RUBICON SYSTEMS AUSTRALIA PTY LTD

&

ENVIRONMENTAL SOFTWARE & SERVICES

PROOF OF CONCEPT
FINAL REPORT

STATE WATER
MURRUMBIDGEE COMPUTER OPERATED RIVER

6 September, 2010
TABLE OF CONTENTS

1. PURPOSE .................................................................................................................. 4
2. SOLUTION OVERVIEW .......................................................................................... 4
3. PROJECT APPRECIATION ....................................................................................... 6
   3.1 REQUIREMENTS ................................................................................................. 6
   3.2 CHALLENGES AND CONSTRAINTS FOR POC .................................................. 9
   3.3 POC OPERATIONAL STRATEGY ...................................................................... 11
      3.3.1 Multi-criteria optimization .................................................................... 13
4. DATA COLLECTION PROCESSING ......................................................................... 14
   4.1.1 Hydro-metrological Data ............................................................................. 15
   4.1.2 Data Quality .................................................................................................. 17
   4.2 DATA INTERPRETATION FOR DAILY OPERATIONS .................................. 19
   4.3 DATA ANALYSIS ............................................................................................. 21
5. WATERWARE SYSTEM CONFIGURATION ................................................................ 24
   5.1 NETWORK TOPOLOGY DEFINITION ................................................................ 24
   5.2 RAINFALL RUNOFF MODEL ........................................................................... 26
   5.3 IRRIGATION WATER DEMAND ESTIMATION .............................................. 28
   5.4 GROUNDWATER REPRESENTATION IN THE WATER RESOURCES MODEL .... 29
   5.5 SYSTEM CONSTRAINTS .................................................................................... 31
   5.6 TEST USER NAMES ........................................................................................ 32
6. KEY ISSUES FOR FULL IMPLEMENTATION ......................................................... 33
   6.1 CO-operative APPROACH ............................................................................... 33
   6.2 DATA SYSTEMS ................................................................................................ 34
      6.2.1 Demand Capture ...................................................................................... 34
      6.2.2 Flow Measurement .................................................................................. 36
7. PROJECT PLAN FOR FULL IMPLEMENTATION (STAGE 3, PHASE 1, OCT 2010 TO NOV 2011) ................................................................. 37
8. CONCLUSIONS ....................................................................................................... 38
9. POC DEMONSTRATION SCHEDULE ................................................................. 40

TABLE OF FIGURES

FIGURE 1 – CONCEPTUAL REPRESENTATION OF WATERWARE ........................................ 5
FIGURE 2 - SELECTION AND CONFIGURATION OF CRITERIA AND CONSTRAINTS ................. 7
FIGURE 3 – RAINFALL RUNOFF MODEL SCENARIO OVERVIEW – YASS CATCHMENT ........... 8
FIGURE 4 – WATER BUDGET TIME SERIES FROM THE IRRIGATION DEMAND MODEL .... 9
FIGURE 5 – NETWORK TOPOLOGY ............................................................................ 10
FIGURE 6 – DEMAND NODE OVERVIEW AND NODE CONFIGURATION INTERFACE ......... 11
FIGURE 7 – SCENARIO OPTIMIZATION INTERFACE .................................................. 12
FIGURE 8 – SUMMARY OF TIME SERIES DATA LOADED IN WATERWARE ...................... 15
FIGURE 9 – TUMUT RIVER STREAMFLOW WITH ANNUAL ZOOM .................................. 16
FIGURE 10 – TUMUT RIVER STREAMFLOW WITH MONTHLY ZOOM ............................... 16
FIGURE 11 – TIME SERIES DATA PATCHING TOOL .................................................. 17
FIGURE 12 – BEREMBED STORAGE WATER LEVELS .................................................. 18
FIGURE 13 – BEREMBED STORAGE WATER LEVELS – OUTLIER DETECTION .............. 18
FIGURE 14: 2008/09 TOTAL ON-RIVER DEMAND (m³/s) VIA WAS USAGE METHOD .......... 20
FIGURE 15: 2008/09 TOTAL ON-RIVER DEMAND (m³/s) VIA SCALED MIA DISTRIBUTION METHOD .......... 20
FIGURE 16 – TIME SERIES COMPARISON – TUMUT RIVER STREAMFLOW TUMUT VERSUS WAGGA WAGGA

FIGURE 17 – ANALYSIS OF STREAMFLOW DATA FOR 59 STATIONS IN THE POC AREA

FIGURE 18 – ANALYSIS OF TEMPERATURE DATA FOR 3 OUT OF 44 STATIONS IN THE POC AREA

FIGURE 19 – FRONT PAGE - EXECUTIVE DASHBOARD, UPDATED, CLOCK SET BACK TO 2009 SIMULATED REAL-TIME (WEATHER FORECASTS ARE ALSO RUN FOR 2010 FOR BMO COMPARISON)

FIGURE 20 – BASELINE NETWORK TOPOLOGY

FIGURE 21 – SAMPLE BASELINE SCENARIO - BLOWERING DAM SIMULATION RESULTS


FIGURE 23: ADELONG CREEK 2005-2006 RESULTS: NON-PARAMETRIC CORRELATION, 0.72 (PEARSON)

FIGURE 24: SAMPLE IRRIGATION DEMAND MODEL OVERVIEW

FIGURE 25: SAMPLE IRRIGATION DEMAND MODEL SCENARIO RESULTS

FIGURE 26: GROUNDWATER MODEL – MID-MURRUMBIDGEE ALLUVIAL AQUIFER
1. PURPOSE

The purpose of this report is to provide State Water with a final report on the Rubicon Proof of Concept (POC) implementation, to identify open issues requiring State Water’s attention and to define future activities towards the possible implementation of a full-featured operational system.

2. SOLUTION OVERVIEW

The Proof of Concept implementation of WaterWare illustrates how the optimal setting of flows from the dams and the setting of intermediate structures can be achieved as an automatic real time control solution.

Conceptually, this based on the real-time integration of:

1. **Numerical Weather Prediction** – the software predicts the weather for the simulation period and produces one or more (ensemble) hourly, distributed (1 km) forecasts based on dynamically downscaled global forecasts (NCEP/GFS data using MM5).

2. **Runoff forecasts**: for a set of tributaries is predicted as a time series of flows using the calibrated (deterministic) rainfall runoff model.

3. **Demand forecast**: water demand is determined from water orders and the demand prediction models, which in turn use the output from the numerical weather forecast for the predictive time horizon, and long-term climate modeling and/or historical data for the entire season.

4. **Baseline scenario**: The time series (or distribution of time series) of daily inputs and demands (forecasted and current water orders) together with equipment settings constitute a scenario. This is subjected to multi-criteria optimization.

5. **Simulation based optimization**: The optimum solution is determined in accordance with the user specified set of constraints on a number of performance criteria. WaterWare then runs the simulation over the entire planning horizon initially on the basis of Monte Carlo techniques, to compute a set of feasible solutions (meeting all constraints). The Genetic Algorithm (a guided search technique with its origins based on genetic theory) framework can be used to improve the efficiency of the search. The number of candidate solutions generated is configured as part of the solution development, depending on timing (daily or hourly updates) and hardware performance.

6. The optimal solution is determined by the software of the basis of the user defined criteria and objective functions (pre-determined or under interactive control) by selecting the best solution from the set of feasible solutions explored. When WaterWare is run in real time mode all of these steps can be taken automatically, including the setting of field equipment.

For the POC implementation “real time” is simulated by working through historic time, as real time data are not available.
This situation is depicted in Figure 1 below.

Figure 1 – Conceptual Representation of WaterWare
3. PROJECT APPRECIATION

This section details our understanding of the project requirements and the challenges and issues to be addressed in the ultimate project. We also discuss how these challenges and issues have shaped and constrained our implementation and configuration of the POC. For illustration, we have therefore added selected screen dumps from the POC implementation to individual topics and sections to document some of these interpretations and the solutions as implemented.

3.1 REQUIREMENTS

The scope of the ultimate project implementation is large and multidisciplinary with a primary focus on saving water and optimising economic value (net benefit in a multi-objective, multi-criteria framework) in the Murrumbidgee Catchment. This will eventually use a simulation based operational control solution for the entire river basin water resources system operations, taking advantage of state-of-the-art Information Technology and Computing (ITC), to achieve a high degree of automation, reliability, stakeholder participation, and efficiency.

These requirements, formulated as objectives and associated criteria, and the necessary primary mechanisms to delivery these improvements in a real-time operational control framework are;

**Overall objective:** to improve the efficiency of water use in the basin (eventually measurable as net economic benefit including the valuation of environmental water use. Applicable criteria include measurable indicators and targets such as

- Supply/demand ratio (basin wide, by (CAIRO) river sections, by use/priority group, by individual users
- Reliability of supply (frequency of meeting supply targets on a daily basis)
- Total shortfall (absolute, relative, by use and users)
- Total unallocated (spilled) water (absolute, relative)
- Economic criteria (including efficiency ($/ML of benefits generated; benefit/cost ration, net benefit (including environmental benefits);)
- Overall water budget/storage including reservoir and groundwater storage development (sustainable yield).

**Strategic level:** to optimize water allocation and use, structures and operational practice including monitoring in terms of the above objectives and criteria;
The objectives are a subset of the criteria that the optimization interface/configuration offers as an initial set from a basically open list of criteria in the multi-criteria approach. The configuration options in the multi-criteria interface include the selection (toggle on/off) of criteria, setting constraints on each (min, max, deviation), and in the final stage (reference point optimization) define (indirect) weights by the definition of a reference point or target solution.

