HRC – GWRI Final Report

INTEGRATED FORECAST AND RESERVOIR MANAGEMENT (INFORM)

Implementation of a Stand-Alone Operational INFORM System for the California Department of Water Resources (DWR)

Prepared for the State of California,
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Table of Contents

Page

1. INTRODUCTION..... 1

2. IMPLEMENTATION CONFIGURATION FOR THE DWR INFORM SYSTEM.. 4

3. LINUX-BASED PREDICTION COMPONENT..... 7

3.1 Implementation Summary..... 7

3.2 INFORM Web Interface Access.....10

3.3 INFORM PC Data Download Module.....13

3.4 INFORM Data Management Strategy..... 14

3.5 Recommendations for Future Activities Pertaining to the INFORM Prediction Component.....16

4. PC-BASED DECISION SUPPORT COMPONENT..... 18

4.1 Introduction..... 18

4.2 Activities and Outputs by Task..... 19

4.3 Recommendations for Further Work..... 32

4.4 References.....34

APPENDIX A..... 35

APPENDIX B..... 47

APPENDIX C..... 49

APPENDIX D..... 65

1. INTRODUCTION

The present Final Report documents the activities that were carried out by the Hydrologic Research Center (HRC) and the Georgia Water Resources Institute (GWRI) of Georgia Tech over the period from January 2016 through June 2018 pertaining to the implementation of a stand-alone version of the Integrated Forecast and Reservoir (INFORM) system onto California Department of Water Resources (DWR) computers for operational use. The system geographical extent covers the main reservoirs of the Sacramento River basin and their drainage areas in Northern California and includes components that allow extension of the natural and controlled flow impacts to the San Francisco Bay for long-range planning assessments. The basis of INFORM consists of *(a)* a forecast component that receives operational ensemble predictions of atmospheric variables from global models and produces high-resolution ensemble forecasts of surface precipitation, temperature and flow ensemble forecasts for the stream network that contributes to the Sacramento River basin; and *(b)* a decision support component that processes the ensemble predictions to determine trade-off tables at a given reliability level that assist manager decisions regarding reservoir releases. The present work adapts a modeling system that was demonstrated over the period 2002 – 2012 with real time data to serve DWR needs as part of its Forecast Informed Reservoir Operations activities.

Detailed descriptions of the INFORM system and its components, as well as performance evaluations are available on line in the California Energy Commission reports:

http://www.energy.ca.gov/pier/project_reports/CEC-500-2006-109.html

http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2010-051

http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2014-019

More recently, *Georgakakos et al. (2014)* discuss the validation of operational ensemble forecasts of precipitation, temperature and flow by the INFORM system

forecast component for a range of lead times extending from 1 day to 1 month, while *Kistenmacher and Georgakakos (2015)* discuss the management of forecast uncertainty by the INFORM decision support system component. Progress Reports submitted to DWR for this project (*Georgakakos et al. 2016; HRC-GWRI 2017*) provides an overview of the stand-alone INFORM system input and output, and system configuration of the operational components.

The operational implementation of the INFORM components was done in two different platforms. The forecast component was implemented on two servers operating under a LINUX environment, while the decision support component was implemented on a PC Windows 10 environment. Appropriate links between these two environments were established for seamless operations. As mentioned, the two organizations involved in the implementation are the Hydrologic Research Center in San Diego, CA, and the Georgia Water Resources Institute of Georgia Tech in Atlanta, GA. The former, the Prime Contractor, lead the work pertaining to the Linux platform software tailoring, development of necessary links to new data on the basis of instruction from the PC interface, and tailoring the HRC interactive web interface for viewing the hydrometeorological forcing for each scenario activated in a mapserver environment. The latter, the Subcontractor, lead the work on the PC implementation of the decision component and associated interfaces. Close collaboration among the two developers, and with the DWR Staff and California Nevada River Forecast Center (CNRFC) Staff of the US National Weather Service (NWS), as their operational duties allowed, was the basis of the successful operational implementation.

The original Project was for the period January 2016 through June 2017. However, due to the unavailability of the DWR and CNRFC Staff for collaboration and training sessions during the very wet (for California) winter and spring/summer seasons of 2017, the project was extended at no additional cost to the funding agency for a second year through June 2018. This situation also lead to the adjustment of the goals for the Project deliverables (with DWR Program-Manager agreement), that essentially focused the effort pertaining to the PC environment

decision support component on the very-significant long-range planning horizon enhancement as described in Section 4 of the present report and outlined in *Georgakakos et al. 2017* (28 September 2017) Project Progress Report.

The present report essentially consists of two parts. The first part reports on the Linux-based prediction-component tailoring by the Staff of the Hydrologic Research Center, while the second part reports on the PC-based decision-support component tailoring by the Staff of the Georgia Water Resources Institute. Prior to the discussion of the two main parts of the implemented system, a short discussion of the implementation configuration and component connectivity is given in the next section. Several Appendices provide ancillary material as indicated in the main text of the present report.

References

Georgakakos, K.P., Graham, N.E., Modrick, T.M., Murphy Jr. M.J., Shamir, E., Spencer, C.S., and J.A. Sperfslage, 2014: Evaluation of real-time hydrometeorological ensemble prediction on hydrologic scales in Northern California. *Journal of Hydrology*, **519**, 2978-3000.

Georgakakos, K.P., Modrick, T.M., Sperfslage J.A., Spencer, C.R., Banks, R.J., Georgakakos, A.P., Kistenmacher, M., Liu, X., and S, Corrado, 2017: Integrated Forecast ad Reservoir Management (INFORM-III) for Northern California, Project Status Report (28 September 2017). Hydrologic Research Center, San Diego, California, 6pp. (Available from the Hydrologic Research Center)

Georgakakos, K.P., Modrick, T.M., Sperfslage J.A., Spencer, C.R., Banks, R.J., Georgakakos, A.P., Kistenmacher, M., Yao, H., and X. Liu, 2016: Integrated Forecast ad Reservoir Management (INFORM-III), Implementation of a Stand-Alone INFORM System for DWR – Phase I Report (15 July 2016). Hydrologic Research Center, San Diego, California, 52pp. (Available from the Hydrologic Research Center)

HRC-GWRI, 2017: Progress Report for the DWR INFORM Project (18 January 2017). (Available from the Hydrologic Research Center)

Kistenmacher, M. and A.P. Georgakakos, 2015: Assessment of reservoir system variable forecasts. *Water Resources Research*, **51**(5), 3437-3458.

2. IMPLEMENTATION CONFIGURATION FOR THE DWR INFORM SYSTEM

As mentioned earlier, the prediction component of the IFRM system was implemented onto two servers running LINUX, while the decision support component was implemented onto a PC platform running WINDOWS. Figure 2.1 shows a schematic of the implementation configuration and component connectivity.

Real-time ensemble predictions from large-scale models (GFS and CFS) running at the National Centers of Environmental Prediction (NCEP) are ingested into the prediction component through the Primary LINUX server by automatic acquisition. After appropriate quality control, such data are used to drive a WRF model running on the Secondary LINUX server (0-16 day forecast lead times with 6hourly resolution), and an Intermediate Complexity Regional Model (ICRM) on the Primary LINUX server (0-45 days forecast lead times with 6hourly resolution).

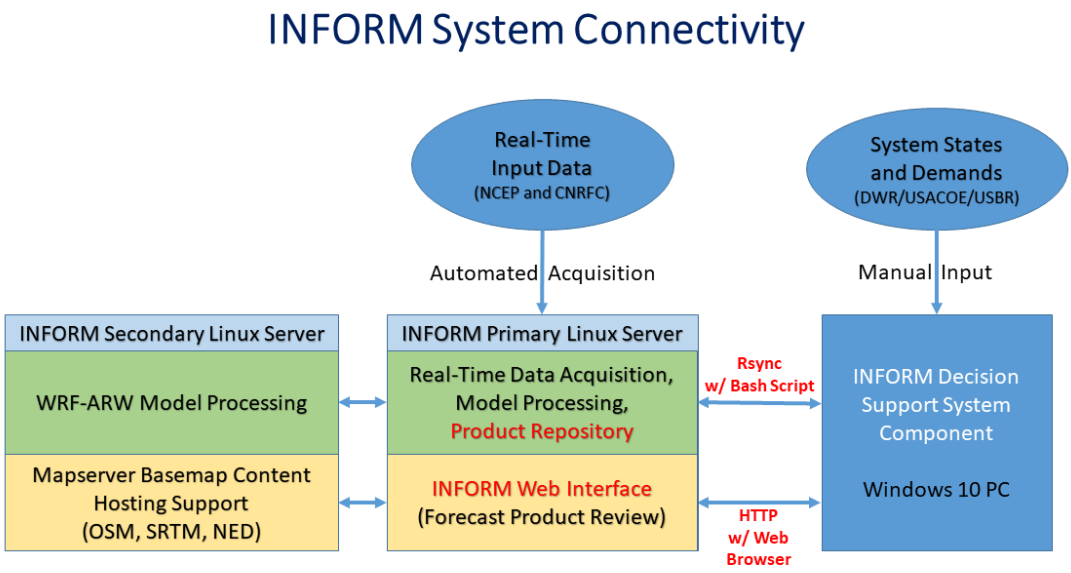

Figure 2.1: DWR INFORM operational system configuration and connectivity.

The ensemble predictions of such mesoscale models are gridded surface precipitation and temperature fields, which feed numerical models of the land-surface runoff production and drainage (a snow accumulation and ablation model, a soil-water accounting model, and a channel routing model). The land-surface models, running on the Primary Linux server, generate ensemble flow predictions for the locations of interest on the stream network draining the Sacramento River basin. Among such locations of interest are the reservoir inflow points for all the major reservoirs on the Sacramento River basin in Northern California.

Automated daily acquisition (at 1200UTC) of the operational estimates of mean areal precipitation and temperature for all the catchments in the Sacramento River basin modeled by the CNRFC is used to generate simulations of the land-surface models between forecast preparation times (every 6 hours) for the establishment of the initial conditions for all the land-surface model states. The same automated acquisition also ingests the current model states of the CNRFC land-surface models and assimilates them at the appropriate scale into the INFORM land-surface models

that have a similar model structure. The latter states, as pertain to the land surface (snow and soil-water components), are also assimilated into the ICRM for more reliable ensemble predictions of surface precipitation and temperature.

Lastly, the Primary Linux server also hosts the INFORM probabilistic procedure (ensemble forecasts conditional on CFS ensemble long-range predictions) for the long-range ensemble prediction of surface precipitation, temperature and flow, with maximum lead time of a year and 6-hourly resolution. The start times of such long range ensemble forecasts are every 5 days on a Julian calendar starting from the 1st day of the year. The 5 days are necessary to accumulate 20 ensemble members of CFS long-range predictions for the probabilistic long-range ensemble forecast procedure of INFORM. Through automated acquisition, the Primary LINUX server also ingests the long-range CNRFC ensemble flow predictions with a maximum forecast lead time of a year with daily resolution produced daily for several (but not all) of the catchments modeled by the INFORM prediction component. At the present configuration INFORM models 72 catchments while CNRFC models 58 catchments in the Sacramento River drainage basin. Every 5 days when both CRFC and INFORM long-range forecasts are available, the Primary LINUX server uses INFORM ensemble forecasts to complete the CNRFC ensemble to have two analogous ensemble forecasts from two different sources/procedures. This provides the User of the INFORM system with the capability to use with the decision support component either the INFORM ensemble predictions or the CNRFC ensemble predictions.

The Primary LINUX server also hosts the user web interface of the prediction component that allows the User to examine the spatial and temporal behavior of the simulations and forecasts at any time. The Secondary LINUX server stores necessary background map information (open street map, 30m terrain elevation data, etc.) that is accessed when a User engages the interface.

Access to the decision support component is through PC WINDOWS implementation. There are utilities that provide the link to the forecast data for any forecast preparation time for which there are data (either for real-time management

or for planning through “what-if” scenarios), and procedures to ingest such ensemble forecasts into the decision support system (DSS) to examine the feasibility and effectiveness of planning and management alternative solutions. The DSS is appropriate for multi-objective, multi-site reservoir management and it is currently implemented to accommodate the long-range ensemble predictions, either from INFORM or from CNRFC as mentioned above. The necessary system states, such as reservoir levels, and demands (available from various reservoir management agencies) are ingested into the PC LINUX platform through manual entry. The PC WINDOWS environment then provides a variety of displays and tables to support management decisions (see Section 4).

3. LINUX-BASED PREDICTION COMPONENT

3.1 IMPLEMENTATION SUMMARY

As mentioned in the previous section (see also Figure 2.1), the prediction component of the INFORM system implementation is comprised of various modules deployed across two Linux servers that are orchestrated together to produce a variety of flow forecast data and other products. The Department of Water Resource California Data Exchange Center (DWR-CDEC) provided the hardware for two (identical) Linux servers that host the various models and a web-based user interface. The basic hardware specifications for these two servers are outlined below.

CDEC-Provided Linux Servers (x2):

- HP Proliant XL420 Gen9
- 2x 24-Core Intel Xeon E5-2670 v3 @ 2.3GHz
- 2x32GB RDIMMs dual-rank x4 data width
- Smart Array P440 Controller

- Smart Array P840ar Controller
- RAID1 with 2x 960GB HP VK0960GFDKK SATA 6Gbps SSD (960GB)
- RAID5 with 8x 960GB HP VK0960GFDKK SATA 6Gbps SSD (6.7TB)
- HPE Apollo 4200 SFF enclosure
- HP 8Gb Dual Channel PCI-E FC HBA
- HP FlexFabric 10Gb 2-port 556FLR-SFP+ NIC
- HP Ethernet 1Gb 2-port 361i NIC

HRC staff transferred the INFORM system modules from development servers at HRC and implemented the system at DWR with the necessary localizations and adaptations for the DWR computing environment and local hosting resources. A PC-based data download procedure was also developed to assist DWR staff and other end users of the INFORM DSS software to obtain the Linux-server-produced forecast data in a simplified manner (summarized below).

3.1.1 INFORM Primary Server (inform.ad.water.ca.gov)

The primary server, **inform.ad.water.ca.gov**, is responsible for all of the INFORM real-time data downloads, model processing (except for WRF processing), product exports and web interface hosting. Figure 3.1 shows the processing flow of the prediction component through the Primary LINUX server. Details are provided in the Figure as to the times of input data downloads, ensemble-forecast characteristics, internet sites from where the data is retrieved, the spatial extent of the downloads, the approximate size of the downloads, and the manner with which data is retrieved from the internet. The functional and numerical model components running on the Primary LINUX server are also indicated with the type and characteristics of generated ensemble predictions. Lastly the short-, medium- and long-range input to the DSS PC-based WINDOWS component are also indicated.

At present the DSS only makes use of the long range ensemble forecasts (either from INFORM or from CNRFC with an INFORM complement for completion) for management and planning.

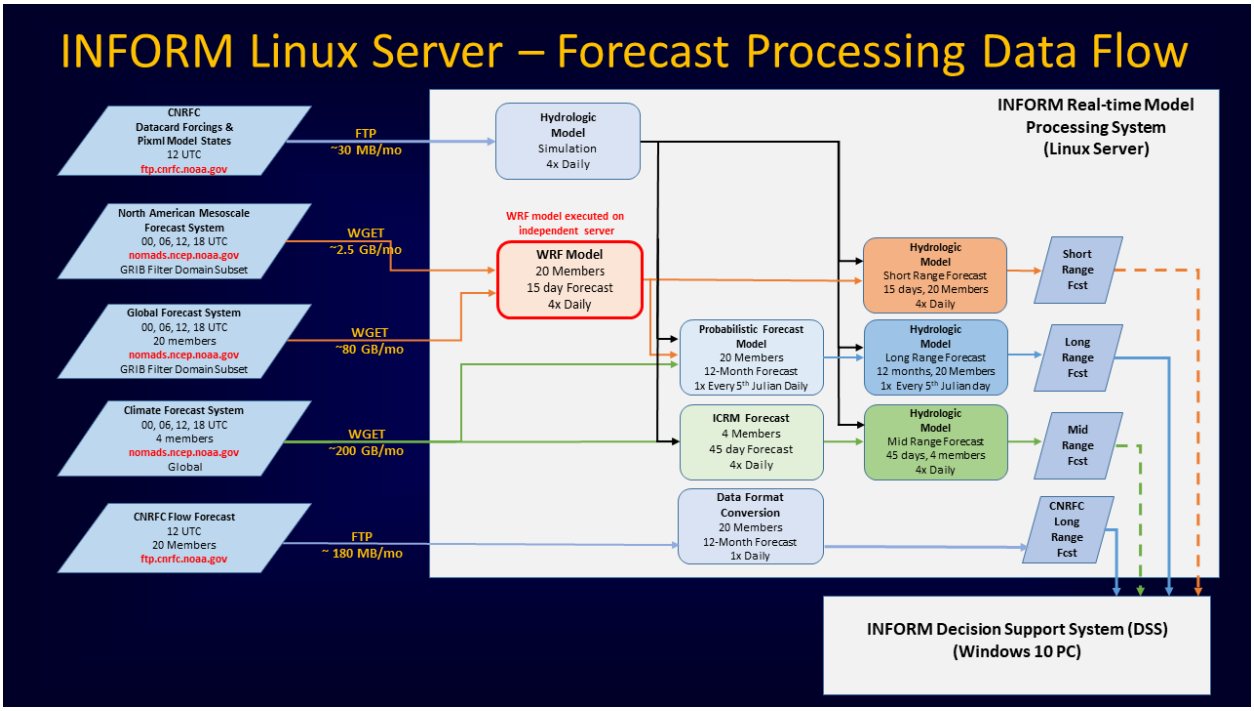

Figure 3.1: Data flow in Primary LINUX server.

3.1.2 INFORM Secondary Server (inform-wrf.ad.water.ca.gov)

Shown in Figure 3.1 is also the Secondary LINUX component (encircled by a red line) that hosts and runs the WRF mesoscale model for ensemble forecasts of surface precipitation and temperature as indicated in the Figure. The secondary server, **inform-wrf.ad.water.ca.gov**, works as a type of backend computational node to the primary server and is responsible for the WRF model processing. It retrieves its input files from and provides its output to the primary server for the WRF-related products. The WRF model runs launch 4-times-daily with CPU-intensive, multi-hour processing demand, keeping 20-cores at a nearly constant 100% load for approximately 4.5 hours throughout each model run. Because of this

intense resource demand, a dedicated server was provided for the WRF model processing. This secondary server also hosts a specific portion of the Mapserver-based interface content relating to the basemaps for Opens Street Maps (OSM) interface layer along with the SRTM and NED digital elevation model layers and their contours. However, this backend-relay strategy for the basemap content is transparent to the end user connecting to the interface hosted on the primary server – it became a necessary work-around solution to certain Mapserver resource conflicts that arose during the localization efforts.

3.2 INFORM WEB INTERFACE ACCESS

The INFORM Linux server products can be reviewed through a password-protected web-based user interface hosted on the INFORM primary server at http://inform.ad.water.ca.gov/INFORM. (User name and password credentials are provided independently.) The user interface provide interactive, map-based review of the INFORM (simulated) and CNRFC (observed) model input products as well as a line-plot interface for review of the various forecast ensemble products.

Examples of displays from the web user interface are shown in Figures 3.2 – 3.4 for the short-, medium- and long-range ensemble flow forecasts of INFORM, and in Figure 3.5 for the long-range ensemble flow forecasts from CNRFC. Further details about the interface and its usage are provided in Appendix A.

A potentially useful information component accessed through the web user interface is the data inventory page (example in Figure 3.6). This page shows the number of the input and of the INFORM generated or stored product files available at each 6-hour processing time. For instance one may notice that the INFORM long-range ensemble forecast product is available every 5 days and it involves 72 basins, while the CNRFC analogous product is available every day but it has only 58 basins, except every 5 days when its value is 72, because there is a complement to that product by the INFORM long-range ensemble prediction for the remaining 14 basins.

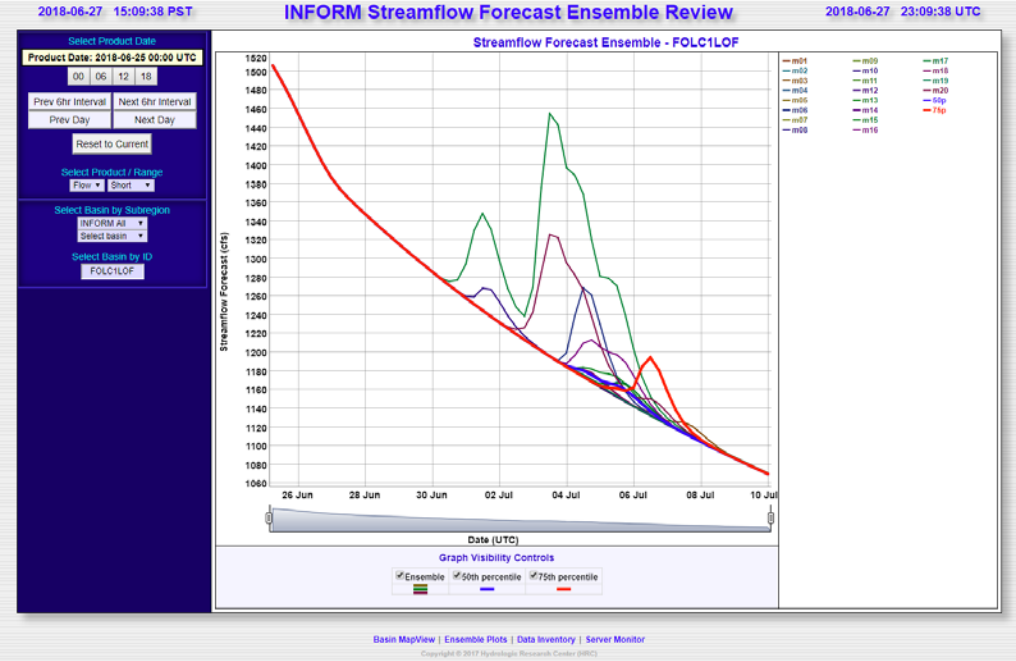

Figure 3.2: Example of web user interface display for the INFORM short-range ensemble flow forecasts for Folsom Lake inflow.

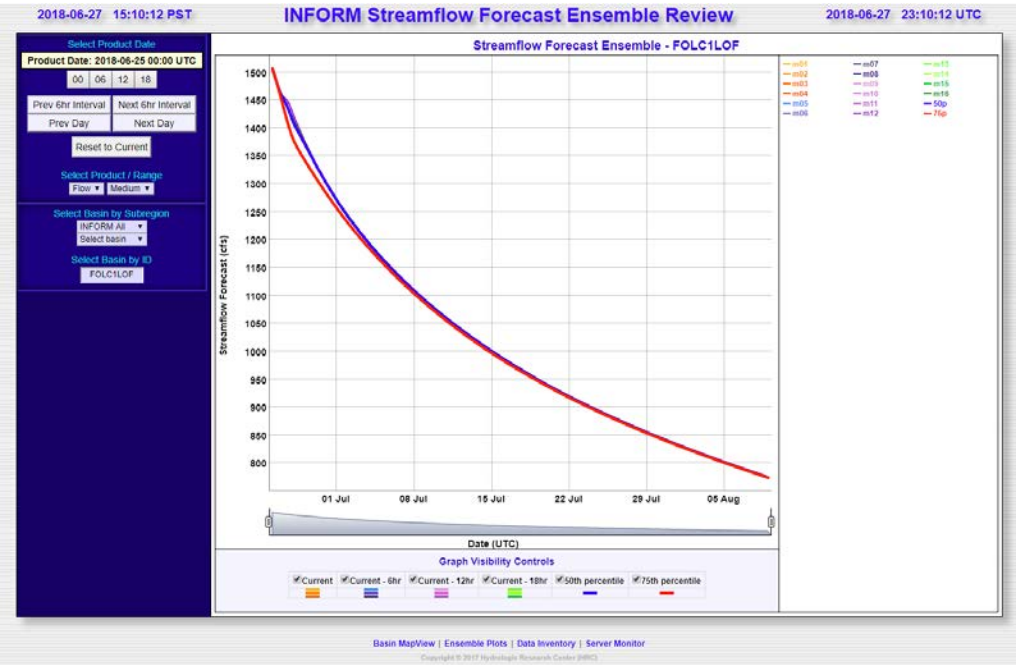

Figure 3.3: As in Figure 3.2 but for the INFORM medium-range ensemble flow forecasts for Folsom Lake inflow.

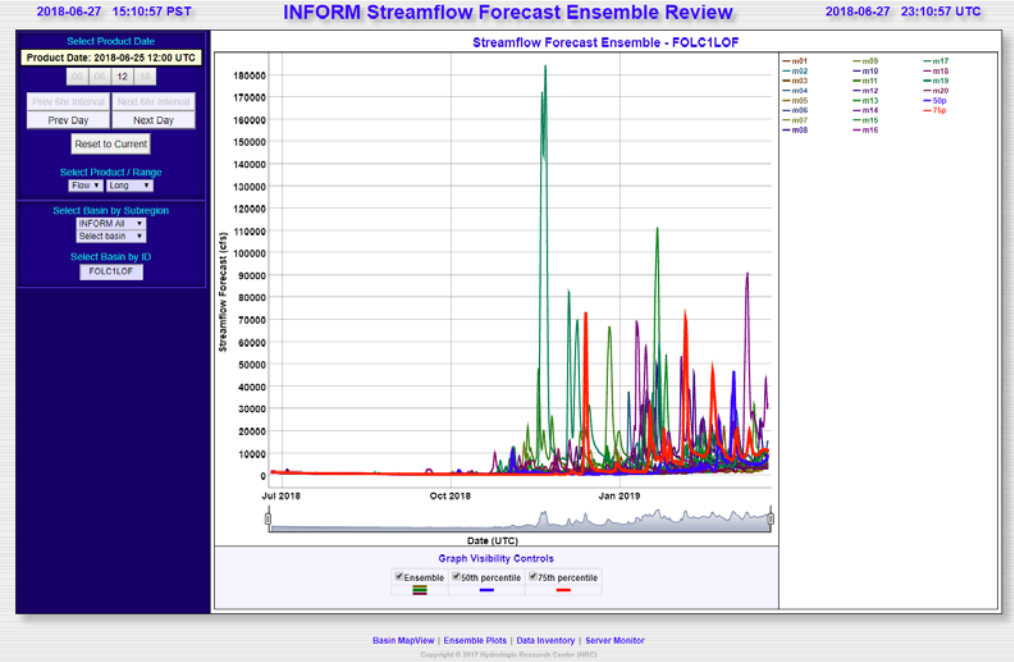

Figure 3.4: As in Figure 3.2 but for the INFORM long-range ensemble flow forecasts for Folsom Lake inflow

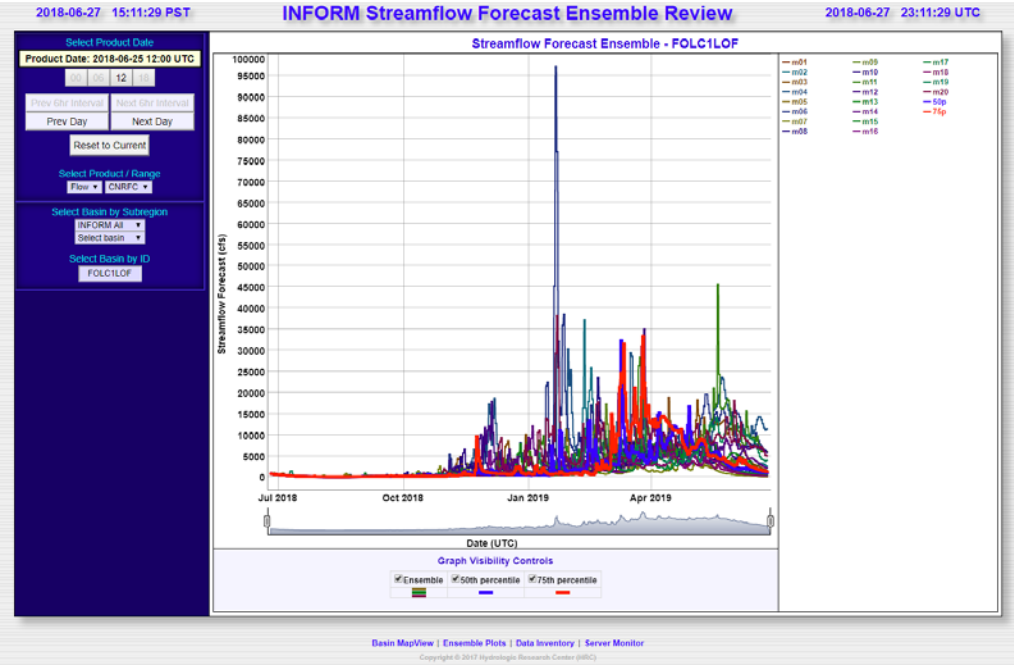

Figure 3.5: As in Figure 3.4 but for the CNRFC long-range ensemble flow forecasts for Folsom Lake inflow

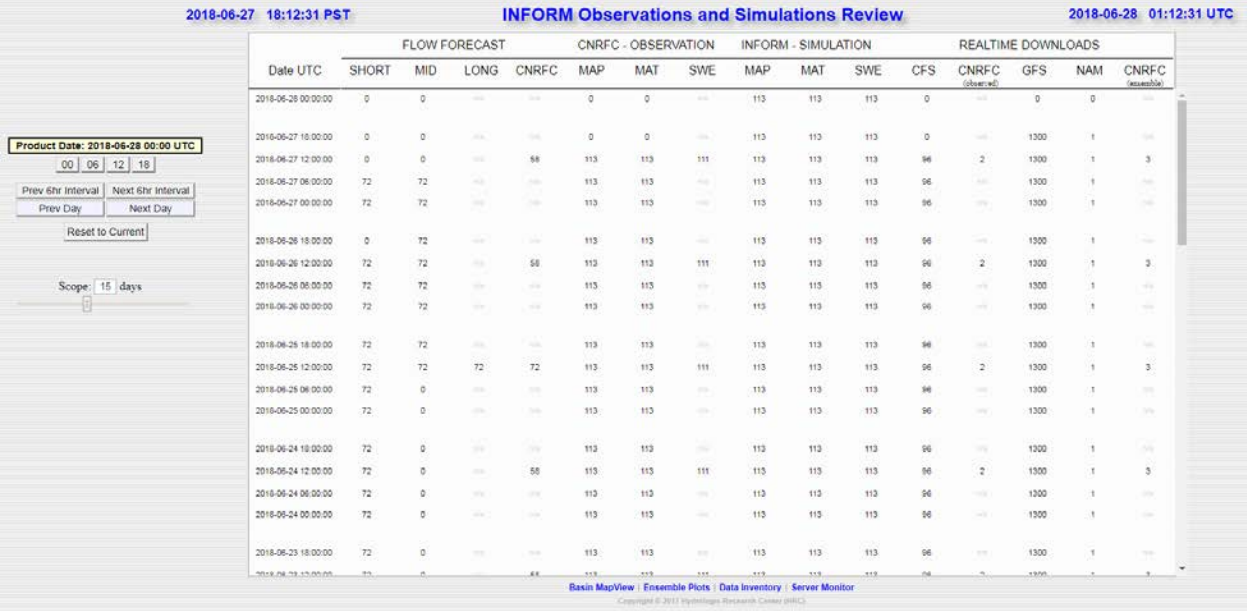

Figure 3.6: Data inventory page

3.3 INFORM PC DATA DOWNLOAD MODULE

In support of the INFORM DSS software (developed by GWRI) hosted on the Windows 10 PCs of DWR Staff, HRC implemented a script-based, semi-automated data synchronizing procedure to download the HRC and CNRFC forecast data files for ingest to the DSS software.

