Proposed water management system for the Great Man-made River Project

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Abstract

The Great Man-made River Project (GMRP), currently under construction in Libya, can be considered as one of the largest water schemes in the world. The main operational objectives of the Great Man-made River scheme are to supply water to consumers as safely, securely and economically as possible. The purpose of this paper is to outline a general approach to achieving these objectives for the Great Man-made River Project in Libya. This involves investigating the available modern techniques and assessing their application for the GMRP scheme in order to propose an Integrated Water Management system to act as a Decision Support system. In order to assess the relevance and application of these techniques to the GMRP system, the GMRP scheme was reviewed with respect to its components description, hydraulic constraints and operation and control philosophy. Based on the review and investigation into using relevant computer models and techniques for the GMRP scheme and assessment of their operational economical benefits, the requirements for an Integrating Water Management system are proposed as a step towards establishing a Proactive Decision support system. The main components of the proposed Water Management System include simulation, pump scheduling and demand prediction models. The paper also covers their integration to leakage detection programmes, information and on-line telemetry systems.

1 Introduction

The Great Man-Made River Project (GMRP), see Fig. 1, is one of the largest water supply schemes in the world. Integration between a Flow Simulation Model and other application systems is essential for the operational management of this huge water scheme to ensure reliable data and analysis output for making important engineering and operational decisions.

A Water Management System (WMS) for a huge water supply scheme like the GMRP will be needed to act as a **Decision Support System** to help staff make their planning, engineering and operational decisions. It allows with experience movement towards a more planned, proactive system with precautions taken ahead of anticipated difficulties, and a more co-ordinated response to problems.

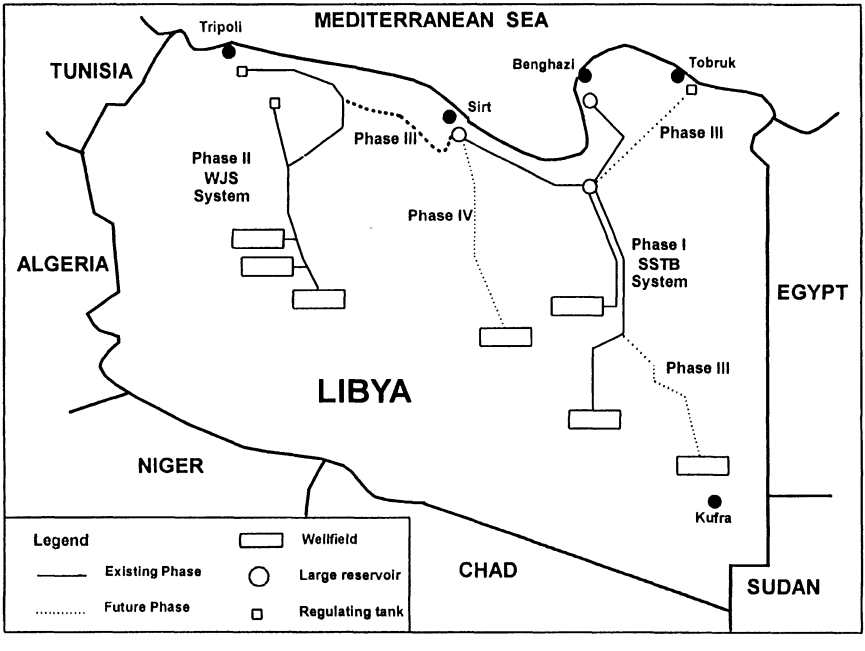


Figure 1 : Schematic view of the Great Man-Made River Project

It is important to develop a special flow simulation model and special application programs for the GMRP project due to the some of the special features and characteristics of the system such as :

1. The size of the GMRP system and its components are unique.
2. GMRP is a multi-phase project (Phase I, II, III & IV) with some different characteristics between phases.
3. GMRP has a multi-regime pipe flow including partially full and full pipe flows.
4. The flow conditions of the GMRP and its parts will be subject to frequent changes during filling, drainage and normal operation of the system.
5. It is important that the control components of the GMRP be modelled due to the size of the hydraulic components and the magnitude of flow encountered.

