that any flood forecasting system has to use remotely sensed information. Conventional flood forecasting systems usually rely on telemetered meteorological and hydrological data provided on a real-

time basis from key points throughout the catchment.

In order to combat these constraints a prototype flood forecasting system was developed using remotely sensed data for the catchment. The aim of this system is two fold:

- (i) To provide a short-range forecast with around two days lead time to forecast peak flows at the Hirmand Fork.
- (ii) To provide a long-term forecast system with one to two months lead time to estimate maximum lake levels and to improve the operation of the Chahnime reservoirs for irrigation and flood mitigation purposes.

An analysis of hydrological data indicated that periods of high flows in excess of a week are generally produced from snowmelt in the mountains of Afghanistan. This snowmelt usually occurs when the temperature rises between March and May with peak flows at the Hirmand Fork typically occurring in April and May. If the amount of water stored in the snow can be estimated in winter, the water volume that will arrive later in the year in the Sistan plain can be forecast.

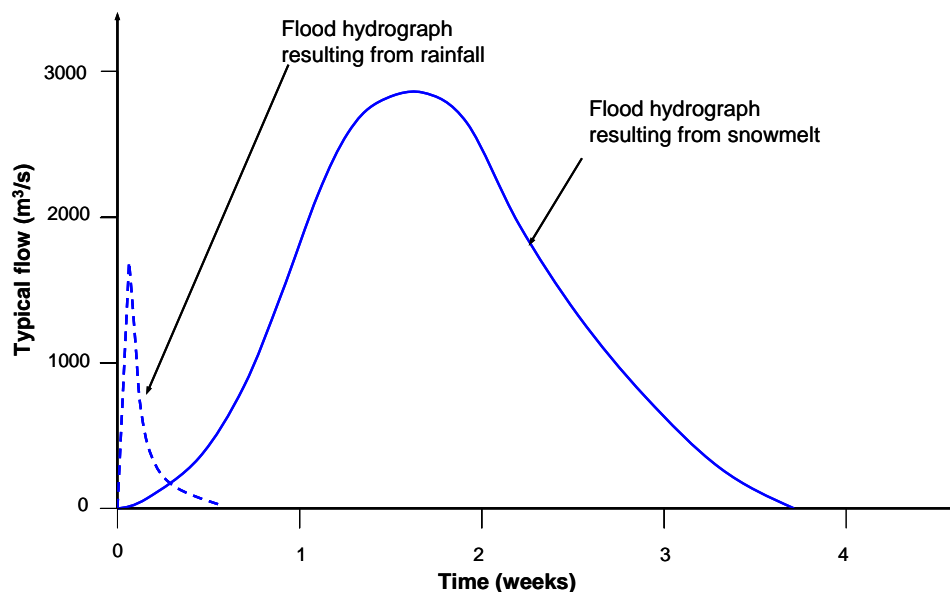


Figure 4 Comparison of typical flood hydrographs resulting from rainfall and snowmelt

With respect to providing a short range forecast, an analysis of the flooding that occurred in the early 1990s indicated that the flood hydrographs were generated by rainfall in the lower reaches of the catchment. Such rainfall events can typically only be predicted a short time ahead (i.e. a few days). These floods occur typically between February and April.

To implement an accurate and reliable flood forecasting system for the Sistan plain that can both provide short term and long term flow forecasts the following were required:

- A digital elevation model of the entire Hirmand catchment;
- Current and forecast precipitation and temperature data at a suitable spatial resolution over the entire catchment;
- A robust and reliable method to model the discharge resulting from rainfall and snowmelt at a catchment level;
- A hydrological routing model;
- A means of calibrating and verifying the proposed system.

Digital elevation model of the Hirmand catchment

A digital elevation model (DEM) of the Hirmand River catchment was created using geographical the GTOPO30 data set that is freely available from the United States Geological Survey (USGS). This data set has a horizontal grid spacing of 30 arc seconds (approximately 1 km). The drainage pattern of the rivers in the basin were derived using an automated procedure in a Geographical Information System (GIS).