The forecast files produced on the INFORM LINUX Server are numerous and structured in date-based directory trees, making manual data retrieval methods impractical to manage. To simplify and streamline the data acquisition process, there are two Bash shell scripts that can be executed within a Cygwin Linux application environment on Staff PCs. One script selectively acquires the data from the Linux server while the other script is used to selectively purge the downloaded data from the PC if it is no longer needed. The acquisition script, **sync_inform_linux_product.sh**, utilizes the Linux "rsync" command to easily synchronize the data structures on the Linux server to matching structures on the PC and is managed with a flexible set of date-based command-line arguments to control the scope of each download session. The data-deletion management script,

purge_inform_local_products.sh, uses the same command line arguments to remove the local downloads. The installation of the Cygwin application environment along with the installation and execution of the two data-management shell scripts was demonstrated during an onsite training workshop at DWR on June 15, 2018. The training outline for the script installation and usage steps can be found in Appendix B. The Cygwin application-environment installation procedure can be found in Appendix C.

3.4 INFORM DATA MANAGEMENT STRATEGY

The INFORM data management strategy aims to balance the operational system footprint to accomplish the following goals: (1) Maximize scope of online retention for INFORM System output data products for input to the GWRI DSS; (2) Retain a period of critical system data content appropriate for contingency handling, system evaluation and retrospective system processing in the event of future parametric or configuration adjustments; (3) Facilitate incidental review and investigation of end-to-end system processing by HRC or DWR; and (4) Provide sufficient buffer space to account for variability in operational footprint of dynamic system data content. Toward that end, HRC has implemented the following data management configuration within the INFORM System.

Preprocessed real-time input data products in their original format accumulate at an estimated average rate of 280GB per month. These files are necessary for the full-system, end-to-end system processing for real-time operations as well as for review in the event that incidental intervention by HRC or DWR becomes necessary. As they represent the lion's share of INFORM dynamic data content, they cannot be retained for a significant period without potentially filling the server to capacity. The window of retention for the preprocessed input data products has been set to 6 months, allowing for a moderate period of availability to HRC or DWR for incidental review but not so lengthy a period that the available storage is fully consumed. After 6 months, preprocessed input data content will expire and be deleted from the INFORM System.

Extracted, subset input data, model states and related internal system data are all retained on the server for a period of 2 years. This processed data content is critical for system modeling continuity and for automatic contingency handling by the system. In the event of future parametric adjustments, the processed data is necessary for retrospective historical processing to spin-up the model states. Because the processed data content accumulates at an estimated average rate of 25 GB per month, it can be retained online for a longer period of operational readiness than the preprocessed input data. The window of retention for processed data products has been set to 2 years, allowing for a sufficiently lengthy period of online operational readiness for any future activities by HRC and DWR. Additionally, 1 TB of storage has been allocated for consumption by the PostgreSQL relational database of the INFORM System. It is estimated that this allocation will be sufficient for the retention of 2 years of system processed internal database content. After 2 years, processed data content, whether located in the file system or the database, will expire and be deleted from the INFORM System.

The INFORM System output data products and exchange files for the GWRI DSS accumulate at a rate of 2 GB per month. As these products are of significant interest for long term retention and contribute negligible storage consumption, the system has been configured to retain this content for a period of 20 years before expiration. This virtually indefinite expiration time is anticipated to allow the user of the GWRI DSS to refer back to any historical event from the beginning of the INFORM System's operations. Similarly, the archival files generated by the INFORM System containing critical database content in a format appropriate for offloading and external retention also consume an estimated average of 2 GB per month. These database archive files have also been configured to expire after 20 years, allowing this critical system content to accumulate virtually indefinitely.

HRC is retrospectively running the full INFORM prediction component software as currently updated at the DWR LINUX servers to cover the period 1 September 2017 through present, so that at least one wet season in California is in the INFORM history. At present this is in process, expected to complete in several weeks.

Analogous history has also been archived on the operational INFORM LINUX servers for the CNRFC long-range ensemble forecasts.

3.5 RECOMMENDATIONS FOR FUTURE ACTIVITIES PERTAINING TO THE INFORM PREDICTION COMPONENT

3.5.1 Prediction Component Maintenance

Because the LINUX server component of INFORM is a tailored configuration for the needs of the DWR INFORM project, it is important to establish a 6-12 month period during which the system software is monitored closely to *(a)* further improve the system efficiency and shorten the system computational prediction cycles to allow good margins for the 6hourly updates of simulations and forecasts; *(b)* to identify any issues of configuration or data ingest that need adjustment and to take appropriate actions; and *(c)* to make changes to the web user interface for more effective monitoring of the system products by the user (based on user feedback).

3.5.2 Prediction Component Validation

Monitoring the performance of the INFORM ensemble forecasts and simulations of precipitation, temperature and flow over *(a)* specific events and *(b)* over the 2018-2019 wet season, will further lead to improvements of reliability of the short-, medium- and long-range forecasts of the operational system. Improvement will result from adjustments in parametrizations of model components (e.g., WRF microphysics, ICRM model parameters, snow and soil water model parameters, routing model parameters, etc.), or, if necessary, even in model structures. This validation effort is necessary in these early stages of system use in an operational environment, and it will quantify the level of reliability of the ensemble forecasts, an element that is critical for the use of these forecasts by the DSS component of INFORM.

3.5.3 Extension of the INFORM Prediction Component to Cover Areas Beyond the Sacramento River Basin

Extension of the domain where short-, medium- and long-range INFORM ensemble forecasts are produced will incorporate the San Joaquin basin and the Bay Delta region, and it will cover fully with operational forecasts the entire domain of the major reservoirs of the Northern California region. At present within the DSS component, these regions are covered by climatological projections of limited skill. For this recommended future task, the existing INFORM components will be retained and the main emphasis of the work would be the development of the necessary real-time databases, quality control and ingest mechanisms to allow INFORM operations in these new areas. Preliminary performance evaluation will also be done with the available data through retrospective runs of the system.

3.5.4 Support the DSS Extension to the Short and Medium Range

The INFORM prediction component already generates in real time short- and medium-range ensemble flow predictions for the stream network of the Sacramento River basin. This envisioned future activity is to make necessary adjustments to accommodate additional needs for the DSS when used for the short and medium range decision support. For instance, the development of software that will transfer the real-time INFORM ensemble predictions of flow and/or surface temperature, or the short-term ensemble flow predictions by CNRFC from the server LINUX environment to the PC WINDOWS DSS environment.

3.5.5 Training Workshops

Two Collaboration and Training workshops in Sacramento are envisioned, each for 1 HRC staff member x 2 days. Both workshops will be coordinated with GWRI so that they cover both the prediction component and the DSS component. A first

workshop will be planned with the purpose of collaborating with DWR, CNRFC and GWRI to receive feedback on plans to complete the proposed activities as discussed above. The second workshop will be planned as a refresher training for CNRFC and DWR staff on the use and interpretation of the INFORM prediction component interface products. Validation results and any adjustments will also be discussed at that Workshop.

3.5.6 Reports

Final Report preparation and updating of INFORM prediction component interface User Guide as necessary based on the results of the proposed activities above. The Final Report with present the results of the INFORM prediction component validation, and will summarize the enhancements made to that component.

4. PC-BASED DECISION SUPPORT COMPONENT

4.1 INTRODUCTION

The purpose of the INFORM-III project was to enhance and operationalize the forecasting and decision support systems developed under previous INFORM project phases. These systems are described in two extensive reports: HRC-GWRI 2007 & 2013.

The main GWRI project tasks under INFORM-III are outlined below, including a brief scope description.

Task 1: **Development of INFORM-DSS Under a Windows 64-bit Platform**

The goal of this task was to convert the long-range INFORM DSS module to the WINDOWS 64-bit computational platform. This task was to be carried out contemporaneously with Task 2.

Task 2: **Development of User-DSS Interfaces**

This task aimed to develop and implement user-data-model interfaces in consultation with DWR and HRC.

Task 3: **Development and Implementation of Mid-/Short-Range Module**

This task aimed to develop and demonstrate a mid-term/short-term decision module under the WINDOWS 64-bit computational platform.

Task 4: **Technology Transfer and Training**

Two training workshops had been planned, one after completion of Tasks 1 and 2 and a second at project's end.

Task 5: **Project Report, INFORM DSS Software, and User's Guide**

4.2 ACTIVITIES AND OUTPUTS BY TASK

4.2.1 Task 1—INFORM DSS v2.0 Software Overview

Under this task, the original INFORM Long Range Decision System was converted from the WINDOWS 32-bit to the 64-bit computational platform. The new software (INFORM DSS version 2.0) is much different than the one initially developed. The redesign of the software came about because after converting the original system into a 64-bit Windows application, it became clear that the old computational platform and overall design could not effectively accommodate all DSS components, including the information management system, various DSS models and ancillary tools, and user-DSS interfaces. This together with project implementation difficulties encountered under Task 3 (described below), motivated GWRI and CA-DWR to redirect project efforts toward the development of a new, expanded, and more flexible computational DSS framework and computational platform.

A new data management system (including more robust relational databases, GIS functionality, and data management and visualization tools) and a new Long Range DSS modeling system were thus developed and constitute INFORM DSS version 2.0. All DSS components were substantially upgraded to include new features and functionalities. For example, the new DSS software allows the user to modify the physical network and includes a wide range of user-specifiable options pertaining to tradeoffs and the visualization of results. This significant development effort had not been anticipated, but it brought to bear a prototypical DSS system that is generally applicable, more efficient, and more able to handle the high complexity and computational requirements of the northern California River and Reservoir system.

The INFORM DSS v2.0 software features several unique capabilities not available in existing river basin decision support software packages. These include:

- Seamless integration of hydro-climatic forecasting and system optimization/simulation.
- Explicit consideration of uncertainty in system optimization. No practical limitations on system size.
- Tradeoff analysis under uncertainty.
- User friendly interface to import, edit, view, and export all required information.
- Integrated framework for planning, management, and operational water and power infrastructure scheduling.
- Applicability to the management of general river basins.

The modeling system is designed to integrate hydro-climatic forecasting and reservoir management to inform stakeholder decision processes as depicted in Figure 4.1. This integrated framework includes technical components (pertaining to climate, hydrology, and river/lake simulation and management); socioeconomic

components (pertaining to water, energy, and environmental demands); and stakeholder information support components as part of planning and decision processes. The figure shows that the use of the modeling system within the decision process is designed to be *iterative*, *interactive*, and *flexible* to incorporate new data and stakeholder preferences.

In particular, the decision support component of the INFORM DSS v2.0 is based on a multilayer structure (illustrated in Figure 4.2). This structure includes multiple interconnected layers each of which models the system at a particular temporal and spatial scale, addresses a certain subset of objectives, and aims to inform relevant stakeholder groups. The linkages among and within the layers ensure that (1) system data, models, and outputs provide an integrative understanding of the system response and (2) decision maker choices are prioritized and implemented consistently as the decision process evolves. This modeling framework has been pioneered by GWRI/Georgia Tech.

The hydro-climatic forecasting component of the integrated system and associated interfaces have been developed by the Hydrologic Research Center (HRC) and aim to provide spatially consistent streamflow forecasts in the form of forecast ensembles.

Detailed discussion of the forecasting, simulation, and optimization methodologies encoded in the integrated Forecasting and Decision Support system can be found in HRC-GWRI 2007, 2013.

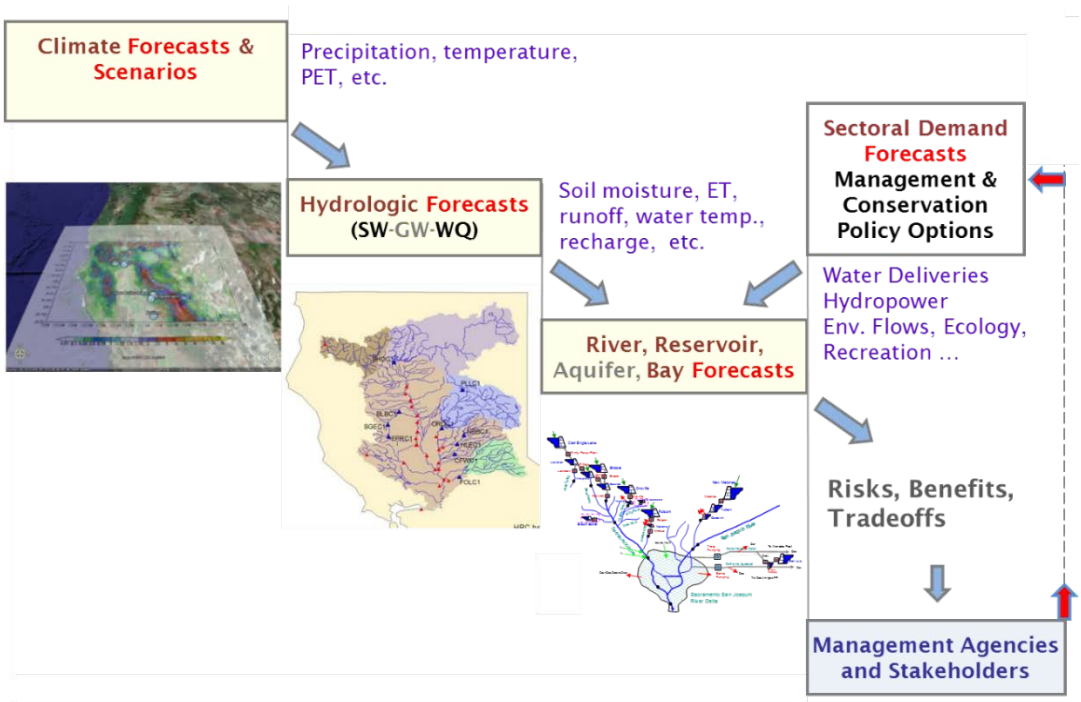

Figure 4.1: Integrated Forecast-Management-Decisions Support Framework

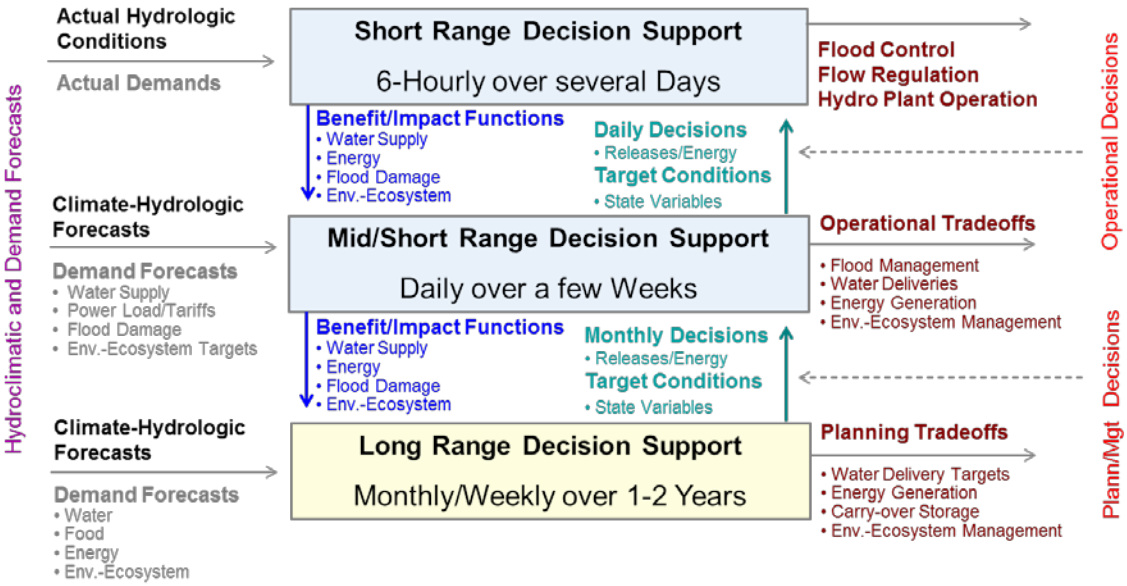

Figure 4.2: Multilayered Management System.

4.2.2 Task 2—INFORM DSS v2.0 Functionalities and User-DSS Interface

Figure 4.3 provides an overview of the INFORM DSS v2.0 workflow. The first step consists of defining the physical components of the basin. A GIS-based interface allows users to draw a water resources network consisting of a series of elements represented by arcs and nodes. Nodes represent discrete locations in space, such as reservoirs, demand nodes, river nodes, and watersheds. Arcs are used to represent flows of water from one node to the next; flows can occur in natural streams, diversions, channels, and return arcs. Once the river network has been drawn, additional data can then be specified for the individual elements. For instance, users can specify the number and types of outlets at a reservoir, as well as define power plants down to the level of individual turbines.

While a network represents the physical characteristics of a river basin, it does not specify how the facilities in the basin are operated. The INFORM DSS contains water resources models that built on the physical characteristics defined in a network to include operational considerations in support of water resources planning and management.

The Long Range Decision Support (LRDS) module is designed to support water management over a user-defined time horizon from several months to a few years. The LRDS module uses inflow forecasts to represent the inflow volumes expected to enter the system at each time step of the planning/management horizon. To incorporate various uncertainties, the forecasts are represented in an ensemble form. An ensemble consists of a collection of individual traces, with each trace representing an equally likely future inflow time series. These ensembles are directly used by the LRDS module to manage the system under the range of hydrologic conditions represented by the ensemble. The final outputs are ensembles of system variables, such as storages, releases, power generation amounts, river flows, etc., over the management horizon, as shown in Figure 4.4.

Users first define element models that describe how water moves through the different elements in the basin. For instance, element models for a reservoir node allow users to specify when and how much water should be released. Element

models for arcs, such as streams, describe how water moves from the upstream to the downstream end of the arc. Multiple element models can be created, and users may choose alternative models for each system element. This represents one possible operational scenario for the river system.

Once users enter the previous data, they can create a Setup that represents how the system is to be operated (by selecting the appropriate element models), the number of traces to include in the forecast ensembles, as well as the time horizon (defined by a start date and length) over which the system should be managed. Users then specify the system conditions at the start of the forecast-management horizon (including the values of the reservoir storages) and the forecast ensembles to be used. Forecast ensembles can be based on the INFORM forecasting system or can be provided externally. For example, forecasts issued by the California-Nevada River Forecast Center (CNRFC) can easily be ingested. This information is then compiled into a model Run which characterizes how the system will respond under the chosen forecast ensembles, release rules, and demand targets.

The LRDS module makes use of two different water resources modeling techniques, as shown in Figure 4.5. The first modeling technique consists of an optimization model aiming to generate management policies that specify the system decisions as a function of system conditions represented by the system states. These management policies are then used as input to a simulation model that simulates the response of the system when these policies (and possibly other user-defined rules) are used to operate the system.

Users can specify the objectives and constraints that define the management problem solved by the optimization model. Objectives represent the operational goals, and constraints represent physical or operational limits that should not be violated. The objectives and constraints are then used to solve a multi-stage stochastic optimization problem over a user-specified horizon. This problem is solved using an optimization algorithm known as Extended Linear Gaussian Quadrature (ELQG), which optimizes the expected value of the objective function over the ensemble while also enforcing reliability constraints on various system

variables. The reliability levels at which such constraints are satisfied are also user-specifiable. A detailed discussion of the algorithm is beyond the scope of this report but can be found in previous INFORM project reports and in several journal articles. The end-result of the optimization model is a set of management policies that specify management decisions as functions of system states. In reservoir systems, decisions typically represent controlled reservoir releases, and states typically represent reservoir storages. Additionally, flows at river nodes can be modelled as states. For the INFORM project, the X2 location (presumed to be the saline-fresh water interface in the Bay delta) is modelled as an additional state, and the pumping from the delta as a decision variable.

The simulation model simulates the flow of water through the system given a set of management policies. These can be the policies derived by the optimization model and/or a set of heuristic operating rules specified by the user. The simulation model simulates the system response (i.e., the time response of each system variable) for each trace of the ensemble forecast. The final outputs are ensembles of system variables, such as storages, releases, power generation amounts, river flows, etc., over the management horizon.

The ensembles resulting from a particular model run can then be analyzed to determine how well different operational objectives and constraints are met. INFORM DSS contains plotting functions that enable users to plot any system variable of interest in ensemble form. Ensembles from multiple runs can be plotted simultaneously to facilitate comparisons and inform the system stakeholder on the benefits and impacts of alternative decisions.

Tradeoffs between different demand target levels can also be automatically created with INFORM DSS, as shown in Figure 4.6. Tradeoffs are based on a base run; users can then construct additional runs (i.e., tradeoff points) that are identical to the base run except for their demand target levels. The resulting ensembles can be plotted and compared using the above-mentioned plotting functions. Additional plotting functions can be used to assess the tradeoffs between different tradeoff points.

Users access the above-described data and models through a graphical, user-friendly interface which has been designed after extensive consultations with the CA DWR and CNRFC staff. The interface features and the above-mentioned model functionalities are described in a detailed User's Manual. This manual is included here as Appendix D and is also accessible electronically from within the INFORM DSS v2.0 software.

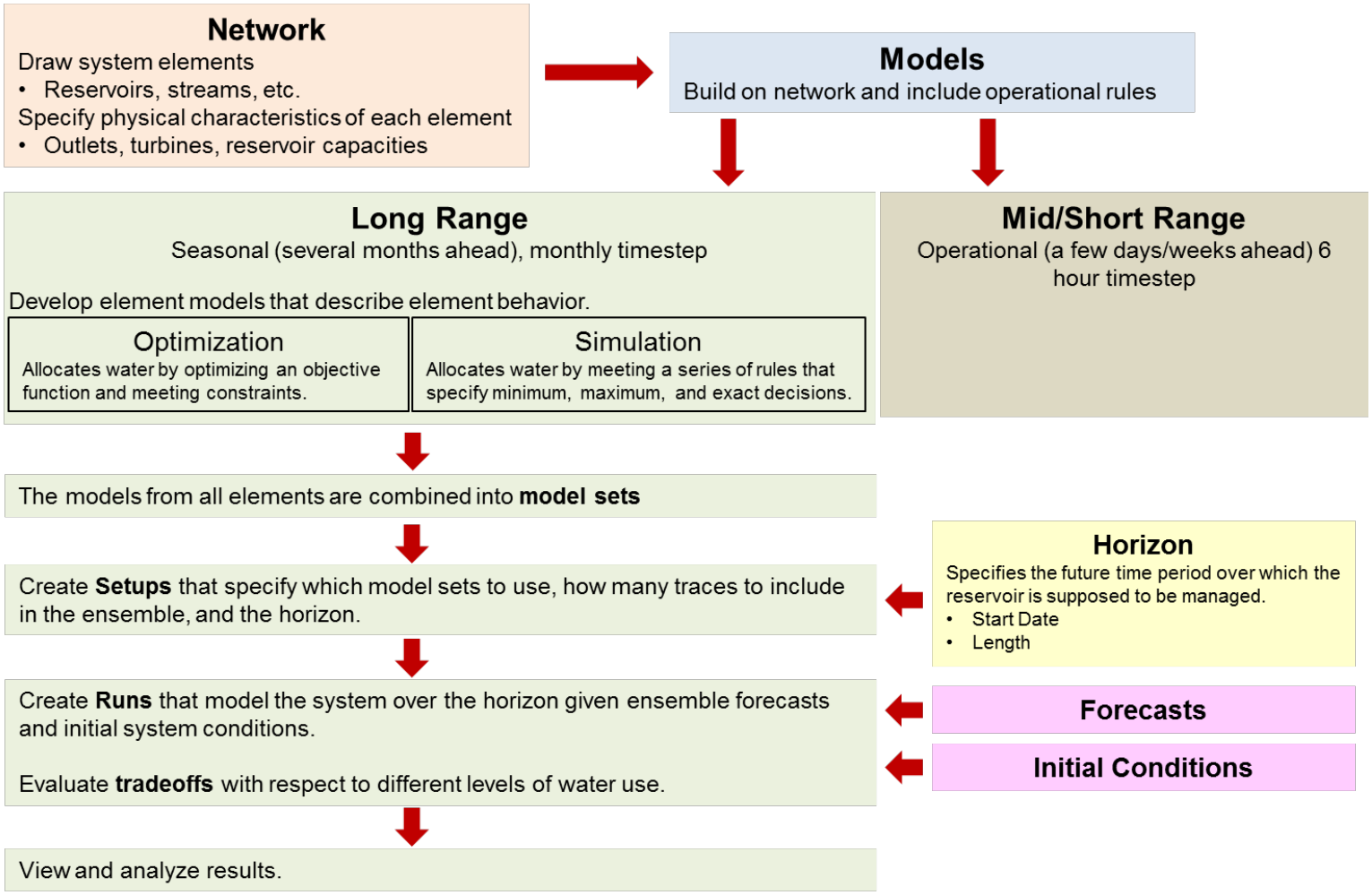

Figure 4.3: INFORM DSS Workflow

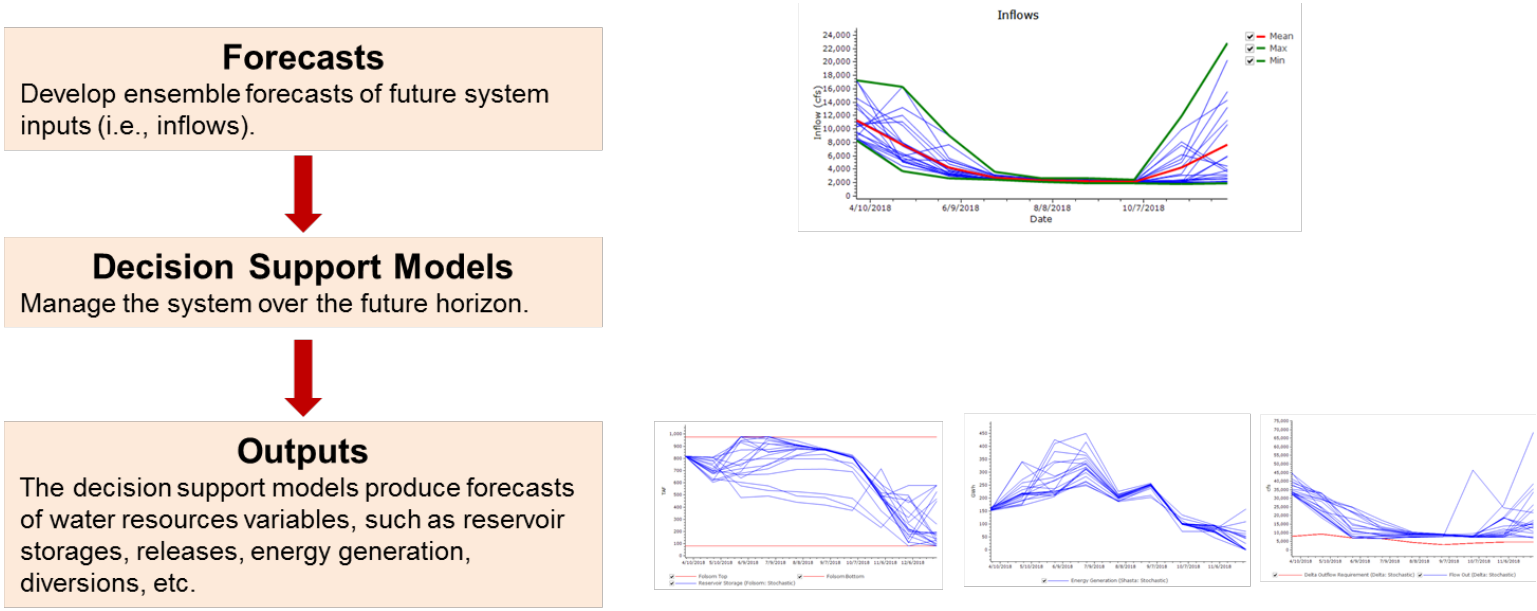

Figure 4.4: System Forecast Ensembles

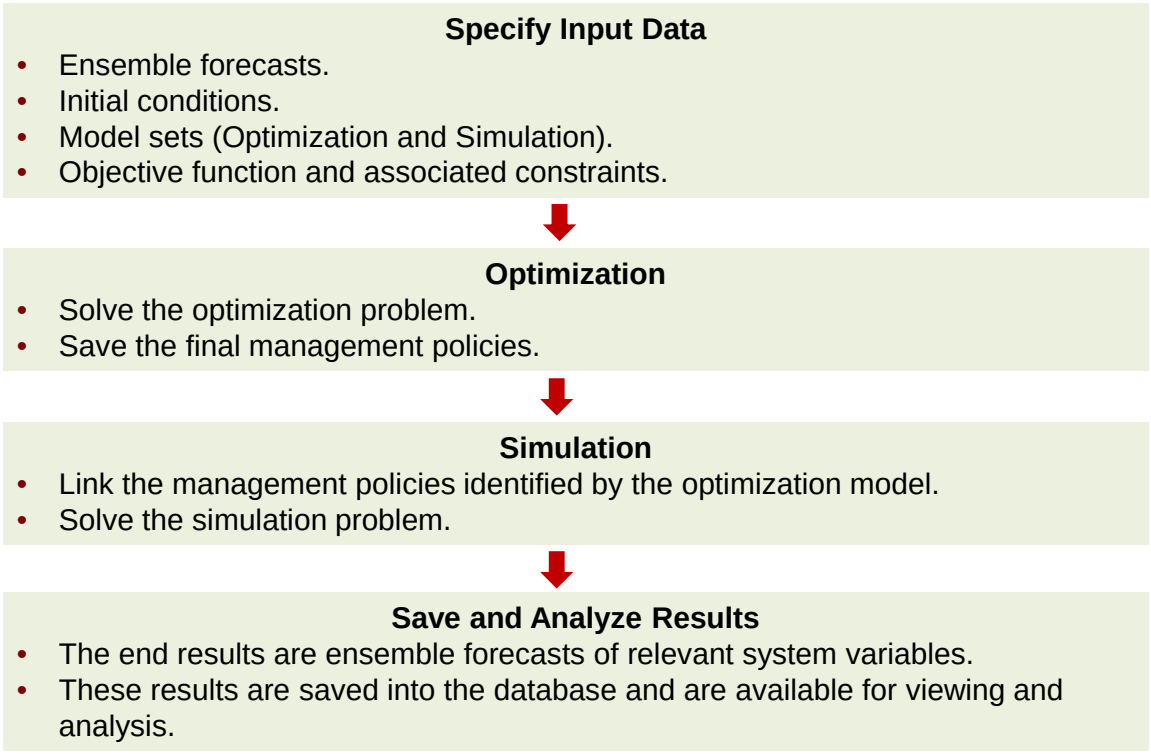

Figure 4.5: Modeling Components of the INFORM Long Range Decision Support System

Base Run

- Specify a base model run against which the tradeoff scenarios will be evaluated.