The Water Management System must be valid for all phases of the GMRP scheme. However the WJS system was selected as the prototype because of its current progress and as it is more suitable for illustration purposes. WJS system is still under the design and construction phase. It has more hydraulic components (such as regulating tanks and conveyance pumps) and it is based on sophisticated operation & control philosophy (supply on demand & automated control).

Therefore the basic requirements for the Water Management System are identified for the WJS system which has been taken as **a prototype model** for other systems of the GMRP scheme.

1.1 System Components

The integrated Water Management System should be a suite of programs which share a data management system with a direct access to telemetry and user interface as shown in Fig. 2.

As a minimum the system should include the following main components :

1. **Data Management System** : to provide smooth access to all types of operational and network data to all models.
2. **Flow Simulation Model** : this is a core simulator to act in two modes, as for on-line and off-line hydraulic simulation, to be available on PC with other application programs.
3. **Application Programs** including : Demand Prediction model, Pump Scheduling model and Leakage Detection program.

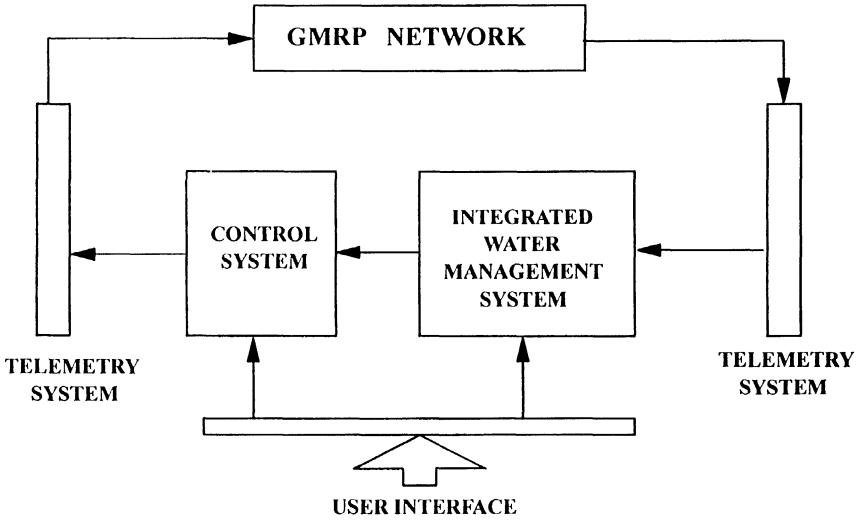


Figure 2 : Schematic view of the Water Management System Interfaces

1.2 Open System Architecture

The hardware of the system has to be **open system architecture,** by adopting industry standard hardware so that stability and compatibility can be retained with newly developed techniques and can be used for other GMRP phases. The software of the Flow Simulation Model and the Data Management System must have a **standard interface** to each other, the SCADA system and graphical user interface.

The software of the applications programs (Flow simulation, Demand Prediction & Pump Scheduling) shall be designed such that it is provided in **complementary modules** which can be fully integrated and accessed through a common graphical user interface. Such an approach will allow the continual development of new applications.

2 Data Management System

The data management system is a computer based co-ordination and management system to provide automated and continuous transfer of operational and reference data between the SCADA system and the application programs for both on-line and off-line applications. The Data Management System should adopt an advanced open database

architecture to ensure that future software and data development can be distributed appropriately throughout the GMRP System, including other phases, and to ensure compatibility with newly developing techniques.

In order to perform its required functions the data management system should contain the following components :

1. State Estimation.
2. Integrated Central Database.
3. Graphical User Interface .

It is considered that this field will have further developments over the coming years. It is further anticipated that it will be possible to establish links between GIS software and distributed databases via a telemetry system. The GIS can be a useful tool in future for storing and manipulating the GMRP network details, particularly if it can be linked with the simulation model to provide the basis for the generation and build up of the hydraulic models.