**Operational level:** Precision water delivery to minimize spill/losses by:

- predicting the meteorological driving conditions (temperature, precipitation at an hourly and km resolution)
- predicting "unexpected" tributary contributions using numerical weather forecasts and rainfall-runoff modeling for all tributaries;
- "precision" release (and use of intermediate storage/control) based on improved travel time/loss modeling (real-time optimization)
- better (explicit) control of environmental water (timing)
- demand forecasting (optimization through negotiation, cooperative gaming):
  - verify/test water orders for plausibility based on farm/irrigation water use modeling combined with meteorological forecasts)
  - provide feedback to the users (eventually) on "better" alternatives, or assumptions made.
- simulate "improved control" to demonstrate needs for better instrumentation (real-time measurements, metering, and extensive use of SCADA for both data acquisition and real-time flow control)
Figure 3 – Rainfall Runoff Model Scenario Overview – Yass Catchment
3.2 **Challenges and Constraints for POC**

The specific challenges for the POC implementation are, in summary, the lack of reliable high-resolution data on water use and in stream flow measurement for the calibration of a reliable distributed and dynamic water budget on a daily basis.

1. **Formal Water Orders** provide a very poor estimate of what consumers extract from the river. For the 2009/2010 water year the total volume of orders in WAS was 163,795 ML and the metered consumption 789,256 ML (Source Kate Colleridge, State Water, 12 July 2010). Whilst it is acknowledged that CAIRO includes the water orders for MIA and CICL, the dominant water users in the valley this is a critical issue for the full implementation. This constraint puts a heavy emphasis on the ability to forecast demands, updated by orders (initial, corrected, delivered) which requires detailed data in any and all (or aggregate) water users and uses in terms of

- Population (domestic use)
- Industrial/commercial use
- Agricultural use, including irrigated agriculture which requires information on areas planted, soil data, crops, cropping patterns, irrigation technologies, local buffer volumes of irrigation systems/canals, and irrigation strategies (MAD,
Management Allowed Draw-down of soil moisture\(|\) and optional/supplementary groundwater use, all as variables of time.

- Environmental water requirements.

2. However, there is no readily available crop data for the users in the POC area to enable the WaterWare crop water demand model (demand predictions) to be configured in a robust manner.

3. There is no access to “real time” information for the POC. The current implementation therefore simulates real-time data by using historical data “as if” they were becoming available in real time.

4. To date there is inadequate information available to enable information in the WAS to be formally related unambiguously to the river network (topology). Furthermore it would appear that the conceptualisation of water licenses, works licences and extraction sites does not enable orders and usage to be unambiguously and precisely assigned/geo referenced to the river reaches. Preliminary analysis suggests that this is a material issue. To address these limitations, it was decided to aggregate the different water user into a total of 27 aggregate DEMAND NODES, each linked to a river reach or segment, based on a look-up table that links the WaterWare reaches (and associated demand nodes) to subsections from the CAIRO data base.

![Figure 5 – Network Topology](image-url)
3.3 POC OPERATIONAL STRATEGY

The basic operational strategy remains unchanged from the discussion in the progress reports: in the ultimate implementation the optimization of water allocation, releases from reservoirs, and control of weirs will be addressed at two levels:

1) In the real-time operational mode, where we simulate a continuous dynamic water budget (daily resolution) with daily updates. This is based on the cascading simulation models for:

   - Meteorology, with short-term (up to 10 days) forecasts nested in annual data for precipitation and temperature that can either be based on seasonal model forecasts (ensembles), or the use of statistical annual data sets based on either model based re-analysis or on historical monitoring data.
   - Rainfall-runoff for the (main, any or all) tributaries, generating daily forecasts based on the meteorology as above;
   - Demand forecasts, based on simulating individual or aggregate demand areas (NODES) for agricultural, domestic, industrial, or environmental water demands, generating daily demand data. In an eventual real-time implementation, this would be combined with water orders and the system would be used for on line scheduling.
   - Dynamic water budget and allocation model. Here we translate the set of demands (predicted and as ordered, the latter subject to feasibility check and eventual negotiation/correction) into dynamic control variable for
a. Reservoir release;
b. In-stream intermediate storage at weirs;
c. Actual water delivery (abstraction).

For the daily update of the allocation/release strategy, we use a dynamic multi-criteria optimization methodology designed for non-linear, dynamic, hierarchical, multi-objective and multi-criteria large and complex systems and problems (basically non-differentiable system) that can combine adaptive heuristics, genetic algorithms, and elements of machine learning. The optimization logic is described in more detail below.

The two-phase optimization in a first step generates a set of feasible solutions that meet all the user defined (and possibly time-varying) constraints, see Figure 7. While the basic optimization methodology is essentially the same as used for the strategic allocation and investment planning below under (2), the second step of reference point optimization is fully automated in the real-time implementation, by using UTOPIA (or any operator defined reference point) as the default reference point.

2) Through scenario analysis based on historical data sets and systematic (heuristic) variation in the decision variables to generate a set of feasible (alternative) scenarios from which an efficient (multi-criteria) compromise solution can be found automatically or interactively, possibly as a group decision making process. Ultimately this would be implemented as a decision on water order acceptance and scheduling of deliveries for abstraction.

Simulated real-time:

For the real-time scenarios in the POC, and in the absence of real-time data, we will simulate real-time by "turning the clock back" for a year, using 2009 historical data, a day at a time, hour by hour, integrating (reading/using) historical data as they "come along" in simulated real-time. The weather "forecasts" will thus be based on the corresponding dynamic global boundary conditions, but using the historical re-analysis data as the starting point for the dynamic downscaling of the forecasts to full spatial and temporal resolution over the basin,
i.e., exactly the same mechanisms and procedures of the prognostic meteorological modelling, but with slightly different (yet dynamic) input data sets for initial and boundary conditions.

### 3.3.1 Multi-criteria Optimization

A key feature of the proposed solution is the multi-criteria optimization of basin operation.

The same logic is used for both the

1. Strategic planning (primarily water allocation strategy, demand management, investment plans (structures, water technologies) to minimize losses and increase efficiencies);
2. Operational control (release strategy/patterns use of intermediate in-stream storage).

The basic logic is the same:

1. We define a DESIRABLE system performance as a set of CONSTRAINTS (on some of the observable properties (criteria), with any relevant distribution in time and space, including any (business relevant) levels of aggregation (integro-differential hierarchical criteria);
2. We select a set of decision variables (see below);
3. We generate, by a range of (possibly nested) strategies, trials of decision variables, simulate them, evaluate them (classify as feasible meeting the constraints, or infeasible, failing in at least one of the constraints);
4. If a feasible set of solutions can be found, we separate dominated from non-dominated solution (pareto optimal subset);
5. We identify an efficient (compromise) solution:
   - interactively by toggling in and out criteria; introducing secondary constraints, or moving the reference point (default: UTOPIA)
   - automatically, by selecting the solution closest to UTOPIA.

Search strategies and time horizon:

To make sure we do NOT borrow water TODAY and run into problems TOMORROW, we solve the entire season every time. This of course means a combination of BETTER KNOWN and more UNCERTAIN inputs (both water demand, a combination of HISTORICAL = KNOWN, ON ORDER (largely KNOWN), and PREDICTED (higher UNCERTAINTY) as well as WEATHER (same basic pattern of historical observer, short-term forecast (more reliable) and seasonal/statistical future (high uncertainty).

The search starts with simple Monte Carlo exploration of the decision space; if this works well and fast enough, we implement the solution found, automatically or under interactive control.

GA, adaptive heuristics and machine learning are all methods to IMPROVE the efficiency of the search strategy, but have direct influence on the solution itself.

Adaptive heuristics can either use production RULES of the type:

\[ \text{IF [conditions]} \text{\ AND/OR [conditions]} \text{THEN ACTION} \]

(and META RULES that change the RULES in a dynamic context, hence adaptive, OR be based on simple evaluation of the set of experiments: we evaluate (currently ex post) the (pairwise) relation between decision variables and performance variables in very simple coincidence matrices, then could nudge the experiments (search areas) toward the regions of decision variables that relate to successful runs with a higher probability (frequency on the coincidence matrices).
GA does this by "local" variations (using basic genetic mechanisms such as recombination and cross-over) of the most successful decision vectors in a given "generation" (= population from a set of model runs), similar to local (constrained random hill climbing) or gradient search.

Machine learning is a more long-term idea: ASSUMING we have reliable and truly commensurate observations, we classify "input situations" (represented by a point in some parameter hyperspace) and relate them to successful decision "solution" = another point in (decision) hyperspace, where success means yet another point (within an acceptable sub-region) in "performance space": these triplets form a CASE; CASE BASED REASONING would then look (for any new situation) for the nearest CASE, and implement (or start with) the known or interpolated decision strategy.

**Optimization scenarios: decision variables**

While both the operational control real-time optimization and the strategic planning version use basically the same set of criteria, constraints and objectives, the decision variables are different for the two cases:

- In the strategic scenario, the decisions to take primarily relate to water allocation, on a seasonal basis, efficiency, loss reduction, structural measures. In the Murrumbidgee context the seasonal allocation will influence the areas of crop grown. However, the model also enables strategic evaluation of other factors such as irrigation application technology, canal lining, size of reservoirs (including new construction, reconfiguration, capacity reduction due to siltation), conjunctive use (groundwater with a comparatively high (pumping) cost, including the simulation and design of a water market; each of the decision variables has associated techno-economic data (investment and operating cost, as well as impact on water use efficiency, demand reduction, loss reduction etc.). Decisions are "investment decisions" that affect water demand and the efficiency of use.

- In the operational scenario, the decisions to take are primarily related to flow control (and only to a lesser degree to allocation (under scarcity). The decisions relate to the release of water from the reservoirs and the use of in stream storage options. These decision do not have direct techno-economic costs associated (with the exception of conjunctive use options under scarcity of surface water). These decisions are operating decisions, SCADA settings, that affect the flow and thus delivery of water, but therefore indirectly affect the economic performance of the system through the efficiency of water based generation of economic value (including possible "valuated" environmental water use.

### 4. DATA COLLECTION PROCESSING

The following information has been sought and paid for where necessary.

1. Surface and Groundwater Data – Pinneena
2. Bureau of Meteorology Climate Data
3. 30m Digital Elevation Terrain Models (Public Domain Sources)
4. Global Weather Forecasts and ensembles (NOAA/NCEP GFS public domain sources)
5. Crop Water Usage information from Coleambally Irrigation Co-operative

The following reference material has been obtained in addition to that provided by State Water.