Tradeoff Points

- Develop several tradeoff points.
- Tradeoff points use the same base scenario but adjust the level of water use (e.g., 25% of base, 50% or base, etc.)

Assessment

- Perform a model run for each tradeoff point

Save and Analyze Results

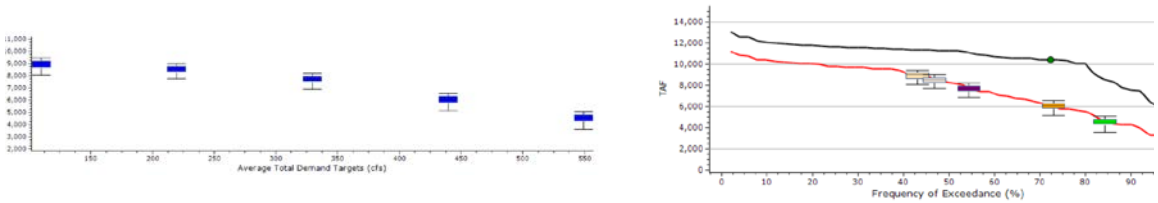

Figure 4.6: INFORM DSS v2.0 Tradeoff Analysis Functionalities

4.2.3 Task 3—INFORM DSS Mid/Short Range Decision Module

The development of the Mid/Short Range Decision Support modeling layer is partially complete. Several components of this modeling layer (including the turbine load dispatching modules for all system power plants, the system optimization and simulation model codes, and the various interfaces) have been completed and incorporated in INFORM DSS 2.0. However, a fully representative river routing model connecting the upstream reservoirs, the downstream river system, and the Delta has not yet been finalized. The activities for the completion of this task had been scheduled for 2017 and included close consultations with CNRFC and DWR staff, aiming to define a representative model for the river system including its various reaches, bypass features, off-channel storage, withdrawals, returns, and junctions. Unfortunately, 2017 was a year marked by high, prolonged, and extensive California floods, which required emergency operations and the full and undivided attention of agency staff. These conditions prohibited the agency staff interaction with the project team and made it impossible to compile the information needed for this activity. Agency interaction became even more challenging by the high number of technical staff retirements and position vacancies that happen to occur in 2017. Because of these unusual and unexpected circumstances, the calibration of the river routing model and its integration within the Mid/Short range management and simulation models could not be completed. Instead, GWRI and CA-DWR opted to redirect the project effort to (a) put in place all of the tools needed to support the development of the Mid/Short Range module and (b) create the new and upgraded INFORM DSS version described above.

4.2.4 Task 4— Technology Transfer and Training

Task 4 included two training workshops. The first of these workshops took place on 24–25 August 2017, later than was originally planned due to the agency emergencies outlined above. The workshop focused on a beta version of the INFORM DSS 2.0, including the information system, Long Range Decision Support

module, and user-DSS interface. The workshop was well-attended by more than a dozen DWR and CNRFC technical staff and included DSS demonstrations, hands-on exercises, discussion of the underlying methodologies, and consultations on desirable interface and other DSS features. The workshop participant input and comments were positive and favorable of the overall DSS design, functionality, and utility for system planning and operations.

Following the first workshop, the GWRI team incorporated the suggestions made by the agency staff (as well as a host of additional software features) and produced a final version of INFORM DSS 2.0 including a detailed user's manual. The final INFORM DSS software package was delivered to DWR during the second training workshop on June 14-15, 2018. The second training workshop was attended by DWR and USBR staff and focused on the new DSS features and functionalities, software demonstrations, and hands-on exercises.

4.2.5 Task 5— Final Deliverables

The INFORM-III final deliverables include the INFORM DSS v2.0 software package, the associated User's Manual, and this Final Report. As mentioned above, the methodologies that underpin the forecasting and decision support components encoded in the INFORM DSS have been the subject of extensive technical reports (i.e., HRC-GWRI 2007, 2013).

4.3 RECOMMENDATIONS FOR FURTHER WORK

The modeling and computational infrastructure developed under the INFORM project can be leveraged in several operationally useful ways. The following areas of development and operationalization represent the shared views of the DWR staff (who participated in the training workshops) and of the project team.

River Routing Model and Mid/Short Range Decision Support System: Development and testing of a river routing model connecting the main reservoirs—Trinity, Shasta, Oroville, and Folsom—with the Bay Delta is a critical component for flood forecasting and management. This model needs to be consistent with the current river routing procedures used by CNRFC and DWR during floods and accurate enough to support flood emergency decisions. For this reason, its development would require extensive consultations with CNRFC and DWR staff. It is noted that the river routing methodology and proof of concept have already been completed, including model calibration for selected Sacramento River reaches. After successful calibration for the remaining river reaches and the off-stream flood retention areas, this model would be incorporated within the Mid/Short Range DSS module to support flood management decisions. Completion of this activity would give rise to INFORM DSS version 3.0, which would realize the development of the DSS system depicted on Figure 4.2.

San Joaquin River Catchment: The San Joaquin River catchment was outside the scope of the INFORM project, and no streamflow forecasts are currently issued for its watersheds. Nevertheless, its main reservoirs have been included in the INFORM DSS, using climatology information in lieu of operational streamflow forecasts. Extension of the forecasting system to the San Joaquin catchment would enable the DSS to represent all relevant hydrologic inputs and support the stakeholder decision process more comprehensively and reliably.

Conjunctive Surface Water and Groundwater Management: The role of groundwater in meeting California's water demands during droughts cannot be overstated. The INFORM DSS has the methodological capacity to include a groundwater component (as per the conceptual schematic in Figure 4.1) and carry out conjunctive surface water – groundwater planning and management.

Agricultural Water Demand Forecasting: The largest portion of California's consumptive water use is associated with agriculture. Reliable agricultural demand forecasts would provide useful information at the beginning of the growing season and would support management policies of increased water use efficiency. GWRI has developed a state of the science agricultural planning tool which can be used for this purpose. This tool simulates the dynamic interaction of crops with soil and atmospheric conditions during the growing season, and estimates crop yield and irrigation demand. The agricultural planning tool can use the INFORM hydro-climatic forecasts (rainfall, temperature, PET, and soil moisture) to generate crop yield and irrigation forecasts. These forecasts can then be incorporated in the INFORM DSS to provide more realistic seasonal water demand forecasts and to support more realistic water sharing policies.

4.4 REFERENCES

HRC-GWRI, 2013: *Integrated Forecast and Reservoir Management (INFORM) for Northern California, System Development and Initial Demonstration.* California Energy Commission. Publication number: CEC-500-2014-019, 529 pp. http://www.energy.ca.gov/2010publications/.../CEC-500-2014-019.pdf

HRC-GWRI, 2007: *Integrated Forecast and Reservoir Management (INFORM) for Northern California, System Development and Initial Demonstration.* California Energy Commission, PIER Energy-Related Environmental Research, CEC-500-2006-109, 263 pp. http://www.energy.ca.gov/pier/project_reports/CEC-500-2006-109.html.

APPENDIX A: User's Guide for the Web User Interface of the INFORM Prediction Component

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The INFORM Prediction Component software, including the mapserver web user interface is protected by copyright laws (*Copyright ©2018 Hydrologic Research Center*). The Hydrologic Research Center retain exclusive title and ownership of any copy of this software and all related materials. The Hydrologic Research Center hereby grants a non-exclusive, non-transferable license to the California Department of Water Resources to use the INFORM Prediction Component software for the INFORM River System. Use of the INFORM Prediction Component software for any other river system or by any other organization or individual must first be authorized by the Hydrologic Research Center through a separate license agreement.

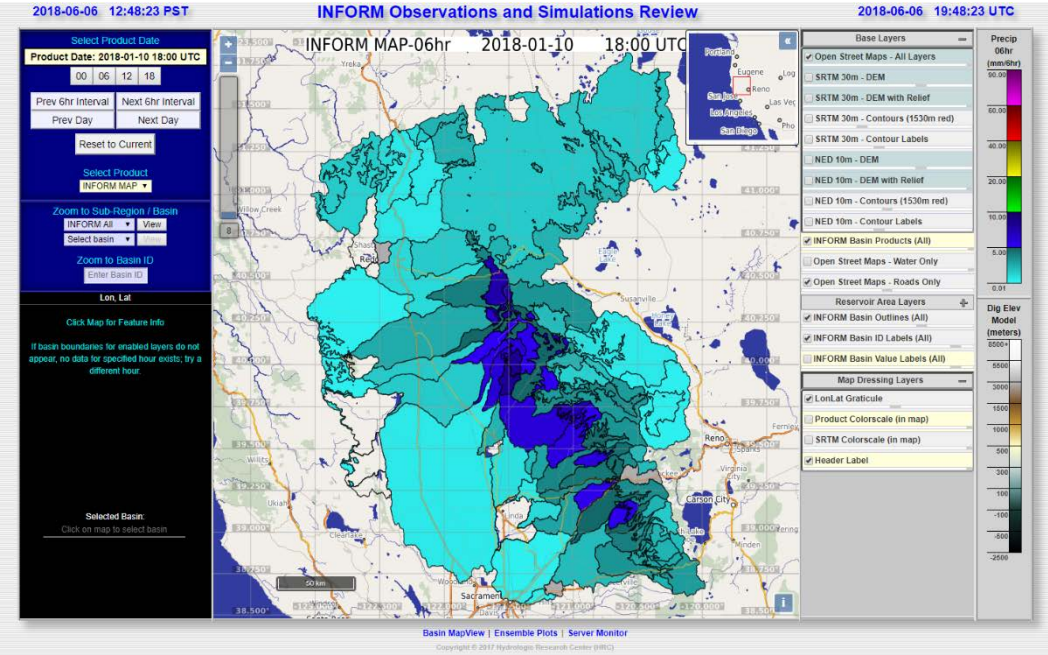
1. Overview

The HRC INFORM web interface is an online interactive tool that allows the user to view observed and simulated precipitation, temperature, and snow-water equivalent data, as well as streamflow forecasts for the Sacramento River basin area. The interface consists of two primary pages – the Basin MapView page and the Ensemble Plots page. The Basin MapView page provides an interactive map to spatially display basin values for precipitation, temperature, and snow data, whereas the Ensemble Plots page provides time series plots to show streamflow forecasts over three different forecast ranges. The interface also provides one auxiliary page: the Server Monitor page. The Server Monitor page provides 9 different line plots that show the health and performance details of the host server over any interval of time; this page is primarily for the interests and benefit of IT staff. Usage of all three of these pages will be detailed in the following sections.

The purpose of this guide is to outline the mechanics of using the web interface. This guide does not cover how to interpret data that is shown by the interface, nor does it cover any use cases.

2. Basin MapView Page

Upon navigating to the INFORM web interface, the first page the user will be met with is the Basin MapView page, as pictured below:



This page consists of an interactive map in the center accompanied by toolbars on either side.

The toolbar on the left of the map contains:

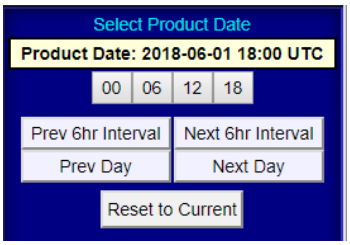
- Date selection tool
- Product selection
- Zoom tool
- On-click map information
- ‘Go to Plot’ button

The toolbar on the right of the map contains:

- Layer selection tool
- Dynamic product color scale
- Static Digital Elevation Model color scale

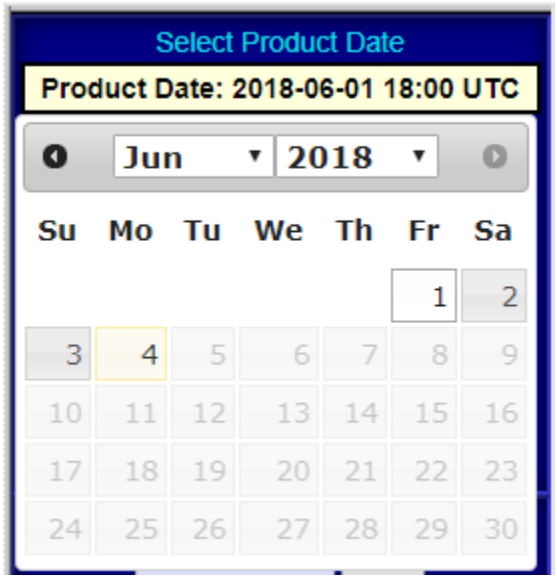
Usage of each component of the Basin MapView page is outlined in the following sections.

2.1 Date selection tool



The date selection tool is used to select the date and hour for which to view product data. It allows the user to select any date where valid data can be found within the system.

To choose between years and months, the user can simply click on the box containing the date string to get an interactive calendar:

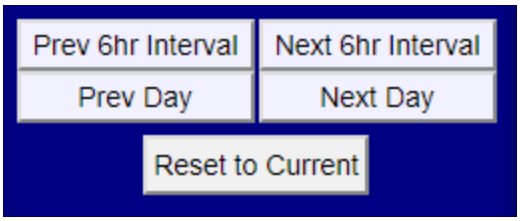


The calendar has dropdowns at the top to change between months and years, as well as a grid of buttons below to select days within the specified month. Future dates and dates before the first day containing data are not selectable.

Once the desired year/month/day has been selected, the user then needs to select the desired hour, using one of the four buttons directly below the date string:

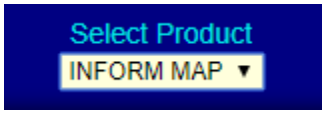
As this is a 6-hourly system, the only selectable hours are 00, 06, 12, and 18 UTC.

Below the hour buttons, there are 5 more buttons used for stepping through time.



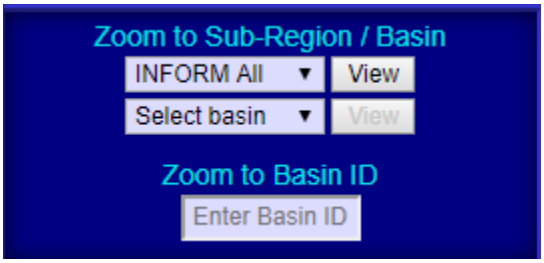
The first two will jump either forwards or backwards to the next 6 hour interval. The next two will jump either forwards or backwards 1 day (exactly 24 hours). The last one will simply reset to the most recent time step. If any of these buttons are used to try to step into the future, the web browser will produce a warning stating that stepping into the future is not allowed.

2.2 Product Selection Tool



This tool is simply one dropdown selection menu used for selecting which data product to visualize in the map view. Selecting a new product will automatically update the basin product layer visualized in the map view.

2.3 Zoom Tool

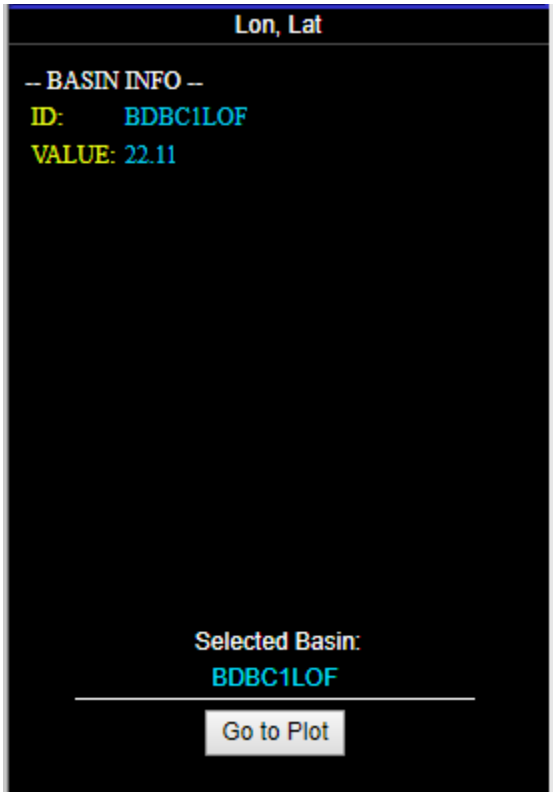


This tool is used for zooming in to the various sub-regions and basins within the INFORM system. By selecting either a sub-region or a basin from the drop-down menus, the map viewer will instantly zoom in as close as possible to the selected feature while still retaining the entire feature in the view. The user can then press the 'View' button at any time to reset the view to their selected zoom.

When a sub-region is selected, the dropdown menu containing basins is limited to contain only those basins that are found within the selected sub-region. When 'INFORM All' is selected, then all basins are available in the drop-down.

The user may also enter in a basin ID manually in the text box labeled 'Zoom to Basin ID'. By entering a valid basin ID and pressing 'Enter', the user can zoom to their selected basin. If an invalid basin ID is entered, then the browser produces an alert saying so.

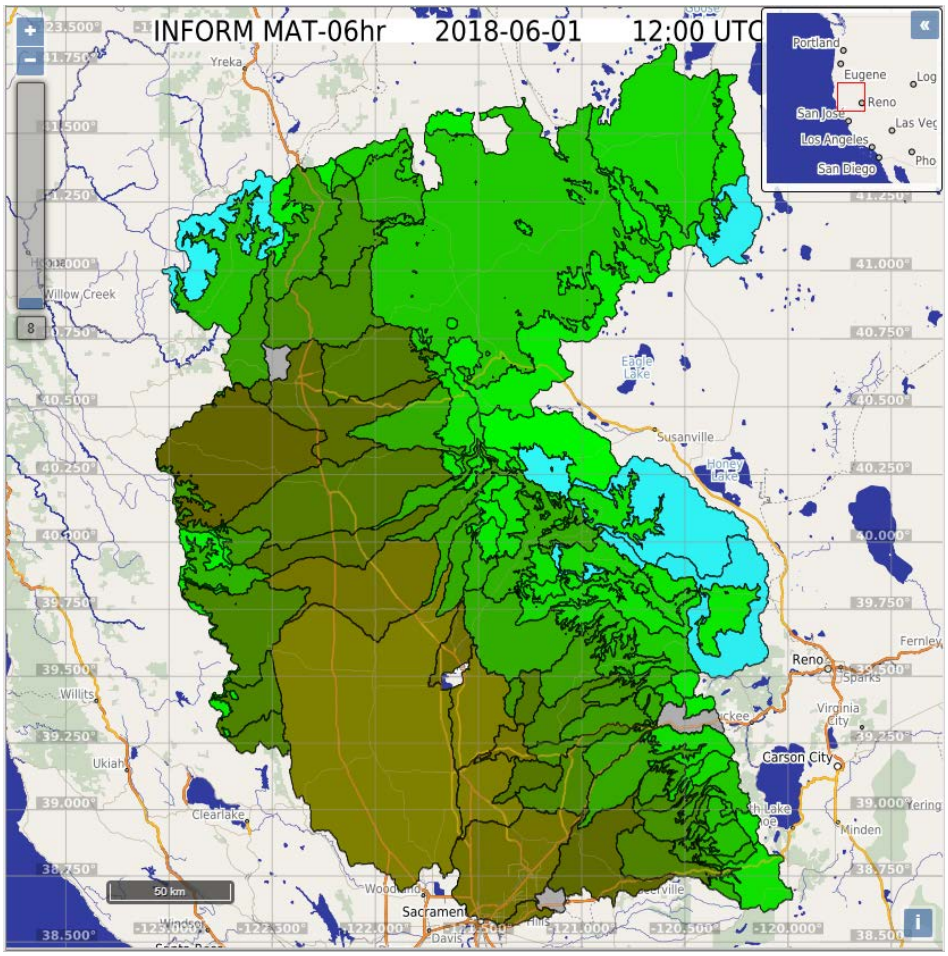
2.4 On-click Map Information Box



Upon clicking on any basin within the map viewer, the on-click map information box becomes populated with the ID and product value of the selected basin at that time. The longitude and latitude of the user's cursor are also displayed and updated in real time at the top of this box. If the user clicks within the map viewer but not within any basins, then this box will appear blank.

At the bottom of the box is a button that appears when a valid basin is selected. This button will jump to the Ensemble Plots page for the selected time and basin. More information on this page can be found in section 3.

2.5 Map Viewer



The Map Viewer is used for viewing the observed and simulated mean areal precipitation, mean areal temperature, and snow-water equivalent basin data. The user is able to interact with the map in the ways they might expect, such as clicking and dragging to pan around and scrolling the mouse wheel to zoom.

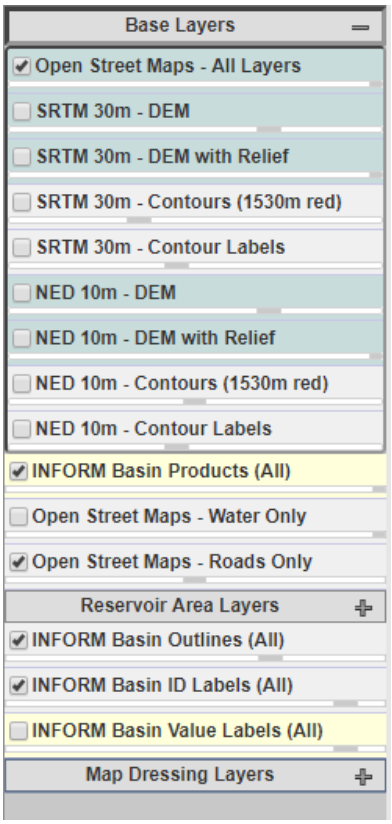
In the top left corner of the map is a zoom slider, which allows the user to zoom in and out of the map between zoom levels 8 and 16. The current zoom level is displayed in a small info box just below the zoom slider.

In the top right corner of the map is a mini map. The red box within the mini map displays the view currently seen in the map. Clicking the button “<<” at the top right of the mini map will hide it, and clicking again will re-expand it.

In the bottom left corner of the map is a distance scale, used to help quantify the scale of features within the map.

In the bottom right corner of the map is the attributions button. Clicking on this will display attribution information for the layers currently displayed in the map.

2.6 Layer Controls

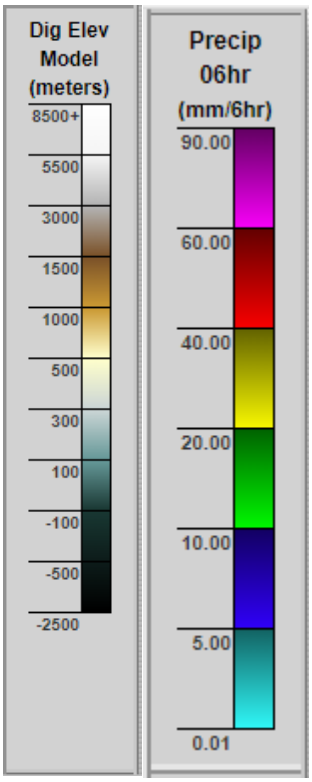


The Layer Controls determines the visibility and opacity of all available layers for the Map Viewer. Each layer component in the list contains: a visibility checkbox; layer name; and opacity slider. Some layers are grouped together inside of contains that can be expanded or hidden – e.g. 'Base Layers' – by simply clicking on the grey header with the '+' or '-' symbol on the right.

To toggle a layer's visibility in the map, toggle the checkbox next to the layer name. To adjust a layer's opacity, slide the slider tool directly below the selected layer – all the way left for 0% opacity, and all the way right for 100% opacity.

It is important to note that the relative ordering of the layers in the map is determined by the ordering of the layers in the layers panel, despite the fact that the layer ordering is immutable. Layers that are farther up the panel will appear *below* layers that are further down the panel. Any changes to the ordering of layers will need to be handled by an HRC software engineer.

2.7 Color Scales

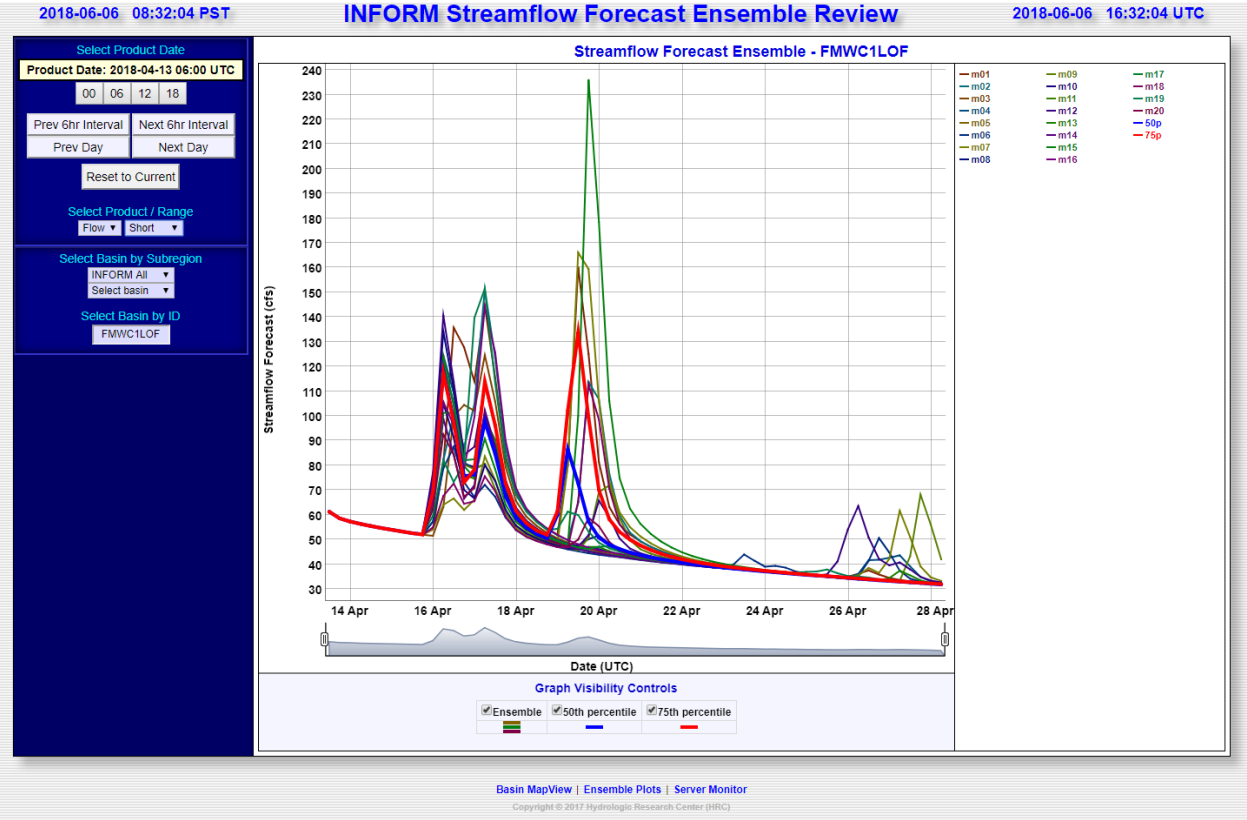


Basin data is displayed using a color scale for each of the different types of products. On the far right hand side of the page is the scales used for coloring the various basin products. On top is the product color scale, which updates according to which product is selected in the Product Selection Tool. Below the product color scale is the SRTM Digital Elevation Model color scale, which is persistent regardless of selected product.

In-map versions of these color scales can be found in the 'Map Dressing Layers' section of the layers panel.

3. Ensemble Plots Page

The next page in the INFORM interface is the Ensemble Plots Page, which is used for visualizing time series streamflow forecast data over three different ranges: short, medium, and long. This page is comprised of a toolbar on the left containing nearly identical controls to those found on the Basin MapView page.



The only differences being: the addition of a range selector; what was the basin zoom controls is now used simply for choosing which basin to view time series data for; and the on-click feature info box has been replaced with a warning message that appears when data is unavailable or the plots experience issues loading.

When an error such as the one above occurs, try navigating to a different time step. If data is unavailable for a basin/time step that you expected to find data for, then something has gone wrong in the data processing flow and the backend needs to be investigated.

3.1 Arriving at the Ensemble Plots

There are two ways to enter the plots page – from the 'Go to plots' button on the Basin MapView page, and from the footer link found on any of the INFORM interface pages. When entering via the 'Go to plots' button, the plots will load for the time and basin selected on the

MapView page. When entering from the footer link, the plots will default to the current time and the first basin alphabetically (at the time this was written, this is basin AKYC1HLF).

3.2 Date Selection

To change the selected date, refer to section 2.1 as the date picker used on this page is identical to the date picker used on the MapView page.

3.3 Product/Range Selection

To change the selected product/range, simply use the dropdown selectors found below the date picker. At the time this guide was written, the only product available for selection is 'flow'. Available ranges are 'short', 'medium', and 'long'. Data availability varies between ranges.