3 Flow Simulation Model

The Flow Simulation Model should be developed based on a Hydraulic Simulator and enhanced to operate in two modes : an on-line mode and an off-line mode. The Flow Simulation Model should be a powerful package. It should incorporate steady and unsteady flow conditions and be capable of modelling all hydraulic and control units in various flow regimes.

3.1 Facilities

The facilities of the Flow Simulation Model shall be developed to ensure that the functions of the simulation program can be implemented effectively. To achieve the main objectives, the model shall incorporate two modules : (1) Analysis Module.
(2) Prediction Module.

3.1.1 Analysis Module

This module should have the ability to :

1. Provide background analyses of water system operations for both steady and unsteady flow conditions.
2. Assess options for future capital works and system improvements.
3. Assess the recommended pump schedules by confirming the water balance and hydraulic feasibility.

4. Evaluate the adequacy and accuracy of the hydraulic system performance during normal and emergency conditions.
5. Enable simulation and tuning of the real control system including the actions of controllers, actuators and pump speed controllers.
6. To assess the control philosophy under a variety of normal and emergency operating conditions

3.1.2 Prediction Module

This module should have the ability to :

1. To provide a look ahead facility to assess operational impact on the water system before any action is allowed on the system itself.
2. To establish operator responses to emergency conditions.
3. To verify the feasibility of implementing proposed pump schedules by checking the physical and operational constraints
4. To predict and assess the behaviour of the hydraulic system and its interaction with the control system (e.g. between the regulating tanks and control valves).

3.2 Analysis functions

The Simulation Model shall be able to carry hydraulic analysis for the flow in steady state conditions and transient flow in unsteady state conditions. By adopting a modular approach to programming of the Flow Simulation Model, the steady state and transient algorithms can be combined as integrated modules. These two analysis units shall be interchangeable allowing steady state and transient simulation to be carried out for the same system.

The central database shall act as an interface tool between the steady state and transient simulation modules. The results of the first simulation shall be used as the definition of the initial conditions in the other simulation. The two main modules involved and the data files involved are as shown in the system overview presented in Fig. 3.

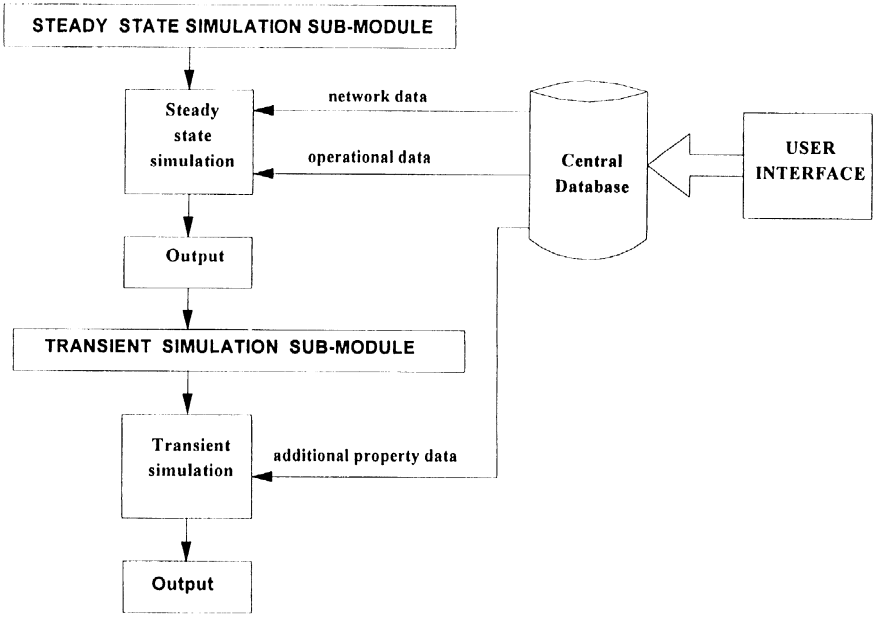


Figure 3 : Interaction between steady state and transient simulation modules

3.3 Representation of the real system

The program shall have access to a comprehensive Model Library of hydraulic and control units which can be selected to represent the GMRP network components normally encountered. The network model shall be built and validated using basic network data contained in the asset database and the model library utilising the relational central data base.