The use of weather models to forecast temperature and precipitation

Owing to the lack of observed data the proposed flood forecasting system relies on forecast data from a weather model. Current weather forecast models, such as that of the European Centre of Medium Range Weather Forecast (ECMWF), provide global weather data for a 0.5° grid. To forecast flooding for

the Hirmand basin precipitation and temperature data are required.

The ECMWF model is continuously updated using a large global network of meteorological measurement stations; hence the current weather forecast is generally reliably represented. The model simulates both current weather conditions, which form the boundary conditions for the weather forecast for the coming days.

Modelling of flood flows

To set up a flood forecasting system for a catchment that covers 178,000 km² requires large quantities of data that varies both in time and space. In order to model the hydrological processes of the Hirmand catchment the GIS PCRaster was utilised. PCRaster is a raster based GIS that allows dynamic (i.e. spatio-temporal) modelling of environmental processes. The catchment was divided into 3 km x 3 km cells

The method used to simulate water in the soil is based on the spatially distributed hydrological model based on the HBV model that is described by Killingtveit and Sælthun, 1995. The hydrological model is written in PCRaster-script. Input data are precipitation, temperature and potential evaporation. The principal output is discharge. The HBV model allows the dynamics of runoff on a catchment wide basis to be described by a few simple equations representing how the ground responds to snow melt and rain. The Hirmand catchment was divided into 12 sub-catchments. The runoff from each of these sub-catchments is routed to the Hirmand Fork using a hydrological model constructed using the RIBASIM (River Basin Simulation Model) software, that includes a flow routing component.

Calibration and verification of the prototype flood forecasting system

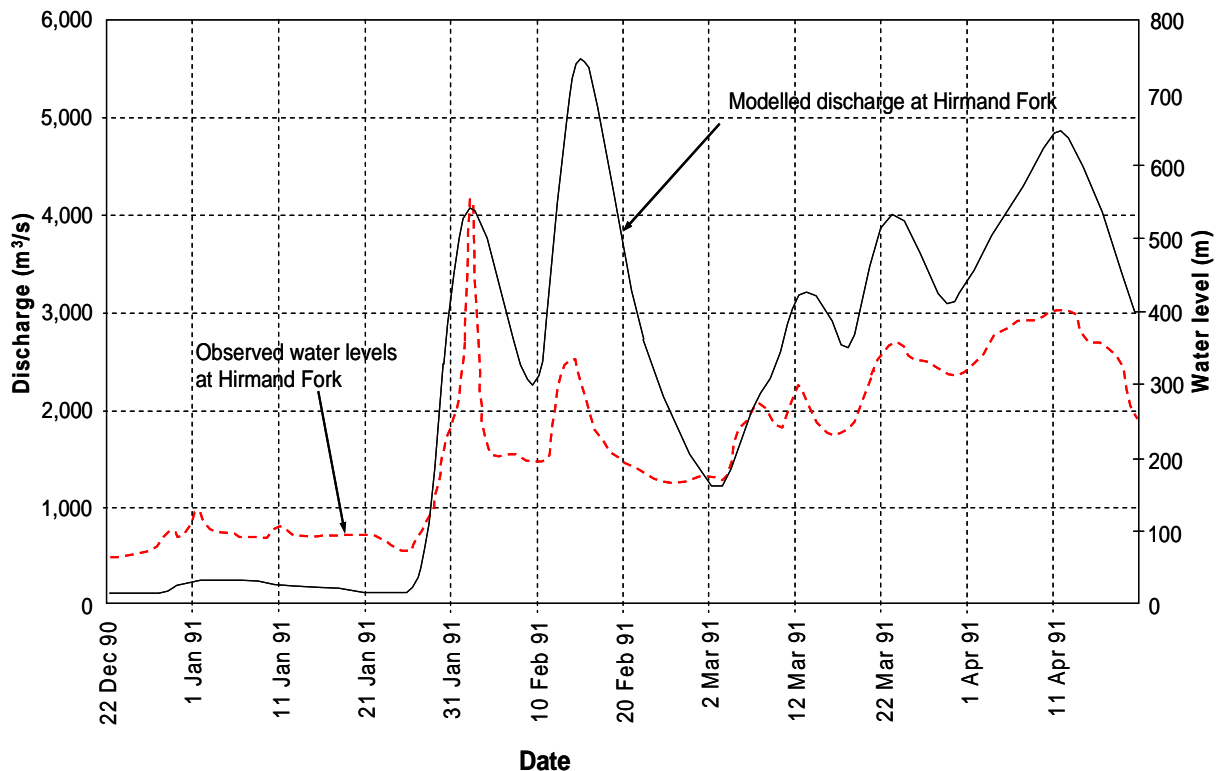
There is a paucity of good quality historical meteorological and discharge data available for the Hirmand catchment. This has made a comprehensive calibration and validation of the flood forecasting system difficult.