1. Water Availability in the Murrumbidgee, a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yield Project, June 2008
2. Rice Water Management Information from Kieran O’Keefe, District Agronomist Coleambally, Griffith Centre for Irrigated Agriculture, NSW Industry and Investment

These data have been import, in part, into the POC system. They are represented in a total of 25 OBJECT classes in the systems Data, Information and Knowledge Base.

4.1.1 HYDRO-METEORLOGICAL DATA

A total of 309 hydro-metrological station objects have been created in WaterWare and most of the time series measurements for the POC period loaded, see Figure 8. For the meteorological stations, we also extract data from the MM5 weather forecasts. The selection mechanism for station is by name, class (meteorology, stream flow, storage or combined), which can also be read back from the basin map display which also supports arbitrary zooming for more spatial detail.

![Figure 8 – Summary of Time Series Data loaded in WaterWare](image)

The time series display (Figure 9 and Figure 10) combines an overview of the entire data set (upper graph) with a user defined sub-period (lower graph), which depending on the temporal resolution of the basic data set, can range from annual to daily.
Figure 9 – Tumut River Streamflow with Annual Zoom

Figure 9 example shows a typical annual flow pattern for the Tumut River. The detail shown in the lower graph is indicated (colour-coded red) in the upper overview graph.

Figure 10 – Tumut River Streamflow with Monthly Zoom
For small gaps (up to a user defined limits, linear or cubic spline interpolation or the setting of a user defined constant to fill the gaps is supported Figure 11.

4.1.2 DATA QUALITY

From the basic monitoring data, input data sets for the simulation model can be extracted. These, however, are expected to be “clean”, without outliers and gaps.

The example (Figure 12) shows the detailed data for a year in the lower graph, that also indicates gaps and outliers (such as large or negative values for storage) in the data set. In the particular example, there are about 25% of missing or implausible data in a one year (daily) data set.
To extract data for the model runs, these outliers must be detected (Figure 13), corrected, and any gaps in the data sets patched. For this, a series of RULES defining absolute and relative ranges for the data are defined, and the outliers indicated in the dataset. If data are replaced by manual corrections, or filled in by patching methods, a corresponding flag is set in the time series META data to clearly indicate any modified data.
4.2 DATA INTERPRETATION FOR DAILY OPERATIONS

A major constraint for the configuration and calibration of a river basin operations model with a (at least) daily time scale is the apparent lack of commensurate demand and abstraction data. The available data seem to be compiled at irregular intervals, or represent measurement periods of one or more months, which simply cannot be used for the calibration of models with a daily time step directly.

Specifically, there is a need to attribute historical daily usage data to each demand node that has been defined in WaterWare, of which each represents an aggregation of pump users who extract water from a section of the river network, plus the usage of MIA via the Main Canal.

For the MIA demand node, daily historical MIA Main Canal diversion measurements, as provided by MIA and inserted in CAIRO can be used. MIA diversions via the Sturt Canal are outside of the POC region so not used for the MIA demand node. A complication is that, MIA daily diversion data in CAIRO is the discharge volume from 7am the previous day to 7am on the day the data is entered in (though recorded in CAIRO as 9am). Therefore, to attribute usage to calendar days, midnight to midnight data was extracted, for a particular calendar day, by the following weighted average formula:

\[
\text{Calendar day discharge} = \frac{(\text{calendar day's Narrandera Offtake Divert} \times 7 + \text{next calendar day's Narrandera Offtake Divert} \times 17)}{24}
\]

For the other aggregated demand nodes, WAS, which stores order, usage and meter data for sites along the river, but, for the following reasons, none could be used as historical daily usage data. Order data cannot be used because orders are not necessarily followed through to the volume of the order, or to the day they are ordered, or water may be taken without ordering. Metered data cannot be used because sites may be metered monthly, 3-monthly, or at an arbitrary time by the farmer, so data has no daily resolution. WAS usage data, is an attempt to estimate actual usage, by attributing metered volumes to the orders made between meter readings, however cannot be used because: (a) as water is not taken when ordered or not ordered at all, assigning metered data to order times does not help with accuracy of daily use, but only corrects for the volume used between meter readings; and (b) analysis of aggregate WAS usage data for the on-river nodes, see Figure 14 below (and as was shown in CORPOC report 2, section 4.2) shows the usage pattern is implausible because there is extremely large daily variability (i.e. too much daily variability) and only a weak seasonal pattern (i.e. seasonal pattern should be stronger).
Figure 14: 2008/09 Total on-river demand (m$^3$/s) via WAS usage method

Figure 15: 2008/09 Total on-river demand (m$^3$/s) via scaled MIA distribution method

Hence, it was decided the most reasonable estimate of daily usage historical river data, was to assume farmers along the river use water the same way as the average farmer in MIA, but
use less water because they (as a collective) are smaller. Therefore, the daily MIA usage pattern was assigned to each demand node along the river, and scaled by the ratio of the Volume of WAS usage for that demand node for a period between meter readings / Volume of MIA water usage for that same period between meter readings. This method distributes the WAS metered volume with the MIA daily usage pattern (see Figure 15).

Daily usage data for MIA which best represents the total usage of farmers comes from the sum of the diversion data for the Main Canal and the Sturt Canal, scaled by the ratio of volume water sales (i.e. actually used for irrigation) / volume of water diversion. This scaling factor comes from MIA annual reports. The difference between MIA diversions and MIA water sales is MIA's water loss used for conveyance to maintain their irrigation channel system. A similar conveyance loss would not apply to farmers along the river as they have no irrigation network to maintain.

Comparing Figure 15 and Figure 14, it can be seen that Figure 15 shows a more feasible distribution of daily usage with a strong seasonal trend, and ups and downs in usage which would correspond to periods of higher evapo-transpiration and rain respectively. Whilst Figure 14 shows only a weak seasonal pattern, but extremely large daily variability due to the (unknown) aggregation periods for any reporting.

4.3 DATA ANALYSIS

WaterWare supports a range of functions for data analysis, such as the comparison of different time series, plotting two user selected time series together with the histograms and a scatter plot with several regressions (parametric and non-parametric methods) coefficients, see, for example Figure 16.

Figure 16 – Time Series Comparison – Tumut River Streamflow Tumut versus Wagga Wagga
The same time series comparison tools are also used with the automated or manual calibration functions to compare simulated versus observed values.

Another tool selects all stations at or around any one of the WaterWare objects, such as reservoirs, structures, sub-catchments etc, and displays both individual time series as well as synthetic data sets generated from more than one station together with a graph of the homogeneity of the data set, that plots any individual time series against the ensemble of neighbouring stations and indicates whether the data are within or outside the resulting envelope. The two examples show stream flow (Figure 17) and temperature (Figure 18) data for the POC area (Upper Murrumbidgee).

Figure 17 – Analysis of streamflow data for 59 stations in the POC area
Figure 18 – Analysis of temperature data for 3 out of 44 stations in the POC area
5. WATERWARE SYSTEM CONFIGURATION

An instance of the WaterWare environment (http://www.ess.co.at/WATERWARE) has been created for the COR POC project on computing infrastructure located in Vienna (64 bit computer cluster under Ubuntu Open Source Linux operating system). The current version of the front page for the system is shown in Figure 19.

![Figure 19](image)

Figure 19 – Front Page - Executive Dashboard, updated, clock set back to 2009 simulated real-time (weather forecasts are also run for 2010 for BMO comparison)

This front page provides navigation functions to all of the major sub-systems in a series of pull-down menus and presents key summary of real-time indicators and statistics. In addition to the Digital Elevation Model of the catchment for the POC area (and eventually the river network overlay with colour coded status indicators) it shows the systems logs and weather forecasts.

5.1 NETWORK TOPOLOGY DEFINITION

WaterWare enables the fundamental components of the system to be defined independently of the network topology and the underlying object definitions, including meta data, time series measurements and rating tables and time series have been loaded.

The network topology for the base level scenario (Figure 20) has been progressively developed. The current development has a basic network, after elimination of demand nodes without recorded water use in the test period from 2004-2010 with close to 160 nodes, including 27 aggregate demand nodes related to the CAIRO sub-sections as described above. This baseline network is currently completed with the node and reach specific data, in part estimated (sub-catchment inflows, water demand) by the cascading models (rainfall-runoff, irrigation water demand) described below.
Figure 20 – Baseline Network Topology
A highly aggregated network design is being used as the basis for the optimization scenarios that use the criteria, objectives and constraints described below in section 5.5, System Constraints.

The optimization combines a first phase of satisficing (generating feasible solutions meeting the constraints) with a subsequent discrete multi-criteria compromise solution (reference point optimization) that eliminated dominated alternatives and finds the efficient solution closest (in a normalized performance space) to UTOPIA. Figure 21 contains a sample scenario result presenting the behaviour of Blowering Dam.

5.2 Rainfall Runoff Model

The configuration of the rainfall runoff model has been completed for several of the sub-catchments, and the automated calibration has been set up and applied for selected annual scenarios. These provide the input for sub-catchment flows.
Figure 22: Rainfall Runoff Model Calibration - Adelong Creek sub-catchment 2005-2006

Figure 23: Adelong Creek 2005-2006 Results: non-parametric correlation; 0.72 (Pearson)

The automated calibration is based on a set of constraints, defined as inequalities for model output such as MIN, MAX, AVG or the range of value over a user defined period that have to be within a user defined interval, thus defining pattern of expected/acceptable model behaviour that is largely independent from a complete observation data set (flows).
Figure 22 above shows such a sample rainfall runoff model calibration for the Adelong Creek sub-catchment in the 2005-06 water year together with the subsequent statistical evaluation against the observation data.

5.3 IRRIGATION WATER DEMAND ESTIMATION

The dynamic (daily time step) irrigation water demand model has been configured for the Southern hemisphere, and first results for (more or less hypothetic due to the constraints on relevant data availability) selected scenario have been generated. This approach was encouraged by Dan Berry at the Project initiation meeting in Sydney on 18 June 2010.