3.4 Basin Selection

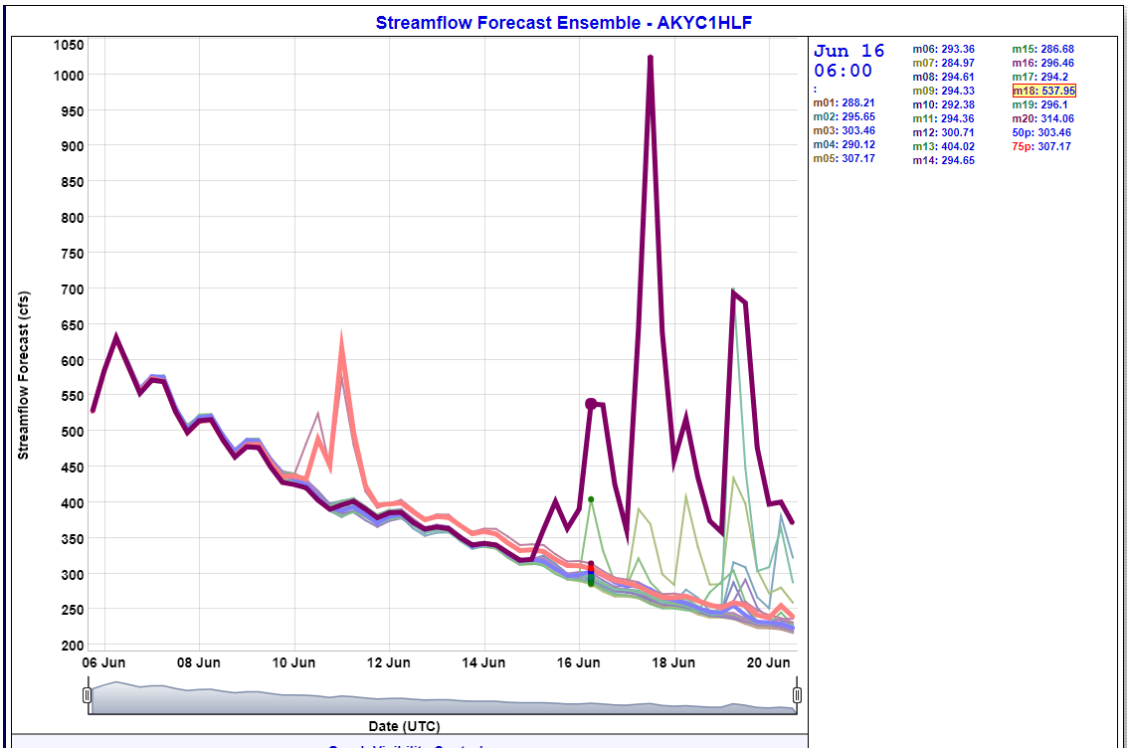
To change the selected basin, refer to section 2.3 on zooming, as these basin pickers work exactly the same (besides the fact that these change the selected basin, rather than zoom).

3.5 Interacting with the plots

The line plots themselves are interactive and allow the user to customize what traces they see, zoom in to any part of the plot, and analyze the exact value of any trace at any data point.

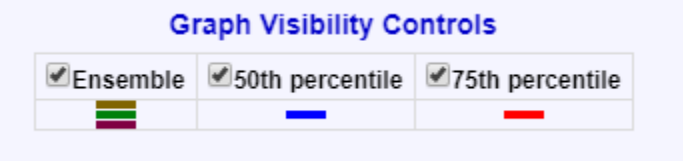
To zoom in, click and drag either horizontally or vertically within the line plots. This will draw out a new region to fit your plots view to, zoom in, and adjust the axis accordingly. To zoom back out, simply double click anywhere in the plot.

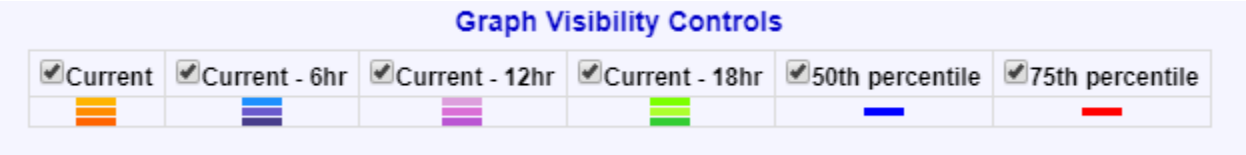
To view trace values at any given time step, mouse over the traces and view their values in the panel on the right hand side of the plot. The trace that your mouse is most directly over will have its value highlighted on the right, as seen below.



By clicking on any of the traces, the user can lock their focus to that trace. This will show the selected trace above all other traces, and have its value permanently highlighted to the right. Clicking again will unlock focus from that trace.

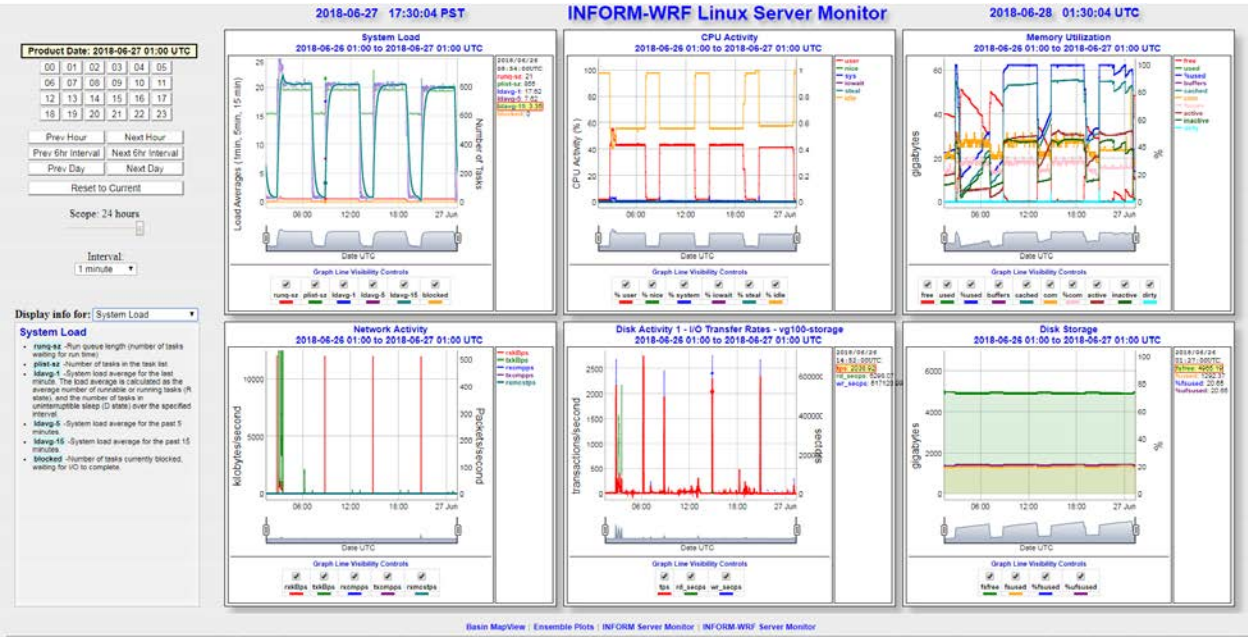
3.6 Trace visibility





The user can toggle which traces are visible in the plot by checking the boxes below the plot. The user will have different trace toggle options depending on which forecast range is selected.

4. Server Monitor Page



The Server Monitor Page is an auxiliary page designed primarily to give IT staff insight into the health of the server that is hosting the INFORM system. This page contains 9 plots, each interactive in all the same ways as the Ensemble Plots.

The left hand side of the page contains a date picker that functions exactly the same as on the other pages, with the addition of hourly buttons for all 24 hours. Below that is a scope slider, which will alter how long of a window each plot is showing data for. Below that is an interval selector, which adjusts the granularity of the data points in each plot. Adjusting the scope and interval selector can give greater insight into system health and performances, at the cost of longer loading times for the plots. At the bottom left, there is an information box that displays details concerning the contents of each plot. By default, the info box is in “automatic” mode which dynamically displays the description for the plot that is beneath the user’s mouse pointer. There is a dropdown menu above this box which allows the user to manually select the info for any one of the plots statically.

APPENDIX B: Outline for Product-Download Script Installation and Usage

INFORM Linux Server Product Sync Script Installation

- Install Cygwin on your PC (requires DTS assistance) – see separate instructions
    - Uses Cygwin default minimal footprint plus rsync, openssh and wget package add-ons
    - Approx 200MB total
    - 3-5 minutes to install
- Obtain the scripts from the Linux server
    - Open the Cygwin64 Terminal application and execute the following command
    - wget -N http://inform.ad.water.ac.gov/INFORM/product_sync/inform_pc_sync_scripts.tgz

      (the command is all on one line)
    - Optionally, get the demonstration SSH keys (only granted access for training purposes):
        - NOTE: This step is not needed if individual SSH keys have already been configured for your PC and installed on the Linux account
        - wget -N http://inform.ad.water.ac.gov/INFORM/product_sync/inform_pc_demo_ssh_keys.tgz

          (the command is all on one line)
- Install the scripts to your Cygwin home directory
    - Open the Cygwin64 Terminal and execute the following command:
    - tar xvzf inform_pc_sync_scripts.tgz
    - See two scripts: sync_inform_linux_products.sh and purge_inform_local_products.sh
    - Optionally, install the demonstration SSH keys
        - **NOTE: this will overwrite any previously configured/individual SSH keys in your local Cygwin user account**
        - tar xvzf inform_pc_demo_ssh_keys.tgz

INFORM Linux Server Product Sync Script Procedure

- Execute the product sync script (only single spaces between arguments are needed)
    - ./sync_inform_linux_products.sh help
    - ./sync_inform_linux_products.sh -24
    - ./sync_inform_linux_products.sh 2018 01 01 12
    - ./sync_inform_linux_products.sh 2018 01 01 12 24
    - ./sync_inform_linux_products.sh 2018 01 02 12 -24
    - ./sync_inform_linux_products.sh 2018 01 01 12 2018 01 02 12
    - ./sync_inform_linux_products.sh 2018 01 02 12 2018 01 01 12
- Execute the product purge script (removes local data from the PC only)
    - All the same argument options as the sync script, e.g.:
    - ./purge_inform_local_products.sh 2018 01 01 12
    - ./purge_inform_local_products.sh -120
    - and so on...
- Default data location
    - Script will automatically create a folder in Documents/INFORM_FORECAST_DOWNLOADS
    - Script will also automatically create a shortcut in the Cygwin home directory to the download folder, using the same name. (In the home directory, “cd INFORM_FORECAST_DOWNLOADS”)
    - Defaults are configured in the ~/include/inform_data_sync_parms.src file (e.g., edit with vi)

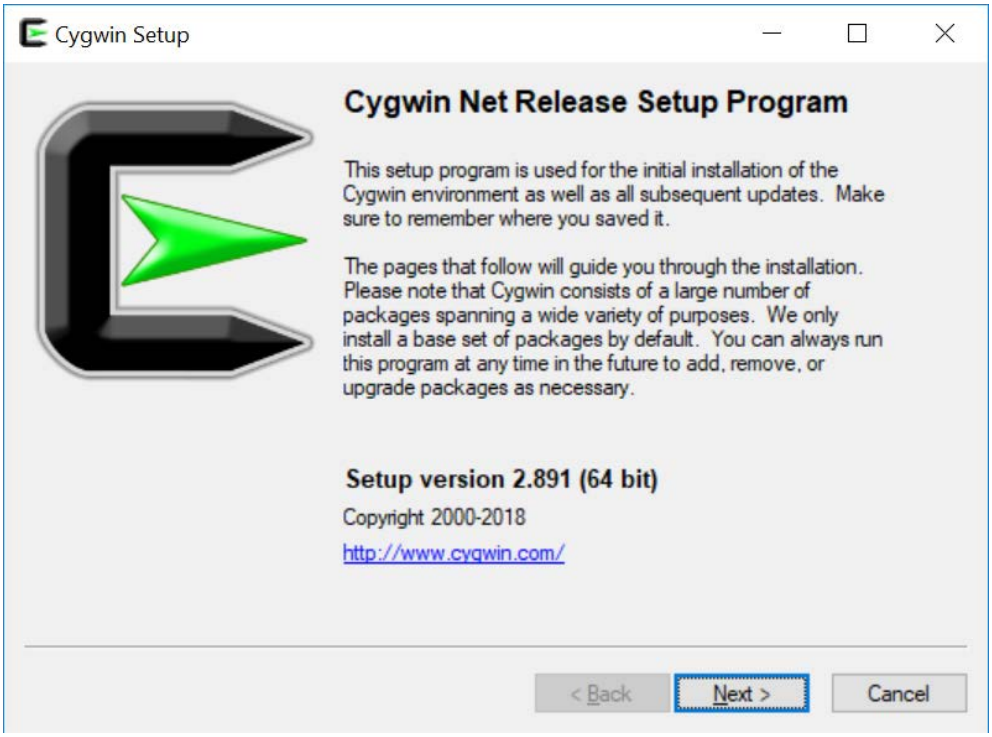
APPENDIX C: CYGWIN Installation and Removal Procedures

1. Cygwin 64-Bit Installation Procedure for Windows-Based Rsync Data Transfer Capability

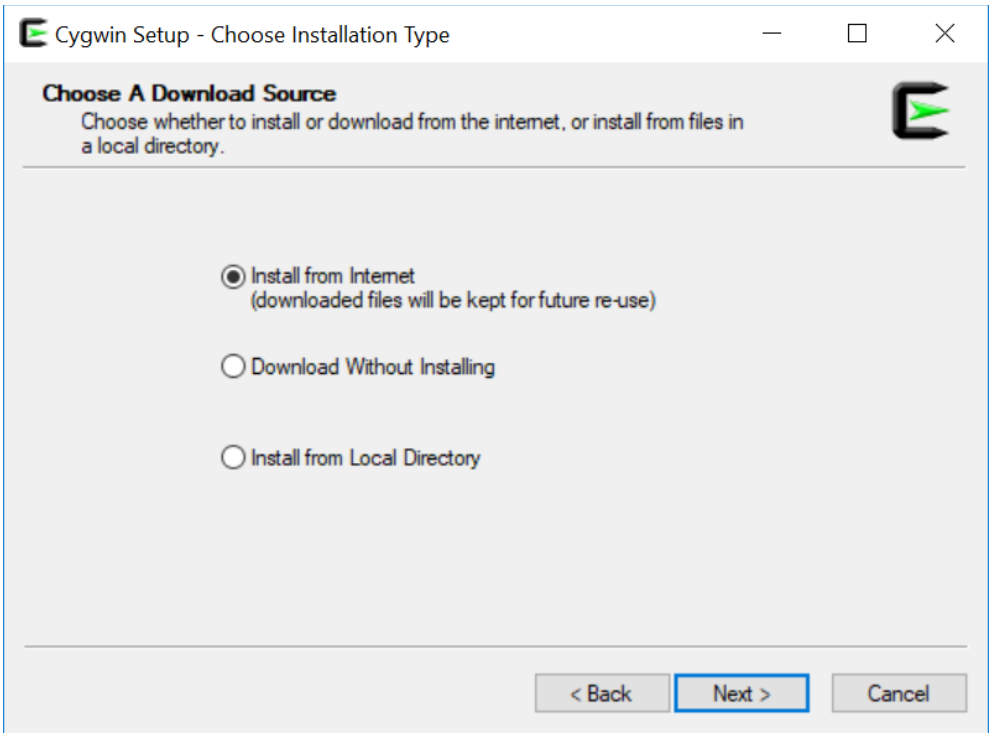
- The following procedure is a minimalistic approach to provide basic "rsync" data transfer capabilities for a Windows PC.
- It is assumed that Windows 10 64-bit is the hosting operating system.
- Point your web browser to www.cygwin.com.
- Click on the setup link where the page shows:
  Install Cygwin by running setup-x86_64.exe (64-bit installation).

- Launch the program after the download completes (THIS STEP WILL REQUIRE ADMINISTRATIVE AUTHORIZATION).
- Click "yes" when prompted to let it make changes to your device.

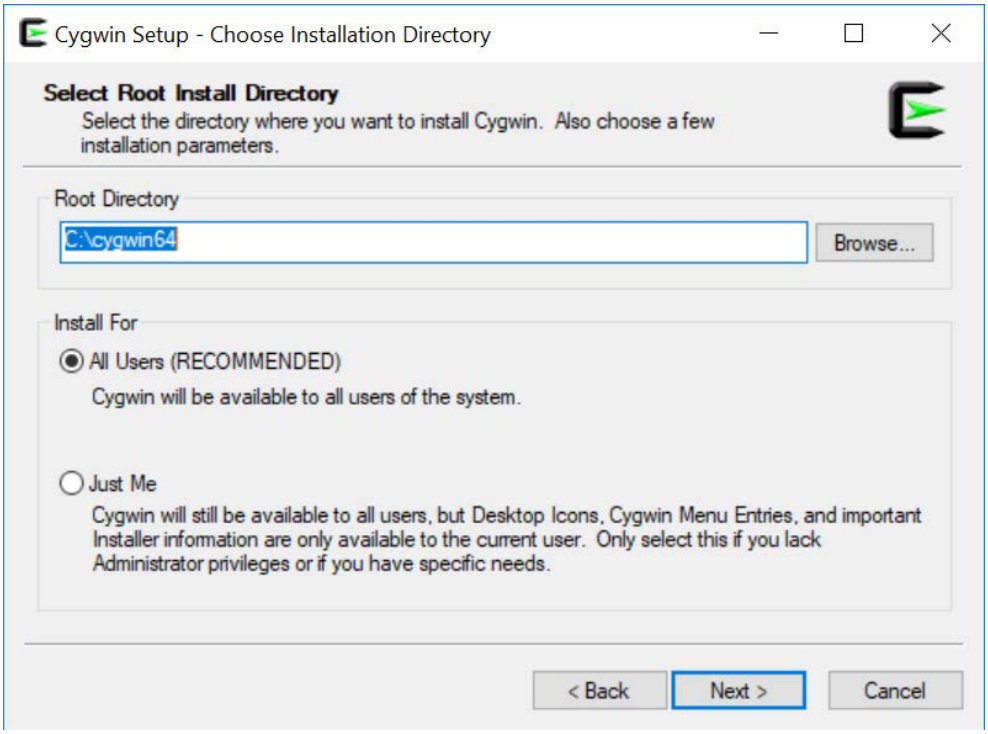
- Click Next on the initial screen.



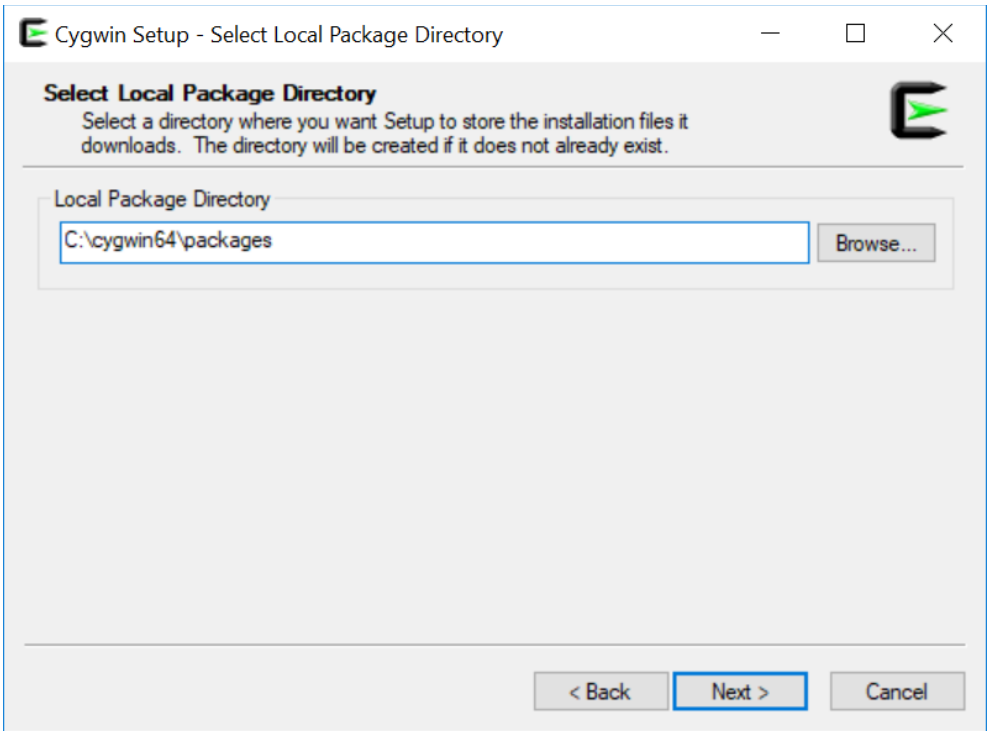
- Leave Install from the internet selected - click Next.



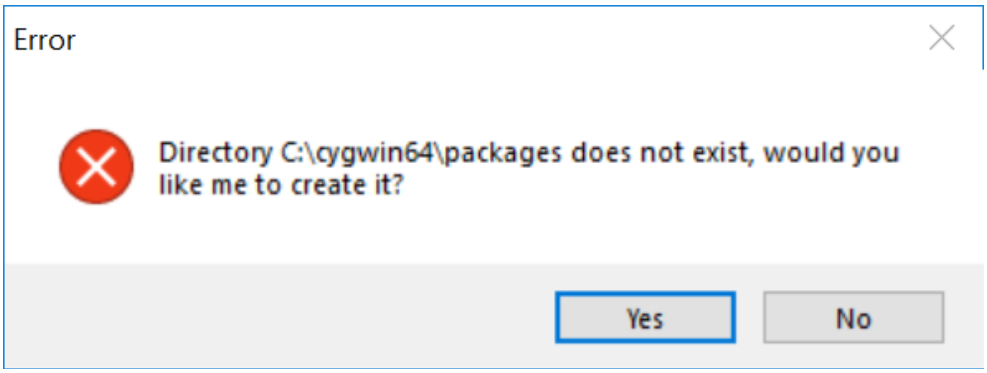
- It is recommended to use the default installation folder - click Next.



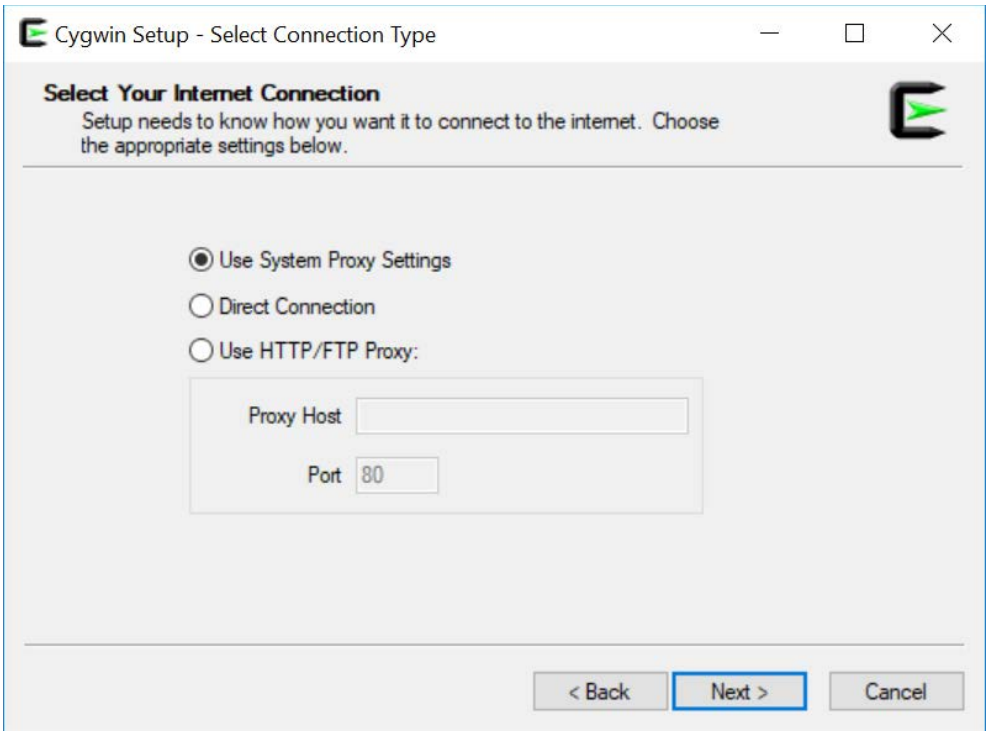
- Modify the package download path to **c:\cygwin64\packages** to keep all related content in one place then click Next.



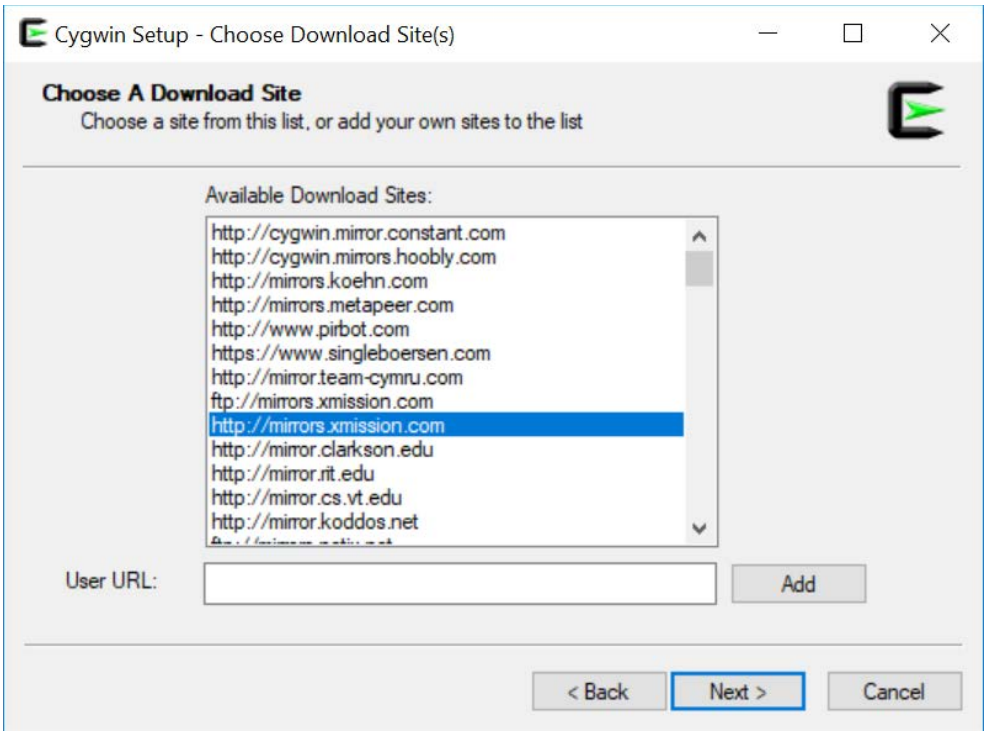
- Click Yes to create the download directory.



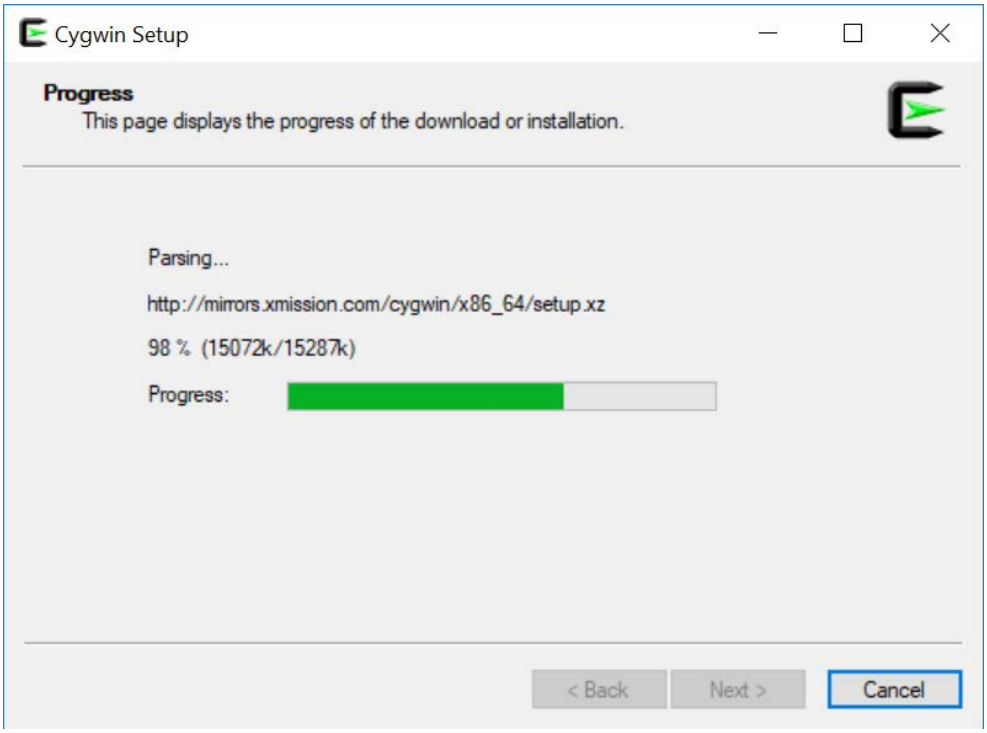
- Use the default here and click Next.



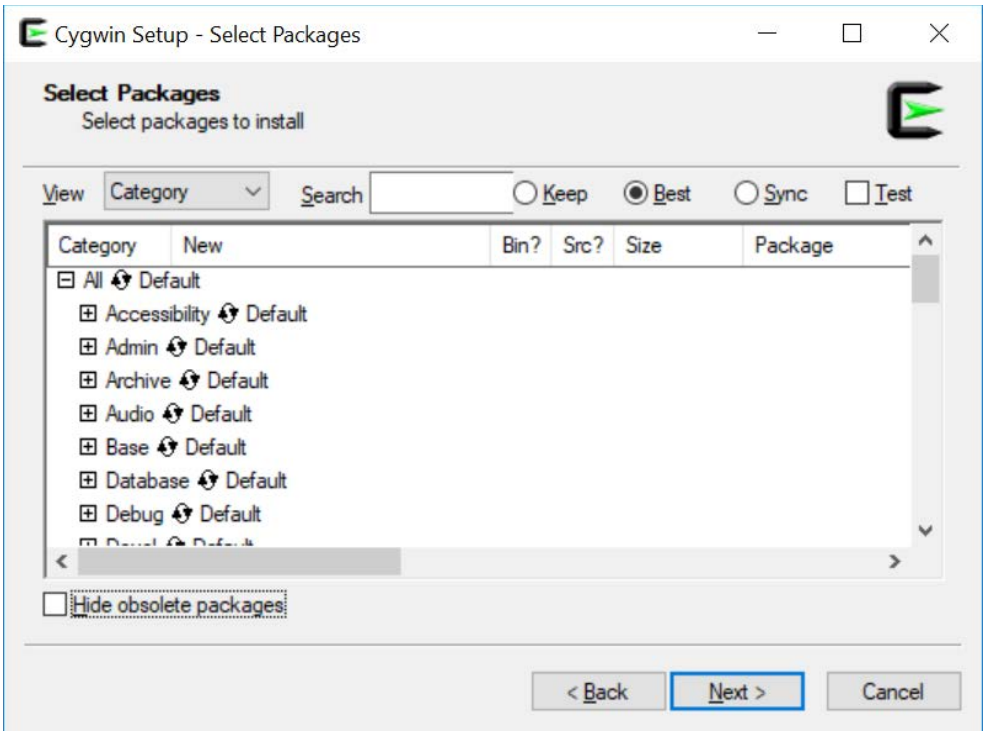
- Select one of the installation mirrors to obtain the packages for installation and click Next.
    - Suggested: http://mirrors.xmission.com



- Wait for the package list to download.