However, despite these limitations an initial calibration of the prototype flood forecasting system has been undertaken using flow data recorded at the Hirmand Fork in 1991 and meteorological data available from the ECMWF.

Figure 5 shows the modelled discharge from the flood forecasting system and the observed water levels at Hirmand Fork. It shows that the forecast timing of the flood peaks is reasonable. However, the time base of the modelled hydrograph is much wider than the observed one. Figure 6 shows observed water levels at Hirmand Fork together with the areal average precipitation forecast by the ECMWF for February 1991. The modelled peak discharges are preceded by a number of days of heavy rainfall. The

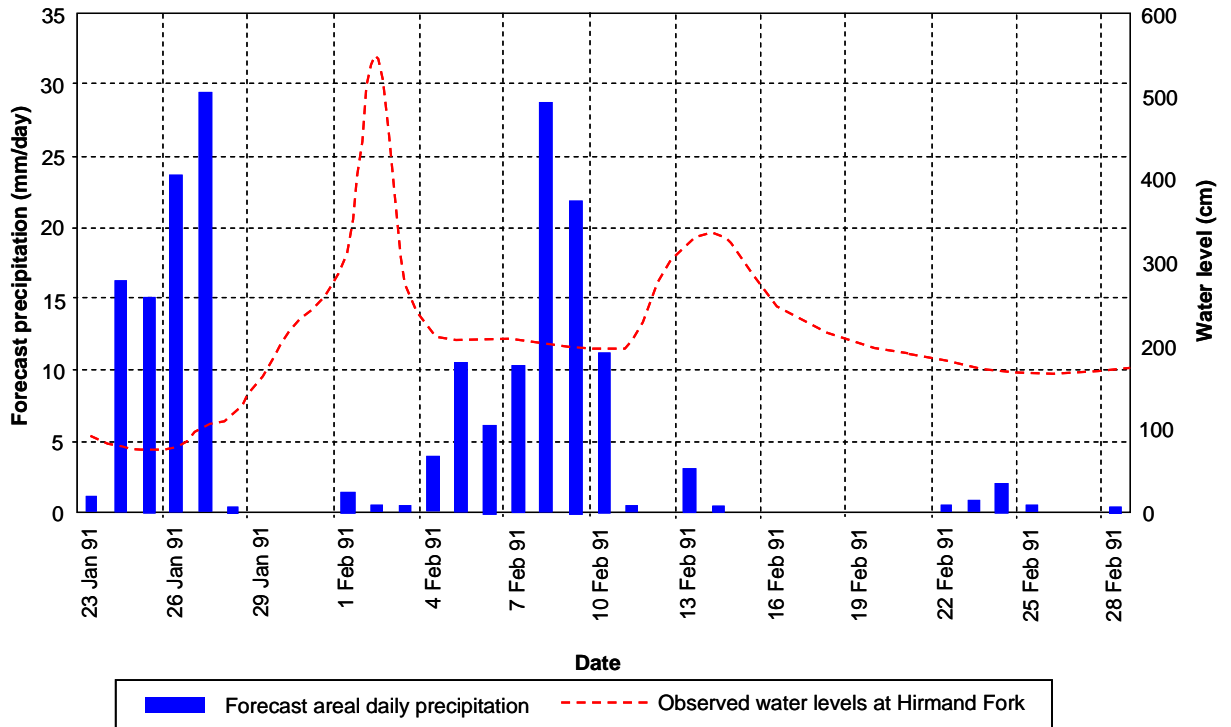
fact that the model is able to correctly predict the timing of the February 1991 peaks indicates that the ECMWF weather model can be relied upon to identify the occurrence of extreme precipitation events for the Hirmand catchment.