The Model Library for GMRP shall include, as a minimum, hydraulic and control units as follows **:**

3.3.1 Hydraulic units

These include the followings :

1. **Pipe units :** The pipe system should use appropriate equations for friction and minor losses.
2. **Boundary units :** the boundary unit actions are described by mathematical equations. These units include :

- **Pumps :** this include fixed speed pumps and variable speed pumps.

- **Valves :** this include flow control valves, block valve and pressure reducing valves.
- **Reservoirs :** including fixed head "large" reservoirs and variable head "small" reservoirs.
- **Nodes :** each node is associated with a mean demand and a demand profile.

3.3.2 Control System units

These include pressure switched and time switched controllers which are associated with any control device at control valves and pump stations.

3.3.3 Interface to SCADA and other systems

Appropriate user interfaces shall be developed as automated linkages with other application programs and the on-line data management system to access predicted demand, schedules and updated process information and status of the water system, as illustrated in Fig. 4.

The Flow Simulation Model should be designed around a central data base management system which offers sharing and independence. This data management system shall be able to provide automated transfer of reference and operational data from the SCADA system to the Flow Simulation Model by means of State Estimation. Upon receipt of SCADA data, the hydraulic simulator will perform calculations and analysis of the new operation conditions and flag any system anomalies.

3.4 The system boundary of GMRP network model

To generate the GMRP network model, all the main components of the real system should be translated into a mathematical model using asset data and the model library.

If we take the prototype model (Phase II network) for illustration purposes, the network model shall be divided into subsystems which can be listed, as shown in Fig. 4, in upstream to downstream order as follows :

(1) Well pumps subsystem.
(2) Well field tanks and well pumps subsystem.
(3) Conveyance pumps subsystem.
(4) Tarhunah/Ashwyrif (central) subsystem.
(5) Ashwyrif tanks/Ashwyrif (Eastern) subsystem.
(6) Garabulli/ Wadi Tummalah subsystem.