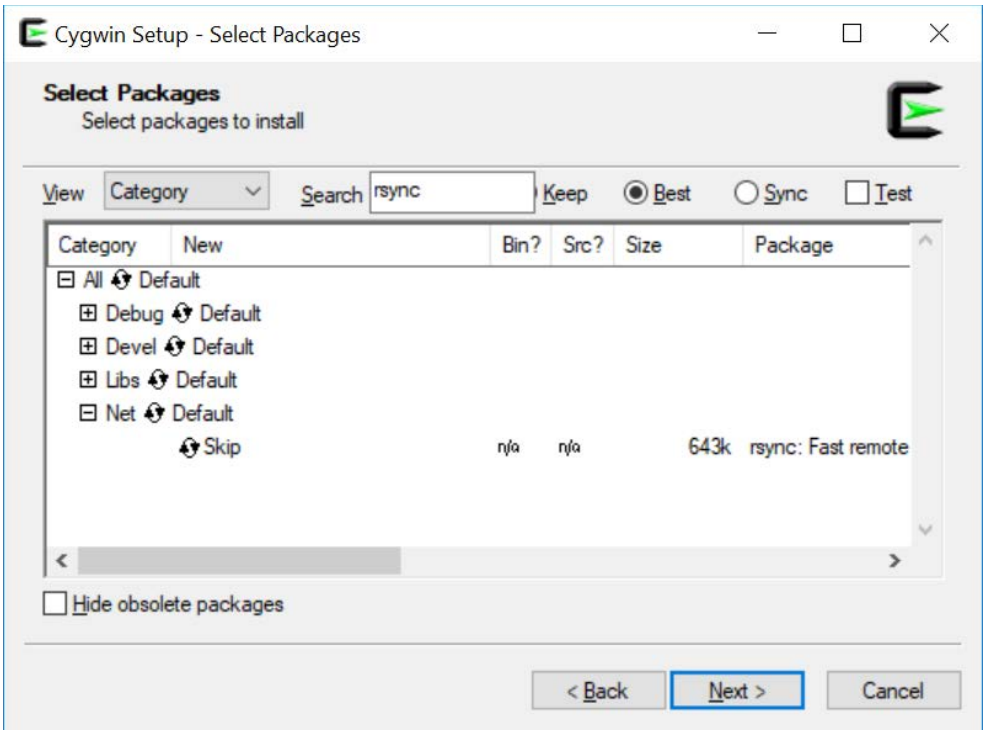


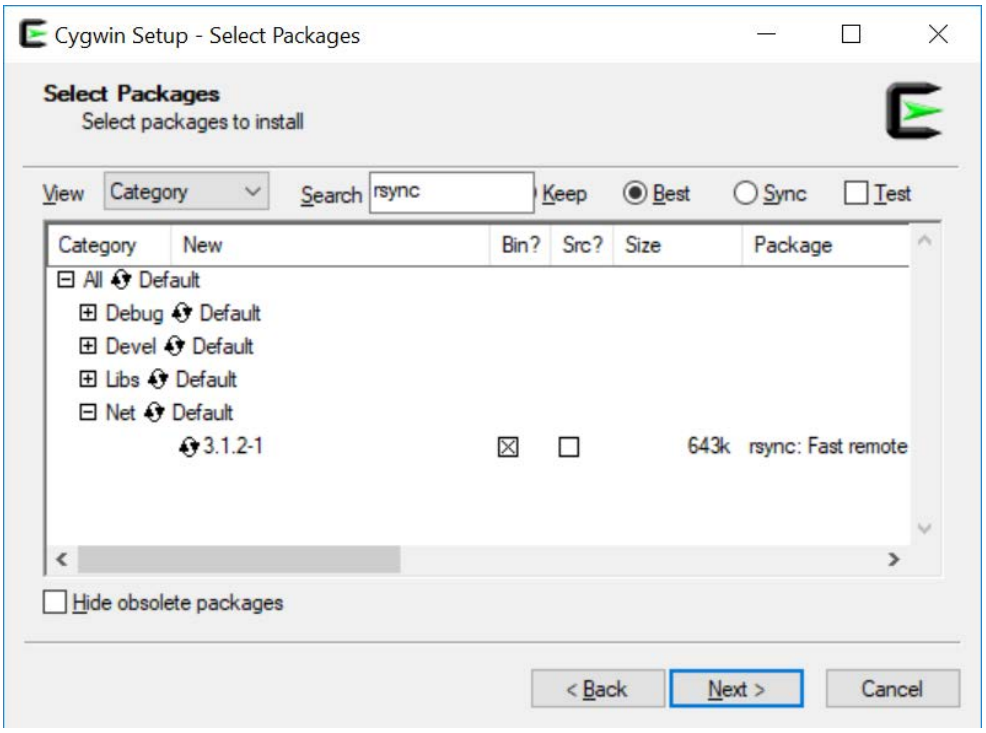
- When complete, the package list will appear. See the next steps to select additional packages from the list.



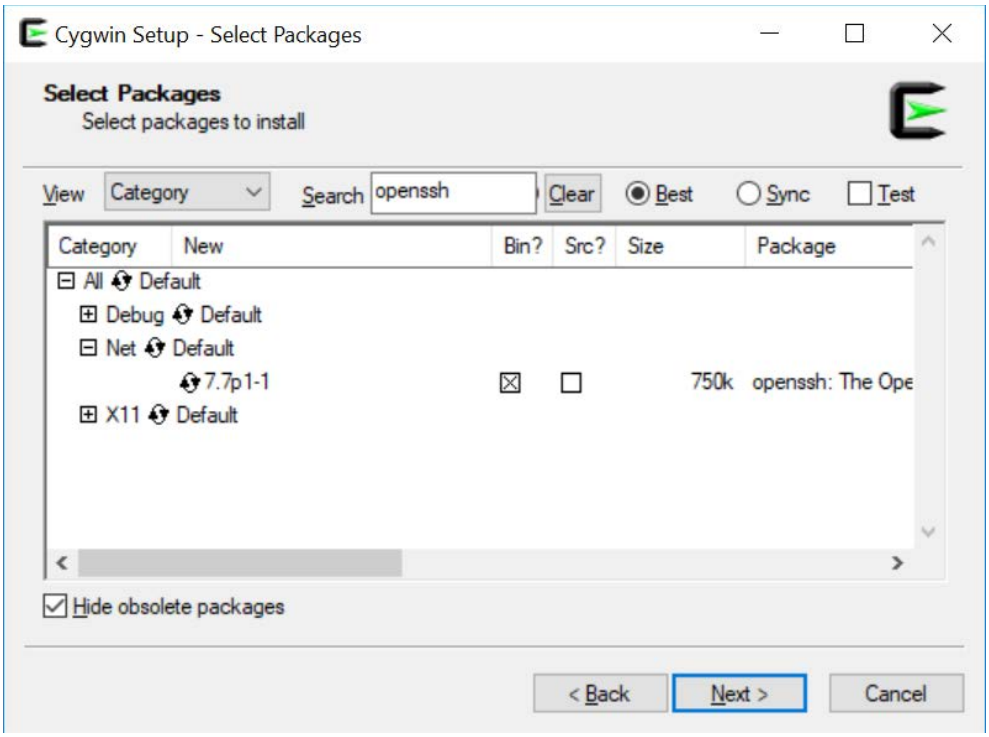
- At this point, the installation selections throughout the package list are preconfigured for the minimal footprint. We must add a few packages for the application requirements to rsync data transfers. To do this, we add the packages for **rsync** and **openssh** as well as **wget**.

- Search for "rsync" in the search box, expand the resulting "Net" section by click the "+" symbol and then click on the "Skip" glyph once to change the status for installation - it will show the version of the package to be installed once it has been changed.

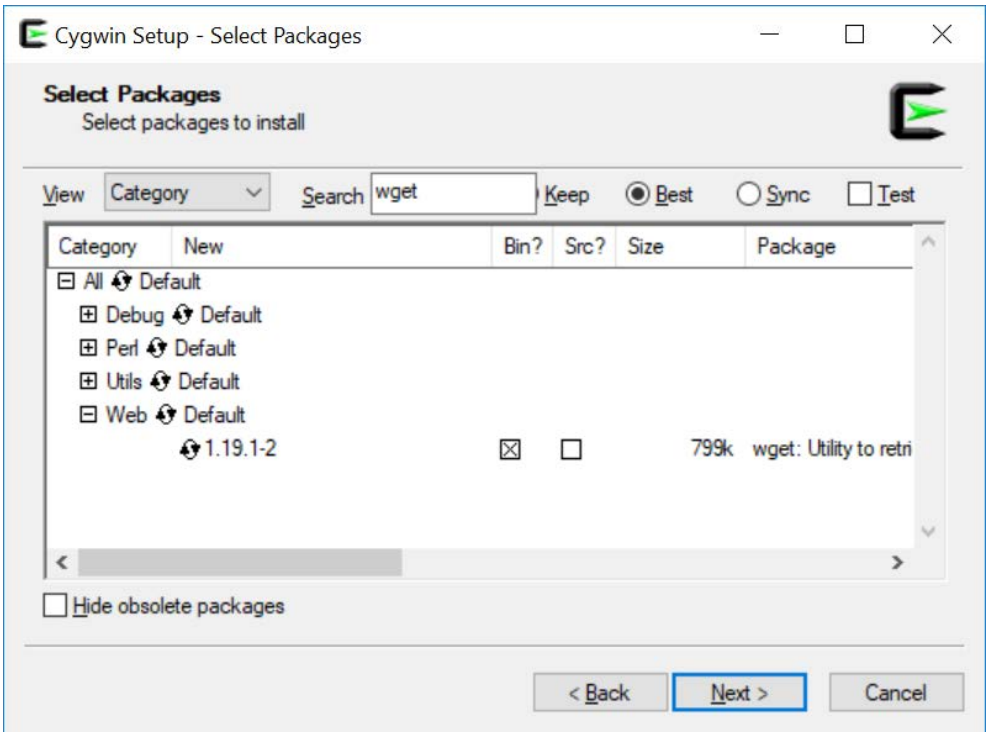




- Search for "openssh" and select it for installation in same way under the Net section.

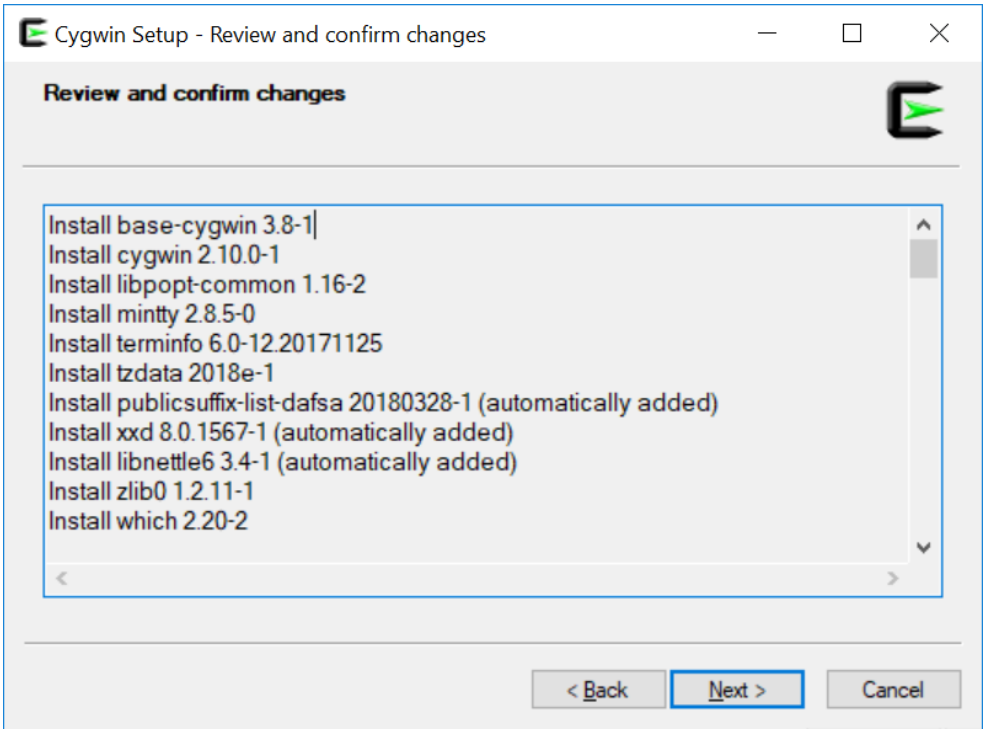


- Search for "wget" and set it for installation under the Web section.

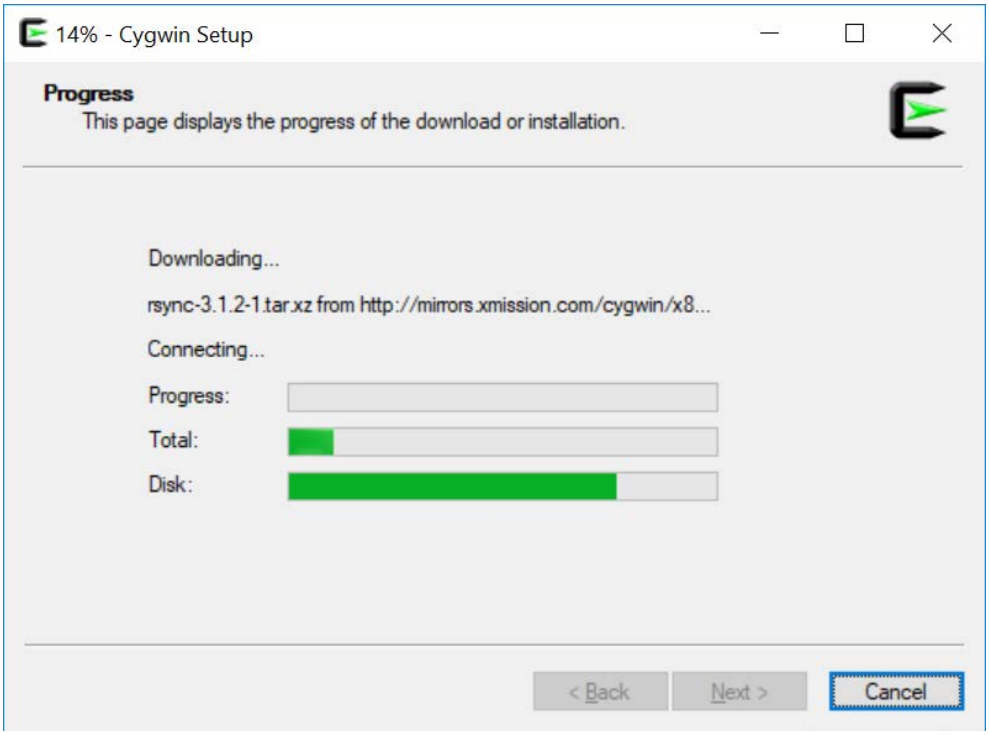


- Click Next to proceed with installation of the selected packages and click Next again on the following screen to confirm the changes (dependency selections

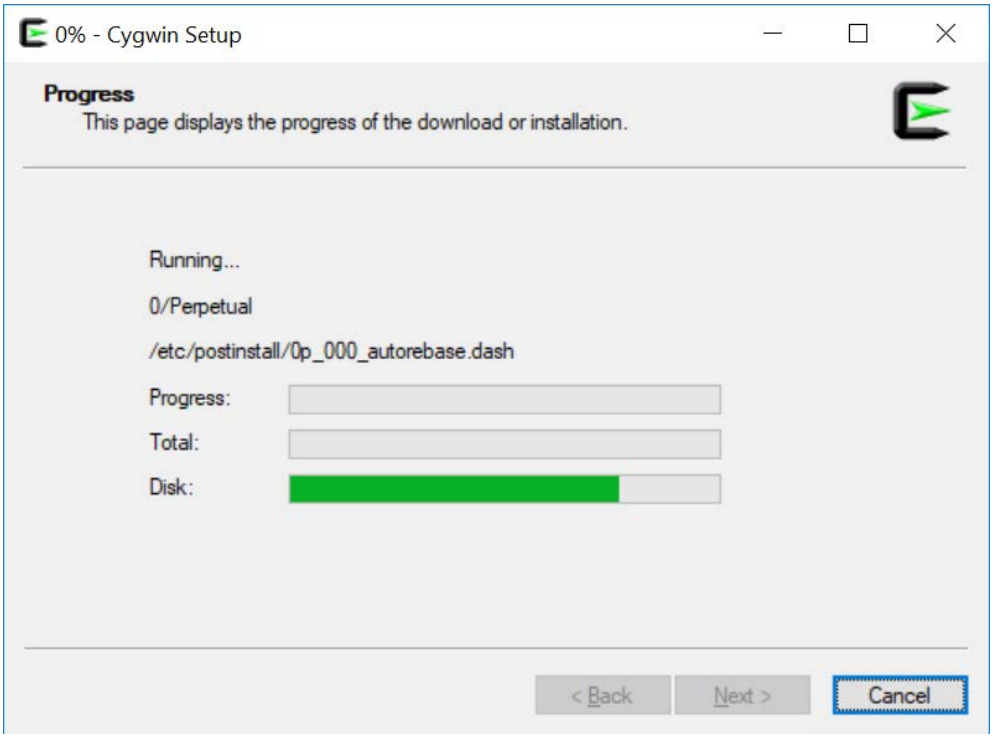
that were added automatically). The installation should only take a couple minutes, depending on download speed.



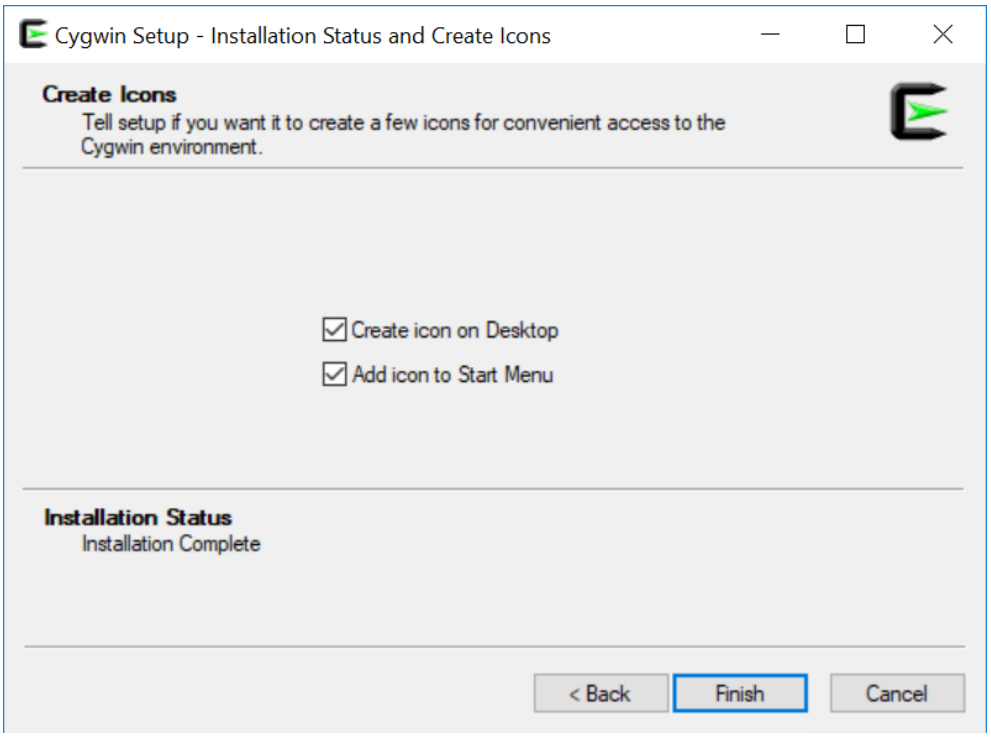
- Wait while the base system and selected packages download and install.



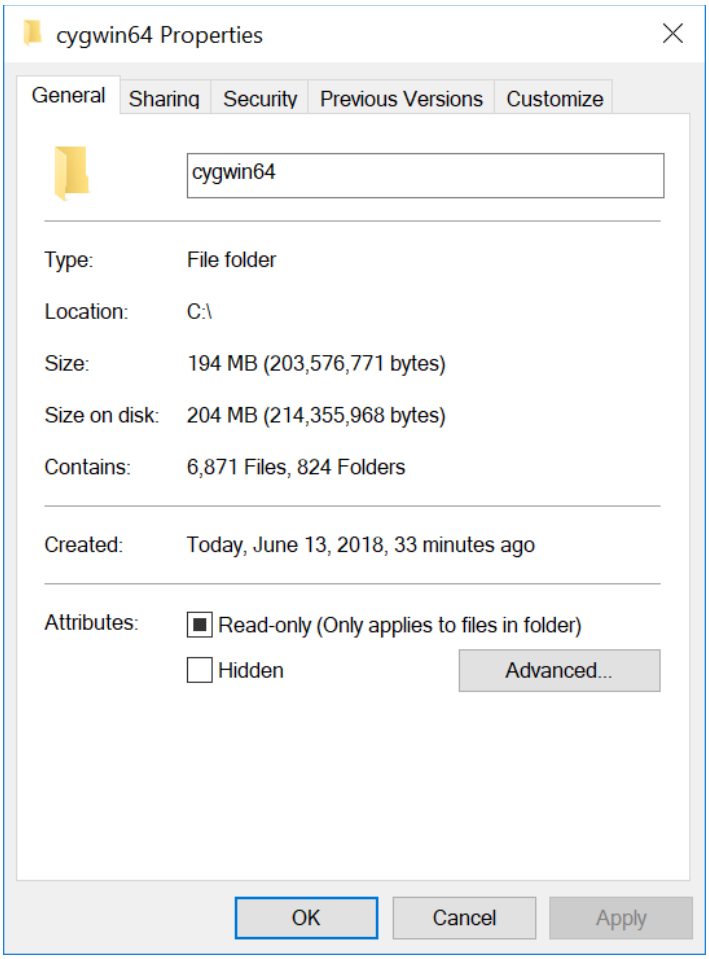
- Wait while the postinstall procedures complete.



- Once the installation is complete, optionally add icons to their common locations and click Finish. **It is strongly recommended to choose the Start Menu option at least.**



- When installation is complete, the footprint should be approximately 200MB.



- In the start Menu, click on the new item called **Cygwin64 Terminal** to launch the Bash shell environment.
  - After a new installation, it should appear at the very top of the application list on the left side of the start menu.
  - You should also be able to find it in the "C" section under the Cygwin folder.
  - When the Cygwin terminal launches a Bash command shell window will appear.

THIS CONCLUDES THE BASIC INSTALLATION PROCEDURE FOR CYGWIN.

2. Cygwin 64-Bit Removal Procedure

- The following procedure outlines the steps required to remove Cygwin from your PC.

- This procedure assumes that the pending Cygwin footprint is the result of the minimal installation procedure for rsync and wget capabilities detailed above.

    - Because the minimalistic approach does not need or install any Cygwin-related services in the Windows environment, there is very little integration to undo.

- Using the Windows File Explorer, locate and delete the C:\cygwin64 folder.

    - NOTE: removing this folder will delete all downloaded Cygwin packages, the installed software footprint and any files the user has stored in their home directory (most notably any individual SSH keys and their copy of the INFORM data sync and purge scripts).

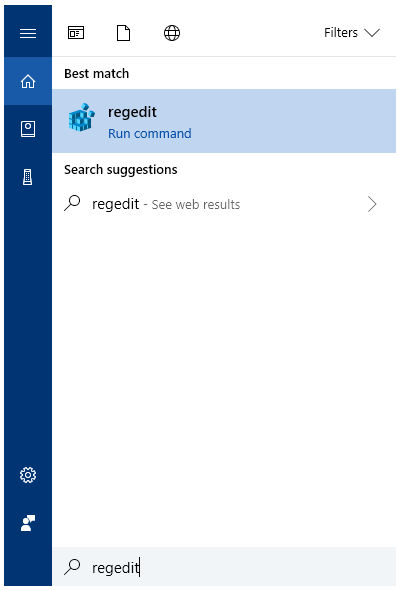
    - Previously downloaded INFORM product files are maintained by default under the user's Documents folder and will *not* be deleted by this removal procedure.

- Review the Desktop, Start Menu and Task Bar items and remove any occurrences of the Cygwin icon.

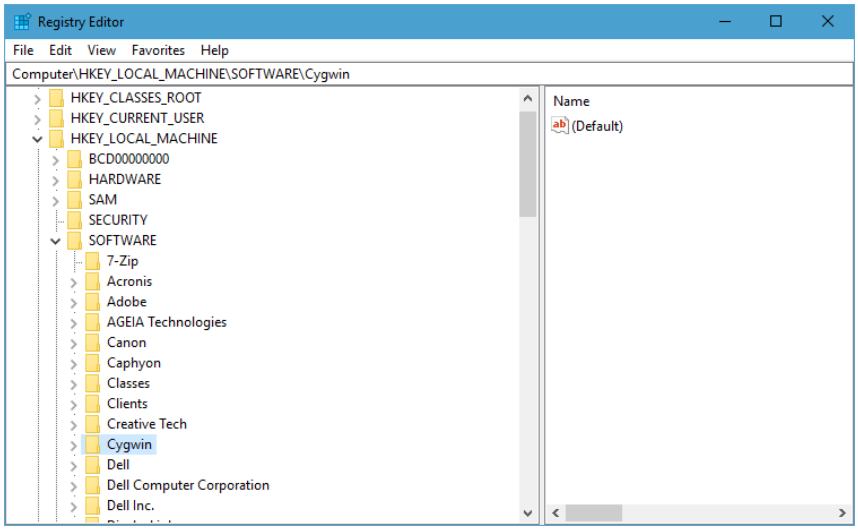
- The last step is to remove the Software\Cygwin keys from Windows registry.

    - For the non-advanced user, it is recommended that you enlist the support of your IT Staff for this step as an erroneous maneuver could have extremely negative consequences. In addition, Administrative privileges will be required.

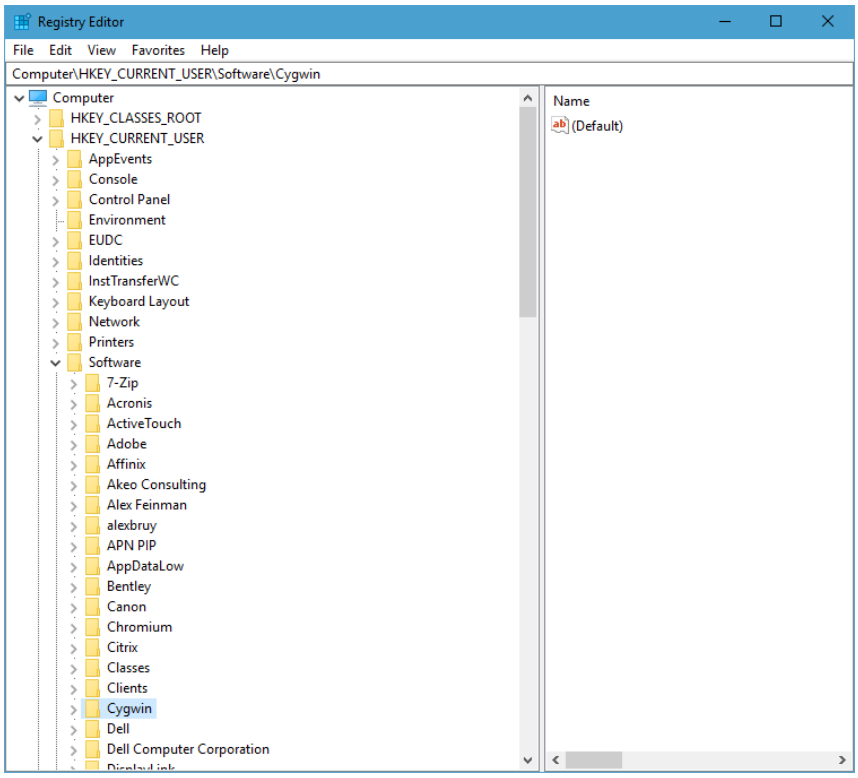
    - Search for "regedit" in the Windows search tool and launch the application (this will require administrative privileges).

- 

- When the regedit window appears, navigate to the "HKEY_LOCAL_MACHINE/Software" folder and right-click on the "Cygwin" item. In the pop-up menu, select "Delete" to remove it.



- Next, navigate to the "HKEY_CURRENT_USER/Software" folder and right-click on the "Cygwin" item. In the pop-up menu, select "Delete" to remove it and then close the regedit window.



THIS CONCLUDES THE CYGWIN SOFTWARE REMOVAL PROCEDURE

APPENDIX D: INFORM DSS v20 User Manual

Copyright Notice

The INFORM DSS v2.0 software is protected by copyright laws (*Copyright ©2018 Georgia Tech Research Corporation*). The Georgia Water Resources Institute (GWRI) and the Georgia Tech Research Corporation (GTRC) retain exclusive title and ownership of any copy of this software and all related materials. GWRI/GTRC hereby grant a non-exclusive, non-transferable license to the California Department of Water Resources to use the INFORM DSS v2.0 software for the INFORM River System. Use of the INFORM DSS v2.0 software for any other river system or by any other organization or individual must first be authorized by GWRI/GTRC through a separate license agreement.