As part of the calibration process the observed and forecast flow volumes at Hirmand Fork between October 1990 and July 1991 were compared. This is shown in Figure 7. The flood forecasting model overestimates observed flow volumes considerably. The total forecast volume of flow at Hirmand Fork over this period was almost three times higher than the observed volume. There are a number of possible causes for this large difference.



Note: Water levels are expressed in relation to a datum of 490.13 above sea level

Figure 5 Modelled discharge versus observed water levels for the Hirmand Fork between December 1990 and April 1991



Note: Water levels are expressed in relation to a datum of 490.13 above sea level

Figure 6 Forecast areal precipitation for the Hirmand catchment and observed water levels at the Hirmand Fork for February 1991

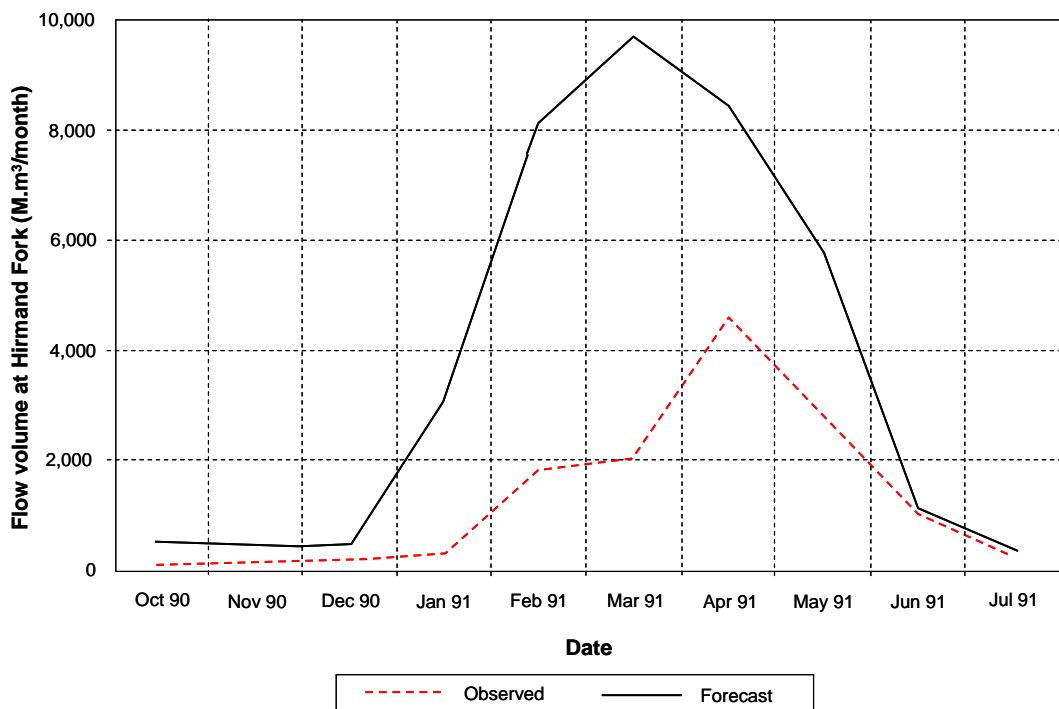


Figure 7 Forecast and observed flow volumes at the Hirmand Fork 1990 to 1991

There are several reasons why the discrepancy between the observed and forecast flow volumes is large. These include:

(i) **Inaccuracies in the recorded flow volumes at the Hirmand Fork.** An initial analysis of the rating curve and flow data at this gauging station indicated that there is a high degree of uncertainty in the flood flow record;

(ii) **Infiltration.** Between Quale Bist and Hirmand Fork, the Hirmand River flows through what is essentially a desert. The floodplain in this area is often between 20 and 30 times wider than the river bed. During floods water depths and velocities in the floodplain are likely to be very low. Hence it is possible that a significant amount of the floodwaters are “lost” owing to infiltration. This is not yet taken account of in the routing model.

(iii) **Uncertainties in the meteorological input.** There is considerable uncertainty in

the ECMWF data for the 1990 to 1991 season since there are no measurements available for Afghanistan to “ground truth” the ECMWF model data.

(iv) **Snow evaporation.** The HBV model assumes that no evaporation takes place from the snow pack. The HBV model was originally set up to estimate runoff in Scandinavian catchments where solar radiation is much lower than in Afghanistan. This may lead to an underestimation of evaporation and overestimation of runoff.

(v) **Diversion of floodwater to ephemeral deltaic branches.** Old maps of the catchment indicate that upstream of the Hirmand Fork there is possibly a distributary of the Hirmand River. There is some anecdotal evidence to suggest that during periods of high flows this deltaic branch becomes active and that a certain portion of floodwater is diverted before it reaches the Hirmand Fork. This may account for the overestimation of flows at the Hirmand Fork from the flood forecasting model.