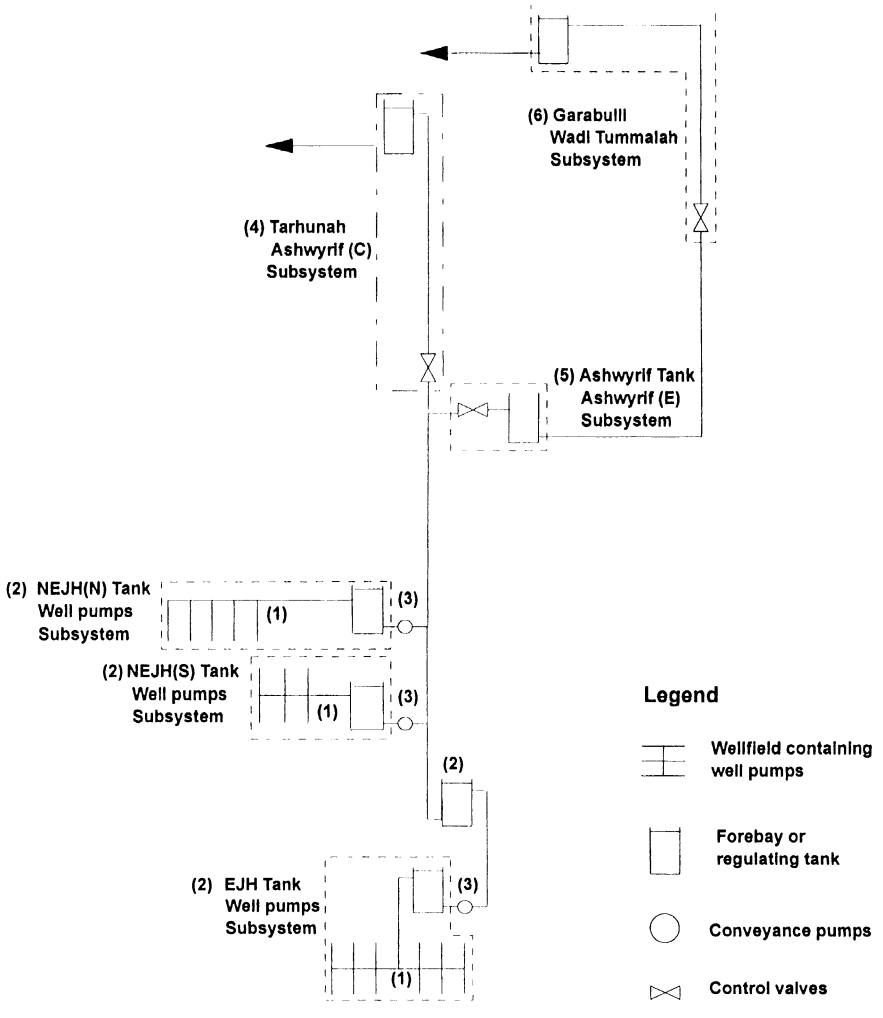


Figure 4 : A schematic view of WJS (Phase II) network and its model boundaries

4 Integration With Application Programs

The hydraulic simulation model shall be integrated into the real time SCADA system and linked with other application programs, mainly the Demand Prediction, Pump scheduling and Leak Detection programs to form an Integrated Water Management System and carry out the overall analysis and management functions. The interaction and the functional relationship is illustrated in Fig. 5.

4.1 Pump Scheduling Model

The pump scheduling program shall comprise two main consecutive processes which shall be carried out by two different modules. These two main processes are : Scheduling Module and Optimisation Module.

4.1.1 Scheduling Module

This module shall be applicable to each entire wellfield and its tank. The main functions are to allocate the required flow for each wellfield and to determine the water levels at each wellfield tank.

The criteria adopted should take into consideration the following factors :

1. The production limits specified for each wellfield obtained from long term plans.
2. The long term and medium term production schedule for the entire system and the production share between the individual wellfields.
3. Minimisation of changes in flow rates from each well field
4. The drain down water which is the discrepancy between the well pumps output from the ground and the flow arriving at the wellfield tanks.

The scheduling procedure shall be based on the System Operation and Control Philosophy of the GMRP System. The scheduling should start with preparation of the tank schedules for the eastern and central tanks (or target levels for the system tanks), and proceed in an upstream direction, preparing flow schedules for the conveyance lines, target levels for wellfield tanks and terminating with pump schedules for each wellfield.

4.1.2 Optimisation Module

This module shall be applicable to both the conveyance pumps and the wellfield pumps. The main function is to determine the optimum choice of pumps to start/stop so as to achieve the required flow schedule from each wellfield, and to satisfy the constraints of the GMRP system in the most cost effective manner.

The criteria adopted should take into consideration the following factors :

1. Pump availability : this information can be obtained utilising the live database.
2. Running times : this can be obtained utilising the historical records.
3. Water quality requirements, such as blending water from different wellfield sources.
4. Energy consumption measured by the pump efficiency : this data requires regular validated records to be obtained.
5. The pumping head required by selecting the optimum routes : this can be translated into power consumption.