These results have been scaled according to the observed (historical) water orders, water allocations, and use patterns for the 27 demand nodes of the WaterWare baseline scenario. As the temporal resolution of MIA demand usage is daily, whilst usage data from WAS is (though time stamped with a day) hard to attribute to any particular day, as discussed above in Section 4.2, the 27 demand nodes might also be calibrated against MIA daily data scaled taking into account relative (estimated) land use, area and population.

The assumptions to be made relate mainly on the area planted by crop, cropping patterns, soil characteristics, irrigation technology and associated losses, as well as irrigation scheduling (time series of target soil moisture over the vegetation period) where the crop specific, plant physiological data are automatically loaded from the embedded crop data base.
The time series of supplementary irrigation water demand as estimated by the model (see, for example, Figure 25) can then be exported into the model input TS database and made directly available to the water resources model as estimated (forecast when driven with forecast meteorology) agricultural water demand under the assumption of optimal growing conditions, but subject to the constraints of the irrigation system (pump or diversion maximum flow) and/or constraints on river water availability, that can be expressed as a fraction of the predicted flow at the corresponding (physical or aggregate) abstraction point.

5.4 GROUNDWATER REPRESENTATION IN THE WATER RESOURCES MODEL

For the Baseline network scenario, the Mid-Murrumbidgee Alluvial Aquifer (Figure 26) has been configured to be connected to any and all nodes and river reaches in the scenario.
Figure 26: Groundwater Model – Mid-Murrumbidgee Alluvial Aquifer

The aquifer interacts with the surface water system through natural and artificial recharge; seepage from reservoirs, demand nodes; and interaction with the river reaches based on infiltration from the channel (for groundwater heads below a reach specific threshold), or exfiltration (for groundwater heads above that threshold).

Loss terms in the aquifer dynamic water budget other than exfiltration into the river channel include evaporation and deep percolation, as well as pumped wells, and natural springs.
5.5 SYSTEM CONSTRAINTS

Definition of the System constraints is based on the main objectives, and expressed in terms derived from the WaterWare optimization criteria (see Figure) including:

- Supply/demand ratio (provide a minimum or maximize supply/demand)
- Reliability of supply (maximize reliability)
- Violation of any supply/flow constraints (minimize violations)
- Limits on maximum storage change (maximize storage)
- Unallocated/spilled water (minimize unallocated water)
- Shortages (global, sectoral, by node, by segment)
- Maximize economic efficiency (subject to the availability of techno-economic data)
Figure 25: Optimization criteria

Please note that the system is open for the extension of the list of criteria, objectives and constraints.

5.6 Test User Names

As requested by State Water, a first group of “anonymous” users CORTESTUSER01 – CORTESTUSER10 has been generated for the current on-line system hosted at ESS. Additional users can be created by any user in the ADMIN group with the interactive user management functions and part of the system presentation to demonstrate the simplicity of the user management by a system administrator.

The development system can also be accessed at ESS, at [http://80.120.147.42/COR/](http://80.120.147.42/COR/) using the abovementioned user names with passwords corpoc01 – corpoc10 respectively. The final POC system has been installed on State Water hardware on the 3 September 2010 and can be accessed at [http://172.16.52.20/COR/](http://172.16.52.20/COR/).

Please note that the installation at SW can not access the Internet due to restriction in SW IT policy, so that functions depending on server Internet access (ongoing real-time weather forecasts for 2010, eMail support for problem reporting) are currently restricted to the version hosted in Vienna.
6. KEY ISSUES FOR FULL IMPLEMENTATION

6.1 Co-operative Approach

WaterWare should be understood NOT as a ready product that users will need to learn to use and adapt to, but rather as a ToolKit that supports a process of (system) model building, where the supplier and users together configure a system that meets the users institutional objectives. The WaterWare framework provide a number of utilities for “concurrent requirements engineering”, where an initial prototype (like the POC) is used as the “language” to define configuration and customization options.

Developing a large and complex WaterWare application is a learning process for both the system developers and suppliers AND the prospective user. The users are the ultimate expert on system use and the required functionality. At the same time, the prototype suggests options and possibilities that may well go beyond original expectations.

Support functions include, beyond more traditional training and coordination workshops during a full implementation period:

- Embedded error, problem and suggestions reporting system, web based with data base back-end;
- A web discussion forum with mail alerts on postings and weekly synopsis of threads
- Developer/user mailing lists;
- On-line user requirements questionnaires.

It is important to understand, appreciate and accept the important role (and inputs) that customers must have in building a truly customized solution, where understanding and control are the ultimate criteria for ownership and user satisfaction.

If Rubicon was awarded the contract for the full system implementation it would recommend to State Water the establishment of

1. A Project Steering Committee whose purpose would be to guide the overall direction of the project to ensure that the outcomes align with all stakeholder
expectations. This committee would need to co-ordinate activities from other State Water initiatives such as metering and improved order compliance.

2. A **Project Management Committee** whose purpose would be to direct and oversee the combined customer/supplier work team and provide direction and support for the Project Manager.

### 6.2 DATA SYSTEMS

It is apparent from review of the background material provided with the project and analysis of the data held within the State Water information systems that there are significant opportunities to improve the operation of the river by improving the processes to capture, store, present and analyse information.

Key drivers for the successful operation of the river are

1. Accurate indications of demand of which there are two feasible and complementary methods to attain
   a. Formal Water Orders
   b. Prediction based on the underlying physical drivers (crop area, crop type, weather, application technology)
2. Accurate control at regulating structures
3. Accurate measurement of flows into, out of and within the river system
4. Feedback on (1) (2) and (3)

Improved presentation and analysis of data is clearly within scope of the Computer Operated River project but the success of this project will be governed to a large degree by the ability to improve the data capture processes. Some of these matters are discussed below.

In terms of CAIRO language a key objective is to minimise the use of the concept of unaccounted for differences. This has two aspects; improved data quality and better representation of physical processes in the river basin.

### 6.2.1 DEMAND CAPTURE

Our analysis suggests that formal Water Orders provide a very poor estimate of what consumers extract from the river. For the 2009/2010 water year the total volume of orders in WAS was 163,795 ML and the metered consumption 789,256 ML (Source Kate Colleridge, State Water, 12 July 2010). Quite clearly a formal decision support system that relies only on these data would be problematic.
Figure 27: Time series of demand from WAS versus synthetic values

Feedback during our interview of State Water staff at Leeton (24 June, 2010) indicated that customers find the existing processes for entering orders difficult and there does not seem to be a sound understanding in the customer base of the critical role of specifying and complying with water orders has on service and system efficiency.

Rubicon’s experience in the design, implementation and support of water ordering system for more than 20 years is that

- Customers need to have a sound understanding of cause and effect.
- Multiple options for interaction with the system are required. It is our understanding that the State Water WAS system does not have an Interactive Voice response interface – this technology still remains the dominant method of customer water ordering in Victoria, despite the increased popularity of WEB ordering. The simplicity and flexibility of being able to use a fixed or mobile phone is considered to be compelling. The example shows a web interface on a mobile phone from AirWare, a WaterWare companion product sharing the same platform and tools. The same 3G mobile client support is available, in principle, for WaterWare to support mobile access also in the field.
- Regular reading of meters is an essential tool in enforcing compliance and our experience over many years is that targeted manual readings can be very effective and is certainly cheaper than implementing real time monitoring. In Victoria there is a very high level of customer order compliance with this being an important formal Key Performance Metric (KPI’s) on the water authorities.
- Incorporating text and voice messages through the customer ordering process is a formal and practical mechanism to build stakeholder participation in the operation and
control of the river. These mechanisms are particularly effective in dealing with issues such as restrictions, out of allocation and prompting for meter readings.

Formal definition of Crop types and areas has been a longstanding requirement of the Murray and Murrumbidgee Valley Irrigation Districts. Rubicon’s water management software has kept these data for Murrumbidgee Irrigation and Coleambally Irrigation for many years. In the case of Coleambally these data combined with informal estimates of weather conditions form the basis of the Coleambally 7 day advanced water order on the Murrumbidgee River. The Crop Usage model in WaterWare offers a more comprehensive structure for formalising the data necessary to estimate crop usage and these data and predictive models integrate seamlessly with the WaterWare climate forecasting, decision support and optimization processes.

Capturing and maintaining these data will involve a significant effort on behalf of State Water, but our experience is that these data may prove more reliable demand indicators than water orders. This is particularly relevant for the lower river customers where the very long (30 day) order notice period makes the ordering process uncertain for the customers and therefore creates an element of uncertainty for river operators.

### 6.2.2 Flow Measurement

The WRM report “Review of Tributary Inflow Reporting for efficient operation of the Murrumbidgee River”, prepared for Water for Rivers, February 2010 canvasses the challenges of accounting for water throughout the catchment. This report and the SKM report “Water Balance Study for Murrumbidgee River”, June 2010, examine in some detail the gauging and rating processes and the overall accuracy of measurement. Interestingly none of this work examines the critical and implicit assumption of hydrographic measurement that there is a single relationship between water level and flow. Based on our experience in irrigation networks that are retrofitted with modern flow measurement technology such as automated gates or time of flight metering, this assumption is often violated and it can lead to significant errors.

It is contended that at key points in the basin where there are flat gradients and poor control sections that alternate technology be deployed for flow measurement. Accurate and timely measurement is critical in eliminating Unaccounted for Differences.

It is also recommended that more frequently spaced water level measurements be collected to enable the COR to explicitly measure water levels and take into account error feedback or deviations, without the need to “invert” flows via rating tables.
7. Project Plan for Full Implementation (Stage 3, Phase 1, Oct 2010 to Nov 2011)

Kickoff Meeting 2-3 weeks after contract signatures, Meeting in Leeton or Sydney for 2-3 days, attended by:

- Rubicon: project team
- ESS: Kurt Fedra and selected team members
- State Water: river operators and selected stakeholders

- Objectives:
  - Meet team members to establish personal contacts;
  - Set up communication structure for the project – including: schedule and preferences for regular visits, email, project website, project online log, online project discussion forum, mechanisms for continuous requirements engineering.
  - Draft Inception Plan – detailed initial workplan and schedule, Milestones (including verification means), procurement suggestions for equipment (computation, monitoring), project management and monitoring structure (external peer review ?), risk management, contingency planning, reporting and payment schedules.
  - Catalogue available Data – discuss sources, who knows what is available and from where? assign responsibilities for data gap analysis and report.

