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Optimising the River Karun system, Iran

M. S. Sadeghian[1], H. Hassunizadeh[2] & A. N. McNaughton[3]
[1]*Director, Mahab Ghodss, Tehran, Iran*
[2]*Consultant to Khuzestan Water and Power Authority, Ahwaz, Iran*
[3]*Associate Director, Scott Wilson Piésold Consulting, UK*

Abstract

The River Karun is Iran's longest and largest river system with a total catchment area of over 67,000 km^2 and a main river stream length of over 800 km. The catchment is located in the south west of Iran. The river system rises in the Zagros mountains in the north and flows into the Euphrates prior to discharging into the Persian Gulf. Mean annual river flows are around 575 m^3/s.

The catchment has unique conditions which feature: annual average rainfall of 250mm, summer temperatures in excess of 50°C, a series of cascade hydro-schemes, major flooding in downstream areas, significant irrigation of agriculture extending to over 280,000 ha, with a further 100,000 ha under development.

The river system has two existing 1,000 MW and 520 MW hydro-schemes respectively at Karun and Dez Dams which were constructed over twenty years ago. Two 1,000 MW schemes at Godar-e-Landar and Karun-1 Dam are currently being impounded. Over eight large hydro-schemes are under various stages of preliminary design and are due to be completed in the next twenty years.

Khuzestan Water and Power Authority (KWPA) is responsible for the planning, operation and co-ordination of the various hydro-schemes, river water control, power generation and energy distribution.

The paper explores historic catchment developments with respect to river management and describes the current system characterisation. The philosophy of a staged approach to improvements is then explained.

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1 Introduction

This paper has been prepared to describe the approach and methodology for the management of water resources in the River Karun system in Iran. An integrated water resource model is being developed to significantly increase the efficiency of water storage in the upper catchment for power generation, irrigation potential for considerable agricultural expansion as well as expanding industrial activities and maintaining a safe and reliable potable water resource and which meets desirable ecological and environmental aquatic standards.

The proposed optimisation model will incorporate the application of systems analysis techniques and will take due account of the system characteristics, objectives and timescale for development. The approach to problem resolution needs to be inclusive and dynamic to achieve a practical and effective solution.

One of the principal objectives in the medium term is to establish a decision support system for the management and planning control of the system reservoirs. The multi-purpose reservoirs provide a buffer between mountain snow storage and flood release to the Gulf. Optimised control and management of these reservoirs is therefore a primary goal to facilitate a water rate and quality control on the downstream system in short, medium and long term horizons. The lower river is also influenced by dynamic saline fluctuations from the Persian Gulf.

2 Statement of the problem

The increasing demand for a significant quantity and quality of water properly distributed in time and space, has forced planners to contemplate and propose ever more comprehensive, complex and ambitious plans for water resources systems. The specific case study under consideration in this paper promotes the optimum planning and management of a complex water resources system. This system consists of numerous multi-purpose reservoirs and many large irrigation systems.

The River Karun is the longest and largest in Iran with an overall catchment area of over 67,000km^2. The River rises in the Zagros Mountains which have peaks in excess of 4,000m. The upper catchment follows a meandering course through deeply incised channels. The horizontal alignment of the river upstream of Shushtar is 75km but the stream length is over 250km due to the indirect alignment. There are many salty streams in the mountain area which increase natural salt levels in the river and result in an aquamarine blue tinge to the water colour. The lower reaches of the river feature extensive floodplains where agricultural development is planned on a large scale.

It is anticipated that through detailed investigations optimal operation of the combined reservoirs will be determined to meet the current and forecasted growth in water demand. The proposed model will integrate historic and real-time water quantity and quality in the system for the management of: irrigation rates, hydropower generation, flood control and municipal and industrial water supply. This model should thus provide a reliable and strategic interface for top

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managers to make the correct decisions throughout the year. The proposed model will also be a useful tool for planning and programming of major projects in the future.

The Karun River has two existing multipurpose reservoirs (Karun and Dez) which control river flows to the Khuzestan plain area. These two reservoirs are operated mainly to provide water for irrigation, water supply, hydropower generation and flood control. The reservoirs also release minimum flows during the dry season for dilution of pollution in the lower reaches and floodplain area. The run-of-river scheme at Masjed-e-Soleman has been impounded and a 1000 MW scheme is under construction at Karun 4.