4.1.3 Inputs and outputs

The inputs and outputs required for the Pump Scheduling Model can be summarised as follows :

1. **Inputs** : Demand prediction, reservoir target levels and pump configuration data.
2. **Outputs** : Pump selection/schedule and Flow/pressure profiles

4.2 Demand Prediction Model

The main function of demand prediction is to predict the consumer demands in order to determine the reservoir target levels and hence the reservoir refill volumes for each scheduling period.

The demand prediction system shall contain a mixture of computer processing of routine calculations and expert human inputs. Therefore the model shall consist of two main stages : (1) Prediction process.
(2) Verification process.

4.2.1 Prediction Process

A suitably realistic technique shall be used for demand prediction. The algorithm chosen should take into account the following considerations:

1. Historical demand data held within the data management system.
2. Long term trend, month of the year, day of the week and also recent forecast errors.

4.2.2 Verification Process

Following the calculation of predictions by the algorithm, the operator should have the option of accepting the calculated quantity or inputting an alternative value. The demand prediction software shall provide

graphical displays of historical demand with future extrapolation to assist in this process.

4.2.3 Time Scales for Demand Prediction

Based on the time horizons of the operational functions, demand forecasting shall be performed on three bases : long, medium and short term planning.

1. **Long term :** This involves forecasting the user demands for one year on a weekly basis. This process requires updating quarterly and assessing against production limitations and forms the basis for long term production plans.

2. **Medium term :** This involves forecasting the user demands for one month on a daily basis. This process requires updating weekly to indicate the deviations from the long term plans and to assess the seasonal variations.

3. **Short term :** This involves forecasting the user demands for a minimum of a 3 days period (WJS system) and for a maximum of one week. This process requires updating on a daily basis. Each day is divided into intervals of several hours to indicate the fluctuations in demand. This short term prediction is then used for pump scheduling to determine the flow discharges which can be verified to satisfy the system operating constraints.

4.3 Leak Detection System

The main function of the leak detection system is to indicate the presence of leakage if it occurs in the pipeline and to provide the best estimate of the leak location. To achieve this, the program shall use a combination of two methods : (1) Leak Detection Method.
(2) Leak Location Method.

4.3.1 Detection Method

This method shall be based on a volume balance algorithm to indicate whether or not a leak is present in the pipeline. Therefore it will rely on the SCADA data of inflows and outflows to assess the volume balance in each pipeline section. These real data shall be driven by the State Estimation Module.

4.3.2 Location Method

This method shall be based on the pressure analysis technique. When leakage is detected, the Flow Simulation Program shall be utilised to carry out dynamic simulation to compute the pressure profile at different boundary conditions. The calculated values of pressure shall be compared against the measured values at a series of intermediate stations to determine the leak location.

5 Other Application Programs

As the water management system will be an open system, it shall have capability to interface with future developed programs which are relevant to GMRP system. These integrated programs are proposed to include a **Hydrology Model**, and a **Water Quality Model**.

6 Interface With The Control System

Under the **automatic mode**, the flow simulation model shall have the facility to simulate the hydraulic units and generate control actions, which shall be sent directly to the control computer. Accordingly, this will activate flow controllers for valves or pumps. The flow controllers will compare these actions with defined set points. If the system is violated then a proper control action will be determined.

7 Operator Interface

Based on the WJS contract requirements and operation and control philosophy, the Water Management System shall have the following facilities, which can be valid and of more benefit to the other GMRP phases :

7.1 Operational facilities

The Water Management System will have an operator interface in two operational modes, advisory and operator mode, as illustrated in Fig. 4.

1. **Advisory Mode :** Under this mode, the flow simulation model shall have the facility to simulate the hydraulic units and provide advice to operators of any control actions to be carried out. The model shall not

however initiate control actions itself until instructed to do so by the operator.

2. **Operator Mode :** Under this mode, the flow simulation model shall carry out any simulation only when requested to do so. The operator shall specify the control actions to be carried out.