Complete, discuss, submit Inception Plan and Report.

Main development: Prototyping Cycles:
The approximately 10 months for the main COR system development (Phase 1) will be organized in three, partly overlapping prototyping cycles (PC). Of similar structure; the successive prototypes will be used to elicit structured user feedback, formulate and test data requirements, and define validation cases around selected test scenarios and real-time test operations. The three prototyping cycles are scheduled as per Table 1 below.

Table 1: Overlapping Prototype Cycles in a Monthly Timeline

<table>
<thead>
<tr>
<th>PM01</th>
<th>PM02</th>
<th>PM03</th>
<th>PM04</th>
<th>PM05</th>
<th>PM06</th>
<th>PM07</th>
<th>PM08</th>
<th>PM09</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

indicates on-site presentation workshop

Beginning and end of prototyping cycle are marked by reporting, presentation and training workshops for client and stakeholders, and the concentrated compilation of feedback in the presentation workshops.

This provides the input for the next cycle, which again leads to a progress report and presentation workshop, that starts with the presentation of the responses to the feedback from the previous cycle.

The basic elements and tasks of each of the three prototyping cycles are:

- T1: User requirements analysis from the previous period, feedback from presentations workshop and the PC start-up meeting;
- T2: Translation of the requirements into a checklist of implementable features;
- T3: Definition of the data requirements for each feature;
- T4: Definition of test and validation cases for each feature;
- T5: Data compilation and pre-processing
- T6: Development and Implementation
T7: Continuous testing by (proxy) users, feedback
T8: Documentation, manual updates
T9/T1: Presentation and discussion workshop to elicit another round of user requirements (continuous electronic feedback or on demand in between workshops), closing the cycle (task T1 for the next cycle).

Please note that while each of these tasks has a period of high, concentrated activity, they all span the entire prototyping cycle at a low level of activity, see the timeline for one prototyping cycle (in weeks) below.

Table 2: Weekly Timeline of Prototype Cycle Tasks (T1-T9)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A special task at the last (third) presentation workshop will be the preparation of the Final Implementation Report, on-line user Manuals, training material/tutorials, including Inception Report for the Transition and Operational Implementation, (Stage 3, Phase 2, to be completed June 2012).

8. CONCLUSIONS

It is our view that a full implementation of WaterWare can undoubtedly meet the project objectives for the tendered price. All the major components as needed are available and fully operational. There are three main areas of endeavour that need to be pursued for the full implementation

1. **Data Systems** – some detailed analysis is required to explore the structure of some of the State Water systems and the interfaces between them and the Computer Operated River (WaterWare). In our view there is a clear case to shift some of the existing transaction processing into WaterWare as it is clearly feasible to process customer water orders in real time. It would appear that there is a significant opportunity to reform the structure of water and works licenses, extractions sites and the techniques for accruing and accounting for usage in the information systems. Removing some of the encumbrances in the existing processes may require institutional and even legislative reform to improve transparency and management. There is also significant work to geo reference extraction sites to enable them to be accurately referenced to the river network topology. A related issue is the compilation of commensurate, reliable and sufficient monitoring data in real time, and clearly related to the basin structure: meteorology, flows, water demand/use.

2. **Monitoring** – a major requirement for an operational control system based on dynamic water budget modelling is the “observability” of the basic hydrological system for calibration, validation, and data assimilation. The current monitoring system in the POC area does not meet this objectives with the coverage and precision required for a reliable use of these data together with numerical modelling.
• The number of monitoring points is insufficient: we would expect to find meteorological measurements (minimally temperature and precipitation, for more advanced estimates of evapo-transpiration one would also need wind, radiation, and humidity data) for each of the tributaries, with one or more representative monitoring locations;

• The location of monitoring points is inadequate to support water budget modelling: especially for flow data, monitoring stations should be placed as closely upstream of any confluence, at the inflow and outflow of all regulated structures, and at major abstraction points (both metering and downstream flow control) as possible. Redundancy for station inter-calibration at critical points would be desirable.

• The quality of monitoring data needs to be verified. Several of the time series data show major gaps, numerous outliers, but also a short time variability difficult to interpret. The conversion of water level data to flow in a natural river that is shallow and with a very irregular natural cross-section and in particular at low flow is a best doubtful.

In general, a major overhaul of the monitoring system based on re-calibration, as well as sensitivity analysis of the model system to determine optimal number and locations of monitoring points should be considered.

3. **WaterWare Configuration** – the POC has demonstrated that WaterWare is capable of representing the basic processes within the Murrumbidgee catchment. The primary focus for an ultimate implementation would be

   a. Formally representing every demand point in the basin as a WaterWare node and managing all transactions within this framework.

   b. Increasing the resolution of the river representation to fine tune the river routing across a broader range of hydrological conditions.

   c. Building the crop database for all farms in the basin.

   d. Calibrating the rainfall runoff and groundwater interactions over the available period of records. Clearly the POC project period is only a small subset of the known hydrological experience in the basin, and not all the available data are adequate for model calibration.

   e. Working closely with State Water to fine tune the structure of the user interface; customization options need customer input.

4. **Stakeholder training** – will involve two elements. “Externally” there is a significant body of work required to educate the stakeholders in the need and value of specifying accurate and timely water orders. Internally there is a significant effort in making the transformation from the existing methods of operating the river to a more technologically based solution. This transformation will need to be nurtured to ensure all staff within State Water are provided with the opportunity to participate and learn through the participatory development process.
9. POC demonstration schedule

This section lists WaterWare features in the context of the POC demonstration schedule defined by State Water as implemented in the demonstrator or as they can be configured subject to available data and sufficient time and end user requirements.

Proof of Concept Schedule RFT Number: SWCDOC10/685 Provision of a COMPUTER OPERATED RIVER SYSTEM for State Water Corporation

POC - Demonstration and Trial Evaluation Schedule

The Tenderers should demonstrate water savings for the POC section as an interactive system. The overall performance would be assessed by the amount of water savings achieved in the head water storages.

The Tenderers to demonstrate

- The ability to use the real-time information,
- Amount of water saved compared to CAIRO,
- Failure to meet the customer demands,
- End of system targets and consequence analysis.

The demonstrations could be separately shown or as part of the requirements listed below:
Primary Objective - Water savings in the POC section through the use of COR system

Minimized operational surplus, Quantity of water retained in the head water storages:

Demonstrate:

- Use of real-time information
- Use weather forecasts during the POC period and model self-correction using observed data
- Amount of water saved compared to CAIRO
- Success rate in meeting the customer demands and end of system targets
- Consequence analysis on instances when the system constraints were not met
- Detailed document on savings achieved using different strategies

WaterWare uses several possible sources of real time data, including:

- Global meteorological forecasts (GFS from NOAA) dynamically downscaled to basin dimension with 3D prognostic models (MM5, optionally WRF); the same model(s) are used to generate high resolution re-analysis data sets for historical periods.
- Any data that can be loaded from network accessible SQL compatible data bases. For this feature, the monitoring time-series data base has a configuration screen for external data loading;
- Customized scripts (as part of the RTXPS real time loop) that fetch data from external sources, web pages (e.g., BOM), check mail accounts of ftp directories for incoming data on a regular basis, initiate scp, ftp or wget data retrieval from external servers/file systems etc.
Performance indicators:

For each model run, WaterWare generates an overall mass budget estimate including Delta Storage (reservoirs and in stream) and any number of performance indicators (which are easy to extend) which also include criteria that can be used in the optimization. The main criteria are printed over a colour coded interpretation:

- Supply/Demand ratio
- Reliability of Supply (measure the relative number of days when customer demands have been met, can also include environmental and in-stream flow requirements)
- Accumulated shortfalls
- Unallocated water
- A number of water economics such as
  - Benefit/cost ratio
  - Economic efficiency ($/m3)

As well as an account of flood events, derived from exceedances of predefined maximum flow at control nodes; (Estimated flood damages can be made part of the overall economic assessment).

These indicators are also used in the direct comparison of dynamic water budget scenarios.

Solution Overview and Summary:

The Proof of Concept implementation of WaterWare illustrates how the optimal setting of flows from the dams and the setting of intermediate structures can be achieved as an automatic real time control solution, that runs concurrently with the underlying scenario analysis and data management functions. Conceptually, this based on the real-time integration of continuously operating model system with daily, six hourly, and hourly updates:
1. **Numerical Weather Prediction** – the software predicts the weather for the simulation period and produces one or more (ensemble) hourly, distributed (3 km prognostic, 1 km diagnostic interpolation) forecasts based on dynamically downscaled global forecasts (NCEP/GFS data using MM5 or WRF). Alternatively, external weather predictions in standard formats (netCDF) can be used.

2. **Runoff forecasts**: for a set of tributaries is predicted as a time series of flows using the calibrated (deterministic) rainfall runoff model.

3. **Demand forecast**: water demand is determined from water orders and the demand prediction models, which in turn use the output from the numerical weather forecast for the predictive time horizon (up to 10 days), and long-term climate modeling and/or historical data for the entire season. Forecasts and order may be reconciled by on-line communication/negotiation with the clients.

4. **Baseline scenario**: The time series (or distribution of time series) of daily inputs and demands (forecasted and current water orders) together with equipment settings constitute a scenario. This is now subjected to multi-criteria optimization, over the entire water year, updated daily or even hourly with the availability of new observation or demand data.

5. **Simulation based optimization**: The optimum solution (time series of release settings for all structures corrected for tributary inflows) is determined in accordance with the user specified set of optimization parameters (performance criteria, evaluation rules, number of candidate solutions to generate). WaterWare then runs the simulation over the entire planning horizon initially on the basis of Monte Carlo techniques, to compute a set of feasible solutions (meeting all constraints). Alternative guided search techniques (adaptive heuristics, genetic algorithms) can be used to improve the efficiency of the search.