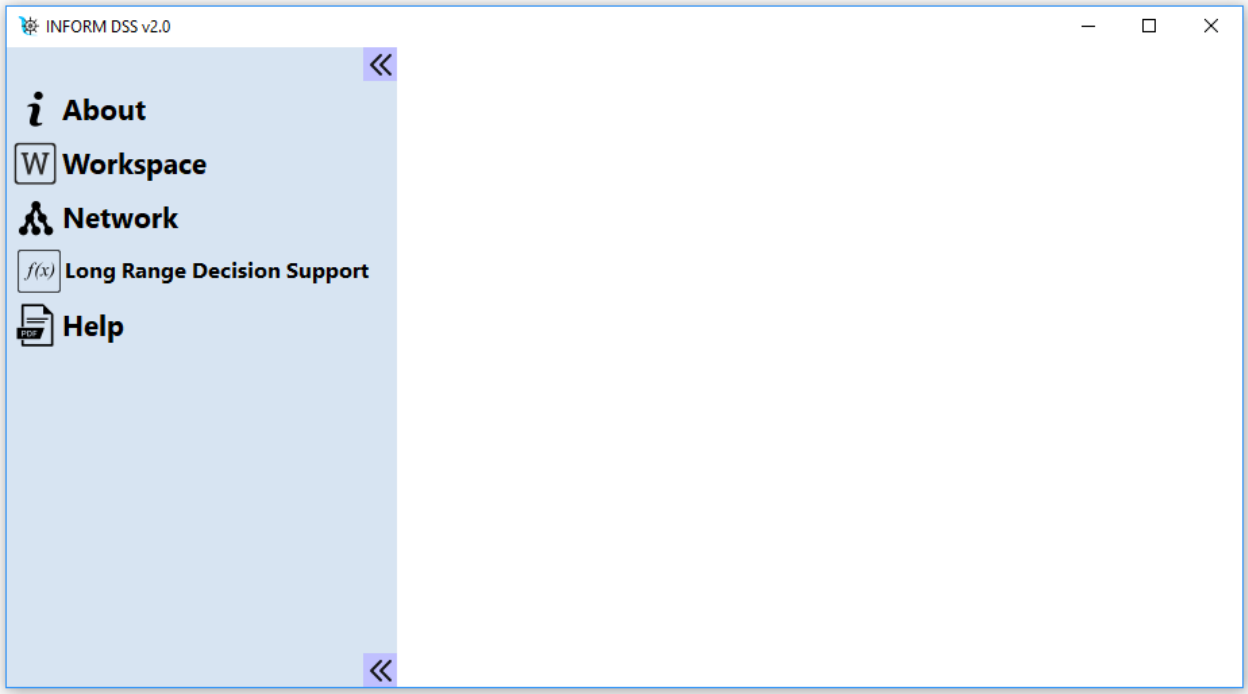
The software also uses the following libraries, whose license files can be found in the installation directory: Dotspatial, Math.Net Numerics, SqlCEBulkCopy, GDAL, and Costura Fody.

Chapter 1: Overview

INFORM DSS version 2.0 is a decision support system for river basin water resources management. This software version contains various modules that can be used to define general water resources networks, develop quantitative models of water movement through reservoirs and river reaches, and assess a range of planning and management options and tradeoffs.

1.1 Main Screen

The Main Screen consists of a Sidebar Menu on the left and a work area on the right.



1.2 Sidebar Menu

The Sidebar Menu contains a set of buttons that can be used to launch different modules contained within INFORM DSS v2.0. The sidebar menu can also be shrunk and expanded by using the arrows at the top and bottom of the menu.

1.2.1 About

The "About" button opens up a form containing the copyright notice for INFORM DSS v2.0.

1.2.2 Workspace

The "Workspace" button opens up the Workspace form. This functionality is used to define the locations on the user's computer where files are stored.

1.2.3 Network

The "Network" button opens up the Network module in the main work area. This module is used to define the physical characteristics of the water resources system.

1.2.4 Long Range Control Model

The "Long Range Control Model" button opens up the Long Range Control Model module in the main work area. This module is used to define water resources models to aid in water resources planning and management. The models have a monthly time step and are designed to support water resources management for the next few months or years.

1.2.5 Help

The “Help” button opens up this user manual.

Chapter 2: Software Installation

2.1 System Requirements

INFORM DSS v2.0 is designed to be used on 64-bit Windows Operating Systems, including 64-bit versions of Windows 7, 8, and 10.

2.2 Software Installation

Please install the following two programs:

- INFORMDSSv20.msi : Installs INFORM DSS v2.0
- SSCERuntime_x64-ENU: Installs utilities needed for accessing the database used by INFORM DSS v2.0. The database engine is Microsoft SQL Compact Edition.

Both files can be installed by double-clicking them and following the installation instructions. Please *uninstall* all older INFORM DSS software versions before installing INFORM DSS v2.0.

2.3 Uninstalling Older Versions of INFORM DSS

To uninstall INFORM DSS v2.0. or older software versions and associated database utilities, please use the official Windows utilities (Add or Remove Programs). Note that uninstalling these programs will not automatically remove any user-created Workspaces.

2.4 Software Activation

INFORM DSS v2.0 is a proprietary software and a license has to be activated before first use. After installation, please perform the following steps:

1. Navigate to the installation directory (most likely "C:\Program Files (x86)\GWRI\GWRI Modeling Platform"), right click INFORMDSS.exe, and select the "Run as Administrator" option. If this option is not available, please seek help from someone with the proper administrator privileges.
2. The license activation form should appear once the application starts. Click "Activate INFORM DSS".
3. Record both "User Code 1" and "User Code 2" and provide them to the GWRI software developers.
4. GWRI will supply you with two new codes, "Activation Code 1" and Activation Code 2". Enter the codes into the license activation form and click "Continue". If the activation is successful, a confirmation message will be displayed.

Please note that software activation with administrator privileges only has to be performed once. From then on, users can start the software normally by double-clicking on the INFORMDSS.exe file or using the Desktop/Start Menu shortcuts.

Chapter 3: General Functionalities

Several features of INFORM DSS v2.0 are designed to function in a similar fashion regardless of which part of the program is being used to access them.

3.1 Plots

The same plotting tool is used to develop all plots in INFORM DSS v2.0.

3.1.1 Navigating Plots

The plots can be navigated via the following commands:

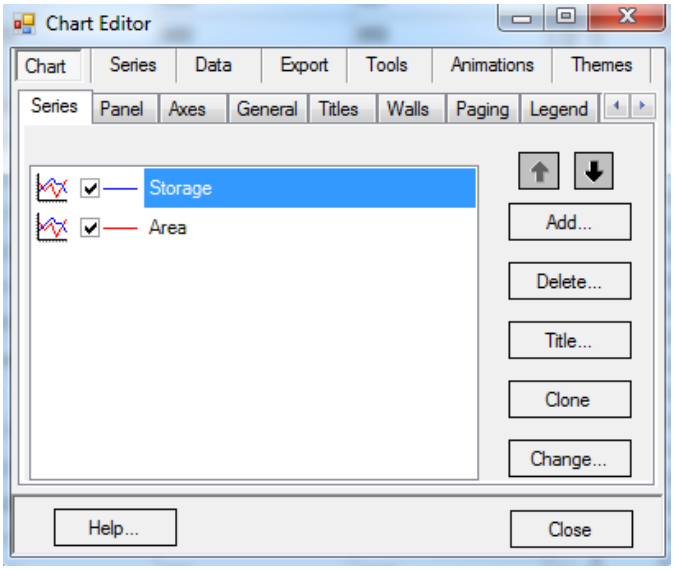
Pan: This function allows the plotted area to be moved up, down, right, and left. Right-click on the plot and keep holding the mouse while moving in the desired direction.

Zoom In: This function allows zooming into a smaller area of the plot. Click the left mouse button on the plot and keep holding it down while moving the mouse to the right (the mouse can also be moved up or down, but it needs to end up to the right of the starting position). A dotted box will be drawn to delineate an area. Releasing the button will zoom into the delineated area.

Zoom Out: This function allows zooming out to the full extent of the plot. Click the left mouse button on the plot, keep holding the button, move the mouse to the left (the mouse can also be moved up or down, but it needs to end up to the left of the starting position), and release the button.

3.1.2 Editing Plot Appearance

The appearance of plots can be changed. Right-click on the plot and select Chart Settings to open the Chart Editor.



The Chart Editor contains a series of options for changing the appearance of a plot. Furthermore, the plots can be exported in a variety of formats.

3.1.3 Data Tables

Data Tables are a tabular way to arrange data. The specific options available for each data table depend on the form in which they are located. Some data tables are just used to display data, while others allow the user to import data into the database.

Storage (TAF)	Elevation (ft)	Area (acres)
4.58	630	248
11.4	650	437
30.25	680	850
51.1	700	1234
80.31	720	1704
98.97	730	2032
121.07	740	2388
146.79	750	2760
176.35	760	3160
210.15	770	3606
248.51	780	4067
291.44	790	4519
339	800	5002
391.74	810	5557
450.37	820	6178

A data table consists of a series or rows and columns. The first row contains the column headings. These headings cannot be removed or edited. If enabled, double-clicking a particular column heading will sort the row entries.

The remaining rows in the data table contain a set of cells that display data. The following list contains commands that may be available for a data table. Please note that not all of these options are available for each data table in INFORM DSS v2.0.

Copy: Data can be copied from a data table to be exported to other applications. Select the cells in the data table to be copied by left clicking (selected cells will usually be highlighted in blue), right-click one of the selected cells, and select “Copy”. The data is now copied into memory and can be pasted.

Paste: Data can be pasted into a data table. Select the starting cell where the data is to be copied, right-click, and select “Paste”. This will paste the data into the data table. If the information to be pasted contains multiple rows and/or columns, data will be pasted into multiple cells.

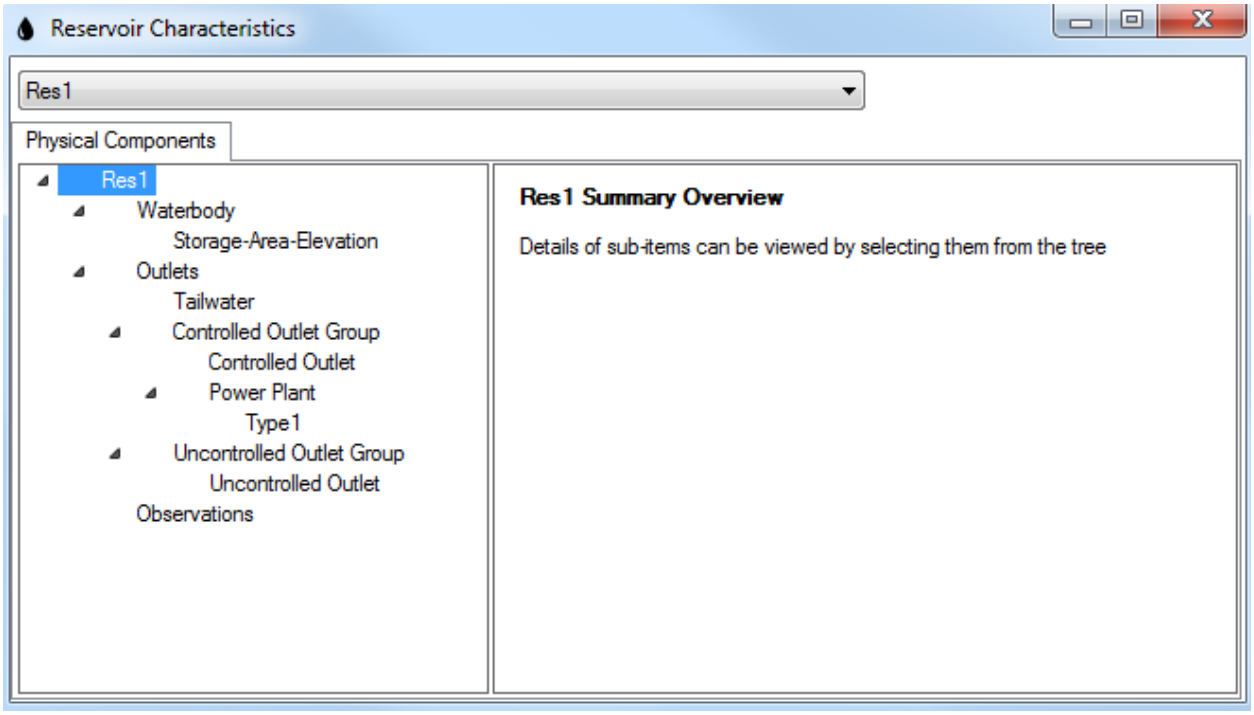
Fill Down: This option allows for quick filling of a data table column. Select the cell(s) containing the value to be filled down, right-click, and select "Fill Down". The value will automatically be copied into the rows below the selected cell(s).

Insert Row: Some data table allow users to insert new rows. Right-click the box at the top right of the data table to and select "Insert Row". Rows can also be inserted by highlighting a row, right-clicking to the left of the row, and selecting "Insert Row".

Delete Row: Some data table allow users to delete existing rows. Rows can be deleted by highlighting a row, right-clicking to the left of the row, and selecting "Delete Row".

3.1.4 Trees

Several interface components of INFORM DSS v2.0 use trees to organize information. Trees are organized hierarchically as a series of items. Trees can contain items at the same level as well as items that exist under other parent items. Right-clicking a specific item in a tree may open up a context menu with options that can be selected. Please note that the specific options depend on which item is selected, and some items may not open a context menu at all.



The following list contains a set of commonly found context menu entries:

Rename: This entry allows users to change the name of an item.

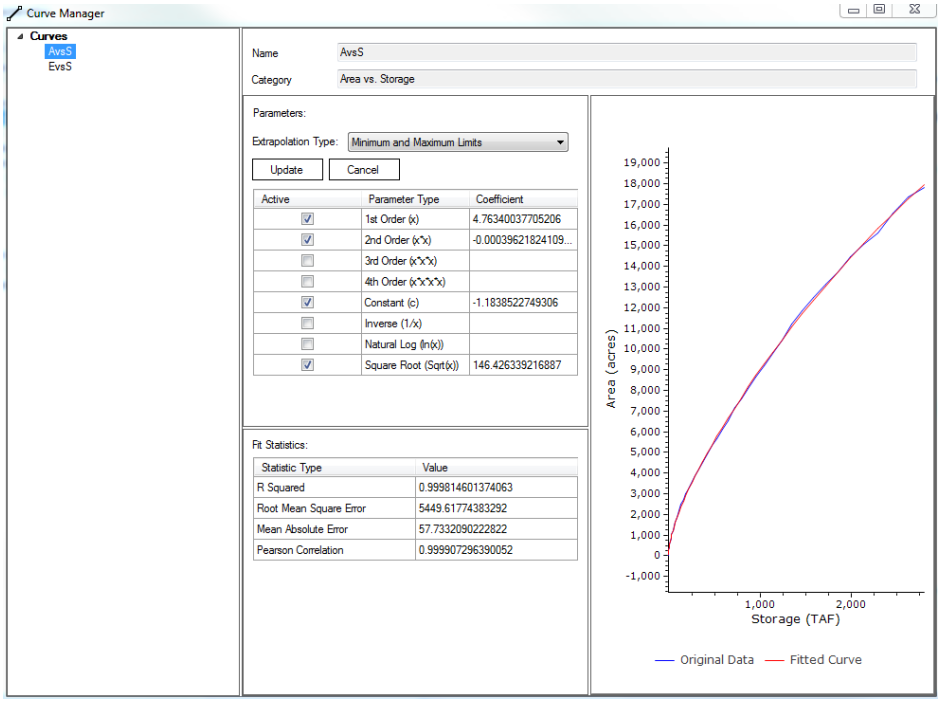
View/Edit Comments : This entry allows user to view, create, and edit user-defined comments about a particular item.

✕ Delete : This entry allows users to delete an item. Please note that deleting an item is an irreversible process, and the item and its associated data cannot be recovered. Additionally, all sub-items existing under a deleted item are also deleted.

i Single Turbine : This entry simply displays the name of the item (in this case, Single Turbine).

3.1.5 Data Fitting Tools

INFORM DSS v2.0 allows users to import data in a variety of formats. A common format is a table consisting of two or more columns, with each column representing a different variable. Several components of INFORM DSS v2.0 allow the users to fit functions to these variables, i.e., to define a variable in one column as an analytic function of a variable in another column. Whenever this is possible, the data entry screen will contain a Fit Analytic Curve button that opens a Curve Manager Tool form, as shown below.



Right-clicking "Curves" in the Item Tree on the left allows users to define a new curve and add the curve to the Item Tree. Left-clicking the item in the tree will open up new functionalities on the right side of the form that can be used to define the type of curve to fit. The following options can be defined by the user:

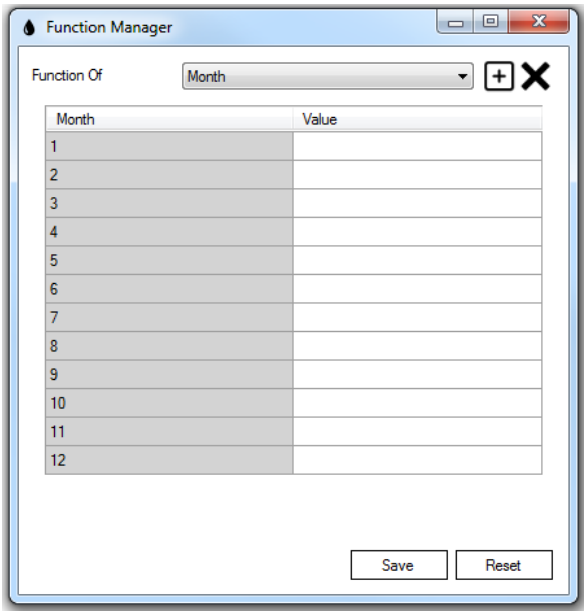
Parameters: A list of several functional forms and corresponding parameters is provided. Setting a parameter to "Active" will include the corresponding functional form in the curve. The analytical function of the curve is a summation of all individual functional forms multiplied by their parameters (coefficients). The values of the active parameters are automatically computed via least-squares regression and are displayed next to the parameters.

Extrapolation Type: Least-squares regression is used to fit the analytical function of the curve over the range of the data provided by the user. If there is a need to extend the curve over a broader range, you may choose among the following extrapolation options:

- *Use Function:* Extrapolated values are computed from the analytical function.
- *Linear Extrapolation:* Extrapolated values are computed by linear extrapolation along the tangent of the analytical function beyond the maximum or minimum limits of the original data range.
- *Minimum and Maximum Limits:* All extrapolated values are set equal to the minimum or maximum limit of the function over the original data range.

3.1.6 Function Manager

INFORM DSS v2.0 allows users to specify timeseries variables. A timeseries is defined by a vector of dates and a vector of corresponding variable values. The Function Manager can be used to define timeseries as a function of different quantities. The Function Manager can be opened as a separate form, but may also be found embedded within other forms.



Click ⊞ to add a new function type and use ✕ to remove an existing one.

The Combo Box next to the "Function Of" label can be used to select the function type to be used. Please note that the function types available for a certain timeseries depend on the timeseries in question; some timeseries may be defined by any function type, while others may only be defined by a subset of the available function types. The following function types are available:

Constant: The user is required to set a single constant value. This value will be used as the entry in the timeseries value vector for each and every date in the date vector.

Month: The user has the option to set a table of 12 monthly values. The entries in the timeseries value vector will then be set as follows: determine the month for each date in the date vector and use it to look up the corresponding value in the user-defined table. These values then become the entries in the timeseries value vector.

External Month: This function type is similar to the "Month" function type. The only difference is that the user does not define the monthly table in the Function Manager. Instead, the monthly table is defined by the user in the External Variable Manager and then referenced in the Function Manager by selecting the desired External Variable.

Computed Variable: The timeseries values are set by a user-selected variable and a user-defined table that relates the timeseries to the selected variable. The user first selects a variable that is computed as part of a model run (i.e., reservoir storages, river node flows, diversion amounts, etc.). It should be noted that, depending on the timeseries, only a subset of computed variables might be available for selection. Once a variable has been selected, a table is used to define the relationship between the selected variable and the timeseries value.

Relationship

	Demand Target (cfs)	Value (TAF)
	1	2
	10	20
▶	100	200

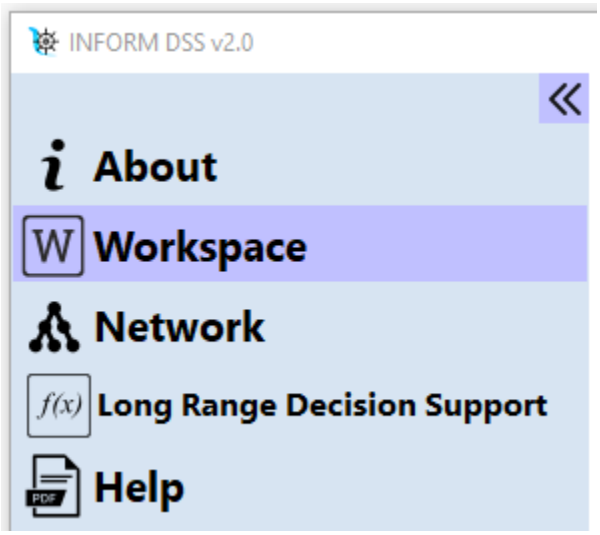
The first column in the table contains the selected variable values, while the second column contains the timeseries values. Each table needs to contain at least two rows of data, and the values in the first column need to be increasing from one row to the next. In the table above, if the selected variable has a value of 1 at a certain date, then the timeseries would get a value of 2 at the same date. Linear interpolation is used if the value of the selected variable is in between the values of two rows. Extrapolation is used if the value of the selected variable is outside the value range. The "Linear Extrapolation" option uses the slope at the first or last row of the table to find an extrapolated value, while the "Minimum and Maximum Limits" option sets the values equal to the first or last rows in the table, respectively.

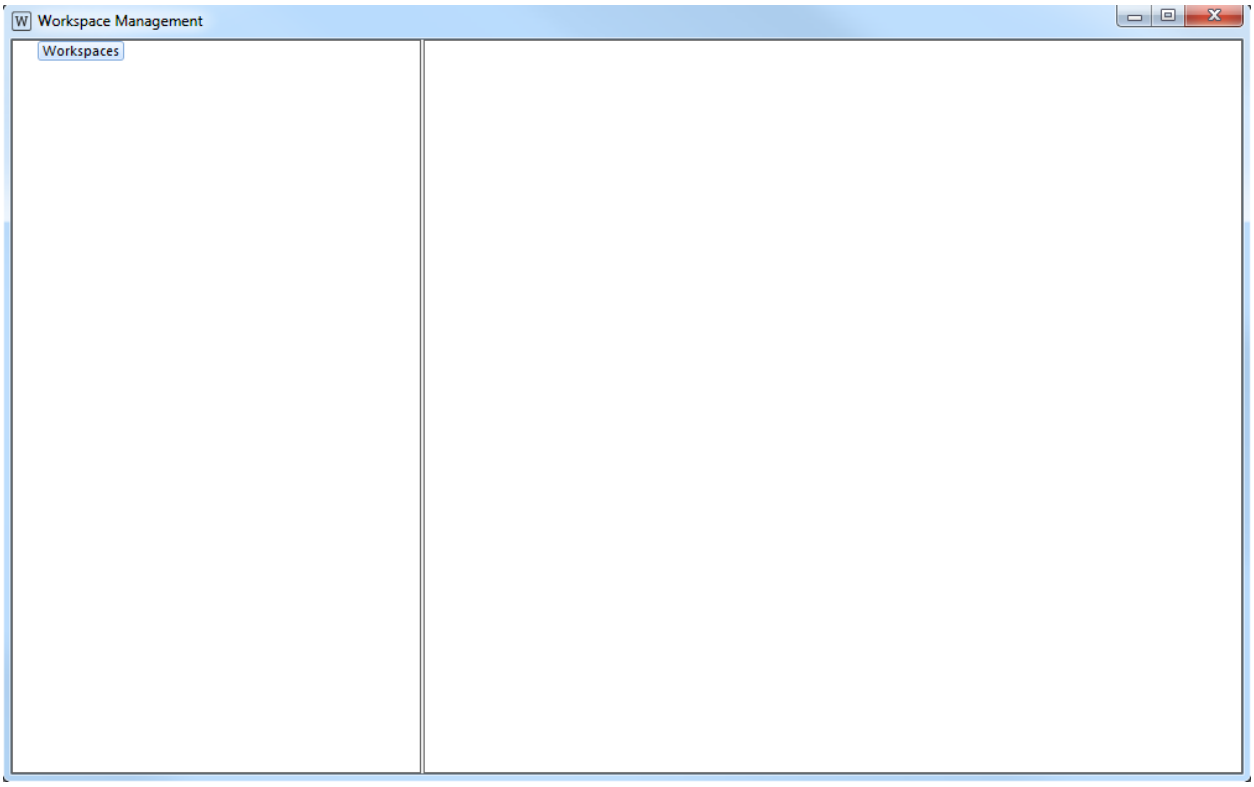
Chapter 4: Workspace Module

The Workspace module provides the means to define the location where files created by the user are stored. Additionally, the module can be used to import existing Workspaces (and the files contained within). A Workspace needs to be defined to enable the successful access and use of the remaining modules of INFORM DSS v2.0.

4.1 Opening the Workspace Module

The Workspace Module can be opened by clicking the "Workspace" button on the Sidebar Menu. This will open the Workspace Management form.



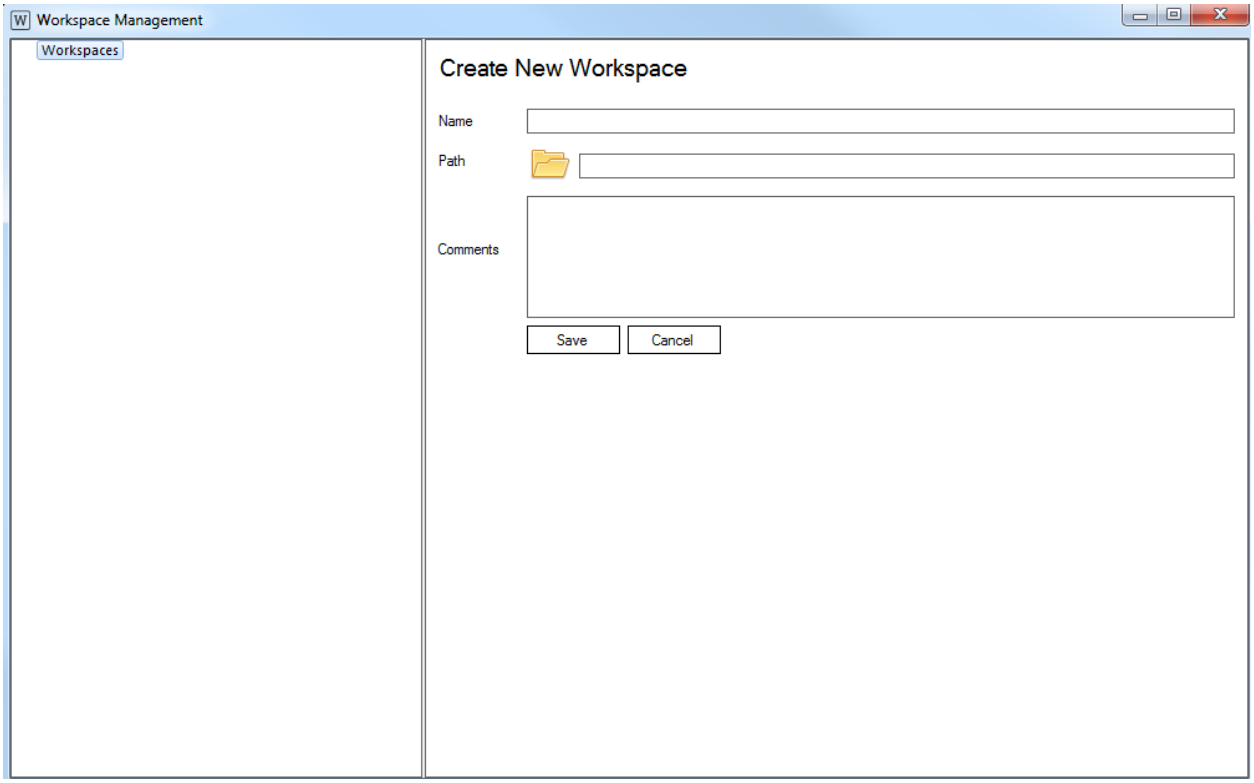


4.2 Workspace List

A list of previously defined workspaces is visible on the left side of the form under “Workspaces”. The Workspace List will be blank if no Workspaces have been defined yet.

4.3 Creating a New Workspace

Right-click “Workspaces” on the Workspace Management form and left click “Add new workspace”.



Fill in the following information on the right side of the form:

Name: The name of the Workspace.

Path: The folder path of the Workspace to be created. Click on the folder icon and use the dialog menu to select the folder path.

Comments: Comments about the Workspace. This section can be left blank if desired.

Then, click "Save" to create a new Workspace. The Workspace can now be selected under "Workspaces" on the left side of the form.

4.4 Importing an Existing Workspace

Existing workspaces created by INFORM DSS v2.0 can be imported. Importing an existing Workspace will allow the user to access all of the files previously created in the Workspace. Follow the same steps outlined in the section "Create A New Workspace". When choosing the path, select the folder in which the existing Workspace resides.

4.5 Activating/Deactivating a Workspace

Workspaces can be activated/deactivated by right-clicking the specific Workspace in the Workspace List and selecting "Activate" or "Deactivate". Deactivated Workspaces will not be visible in the other modules of INFORM DSS v2.0. Activated Workspaces are shown in the Workspace List in regular font, while deactivated Workspaces are shown in strikethrough font. Newly created or imported Workspaces are activated by default.

4.6 Removing a Workspace

Workspaces can be removed from the Workspace List by right- clicking the Workspace and selecting “Remove”. Note that removing a workspace will not delete the underlying files residing in the Workspace path. Users should navigate to the Workspace folder using Windows and functionalities.

Chapter 5: Network Module

The Network module is used to define the physical components of a river basin by defining a Network. The module contains a GIS-based interface that can be used to draw a water resources network consisting of a series of elements represented by arcs and nodes. Additional data can then be specified for the individual elements.