7.2 Display and Reporting Facilities

1. **Graphical Interface :** The water management system shall have a common graphical interface utilising the data management system. The interface should be user friendly which requires the minimum amount of operator training to enter data, run simulations and interpret the output data. The interface shall capabe able of supporting a range of standard graphical applications including Windows and Auto-cad.

2. **Alarming :** Under automatic, supervisory and, when requested, under operator operational mode, the flow simulation program shall carry out the required simulation runs every time step and set an alarm for any anomalies. This alarm will inform the operator of potential operational problems such as flow imbalances (as an indication of a possible leak problem) or pressure instability (as an indication of a possible surge or cavitation problem).

3. **Reporting :** The Data Management System shall be able to edit, store and print standard and specific reports. These include operational, technical and statistical reports which describe the analysis of incidents, logs and records of jobs, schedules, etc.

4. **Mimic Interface :** The main control centre shall contain a mimic panel. This mimic panel shall be automatically able to display the network configuration showing a nodal representation of the wellfields, conveyance systems and the tanks. The mimic panel shall be able to display the main operational parameters such as inflows, outflows through the main nodes and the tank levels. The Water Management System shall have an interface with the mimic panel software in order to provide a link with the asset database and with the live database and to access the network and real time data.

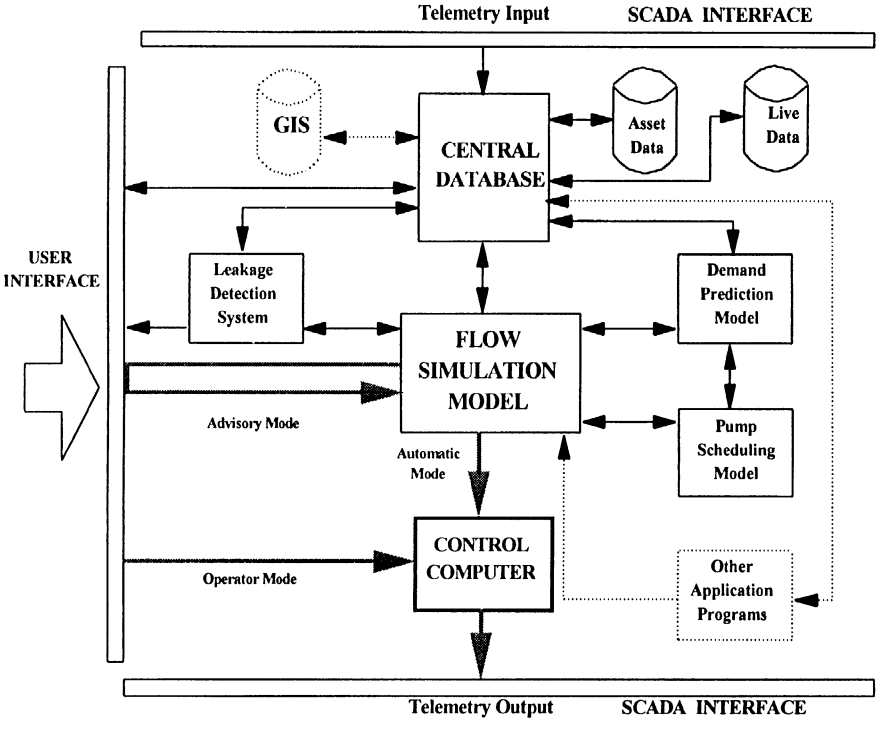


Figure 5 : Proposed Water Management System for the Great Man-Made River Scheme

8 The Benefits

This technical paper indicates that the modelling techniques and the associated systems, which have been reviewed and investigated in practice, can provide a number of significant benefits if they are implemented in GMRP scheme, all these benefits will lead to the improvement of system efficiency.

These **major benefits** can be outlined as below :

1. Simulation models enable review and analysis of the system performance and provide a realistic training environment for staff and operators including training in handling failures and other emergency conditions.
2. Implementation of the information systems within the water industry has shown major benefits resulting from storing the data in advanced

relational databases and other systems. These include reduction of response times for providing data and information, ensuring data integrity, utilisation of collected data and standardisation of reporting.