6. The **optimal** solution is determined automatically on the basis of the user defined criteria and objective functions (pre-determined or under interactive control) by selecting the **best** solution from the set of feasible solutions explored. When WaterWare is run in real time mode all of these steps can be taken automatically, including the setting of field equipment (SCADA interface). A number of (rule-based QA/QC) checks are performed to guarantee system performance within pre-defined envelope of control parameters, all steps logged, including a range of communication strategies, warning, alerts and alarms, and optional operator override.

7. **Continuous updates**: this sequence of cascading model steps is run continuously, with new monitoring (and water order) data used to update the initial conditions for every new hourly model run, and re-calibrate the models and optimal solution where necessary with new data becoming available.
SOLUTION EXAMPLE:

The example below contrasts two versions of the same simplified and highly aggregate scenario, primarily constrained by demand data availability and insufficient monitoring data for the calibration of distributed (reach specific) loss terms. However, the main objective is to demonstrate the DIFFERENCE (relative improvement) between the two scenarios to illustrate the efficiency of the optimization approach. Everything else being equal, they compare historical/observed flows (left) with an optimized version (right) of the reservoir release strategies that include corrections for tributary inflows. The two hypothetical and only comparative example show a dramatic improvement of the basic performance indicators, and a potential water saving (measured as reservoir content change, see “Delta storage”) of about 30% of the initial reservoir storage volume (assumed to be at 75% at the beginning of the simulations in July 2008).
POC 1 - A configurable generic river operations model with customisable features

(e.g. Hydrometric measurement points, Regulated diversion points) to represent basic hydrological processes of the river system

Highly user-friendly software system for the operators, reduced dependency on specialized knowledge for normal river operations: Users able to set-up simple river operations model and add nodes (specify properties)

Demonstrate:

- Ability to add features present in current Murrumbidgee CAIRO and link features to data sources
- Document giving the methods adopted

WaterWare has been configured for a basic Murrumbidgee river network, with more than 150 NODES representing the basin's main features, structures, and river network.

The input data have been derived from data sets imported from the Pinneena DVD, and augmented from CAIRO/WAS data sets retrieved from the ORACLE data base.
The data have been imported into the WaterWare OBJECT data base, geo-referenced, and cleaned (patching of time series) where necessary to obtain continuous input data time series for the model runs. The data base includes now 24 OBJECT CLASSES, including 345 monitoring stations with time series covering the period starting July 2004, 25 sub-catchments, and several structures (dams, weirs).

The OBJECT data base uses a simple triplet ID – attribute – value structure that supports dynamic extensions to the data base structure, i.e., the addition of new OBJECT attributes; they are linked to the graphical user interface through HTML TEMPLATES with customized tags to link to the data base and the variable definitions from the Knowledge base.

Editing (the same tools are used for the OBJECT data base and model scenarios) is supported by a simple pop-up dialog that describes the variable in question, defined legal range of value, provides symbolic labels as a short cut, and support both graphical or numerical data entry in addition to the selection of the pre-defined (but easy to configure) symbolic default values.

Another feature of the editor is the possibility to convert units for the variable in question, e.g., from Mega Litres/day to m3/s and back. The editor also keeps track of value changes, i.e., user, data and value entered to provide a complete log of all user interactions and specifications.

Finally, first order production rules can be defined to support the editing with a simple rule-based inference.
POC2 - Ability to use for normal river operations, operational planning, flood and drought operations

Reliable forecast of flows, System able to simulate low flows and high flows in the main river

Demonstrate:

- Goodness of fit between observed and modelled flows \( \geq 0.8 \) with special emphasis when there is a high flow event (upper extent of normal river operations)
- Document giving the methods adopted

WaterWare is using physically based (rather than statistical/empirical) models, so that we can expect them to operate over a very wide range of hydrological conditions. Testing and calibrating this for very different flow regimes would require the historical data that cover the entire range of hydrological regimes. Please note that the calibration tools can be configured to place emphasis on different parts of the observations spectrum such as average flow (water budgets), peak flow (floodings) or low flow (drought) events.

Goodness of fit between observed and modelled flow is analysed and displayed for both individual scenarios (rainfall-runoff) as well as the water budget model WRM at any control node, where the computed flow can be compared with an observed flow time series linked to the control node. However, as some examples demonstrate, there is very poor correlation between some of the input data to the models such as rainfall runoff, where the relationship between observed rainfall and observed runoff shows no statistically significant correlation (see also section 3.3 discussing data quality).

The automated calibration tool (currently implemented for RRM) can be configured to put a high emphasis on high-flow events (compare Figure 3 and Figure 22).
POC3 - Ability to create & maintain river section models

Highly user-friendly software system for the operators, Users able to modify the channel network

Demonstrate:

- Existing channel network is modified by adding/removing components
- Operating rules could be introduced/modified
- Document giving the methods adopted

WaterWare includes an interactive network editor that facilitates the design of any number of network scenarios. The possibility to link OBJECTS for the individual NODES and REACHES of a network scenario ensures consistency between the different scenarios, which a user-defined set of OBJECT attributes that can be inherited from the OBJECT.
POC4 - Ability to forecast tributary inflow with rainfall-runoff

Improved ability to forecast water available from uncontrolled sources, Efficient mitigation of floods, Surprise elements in operational tasks are removed, Reliable forecast of flows, Minimized operational surplus, Environmental flow rules are fully satisfied:
Customised models to forecast tributary inflow including ability to route the flow up to the next gauging site in the main river
Comparison of modelled tributary inflows Vs observed flows, Ability to make use of weather forecast by third party agencies, Ability to do automatic update of model parameters to enhance real-time forecasting

- Goodness of fit statistics such as coefficient of correlation ≥ 0.7 and coefficient of efficiency for daily flow ≥ 0.6 for at least two gauged tributaries of Murrumbidgee for the validation period using historic data
- Goodness of fit statistics such as coefficient of correlation and coefficient of efficiency for 1-5 day forecasts for at least one gauged tributary of Murrumbidgee for the validation period
- Visual fitness of flow peaks for observed and modelled hydrographs
- Flags for environmental flows when the inflow triggers are met (as per Water Sharing Plan rules)
- Flow duration curves for observed and simulated flow to be compared (chart)
- Document giving the methods adopted

RRM is a lumped or semi distributed rainfall-runoff model for the prediction of tributary inflow, using either one or more meteorological station data, or meteorological driving variables derived from the prognostic meteorological mode (MM5 or WRF) where the data over a hydrographic catchment area are extracted from the 1 km grid results of the meteorological forecasts.

The rainfall–runoff model can be run with a daily timestep over an annual period, or alternatively, with hourly resolution, over 15 days or 360 hours.
Where matching observation data on flow are available, the model includes options to:

- calibrate based on the observations
- compare simulated and observed flow data.

Please note that no observation data to calibrate the hourly resolution version are currently available. The example below shows a validation example, using a calibrated version (2004/5) of the RRM model for Adelong Creek with meteorological data from 2008/9, but retaining the same data set as calibrated (one of 100 feasible solutions) for 2004/5:
POC5 - Ability to forecast irrigation demand

Improved forecast of irrigation demand, Efficient delivery of customer service, Enhanced customer service, Minimized operational surplus: Customised models to forecast irrigation daily demand, Ability to make use of weather forecast by third party agencies

Demonstrate:

- Goodness of fit statistics such as coefficient of correlation $\geq 0.7$ and coefficient of efficiency for daily demand $\geq 0.5$ for at least one major irrigation area in Murrumbidgee.
- Plot of cumulative simulated and actual daily demand (also show 3-day moving averages)
- Reliability of the model as percent of daily demand forecast within 25%
- Document giving the methods adopted

WaterWare includes an irrigation demand model IWRM; this estimates the daily water (abstraction) requirements for an irrigation area, farm or district defined by a number of parameters. The models run over one season (water year) at a daily timestep.

Model parameters include:

area irrigated, crop distribution (crops are loaded from an embedded crop data base), soil characteristics, an optional buffer reservoir, dynamic abstraction constraints, irrigation technology, and a (crop specific) target soil moisture profile (expressed as MAD, Management Allowed Drawdown of soil moisture) over the vegetation period of each of the crops considered. The model considers temperature and precipitation, and estimates supplementary irrigation water requirement to maintain the (crop specific) optimal soil moisture profile.
POC6 - Compute & forecast channel net evaporation loss

Improved accounting for all in-channel hydrological processes, Minimized operational surplus, Surprise elements in operational tasks are removed: Customised models to simulate channel net evaporation loss, Ability to make use of weather forecast by third party agencies.

Demonstrate

- Chart showing variation of daily evaporation loss for the river reaches
- Coefficients / parameter values used in models comparable to published values in similar climatic zones.
- Document giving the methods adopted with details on how the channel surface area was estimated

WRM computes a complete water budget on a daily basis for each well configured reach. Evaporation is estimated with a simple degree day function from daily average air temperature, surface area (currently static/average, but can be computed from flow with the help of segment specific rating curves).

The reach water budget also includes evapo-transpiration from bank vegetation, based on

- average air temperature
- bank vegetation (symbolic classification) and associated degree-day parameters
- extent of the bank vegetation (that draws water from the river channel through taproots and osmosis/soil moisture) along the river
POC7 - Compute & forecast channel evapo-transpiration loss

Improved accounting for all in-channel hydrological processes, Minimized operational surplus, Surprise elements in operational tasks are removed: Customised models to simulate channel evapo-transpiration loss, Ability to make use of weather forecast by third party agencies.

Demonstrate:

- Chart showing variation of daily evapo-transpiration loss for the river reaches;
- Evapo-transpiration loss as a percentage of Potential ET (monthly time-step, chart)
- Coefficients / parameter values used in models comparable to published values in similar climatic zones.
- Document giving the methods adopted; with details on land use data used and how the area contributing to the ET loss from the channel was computed.

Bank vegetation density and extent are user-specified, reach-specific parameters that could also be derived from high resolution satellite imagery or aerial photography.