Four additional dams are being designed and are under the early stages of site works. An additional 15 dams are being considered for further development.

The combined system of reservoirs is planned to provide an increasing amount of irrigation water for an ultimate development area of 480,000 ha. At present 280,000 ha. is under irrigation in the basin and the planned increase is 100,000 ha. The dams are also projected to increase the hydropower production up to a total of 10,000 MW in twenty years.

River water quality is an increasing concern in the lower part of the Karun river during the dry season. The major pollution sources are from untreated urban sewage, industries (large sugar cane and paper pulp factories discharge untreated wastewater) and return flow from agricultural areas. The primary concern at present and for the future is to keep the lower part of the Karun River alive.

Municipal sewage in the catchment is largely discharged untreated to the river system. Alleviation of this pollution relies on the considerable dilution potential of the river. At Ahwaz for example, the historic mean river flow is 773 m^3/sec whilst the catchment population of over 1.5 million result in an average daily sewage flow of around 2 m^3/s. This considerable dilution has allowed the river system to sustain water demands historically although the concentrations are now reaching unacceptable levels.

3 Development potential

The Karun River can be divided into three principal geographic zones (Figure A) based on the potential for development taking due account of geology, topography, agricultural potential, rainfall, river flow and climate:

Zone 1: From Arvand Rud or Euphrates at the mouth of river to Gotvand; 360 km; development potential includes irrigation, municipal and industrial water supply. This 360 km reach is not suitable for power generation or storage schemes.

Zone 2: From Gotvand at 360 km to Karun dam at 480 km; the river flows in steep-sided valley through the foothills of the Zagros mountains. Although a number of potential dam sites exist on this reach, the geological formations are not suitable for high storage dams. Thus, this length of the river has exploited a series of run-of-river power installations.

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Zone 3: The most important stretch of the river from a development and water storage point of view is from 490 km to 670 km. Here the river has a considerable long-term average discharge and a relatively steep slope. The river drops some 450 m along this reach and with a long term average flow of approximately 300 m^3/sec, has very considerable hydropower potential. In addition, the topography of the river valley is such that dams would retain reservoir storages of adequate size to give significant regulation of river flows. So far, three main dam sites are being developed in this stretch of the river, which can provide almost complete regulation of the river. The headwaters of the river above 670 km include a number of major tributaries such as the Khersan, Bazuft and Vanak rivers. Several additional potential dam sites have been identified at 670 km, 705 km and 747 km.

The Iranian Government has chosen to invest in the development of large irrigation schemes throughout the catchment area as well as a considerable increase of water reservoir storage. The application of many of these schemes is underway and the long term individual and combined consequences on the river are under careful detailed consideration.

4 Objectives and solution methodology

4.1 Objectives

The principal project objectives can be summarised as:
Develop an integrated water resources and power management model which optimises the available resources to achieve the following targets:

- Provide reliable water resources for irrigation demands from existing and proposed agricultural developments,
- Provide reliable power generation to meet existing energy demands and future regional growth,
- Improve water quality during summer and drought periods to ensure a reliable potable water resource for the Khuzestan people,
- Control floods from both snow melt and extreme rainfall events using both reservoir storage and early warning systems, where appropriate.