5.1 Overview

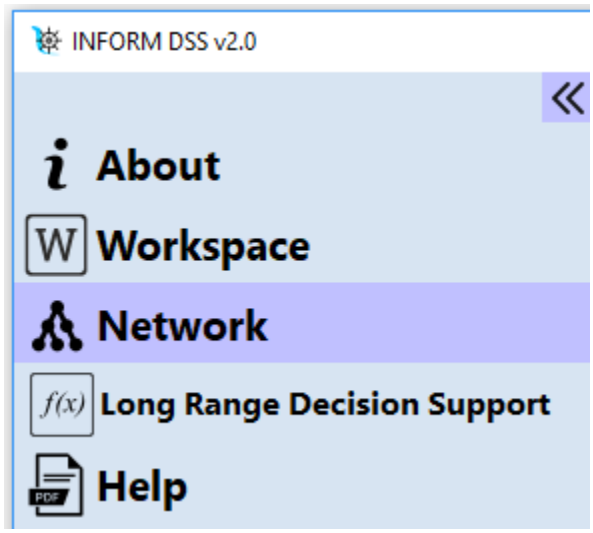
The general process of developing a new Network consists of the following steps:

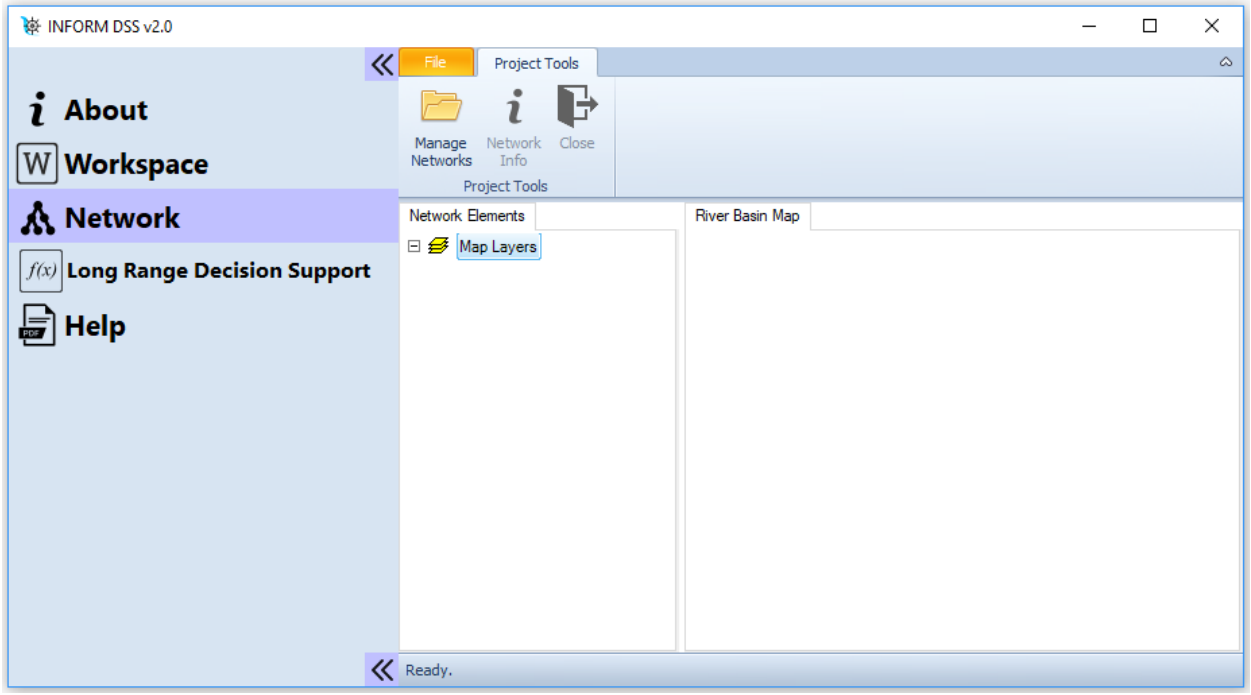
- Create New Network
- Draw Network Elements
- Specify Element Data

The following sections describe how to perform these steps.

5.2 Opening the Network Module

The Network module can be opened by clicking the "Network" button on the Sidebar Menu. The module will then be loaded into the main screen of INFORM DSS v2.0.





5.3 Ribbon Options

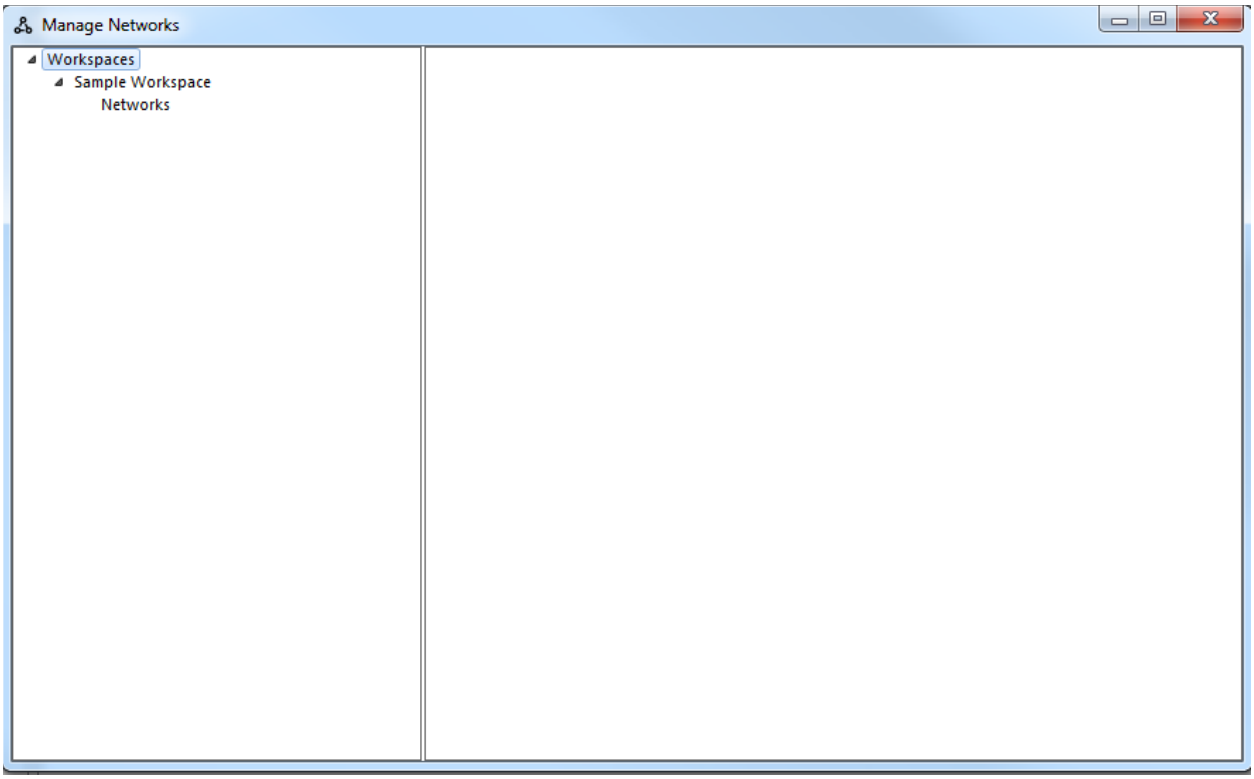
The Network module contains several options arranged in a ribbon control. Some options are available upon opening the module, while other options only become available once a Network has been opened.

5.4 Exiting the Network Module

The Network module can be closed by clicking on the “File” ribbon tab and selecting “Exit Module”.

5.5 Managing Networks

Networks can be created, re-opened, and deleted by selecting “Manage Networks” on the “Project Tools” of the ribbon tab, and opening the Manage Networks form.

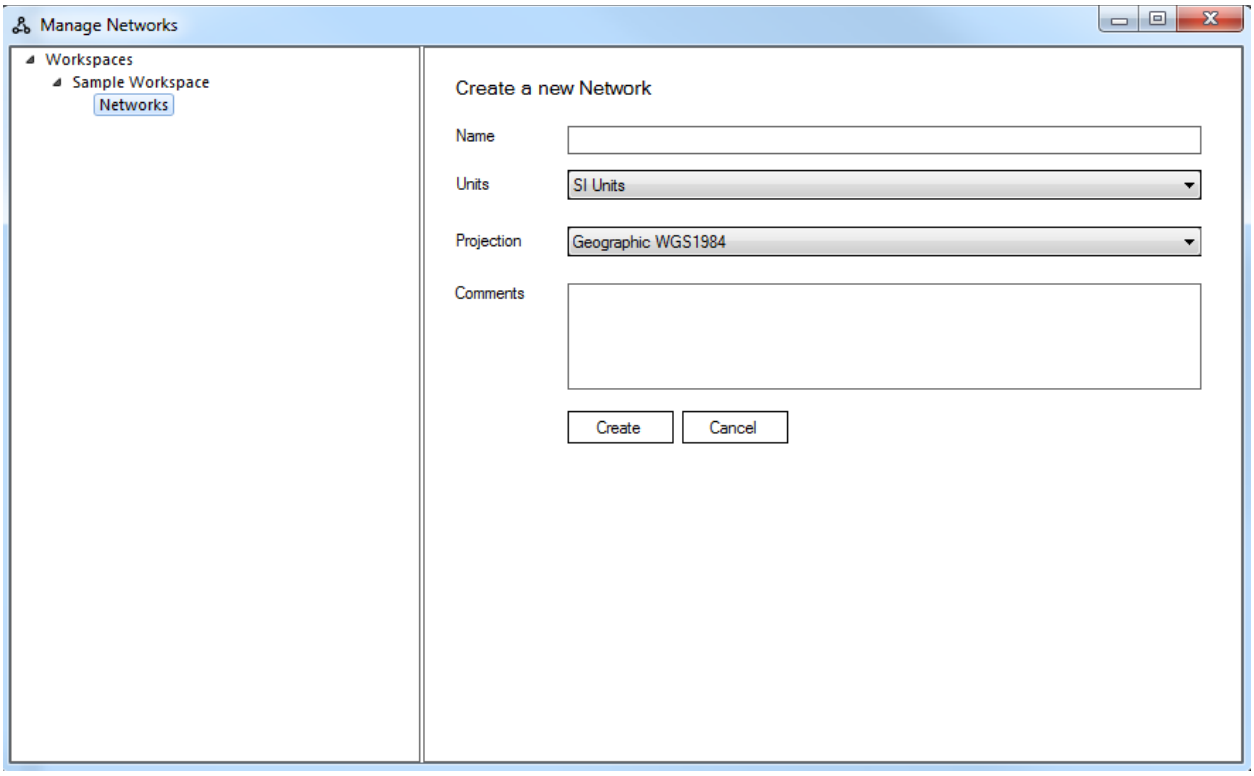


5.5.1 Network List

The Manage Networks form displays a tree of all existing Workspaces and Networks. A list of existing Networks is displayed under each Workspace. If a Network list is blank, then no Networks have been created yet.

5.5.2 Adding a New Network

New Networks can be added under any of the available Workspaces. To do so, identify the Workspace under which the Network is to be created, right-click “Networks” immediately under the Workspace, and select “Add New Network”.



Next, you will need to fill in the following information on the right side of the form:

Name: The name of the Network you wish to create.

Units: The units system to be used for the Network. Presently, the options include SI or English units.

Projection: The projection to be used for the GIS-based interface.

Comments: Comments about the Network. This section can be left blank if desired.

After you enter this information, click "Save" to create a new Network. Any files associated with this Network are automatically saved under the Workspace path.

5.5.3 Selecting an Existing Network

An existing Network can be selected on the left side of the form by finding the Workspace under which it was created and left-clicking the Network name.

5.5.4 Deleting an Existing Network

Right-click the Network to be removed from the left side of the form and select "Delete". Please note that deleting a Network will *permanently* delete all of its associated files from the Workspace.

5.5.5 Opening an Existing Network

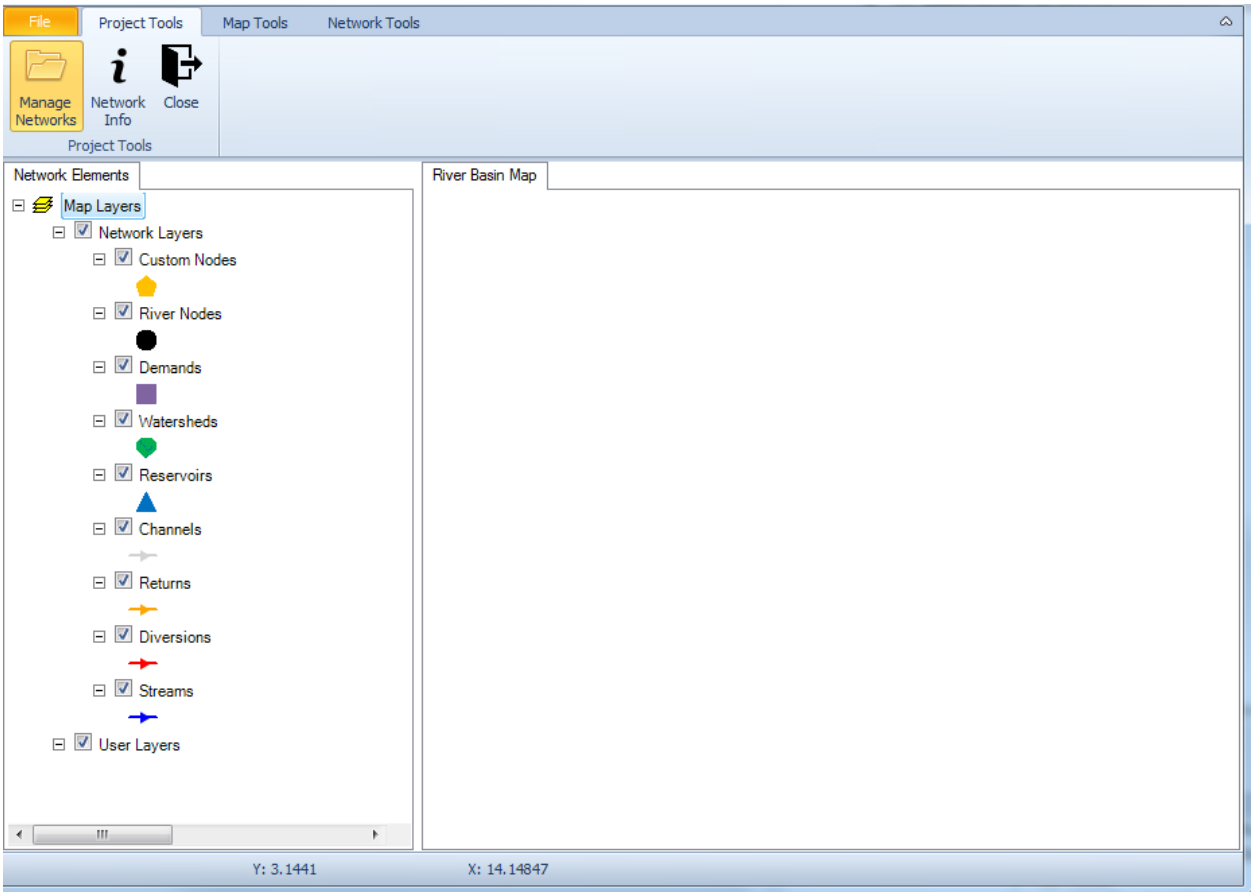
Left-click the Network you wish to open from the left side of the form, and select “Open” from the right side of the form.

5.6 Network User Interface

Networks can be created and edited by using a GIS-based map interface. The ribbon menu will also display additional items once a Network is created or opened.

5.7 GIS Control

GIS Control is used to display the elements of the river basin. The control consists of a legend with Network Elements on the left and a River Basin Map on the right.



5.7.1 River Basin Map (Map)

The River Basin Map displays the spatial locations of the elements in the river basin. Users can add new elements onto the map by using the buttons under the Network Tools ribbon tab. The map can also be used to display user-imported shapefiles.

5.7.2 Network Elements (Legend)

The legend lists all of the layers in the map. There are two main groups of layers: Network Layers and User Layers.

Network Layers: Network Layers are automatically created each time a new Network is created. Each individual layer represents a different type of water resources element. Network layers cannot be removed, but the appearance of the layers can be changed by right-clicking the layer on the legend and selecting the relevant option.

User Layers: Users have the option of importing their own GIS layers by using the "Add User Layer" button on the "Map Tools" ribbon tab. A variety of raster and vector formats can be added. Imported layers will then appear under the User Layers group. The appearance of the layers can again be edited by right-clicking the layer name and selecting the relevant option. User Layers can also be removed.

5.7.3 Map Tools Tab

The Map Tools Tab on the ribbon contains several options for navigating the map. These include:

Save Map: Saves changes made to the appearance of the map.

Add User Layer: Allows users to import their own GIS layers.

Pan: Moves the map in a desired direction.

Zoom In: Reduces the extent of the map displayed.

Zoom Out: Increases the extent of the map displayed.

Full Extent: Zooms up so that the displayed map extent contains all visible features across all layers.

Select From User Layer: Allows users to select features from a layer under the User Layers group. Multiple features can be selected at once.

Select from Network Layer: Allows users to select features from a layer under the Network Layers group. Only one feature can be selected at once.

Deselect All: Deselects any selected features from any layer.

5.8 Network Tools Tab

The Network Tools Tab contains several buttons that can be used to define the elements of a water resources network. The Add Arcs section of the tab contains a palette of arcs that can be drawn, while the Add Nodes section contains a variety of nodes.

5.8.1 Adding A New Element

The following steps are used to draw a *node* element: On the Network Tools Tab, click the button corresponding to the type of node to be drawn. Then, click on the part of the map where the node should be created. Once prompted, enter the name of the new node. Two nodes of the same type may not have the same name. Click Save. A new node should now appear on the map.

The following steps are used to draw an *arc* element: On the Network Tools Tab, click the button corresponding to the type of arc to be drawn. On the map, find the desired start node and left-click it. A red line should now appear when moving the mouse away from the start node. An arc can be drawn as multiple linear segments by left-clicking on the map to define the beginning point of a new segment. On the map, find the desired end node, right-click it, and select "Finish Shape". Once prompted, enter the name of the new arc. Two arcs of the same type may not have the same name. Click Save. A new arc should now appear on the map.

Arrows in the middle of an arc denote the flow direction. Please note that arcs can only be created by connecting them to a start and end node. Additionally, some arcs cannot start or end at certain nodes. The following table lists the types and maximum numbers of arcs allowed to start and end at each type of node.

Number of arcs that can start at these nodes

		Arcs			
		Stream	Channel	Diversion	Return
Nodes	Reservoir	1	Unlimited	Unlimited	0
	Watershed	1	0	0	0
	Demand Node	0	0	0	1
	River Node	1	Unlimited	Unlimited	0
	Delta Node	1	1	Unlimited	0

Number of arcs that can end at these nodes

		Arcs			
		Stream	Channel	Diversion	Return
Nodes	Reservoir	Unlimited	Unlimited	0	Unlimited
	Watershed	0	0	0	0
	Demand Node	0	0	1	0
	River Node	Unlimited	Unlimited	0	Unlimited
	Delta Node	Unlimited	Unlimited	0	Unlimited

5.8.2 Selecting an Existing Element

An existing element can be selected by first clicking the "Select from Network Layer" button on the Map Tools tab, navigating to the map, and left-clicking the element to be selected. Selected arcs should turn light blue and selected nodes should appear larger than unselected nodes. You can only select one element at a time.

5.8.3 Editing an Existing Element

Existing elements can be edited by first selecting them. Once an element has been selected, right click on the element to open up several options:

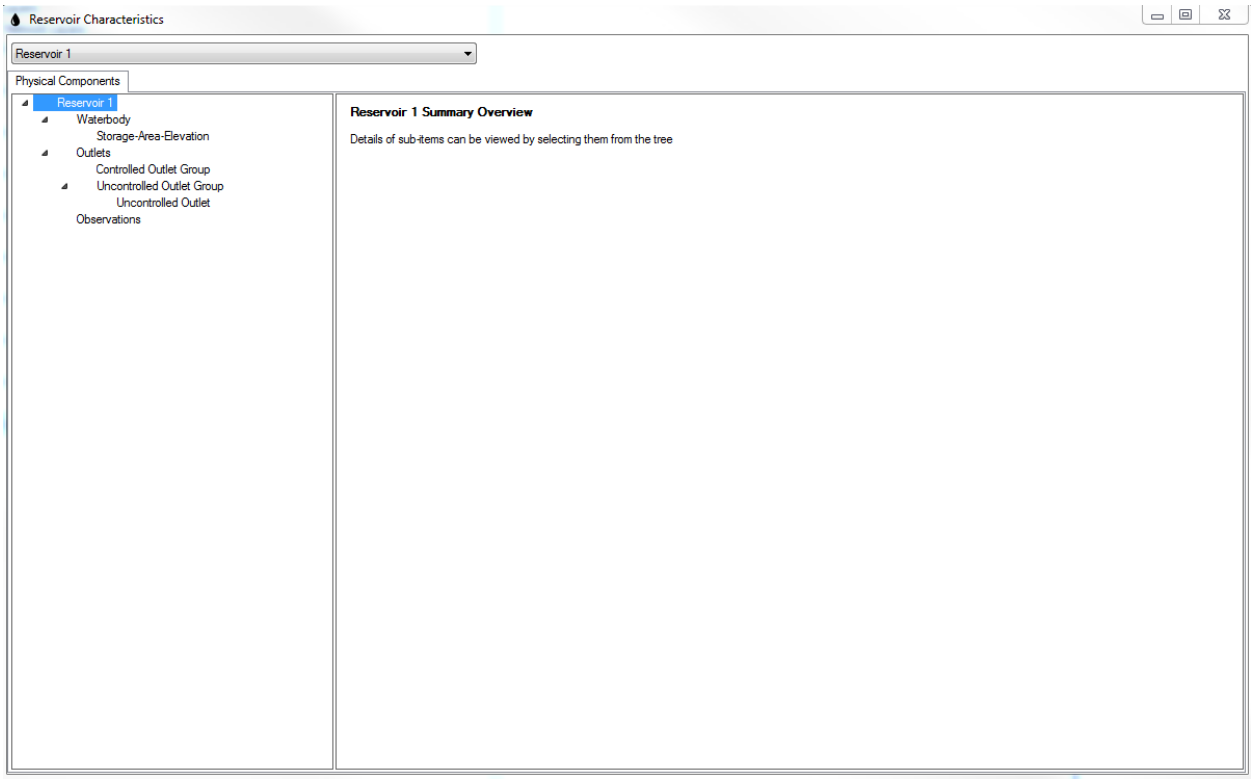
Rename: This option can be used to change the name of an existing element.

Delete: This option deletes the element. Please note that this operation cannot be reversed, and all of the data associated with the element will be deleted. When deleting a node, any arcs attached to it will also be deleted.

Details: This option opens up a new form that can be used to view and edit data associated with the element. Please refer to next section for more information.

5.9 Element Data

The data associated with an element can be viewed and edited by using the "Details" option described in the previous section. This option opens a new form as shown below (in this case, for an element of type "Reservoir").



The Combo Box at the top of the form can be used to select different elements of the same type as the element that was used to open the form.

The left side of the form contains an Item Tree with a list of items that can be defined for the element. Left-clicking on any item of the tree will display further information on the right side of the form. Right-clicking on any item may open up several additional options as described in the

following sections. The user may have the option to add new items or delete existing items. Please note that if an item is deleted, all associated data (including any items under it) will be removed and cannot be recovered.

The purpose of the Network module is to define the physical characteristics of the system. However, the option to add information associated with the system elements, such as reservoir operation policies, river routing models, or inflow quantities, may be provided in other modules rather than in this module.

5.9.1 Stream Element Data

The stream element does not contain any additional data that can be added here.

5.9.2 Channel Element Data

The channel element does not contain any additional data that can be added here.

5.9.3 Diversion Element Data

The diversion element does not contain any additional data that can be added here.

5.9.4 Return Element Data

The return element does not contain any additional data that can be added here.

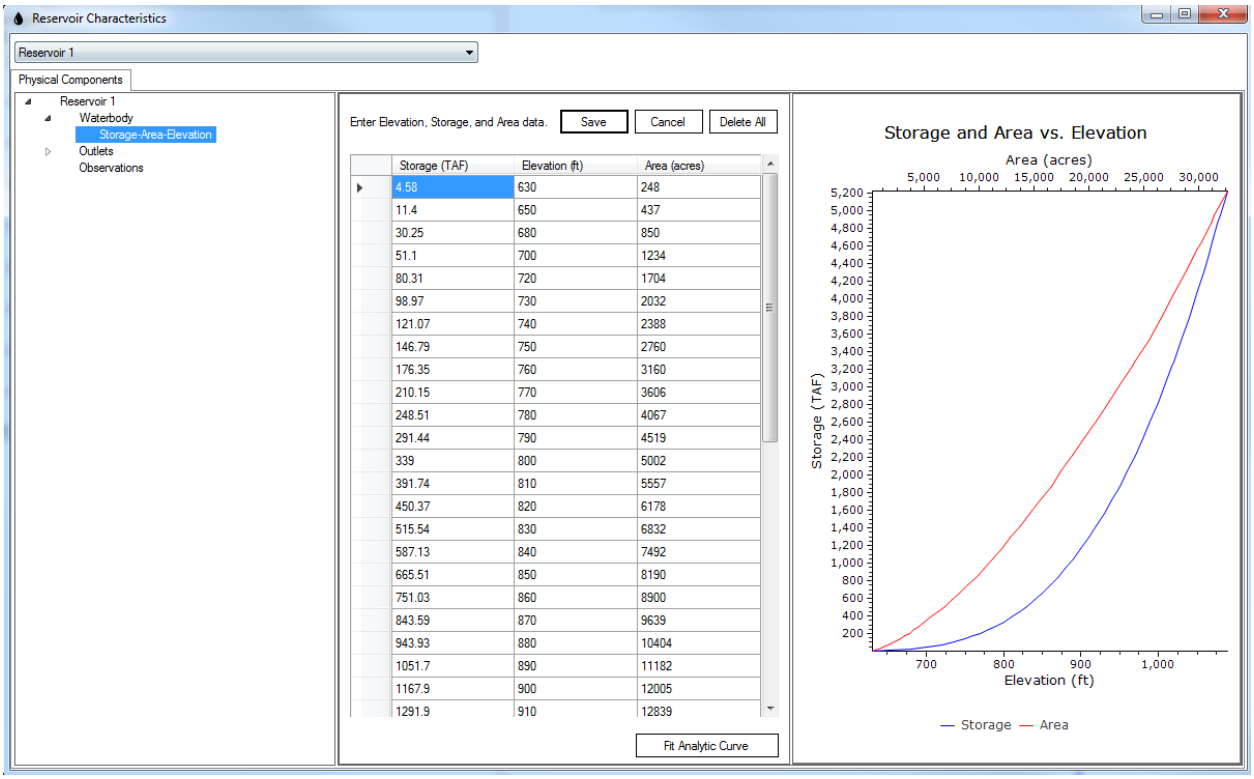
5.9.5 Reservoir Element Data

Reservoir elements require several items to be defined and added. These items are described next.

5.9.5.1 Waterbody

Each waterbody contains a Storage-Area-Elevation curve that defines the relationship between reservoir storage, area, and elevation.

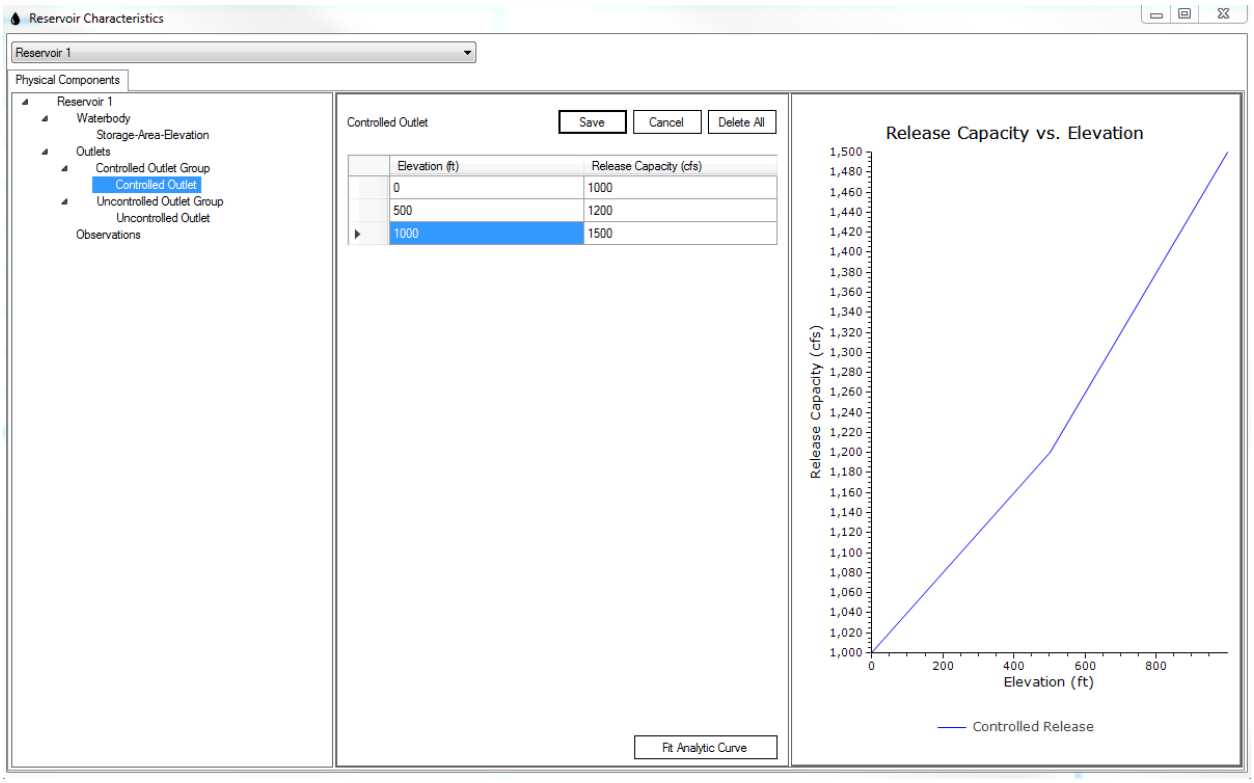
Selecting “Storage-Area-Elevation” from the tree on the left side of the form will open up a data entry table on the right side of the form. The data entry table can be used to input the relevant information for the reservoir. Click Save to import the data into the database. Once data has been imported, the right side of the screen will plot the data.