Due to the lack of detailed meteorological data, a simple degree data method is used (Blaney-Criddle equation).

For comparison, MM5 generated evaporation data (based on energy flux) can be used.
POC8 - Ability to compute & forecast bank-storage flux

Improved accounting for all in-channel hydrological processes, Minimized operational surplus, Surprise elements in operational tasks are removed:
Customised models to simulate bank-storage flux, Compare model predictions with established independent model predictions.

Demonstrate:

- A coarse model for the POC reach;
- Demonstration of successful application of the models in other river basins
- Document detailing the methods adopted

Bank storage flux as part of the reach water budget is currently represented by a combination of lateral inflow (primarily precipitation driven) and groundwater interaction (see below POC9); an explicit representation is under development.
POC9 - Compute & forecast groundwater flux in and out of the river channel with hydraulically connected aquifers

Improved accounting for all in-channel hydrological processes, Minimized operational surplus, Surprise elements in operational tasks are removed:
Customised models to simulate river – groundwater interaction (recharge/discharge), Compare model predictions with established independent model predictions.

Demonstrate:

- A coarse model for the POC reach
- Demonstration of successful application of the models in other river basins
- Document detailing the methods adopted

Reaches interact with the associated (shallow) aquifer by two related processes:

- Percolation losses from the channel to the aquifer when the groundwater table is below a reach specific threshold;
- Exfiltration from groundwater into the channel when the groundwater head exceeds that threshold.

The speed of exfiltration depends on the groundwater level above threshold, and a coefficient that defines the speed of draining the excess groundwater: the parameter describes the fraction of this excess head over the interface area (corresponding to the reach surface area) as a fraction of the delta head per day.
POC10 - Ability to compute channel reach water balance determined by flow monitoring stations

Improved use of available water in the river / stream channel, Minimized operational surplus: A reach water balance model that considers all possible gains and losses in the river system.

Demonstrate:

- The water balance is closed hourly/daily/weekly/monthly time steps especially when the model configuration is changed (when components are added / removed).
- Document giving the methods adopted

WaterWare can use any number of control nodes in the network, that compare observed and simulated flow, together with the detailed daily water budget summary by node or reach of the network. The example below shows observed and simulated flow at the outflow of Burrinjuck (near perfect agreement at Glendale, left) and downstream at Gundagai (right), where the accumulated error (the scenario uses only default reach/routing data settings) becomes visible. In these pictures, REFERENCE_TS (red) are the measured flows at Glendale and Gundagai and INFLOW_TS (blue) is the simulated flow at these locations routed through the model.
POC11 - Ability to estimate and forecast unaccounted differences

(other flux across the system that is not explicitly accounted for by the above processes).

Improved use of available water in the river / stream channel, Improved forecast of basic rights extraction, Improved ability to reduce theft of water: Compute and forecast unaccounted differences at different time steps as part of reach water balance

Demonstrate:

- Display estimated and observed unaccounted differences as line chart
- Standard deviation in daily time-step is minimal
- Daily AUD closer to the measurement errors associated with the reach water balance
- The model should flag any outliers to enable identification of water theft
- Forecast unaccounted differences
- Line charts (with goodness of fit) showing modelled seven day and fourteen day advance forecasts and observed daily flow at Narrandera
- Document giving the methods adopted

Direct comparison of computed and observed flows at all control nodes representing flow monitoring stations is possible (see example to the right). Though not explicitly plotted in the current implementation, the difference between the observed and computed flows is the residual or “unaccounted difference” and could be plotted in a future implementation if required.
POC12 - automated / manual calibration of the above model components and to select a best set of calibration parameters; Highly user-friendly software system for the operators; User friendly tools for model calibration used in the proposed system.

Demonstrate:

- Auto-calibration tools demonstrated in the customisation of the rainfall-runoff model for one of the tributaries.
- Document giving the methods used

WaterWare uses a method similar to the multi-criteria optimization to automatically calibrate model; this is being demonstrated for the rainfall-runoff model, but is equally applicable for all other models where commensurate and reliable observations exist.

The calibration procedure for a scenario consists of two steps:

- selection of the parameters to calibrate, definition of plausible range for each the parameters to search;
- definition of a number of constraints on the allowable model behaviour;

The results is a user defined number of feasible solutions that meet all the constraints, which can then be ranked and explored by re-running any of the parameter vectors identified.

The same discrete multi-criteria analysis that is used for the WRM optimization can be used here as well.
The Figures show the selection of parameters for calibration and the range definition; and the statistical results for a feasible set of solutions with the histogram for one of the parameters, that shows the frequency distribution for the parameter values that give rise to a feasible solution, the feasible subset.
POC13 - Choice of operational modes - automatic and manual modes

- Automatic – regular river operations within defined protocols with no manual changes allowed to model set-up or system interfaces.
- Manual - emergency operations (in case of Auto-mode protocols) to ensure water delivery processes to continue with out disruptions.
- Manual - operations planning with changes allowed to model configurations

Risks in water delivery operations well managed: System demonstrated for three different operations environment:

- Show automatic operation work-flow process with daily/sub-daily time step; auto mode protocols to be described.
- Provide the “checks and balances table” used for the automatic operations
- Manual operation facility for parts of the work-flow demonstrated by triggers and manual operations; including message alerts to the operators
- Transfer of daily / sub-daily information to required time step (weekly/monthly/annual)
- Document giving the methods adopted

In the POC implementation, WaterWare combines the automatic, real-time mode and manual operations (scenario analysis) in one system. While the automatic version runs continuously, driven by the real-time expert system RTXPS and its rules, the scenario analysis and data management is fully interactive, but concurrent.

The real-time automatic scheduling is driven by a set of rules that are executed in a continuous forward chaining (rule-based) loop, which

- maintains the communication with all external data sources, downloads external data as needed;
- executes (conditionally a series of model runs and the data pre-processing steps (updates)
- set any control for the SCADA interface;
- updates the system logs and issues any messages, warning, alerts and alarms to the operator (viz the red background for the top two log entries, highlighted as ALARM messages indicating exceedance of the computed reservoir release compared to the table of checking rules).
An example RTXPS script or rule-base as shown in the system interface is shown below: the regular daily and hourly model runs are based on the continuously updated input data time series; these combine the historical data (up to the current execution time) extended by the forecasts starting with the weather forecasts that drive the estimation for tributary inflows and water demand.

These time series of (incrementally updated) driving conditions are used for the optimization of reservoir (and intermediate weir) release settings, with continuously updated initial conditions (data assimilation and nudging of initial conditions); if the input conditions change dramatically compared to previous forecasts, the models can also be re-calibrated. The model system can also switch on a parallel (and specifically calibrated) flood forecasting mode with six hourly updates of the weather forecasts.

The optimal release settings are compared against the pre-defined operational boundary conditions, communicated to the SCADA system, and logged; if necessary, appropriate communication steps (warning, alerts, alarms) to the operator are initiated, the system maintained at a conservative release policy until operator confirmation.

All automatic or user defined interactive control settings are logged for ex post analysis, and as the basis for an optional long-term machine learning cycle using case based reasoning.
POC14 - Advanced system optimisation capability for a range of operational objectives and constraints.

Risks in water delivery operations well managed: User friendly and versatile optimiser with capability to rank the objectives and edit the constraints, System demonstrated how scenarios are run, risk assessed and making or facilitating the decision making.

Demonstrate:

- A very well written document on how the optimiser works
- Quantify water savings achieved as against CAIRO for the POC period; give charts with daily time-step
- Sensitivity of the optimiser to different risks
- Statistical report/chart on number of objectives met and constraints satisfied

Examples from the optimization model interface:

- setting of constraints
- setting of instruments (decision variables),
- analysis of results,
- ranking of alternatives
- DMC (discrete multi-criteria DSS)

The optimization finds, for each pair of upstream release and downstream demand node, the coefficients (loss correction and delay) that lead to a feasible candidate solution. Tributary inflow (as predicted by the rainfall-runoff model on the basis of the updated weather forecasts) is considered as a “negative” demand, which will reduce the required release from a storage facility, again adjusted by loss correction and delay (travel time). The structural simplicity of this representation can be scaled over a very large number of demand nodes efficiently, while the continuous updates build the basis of an increasing refinement of the search strategy (adaptive heuristics) the attempts to “learn” from the continuously growing number of previously successful solutions in the preceding time steps.

Further explanation of the optimization process is contained in Section 3.3.1: Multi-criteria optimization, above.
POC15 - Facility to create, save and retrieve operational/planning scenarios.
Efficiently provide long-term sales forecast for business improvement, Reports to regulators are on time: Scenarios generated during manual-operations planning sessions are saved and retrieved.

Demonstrate:

- At least one planning scenario for 12-month duration starting in July 2008 is created and saved.
- The scenario to include the supplied statistical inflow sequence starting in July and all account balances and allocations announced as per actual data provided
- Document giving the methods adopted

WaterWare maintains any and all scenario under complete user control. Available scenarios are listed for selection by name, owner, modification date, and the first part of the descriptive (user generated) META DATA, see right.
POC16 - Facility to review selected scenarios with provisions to enter commentaries on any model input/output data
Efficiently provide long-term sales forecast for business improvement, Timely and clear information to stakeholders
Demonstrate: The scenario created in POC15 is retrieved and reviewed
Demonstrate:

- The scenario created in POC15 is retrieved and reviewed;
- Demonstration to include steps to show how the comments will be added and data modified during review
- Document giving the methods adopted

Any OBJECT in WaterWare has several META DATA (automatically generated) as well as a text field to enter user defined META DATA text.