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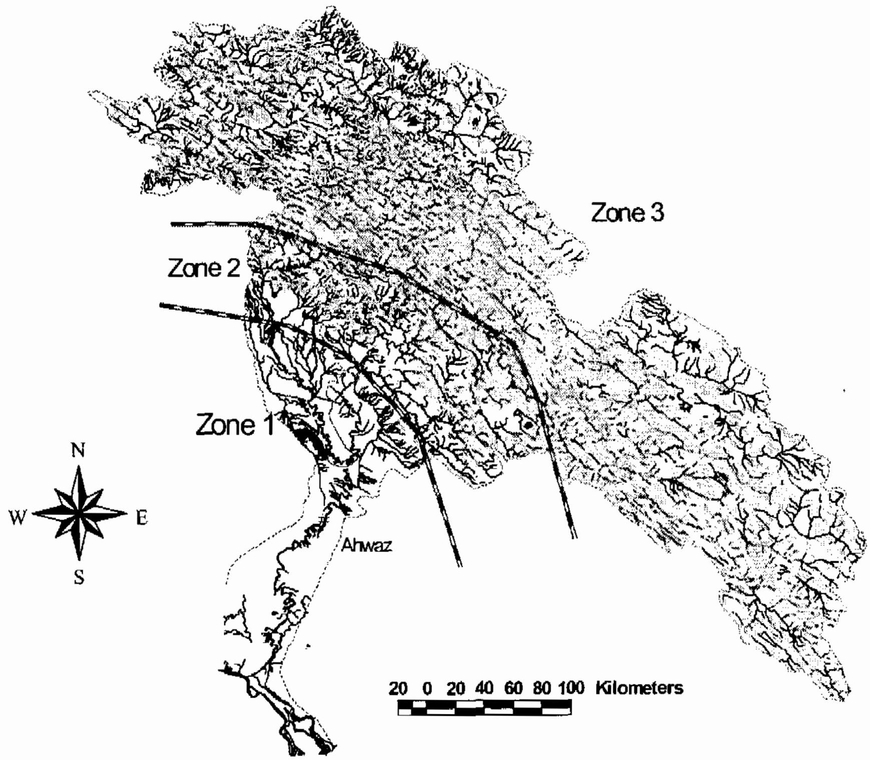

Figure 1: The Karun River catchment illustrating development zones

4.2 Methodology

The project is comprehensive with a wide and diverse range of components. The development of the methodology to meet the primary objectives has been broken down into a number of sub-activities which can be developed by teams under the control of the project manager

Although the overall objective will be the product of a number of particular component models, a decision support system will be used to formulate the application of these data computations into information which will be used by top managers to operate and control the system in a wise and dynamic manner.

4.2.1 Short term activities

The short term activities are well underway with teams from International consultants working with local consultants and client authorities. The intended duration of these short term activities is twelve months. The main tasks can be summarised briefly as:

- Project Register; Preparation of a comprehensive register of all of proposed projects in the catchment area, including the relevant characteristics of water related infrastructure such as reservoirs, turbines and spillways, pumping stations, barrages and bridges,
- Abstraction and Discharge Inventory; Preparation of a detailed regional database of all existing abstractions and discharges in the river,
- Hydraulic Characterisation; Quantify the present and historic river system condition using historic and present data,
- Monitoring and Central Control Room; Install an appropriate water quality and flow monitoring system with a new integrated control room in Ahwaz and a new water quality laboratory,
- Pollution Sources; collect and database the spatial and temporal data on use and discharge of agrochemicals, industrial and municipal pollution,
- Crash Water Quality Monitoring Programme; extending the recent intensive short term water sampling and analysis throughout the catchment to provide sufficient data to calibrate the water quality model development,
- Real Time Monitoring; water quality and quantity monitoring with telemetry system for central monitoring and reporting,
- Telemetry Links; telemetry links to all remote stations including fixed line, microwave communication and satellite data transfer,
- Flood Forecasting; Real time monitoring will be extended to include flood forecasting through the integrated optimisation model,
- A Data Collection System; providing updated information on conditions in the basin in the form of Hydro-meteorological and water quality related data, and various types of spatial and temporal analyses,
- A Basic Hydrological Model; providing input to the water resource models in the form of runoff characteristics from the various sub-catchments generated on the basis of precipitation temperature and potential evaporation,
- Historical Hydro-meteorological Data; from the river basin including: hydrometric station information and time series of: precipitation, snow, temperature, potential evaporation, river flows and water levels, water quality and data of reservoir releases and reservoir water levels,
- Initial Action Water Quality Improvement Action Plan; Characterisation of water quality condition on reaches and seasonally. Mitigation action plan for immediate improvement strategy,
- Development of Graphical User Interfaces; for data input from both manual and automatic data entry. System to include data quality control and auditing.