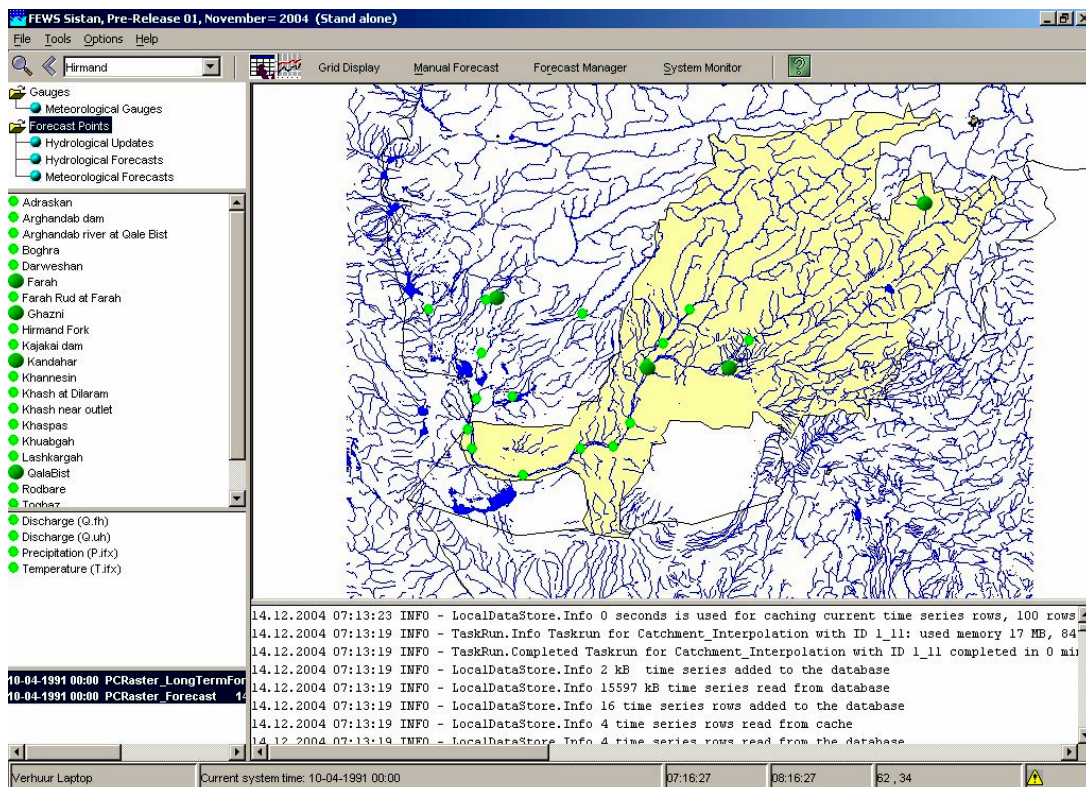


Figure 8 Typical flood forecasting system main display

Setting up the prototype flood forecasting system

This section briefly describes the settings up the prototype flood forecasting system. Figure 8 shows a typical start up screen from the flood forecasting system.

At present the system is capable of importing the ECWMF data, running the PCRaster based HBV Model and RIBASIM model. Figure 9 shows a schematic diagram of the flood forecasting system for the Hirmand River basin in Afghanistan. This is used to generate the simulated and forecast discharge at the Hirmand Fork.

CONCLUSIONS

The implementation of flood control project over the past decade in the Sistan plain will assist in mitigating floods in the area and improving the efficiency of the operation of the irrigation infrastructure. However, in order to operate the flood control infrastructure effectively and provide sufficient warning time to the local population a flood forecasting system is

required. Owing to the a lack of hydrological and meteorological data, available for the Hirmand catchment it was not possible to implement a conventional flood warning system based on telemetered rainfall and water level data. The development of a GIS based flow forecasting computer model utilising data from the ECMWF, an HBV runoff model and hydrological routing software forms the basis of a viable flood forecasting system.

There is a lack of good quality hydrometric data against which to calibrate the flood forecasting model. The forecasting model would currently appear to overestimate flows at the Hirmand Fork. However, there are a number of reasons why this is likely to be the case. The process of calibration and verification of the flood forecasting system will be ongoing over a number of years. Improvements to the accuracy of the forecasting models will be made by calibrating against observed snow cover on the Kuh-i-Baba mountains and by implementing a flow gauging programme at the Hirmand Fork.

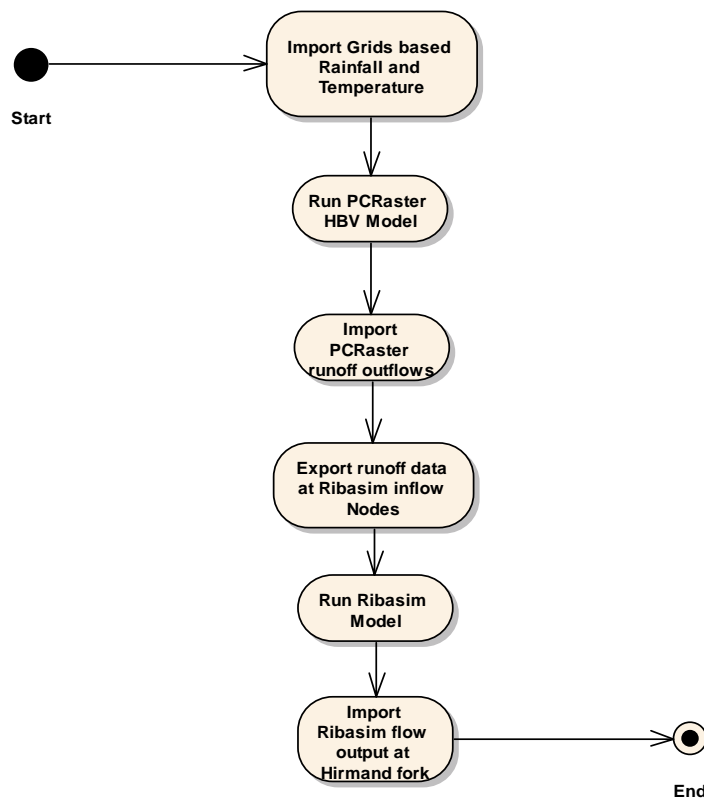


Figure 9 Schematic representation of the flood forecasting system

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