The example shows the relevant section from the WRM scenario OBJECT for the scenario: BASELINE 2008/9

![WRM - Scenario Editor](https://example.com/wrm-scenario-editor.png)

**WRM - Scenario Editor**

- scenario info.
- nodes
- reaches
- aquifers
- help

**BASELINE 2008/9**

Murrumbidgee, from Burrimjuck dam to Narrandera
META DATA FIELD for user generated text description

- **start date**: 2008
- **time step**: daily
- **Location**: Murrumbidgee
- **Area**: 40000 km²
- **Population**: 150 - 1000 people

- **Author**: kurt
- **Last modified**: 2010-08-26 11:42:05
- **Duration**: 365 days
- **Network Length**: 790889 m

POC17 - Ability to re-run the operations model after fixed time interval

To verify if the required changes in the infrastructure settings & stream flows have been achieved; Efficient operation of head-water storages, Improved use of available water in the river / stream channel: Operations system re-run in auto-mode to verify if the model performs correctly

Demonstrate:

- Demonstrate with both correct and incorrect SCADA settings to show that the system will perform as expected; including raise of alarms and re-setting of other river structures to optimise the unexpected supply/demand situations
- Document giving the methods adopted

The operations model uses a "standard" WaterWare scenario (REAL-TIME); this can, at any point, be copied (for security reasons) and run manually. Also, from an interactive optimization run, any one of the feasible solutions (parameter vector, input time series) can be run in interactive mode for detailed model output inspection

The primary output on the main (dashboard) page includes hotlinks to the individual node results pages related to the structures (reservoir, weir) for which the optimization has computed the optimal release strategy.

The underlying scenario can be re-run manually at any point (with the appropriate user/group privileges), and will be updated at the next cycle within a user defined interval of a few minutes.
POC18 - Interoperability with water accounting database in the corporate Oracle database

- NOTE1: The information to read includes water orders, usage, account balances, extraction site identifiers and customer information from the existing data tables.
- NOTE2: The information to write includes calculated surplus / deficit flows at hydrometric nodes or extraction sites and change in travel times which requires demo database tables to be created by the successful Tenderers.

Improved ability to reduce theft of water, Timely and clear information to stakeholders, Reports to regulators are on time, Efficient delivery of customer service, Reports to regulators are on time: Import / export of COR data to Oracle database

Demonstrate:

- Demonstrate import of WAS data into COR
- Interops logs
- Demonstrate export of calculated surplus/deficit at each ESID to COR-WAS (specially created Oracle demo database-table)
- Demonstrate the export of travel time (lead water order time) information to the specially created COR-WAS demo table.
- Document giving the methods adopted

The examples show access to and retrieval from the ORACLE data base (water orders) including connection status and error messages for time out in the connection.
POC19 - Interoperability with Corporate data systems to automatically retrieve hydrometric data

NOTE: The information to be retrieved includes mean flow rates at different hydrometric flow monitoring stations, valve release from the storages, etc.: Improved ability to reduce theft of water, Timely and clear information to stakeholders, Reports to regulators are on time: Import hydrometric data from corporate Hydstra

Demonstrate:
- COR data to matched against manually extracted Hydstra data (chart and statistics) to demonstrate there is no data transfer error
- Interops logs at 15-minute time interval
- Document giving the methods adopted

Capability to access data from Hydstra has been demonstrated by extracting Burrinjuck Dam storage volume (derived from the level) from the Hydstra installation on Corapp03, and loading it into table hydstra_load(site_id, data_id, event_time, event_value) on the State Water Oracle database.
POC20 - Interoperability with SCADA systems to simulate changes to valves / gate settings by read/write to a ODBC compliant database.

NOTE1: The information to read from the SCADA database may include data on gate openings, flow rate, etc., while the write includes the set-points required by COR system.

NOTE2: For the purpose of demonstration/trial database tables need to be created by the successful Tenderers

Efficient operation of head-water storages, Improved use of available water in the river / stream channel, Efficient use of re-regulation storages: Write set points in a ODBC compliant database, Read operational mode of a structure, and constraints (maximum release) from the same ODBC table.

Demonstrate:
- Demonstrate read/write of information from the specially created ODBC compliant database during the auto-mode COR
- Document giving the methods adopted

The SCADA interface demonstrates reading from and writing to the simulated SCADA interface, where user defined values can be set, and read back for conformation, from the ORACLE data TABLES that simulate the SCADA system.

To demonstrate the concept of detecting and acting on SCADA flow settings outside of an acceptable range, a message was written to the System Log (highlighted in red) to indicated such an event has occurred.
POC21 - Accept data from a different data supply systems including Hydstra and Oracle database
Highly user-friendly software system for the operators: Accept data from third party data sources

Demonstrate:

- Demonstrate data acceptance from a different data source (example BoM WDTF)

The example demonstrates access to BOM weather forecasts for comparison (through the WaterWare menu system and user interface) with the MM5 generated numerical weather forecasts.

For demonstration purposes, data from Hydstra (installation on Corapp03) have also been loaded to an ORACLE TABLE (hydstra_load(site_id, data_id, event_time, event_value) on the State Water Oracle database. Since all hydrological time series for the POC period have already been loaded to the POC’s data bases, no further operational use of the (historical and fully redundant) data could be made.
POC22 - Smart-tools to check, validate and in-fill missing input data
Highly user-friendly software system for the operators: Tools available for both auto- and manual-mode for data checking/validation

Demonstrate:

Document describing the methods used for checking & infilling missing input data

- Check missing data as part of import routine from the Hydstra
- Validate imported data from Hydstra
- In-fill missing Hydstra hydrometric data as required
- Flag and save edited data as a different data-set

WaterWare time series data management provides several tools to

- identify outliers and data gaps
- fill in missing data.

Completion of time series can be based on

- interpolation for shorter gaps (user defined maximum gap size)
- filling gaps with user defined values
- extracting values from one or more related stations through the selectMS tools associated with spatially defined objects such as river basin, monitoring stations, or RRM scenarios.

Please note that all operational (model input) time series data have been patched to ensure error free model operation in the POC. The patched values, however, are marked with appropriate META data, so that any of the corrected or patched values can be reverted to their original value (or missing data codes) if required.
POC23 - Addition, deletion, modification or enhancement of one or more of demonstrated system components/modules without the need for major re-writes (the system design should be modular)

Highly user-friendly software system for the operators:
Demonstrate modularity of the system
Demonstrate:

- Demonstrate the system with tributary inflow forecast for at least one tributary turned on and then off.
- Provide system diagrams to show the system architecture with the modularity clearly explained
- Document giving the methods adopted

WaterWare models communicate via the data base; they read and write standard format time series of OBJECT files, including the variables (DESCRIPTORS) managed in the (dynamic) knowledge base together with any applicable RULES. The linkage between modules is achiever by selecting as an input data time series the output from one of the precursor models. Thus any model can be replaced by an external model which writes its output into the data base in the correct format, as its output will in turn be read from the data base as input by WaterWare’s next model. The time series must be completely specified, but can be “switched off” through a multiplier that is associated with any one of the input time series.
The example below left shows how a modelTS for the rainfall runoff model is selected from the data base; After the RRM run, the result (tributary outflow) is exported to the same modelTS data base, from where the WRM model can link it for one of its scenarios.

In the example below right, appears the Nash-Sutcliffe efficiency coefficient (lower grey box to the left), an extra statistic which was suggested to be incorporated by one of State Water’s hydrologists at the final presentation (Sept 1st 2010), and several days later has been implemented. This demonstrates WaterWare’s modular flexibility in adding new features as suggested by customers in short periods of time. This Nash-Sutcliffe statistic will now be calculated whenever two time-series are compared.
POC24 - to be scalable and adaptable for use in other regulated river valleys (e.g. Murray, Lower Darling, Lachlan, Macquarie, Namoi, Gwydir, Border, Hunter and Coastal) in NSW and allow sharing of the modelling resources.

Highly user-friendly software system for the operators: Demonstrate scalability of the system

Demonstrate:
- Demonstrate scalability with more gauging stations, inflow nodes, extraction sites, and headwater storages (in series and in parallel).
- Demonstrate scalability with basic information used from Pinneena
- Document giving the methods adopted

The different scenarios for Murrumbidgee demonstrate the wide range of size and the adaptability of the model system. The examples show two different scenarios at different level of aggregation but for the same basin with 155 nodes and 27 nodes, respectively.
POC25 - To allow multiple users (up to 20 users) to simultaneously use the system and view the model results and river status
Highly user-friendly software system for the operators: Demonstrate simultaneous access by multiple users

Demonstrate:

- At least 20 simultaneous logins in the manual mode
- Document giving the methods adopted

Water Ware is a client server system that has NO LIMITATIONS on the number of concurrent users other than hardware and network performance. The number of user is “open”, new users can be generated as required through the systems administration menu, where users can be assigned to individually configures groups with group specific access rights.

All dataset in WaterWare are “owned” by the user that created them (e.g., though import or copy). Multi-user access is controlled through login (named users) and session variable in the web interface. In principle, access can be controlled by any and all security mechanisms available for web-based system through TCP/IP such as filtering by domain or IP, VPN security (as demonstrated in the current test implementation), etc.

POC26 - Provide a Graphical User Interface that is easy to learn, intuitive and consistent across all modules
E.g. calibration screens & charts; scenario screens & charts etc. similar to MS Windows ®, Highly user-friendly software system for the operators: Demonstrate look and feel.

Demonstrate:

- Model calibration
- Scenario creation/review
- Schematic view with probability chart display
- Dockable windows with screen Tooltips
- Documentation on the GUI

WaterWare is fully web based, and all user interaction is through a graphical interface is through standard web-browser (currently, based on the HTML 1.1 standards and Javascript, dynamic rendering through client side PHP and cgis;, updates to HTML 5.0 is expected during the coming year subject to widespread browser support.

Automated model calibration is demonstrated using the example of the rainfall-runoff model RR< (see Figure 20, p 23).
POC27 - Optional spreadsheet format table view for all time-series data and model results (similar to CAIRO)
Highly user-friendly software system for the operators: Tabular view of input data and model outputs

Demonstrate:

- Demonstrate with output similar to current Murrumbidgee CAIRO; and export facility to spreadsheet
- Document giving the methods adopted

WaterWare has a number of export tools that can export various data sets such as model generated time series in MS Excel and compatible spreadsheet formats as CSV files. Individual functions also provide tabular output or output summaries, in general however, preference is given to more intuitive (parallel) graphical representation formats.
The example shows a combination of graphical and interactive tabular (spreadsheet-like) display of runoff data.