4.2.2 Medium term activities

Medium term activities are programmed to commence after the substantial completion of the short term activities. This is after the initial year of the project. The data gathering protocols and systems will form the foundation of on-going maintenance and operation of the resource systems.

The principal activities include the following main study areas:

Water Resources Model

The catchment has been subdivided into an appropriate number of sub-catchments so that rainfall runoff modelling will be used on the gauged sub-catchments and used for extension and gap-filling of series and for generation of runoff from the numerous un-gauged sub-catchments. Long time series of daily runoff, observed as well as naturalised, will be developed for input to the water resource model and shorter series will be identified and applied for calibration of the hydrodynamic model. Single and multiple reservoir modelling will be undertaken to synthesise the cascade and conjunctive use to existing and future reservoirs, as well as the interim conditions of scheme impoundment, drought and flood conditions. These models will also include power generation, flood control and low flow releases.

Low Flow Management Model

The application of the low flow model is fundamental in meeting the planning and optimization objectives. An important feature of this model is the ability to simulate the effects of upstream reservoir operation and releases to support various water allocation strategies. The criteria for success will be defined as the degree of demand satisfaction from the various water users in the basin and meeting hydro-power generation objectives. The development of the low flow model will include hydrodynamic simulations, short term forecasts, flood conveyance, and water quality simulations. Initially, this work will assist in the establishment of minimum and maximum flow and water quality targets and key positions in the system.

Short-Term Inflow Forecasting

Development of a confident short term inflow forecasting model will provide valuable predictive data for short term reservoir management and operation. The system will include snow melt assessment from measured and captured data from satellite image interrogation as well as the prediction of flows from high intensity rainfall.

Energy Review and Power Planning

A thorough review includes the collection of all regional generating data as well as distribution and system security. The most effective and economic power source will be reviewed to make appropriate recommendations for hydro-power and thermal power production.

Flood Modelling

Flood prone areas will be included in hydrodynamic models and the areas with the highest risk of flooding will be identified and classified. Regional flood damage assessments will assist in determining the optimum strategy for managing and mapping flood risks. It is anticipated that the more appropriate strategy in the early stages will be the introduction of a flood forecasting and warning system which will form part of the on-line monitoring system. Calibrated hydrodynamic models could be used in the later stages to investigate flood dynamics and flood inundation areas. Various flood management release strategies will be investigated to maximise flood retention without compromising the long term security of the system reservoirs.

GIS and Development of Optimisation Model

The GIS will play an important role in the determination of storage and organization of these environmental data. The GIS will interface with the model outputs. The environmental database will be linked through the graphical functionality of the GIS as well as acting as a data management system and storage repository of all temporal and spatial data.

4.4.3 Long term activities

The long term activities extend well beyond the scope of the consultants direct involvement. The present proposals need to include appropriate foundations for future integrated management of the river basin. The following tasks are the final activities which will enable a transfer of technological assistance and the handing over of the developed models to allow for the effective operation of the optimisation system.

Further Development of Decision Support System for Reservoir Operation

The fully developed hydrological model will work in parallel with the hydraulic model and water quality modules to form a predictive tool for future forecasting of selected environmental parameters in the system. This will include the integrated reservoir model and recession predictions. Performance will be compared against measured flow and water quality data collected from the telemetry system and central control room archive. The decision support system will thus be developed to meet the client's staged objectives. The planning and optimisation model will be focused on meeting pre-defined optimisation criteria using a logical series of system priorities. These priorities will include the various actual and projected water demands in the system. A natural outcome form this decision support system will be the setting of optimal intermediate and long term release strategies from the various reservoirs. These will be manifest through altered control curves and dynamic and proactive system management. A flood forecasting model will be developed to analyse real time events. This strategy will give clear guidance on preferred short-term release scenarios during flood conditions and detailed water level and water quality forecasts in the system for given release scenarios. The effects and impacts of the various operation strategies will be illustrated through the GIS interface which will have bespoke graphical user interfaces. The immediate priority will be the identification of critical system locations which will suffer from supply deficits, reservoir security, environmentally unacceptable low flow conditions or critical reservoir volumes and levels.