3. Confidence can be increased about the reliability of predicted demand. This can lead to increased confidence in the optimality of pump schedules, which on application can lead to reduced operational costs. From previous studies, an accuracy of about 5 to 12 % in using demand prediction models has been reported, and about 15 to 20 % cost saving, by using pump scheduling models.
4. Saving of huge water quantities can be achieved through improved leakage and pressure control. Some of the water companies reported that active leakage detection systems resulted in reduction of unaccounted water by 18 to 30% of water demand.
5. System monitoring using state estimation has proved to be of vital importance giving early warnings of unexpected high and low demands, fluctuation in reservoir levels, imbalance of flows, raise or fall in pressures, pump failure and other unpredicted events.
6. Integrating the application models together and linking them with telemetry, loggers and information systems, will increase the confidence in using such techniques for day to day network analysis and operational activities to simulate the dynamic nature of the actual GMRP network. This can be a major step forward toward a proactive style of analysis and management of the GMRP scheme.
7. Improving and maintaining standard service levels by avoidance of interruptions to supply and minimising the number of complaints that could arise from the water consumers.
8. If the models are integrated in a systematic framework, this will establish a coordinated operational control of the water system, maintaining a feasible operation with short and long term planning and offering the opportunity for efficient and effective development and modification of the control system.
9. There are other benefits for design and construction of future works These include providing large cost savings in planning and design of capital schemes, achieving a smooth transition during the commissioning phase of the current and future schemes and transferring the water system from partial operation into full operation.

9 Conclusion & Recommendations

9.1 Conclusion

A critical success factor in the development of these proposed programs and will be the design of the software such that it is provided in complementary modules which can be fully integrated and accessed through a common graphical user interface and to establish an Open System Architecture to cater for any future developments. This approach will make it feasible to consider and study further integration in a common environment with other systems which are important for GMRP scheme such as GIS, Expert Systems, Water Quality and Hydrology Modelling.. Such an approach would allow the continual development of new applications in a common environment.

It is recommended to the management of the Great Man-Made River Project that these proposed requirements be considered and their contractual requirements be assessed for the benefits of the entire GMRP scheme. These contractual matters are outside the scope of this present research study. However it is concluded that cost impact of developing these additional requirements to be imposed on the existing contract for the WJS system, can be greatly offset by the cost benefits and efficiency improvements that are expected for GMRP scheme as a whole. When "phase 3" is implemented, this will link all GMRP phases together (SSTB, WJS & phase 3) in one water supply system. To avoid any duplication of effort, works and additional cost, we believe that the requirements proposed in this research study can form the basis for establishing an efficient and cost effective **Integrated Water Management System to act as a Decision Support System for the entire GMRP scheme.**

9.2 Recommendations for Further Work

It is demonstrated by carrying out this research study, over a limited period of time and consequently of limited scope, that further work and development in certain areas is desirable and recommended, in order to enhance the applicability and reliability of implementing this proposed computer based Decision Support system.

These recommendations can be highlighted and summarised as below :

1. An Expert System can be introduced as a knowledge based system. This will enable verification and evaluation of the operational parameters and provide an input to the demand prediction and pump scheduling models so as to ensure an achievement of an optimised control scheme.
2. It is considered that the advances in Geographic Information Systems (GIS) will be far reaching in the near future. As recommended previously, a flexible future development patch should be kept open to allow follow up of developments in this field. GIS may well be worth implementing in the GMRP system in the near future, especially if links with telemetry and on-line systems become feasible in reality.

3. Another areas which need further investigations are the integration of other related models into the Water Management System. These are :
   - Water Quality Model including analysis of chlorine decay, which may be integrated with the simulation model and on-line telemetry.
   - Hydrology Model to predict the performance of the aquifer, which can be integrated with the pump scheduling model.

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