Planning and Optimisation Modelling

The planning and optimisation model will provide an integrated overall representation of the water resources in the system in a dynamic manner and will take proper account of the demands of all water users. Water allocations can

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thus be established which can form the basis of a controlled water allocation strategy which could be enforced through legislation. Optimal reservoir operation strategies constitute a fundamental element in water allocation. An appropriate mathematical profile of the river basin will encompass a representative configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing major schemes and their various demands of water. The model will operate on time steps ranging from one day to one month and hence will be suitable for multi year simulation, prediction and optimisation based on long simulation periods. The model will be capable of operating on daily, weekly and monthly time steps. The hydrodynamic model component of the optimisation model will be used for low flow and flood forecasting and early flood warning. It is also hoped to expand the use of the lower reaches of the river system for navigation. Water quality conditions will be predicted and analysed with oxygen concentration as a primary index. Pollution will be tracked through organic signature, which will be based on the transportation and chemical stabilisation of nitrogen, phosphorous and other defined compounds.

5 Summary

This paper has described the Karun River System and the study which is underway to develop an optimisation model for the most effective management and planning of the available resources for the maximum benefit of all water users. The particular climatic and geological conditions bring enormous opportunities as well as particular difficulties to reap the maximum benefit.

The many and varied water users will participate in the development of the proposed optimisation model. The long term sustainability of the system will however require water resources to be controlled carefully under summer conditions to ensure that sufficient water is available for consumption, agriculture and power generation, as well as preserving the ecological balance of the natural environment.

A staged approach to the development of an effective management system is promoted. This will allow mathematical representation to be used to monitor and control the complex systems of the River Karun. Objectives have been defined and these form the basis of a strategy of water resource management. To meet these objectives, short, medium and long term actions are defined and these form the basis of the overall methodology for the definition of the conceptual model for the analysis and optimisation of water resources in the catchment.

References

[1] Sadeghian, M.S., Development of the Karun River Basin (Iran) based on integrated water resources modelling. *Proc. of the Int. Comm. on Large dam (ICOLD)*, Dresden, Germany, 2001.

[2] Sadeghian, M.S., *Systems Analysis of Complex Water Resources System*, Ph.D. Thesis, University of Roorkee, India, 1993.

Transactions on Ecology and the Environment vol 60, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

[3] Bargur, J., Dynamic multi-sector programming approach to regional water resources management. *Wat. Resour. Res.*, **8 (4)**, August , pp. 801-808, 1972.

[4] Bony, M., *Technoeconomic and Management (TEAM) Approach to River Basin Planning* , Ph.D. Thesis , WRDTC, University of Roorkee, India, 1993.

[5] Chaturvedi , M.C. & Srivastava, D.K., Study of a complex water resources system with screening and simulation models. *Wat. Resour. Res.*, **8 (3)**, pp. 311-328, 1981.

[6] Goodman, A.S., *Principles of Water Resources Planning*, Prentice-Hall Inc: Englewood Cliffs, New Jersey, 1984.

[7] Hydrologic Engineering Center, U.S. Army Corps of Engineers, System simulation for integrated use of hydroelectric and thermal power, *Technical paper No. 33*, 1972.

[8] Loucks, D.P., Water resource systems models: Their role in planning. *J. Wat. Resour. Plang. & Mgmt.*, **118(3)**, pp. 214-223, 1992.

[9] Srivastava, D.K., & Patel, I.A., Optimization-simulation models for the design of irrigation project. *Wat. Resour. Mgmt.*, **6(1)**, pp. 315-320, 1992.

[10] Strzepek, K.M., A user manual for Mitsim-II: A planning and operational river basin simulation model. *Lecture Notes, International workshop on systems analysis of problems in irrigation, drainage and flood control*, CBIP, New Delhi, India, 1981.

[11] Strzepek, K.M., MITSIM II: a simulation model for planning and operational analysis of river basin systems. *Lecture Notes, International workshop on systems analysis of problems in irrigation, drainage and flood control*, CBIP, New Delhi, India, 1981.

[12] McNaughton, A. N., Opportunities and difficulties with hydraulic modelling. *Proc. of the 6th Int. River Conf.*, Ahwaz, Iran, 2002.