The data table can be used to input the relevant information for the reservoir. Click Save to import the data into the database. A plot of the imported data is displayed on the right side of the screen.

5.9.5.2 Outlets

Each reservoir may contain two different outlet groups: controlled and uncontrolled. Controlled outlets represent reservoir outlets where outflows can be controlled to be between zero and a maximum release capacity level specified by the user. You can add multiple controlled or uncontrolled outlets. By default, each reservoir contains one uncontrolled outlet that cannot be removed.



Controlled Outlet Group: Controlled outlets represent reservoir outlets where outflows can be controlled to be between zero and a maximum release capacity level specified by the user. Release capacity can vary as a function of elevation. To add a new controlled outlet, right-click the Controlled Outlet Group in the Item Tree and select "New Controlled Outlet". Once a new outlet has been created, the associated data can be entered by selecting (left-clicking) the outlet from the Item Tree and filling in the data on the right side of the form.

Uncontrolled Outlet Group: Uncontrolled outlets cannot be controlled, and release at the exact amounts specified by the user. Releases can vary as a function of elevation. Uncontrolled outlets can be added by right-clicking the Uncontrolled Outlet Group and selecting "New Uncontrolled Outlet". Once a new outlet has been created, the associated data can be entered by selecting (left-clicking) the outlet from the Item Tree and filling in the data on the right side of the form.

5.9.5.3 Power Plants

Power plants are special types of controlled outlets that can be added under the controlled outlet group. Power plants differ from regular controlled outlets in that the discharge passing through the outlet can be used to generate electricity.

To add a new power plant, right-click the Controlled Outlet Group in the Item Tree and select "New Power Plant". Once a new power plant has been created, several sub-items can be added by right-clicking it.

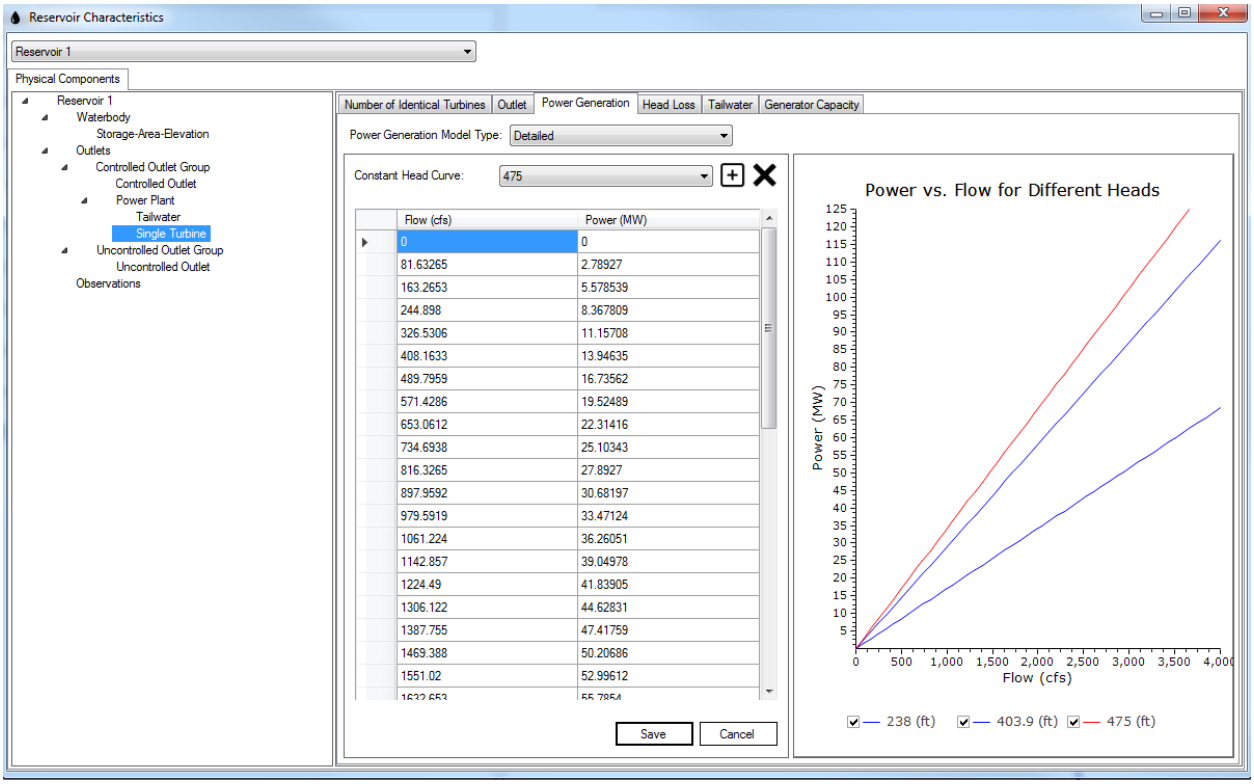
5.9.5.3.1 Single Turbine

A single turbine represents a specific turbine type that is part of a power plant. The following information should be defined for each single turbine:

Number of Identical Turbines: If a power plant contains multiple turbines of the same type, the user can define an individual single turbine type for each turbine. Alternatively, only one single turbine can be defined and the number of identical turbines can be set to correspond to the total number of turbines of the same type.

Outlet: This section defines the outlet discharge capacity of the turbine type. The procedure used to specify the required data is identical to the procedure used to define other controlled outlet capacities.

Power Generation: This section defines the power generation that results from a given head and discharge quantity through the turbine. This information is specified by adding a series of curves that provide the power generation as a function of flow discharge for a constant head level. The following steps can be used to specify these curves:



Click the ⊞ button to add a new constant head curve. (When prompted, add the numerical value of the constant head.) A new entry in the Combo Box will be created, and a data entry table will appear.

Enter the data (power as a function of flow discharge for the chosen level of constant head) into the data entry screen and press Save. The curve should appear in the plot on the right.

Repeat the same process for other constant head levels. Each individual constant head curve can be accessed by selecting its value from the Combo Box (the plot will also show the curve associated with the selected value in red).

Existing curves can be removed by clicking the ✖ button.

Head Loss: Head losses reduce the head acting on the turbine. Head losses can be specified as a function of reservoir elevation.

Tailwater: Tailwater elevation reduces the head acting on the turbine. An existing tailwater relationship should be selected. Refer to the Tailwater section for defining a new Tailwater-Elevation relationship.

Generator Capacity: The generator capacity represents the capacity of the generator that converts the turbine power into electricity. The maximum power produced by the turbine is the lesser of the generator capacity and the amount being generated by the turbine (a function of the head, turbine discharge, and power generation curves).

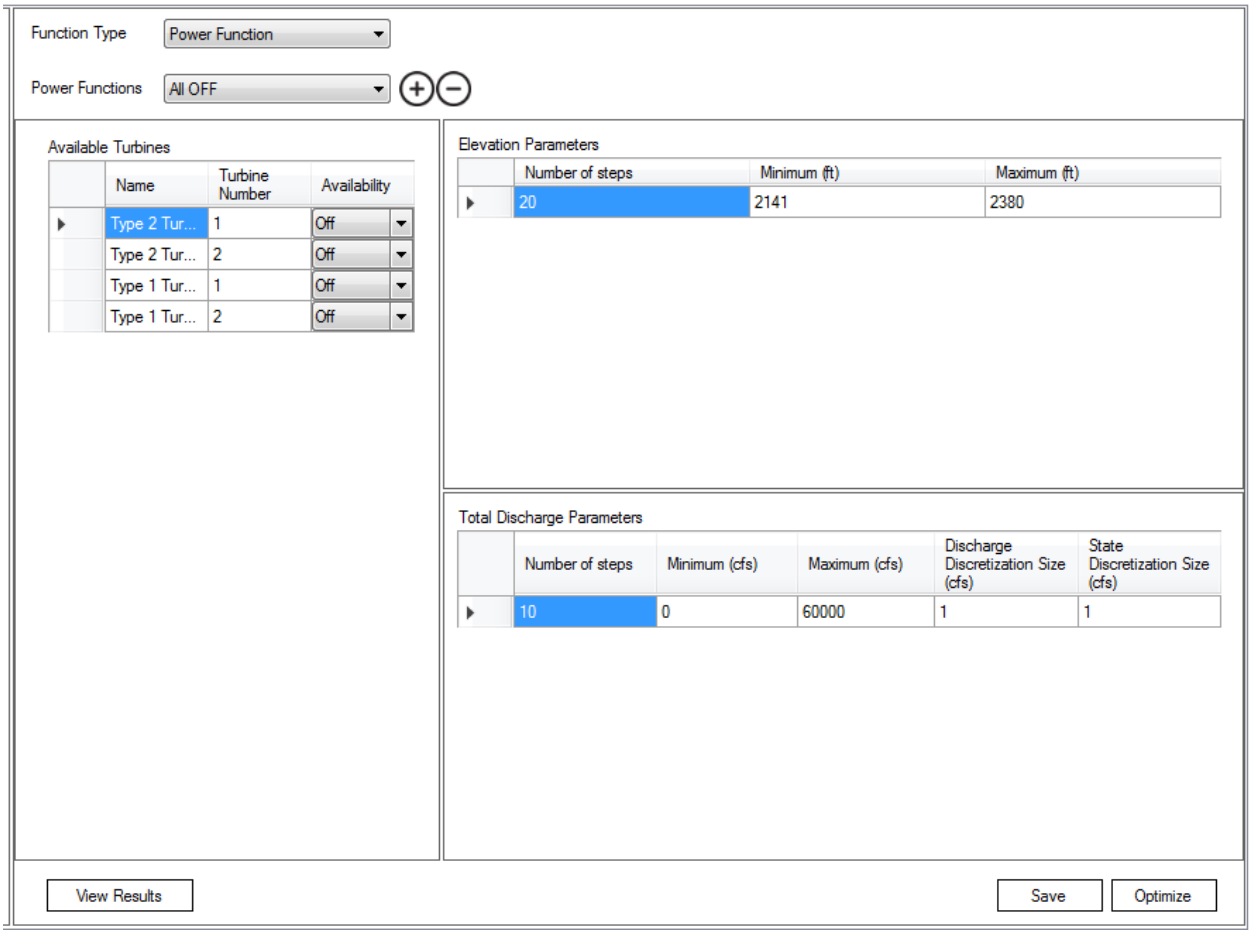
5.9.5.3.2 Aggregate Turbine

A single power plant can contain several individual turbines. In order to model such configurations, rules that specify how much water is being released from each reservoir have to be defined. Aggregate turbines provide an alternative to this approach by aggregating the entire power plant into Power and Energy functions.

5.9.5.3.3 Power Function

Power Functions represent the total amount of power produced by an instantaneous discharge from the reservoir at different reservoir elevations. The Power Function is generated by an algorithm that choses the discharges through each individual turbine so that the power generation across the entire power plant is optimized. The algorithm determines how to operate the individual turbines so that the maximum amount of power is generated for a given reservoir elevation and total instantaneous reservoir discharge. The same process is repeated for many combinations of reservoir elevation and instantaneous discharge. The end-result is a Power Function that consists of individual constant elevation curves. Each constant elevation curve specifies the power generation as a function of total reservoir discharge at a specific elevation.

Adding An Optimized Power Function: Left-click the Aggregate Turbine on the Item Tree on the left side of the form to open up a new section on the left side of the screen. Select the “Power Function” option from the Aggregation Type Combo Box. Then click the ⊕ button to open a new form. Enter the name of the new function, select “Optimization” from the Type Combo Box, and click “Save” to add a new Power Function. This will open up a new section with several options that have to be set.



You first need to choose which turbines to include in the Power Function. Turbines can be turned on and off by selecting "On" or "Off". We recommend that a different Power Function be created for each combination of available turbines so that models in other modules can accurately compute power and energy generation for different turbine availabilities.

The number of constant elevation curves can be specified by setting the Elevation Parameters table. Enter the number of constant elevation curves to create, as well as the minimum and maximum constant elevation values. The Power Function algorithm will automatically create the desired number of constant elevation curves between the minimum and maximum values. Additional rows can be added to the table and used to define more ranges. Different ranges should not overlap.

The number of reservoir discharges to be used in developing the constant elevation curves can be added to the Total Discharge Parameters table. Insert a new row into the table by right-clicking the box under the "Total Discharge Parameters" label and filling in the parameters. The number of steps and minimum and maximum values will be used to generate the range of discharges to be used when constructing the constant elevation curves. The two additional parameters, "Discharge Discretization Size" and "State Discretization Size", are parameters used by the optimization algorithm to generate the Power Function. Setting these values to be very small will increase accuracy of the results, but will also increase the amount of time it takes for the algorithm to terminate. A general rule of thumb is to set these values at roughly 1/100th of the individual turbine capacity. However, we recommend that you perform a sensitivity analysis, starting with large steps

and gradually reducing them. Additional different non-overlapping ranges can be added to the table.

Once all of the parameters have been set, click the "Optimize" button at the bottom of the screen. A green bar will appear next to the button highlighting model progress.

The Power Function computed by the algorithm can be viewed by clicking "View Results". Users also have the option of manually editing the results, if they so desire.

Adding A User Defined Power Function: Power Functions can also be generated without using the optimization algorithm. In that case, the user will need to enter a number of constant elevation curves, similar to entering the constant head curves used to define power generation for a Single Turbine.

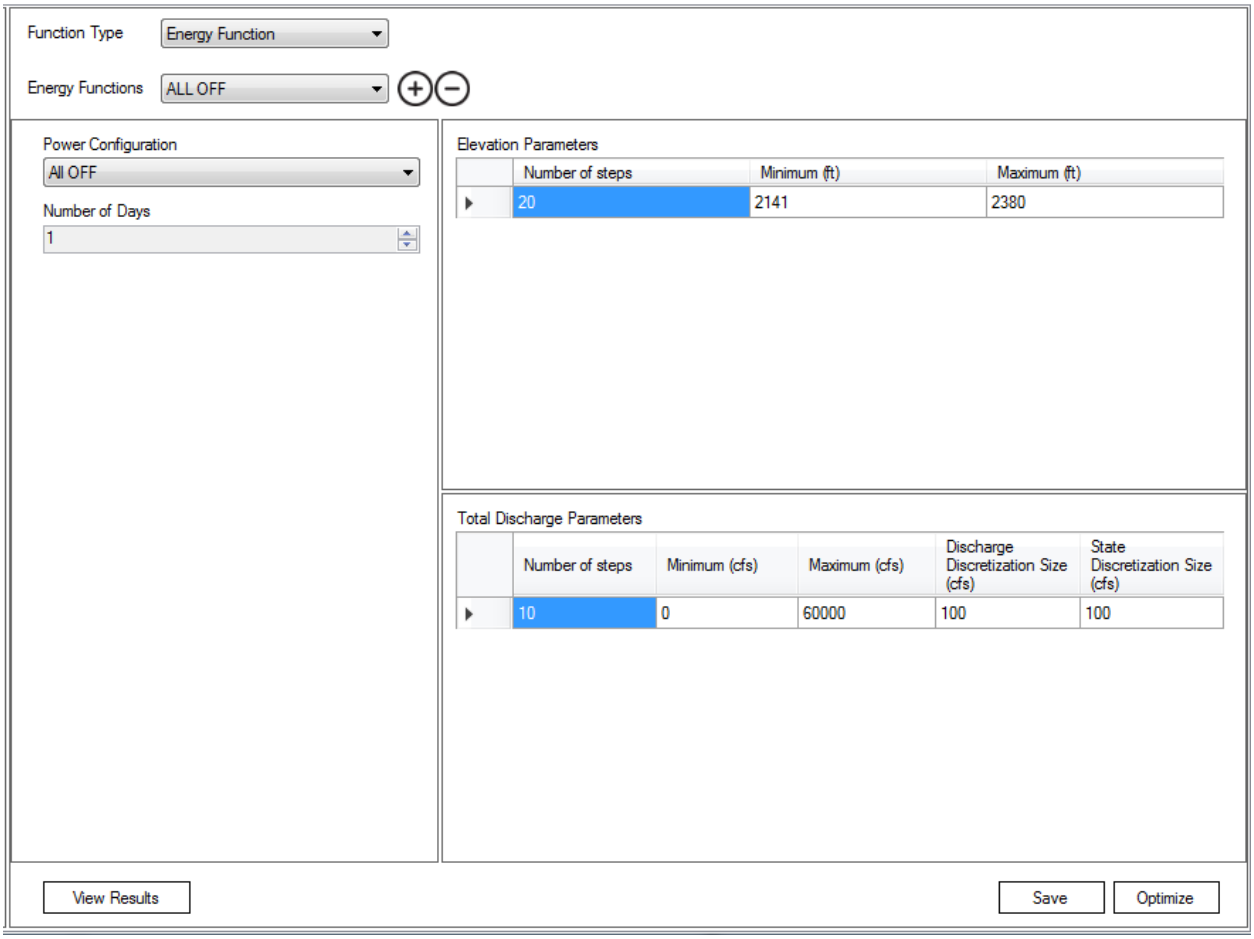
Left-click the Aggregate Turbine on the Item Tree on the left side of the form to open up a new section on the left side of the screen. Select the "Power Function" option from the Aggregation Type Combo Box. Then click the ⊕ button to open a new form. Enter the name of the new function, select "User Defined" from the Type Combo Box, and click "Save" to add a new Power Function. This will open up a new section with several options that have to be set.

5.9.5.3.4 Energy Function

As second challenge that modelers occasionally face is when the model time step is relatively long and computing hydropower generation would result in large inaccuracies. For instance, when using a monthly time step, the release variables (needed to compute power generation) would represent monthly averages. However, the release quantities (and the subsequent tailwater elevations and head losses) resulting from real-life instantaneous power generation often differ significantly from monthly averages; as a result, power generation amounts computed from monthly averages often do not adequately correspond to actual power generation. The second purpose of the Aggregate Turbine is to develop an Energy Function that more accurately estimates energy generation over such long time steps.

Energy Functions are created by first selecting a Power Function. An optimization algorithm is then used to determine how to operate the power plant (using power generation as defined by the Power Function) on an hourly basis for a user specified timespan. Given a total volume of water to be released over the timespan, the algorithm determines how much water to release during each hour so that the total energy generation over the whole timespan is maximized. The end-result is an Energy Function that consists of individual constant elevation curves. Each constant elevation curve specifies the energy generation as a function of total reservoir release in the timespan.

Adding An Optimized Energy Function: Left-click the Aggregate Turbine on the Item Tree on the left side of the form to open up a new section on the left side of the screen. Select the "Energy Function" option from the Aggregation Type Combo Box. Then click the ⊕ button to open a new form. Enter the name of the new function, select "Optimization" from the Type Combo Box, and click "Save" to add a new Energy Function. This will open up a new section with several options that have to be set.



The user first needs to choose the Power Function upon which the Energy Function will be derived by selecting the function from the Combo Box. We recommend that a different Energy Function be created for each Power Function, so that models in other modules can accurately compute energy generation for different turbine availabilities.

The timespan over which the energy is to be produced can be set under the “Number of Days” label. The timespan has to be specified in whole days.

The number of constant elevation curves can be specified by setting the Elevation Parameters table. Enter the number of constant elevation curves to create, as well as the minimum and maximum constant elevation values. The Power Function algorithm will automatically create the desired number of constant elevation curves between the minimum and maximum values. Additional rows can be added to the table and used to define more ranges. Different ranges should not overlap.

The number of reservoir release volumes to be used in developing the constant elevation curves can be added to the Total Discharge Parameters table. Insert a new row into the table by right clicking the box under the “Total Discharge Parameters” label and fill in the parameters. The number of steps and minimum and maximum values will be used to generate the range of release volumes to be used when constructing the constant elevation curves. The two additional parameters, “Discharge Discretization Size” and “State Discretization Size” are parameters used by the optimization algorithm to generate the Energy Function. Setting these values to be very small will increase accuracy of the results, but will also increase the amount of time that it takes for the

algorithm to terminate. A general rule of thumb is to set these values at roughly 1/100th of the individual turbine capacity. However, we recommend that you perform a sensitivity analysis, starting with large steps and gradually reducing them. Additional different non-overlapping ranges can be added to the table.

Once all of the parameters have been set, click the "Optimize" button at the bottom of the screen. A green bar will appear next to the button, highlighting model progress. The Energy Function computed by the algorithm can be view by clicking "View Results". Users also have the option of manually editing the results, if they so desire.

Adding A User-Defined Energy Function: Energy Functions can also be generated without using the optimization algorithm. In that case, the user will need to enter the constant elevation curves, similar to entering the constant head curves used to define power generation in Single Turbines. Left-click the Aggregate Turbine on the Item Tree on the left side of the form to open up a new section on the left side of the screen. Select the "Energy Function" option from the Aggregation Type Combo Box. Then click the ⊕ button to open a new form. Enter the name of the new function, select "User Defined" from the Type Combo Box, and click "Save" to add a new Energy Function. This will open up a new section with several options that have to be set.

5.9.5.4 Tailwater

Tailwater level is the stage of the river downstream of the reservoir. Tailwater is defined as a relationship between flow discharge and river water elevation at the outlet. Tailwater relationships can be added under the following items:

Outlets: The tailwater elevation is a function of the total outflow discharge (i.e., all controlled and uncontrolled outlets) of the reservoir.

Controlled Outlet Group: The tailwater elevation is a function of the total controlled outflow discharge (i.e., all controlled outlets) of the reservoir.

Uncontrolled Outlet Group: The tailwater elevation is a function of the total uncontrolled outflow discharge (i.e., all uncontrolled outlets) of the reservoir.

Individual Controlled Outlet: The tailwater elevation is a function of the outflow discharge of the particular controlled outlet for which the tailwater is created.

Individual Uncontrolled Outlet: The tailwater elevation is a function of the outflow discharge of the particular uncontrolled outlet for which the tailwater is created.

Power Plant: The tailwater elevation is a function of the outflow of the particular power plant (i.e., the sum of all single turbine outflow discharges) for which the tailwater is created.

Single Turbine: The tailwater elevation is a function of the outflow discharge of the particular single turbine (i.e., the single turbine outflow times the number of identical turbines of that type) for which the tailwater is created.

5.9.6 Watershed Element Data

The watershed element does not contain any additional data that can be added here.

5.9.7 Demand Node Element Data

The demand element does not contain any additional data that can be added here.

5.9.8 River Node Element Data

River nodes can contain hydropower generation facilities similar to those defined at reservoir nodes. Unlike reservoirs, however, river nodes do not compute the storages or elevation in a waterbody. Rather, river nodes are only intended to compute hydropower generation in constant elevation power plants, such as those at smaller run-of-river facilities.

Power generation items can be added to a river node by right-clicking facilities and selecting the appropriate options. These items are identical to those described in the section discussing reservoir element data.

5.9.9 Delta Node Element Data

The delta node element is a custom node created specifically for the INFORM system to represent the Sacramento–San Joaquin River Delta. The delta node element does not contain any additional data that can be added here. The node keeps track of the mass balance in the delta as well as of the isohaline interface position (X2).

Chapter 6: Long Range Decision Support

The Long Range Decision Support (LRDS) module includes water resources models designed to support water resources systems planning and management over a user-defined time horizon from several months to a few years. The LRDS module employs a monthly time step and utilizes inflow forecasts provided in ensemble form. The aim of the LRDS module is to identify management options that meet multiple user-defined system objectives and requirements as best as possible. Because water management objectives and uses are likely to compete, the LRDS module is designed to (*a*) generate critical tradeoffs among the system uses and (*b*) assess the system response across the tradeoff regions. The LRDS module includes both optimization and simulation models to ensure that the generated tradeoffs are optimal (in a Pareto efficient sense) and that *simulated* system conditions under different management options adequately reflect *actual* conditions that would occur in the system under the same management options.

6.1 Overview

The LRDS module of INFORM DSS v2.0 contains two main functionalities. The first facilitates the definition of operational models, objectives, and requirements as well as the modeling of how water moves through the system. The second builds on the first to facilitate the evaluation of system performance with respect to the stated objectives and performance metrics over a user-specified horizon and for particular inflow forecasts. The forecasts can be the output of an external forecasting model or constructed using the DSS.

6.2 Modeling Approach

The LRDS module makes use of two different water resources modeling techniques. The first modeling technique consists of an optimization model aiming to generate management policies that specify the system decisions as a function of system conditions represented by the system states. These management policies are then used as input to a simulation model that simulates the response of the system when these policies (and possibly other user-defined rules) are used to operate the system.

The LRDS module uses inflow forecasts to represent the inflow volumes expected to materialize and enter the system at each time step of the planning/management horizon. Due to uncertainties in predicting future inflows, the forecasts are represented in an ensemble form. An ensemble consists of a collection of individual traces, with each trace representing an equally likely future inflow timeseries. These ensembles are directly used by the optimization and simulation models to manage the system under the range of hydrologic conditions represented by the ensemble. As a result, the output of the optimization and simulation models is also provided in the form of ensembles predicting the response of different system variables such as storages, releases, hydropower generation, river flows, and environmental indicators. These system variable forecasts can be analyzed to determine the range of system responses that may materialize over the forecast/management horizon.

Users employ objectives and constraints that define the management problem solved by the optimization model. Objectives represent the operational goals, and constraints represent physical or operational limits that should not be violated. The objectives and constraints are then used to solve a multi-stage stochastic optimization problem over a user-specified horizon. The optimization algorithm, known as Extended Linear Gaussian Quadrature (ELQG), optimizes the

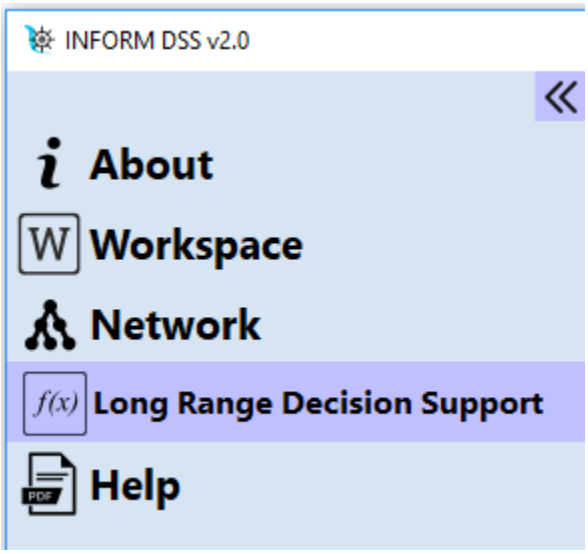
expected value of the objective function over the ensemble while also enforcing reliability constraints on various system variables. The reliability levels at which such constraints are satisfied are also user-specifiable. A detailed discussion of the algorithm is beyond the scope of this user manual but can be found in previous INFORM project reports and in several journal articles.

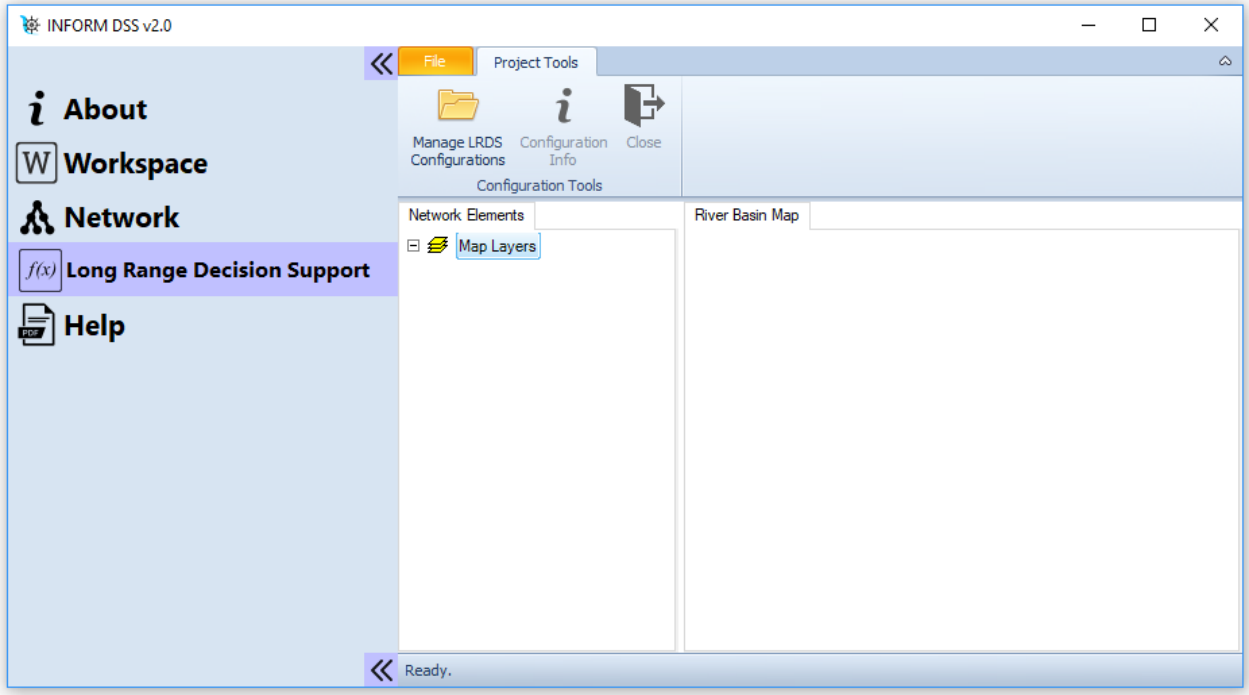
The end-result of the optimization model is a set of management policies that specify management decisions as functions of system states. In reservoir systems, decisions typically represent controlled reservoir releases, and states typically represent reservoir storages. Additionally, flows at river nodes can be modelled as states. For the INFORM project, the X2 location in the delta is modelled as an additional state, and the pumping from the delta as a decision variable.

The simulation model simulates the flow of water through the system given a set of management policies. These can be the policies derived by the optimization model or a set of heuristic operating rules specified by the user. The simulation model simulates the system response (i.e., the time response of each system variable) for each trace of the ensemble forecast. The final outputs are ensembles of system variables, such as storages, releases, power generation amounts, river flows, etc., over the management horizon. Lastly, the ensembles resulting from a particular combination of inflow forecasts and management policies can be analyzed to determine how well different operational objectives and constraints are met. Repeating such analyses systematically and interactively across a range of management policies can help the system stakeholders identify the policy that best satisfies their collective interests. The INFORM DSS v2.0 is designed to inform the stakeholder decision process.

6.3 Opening and Exiting the LRDS Module

The LRDS module can be opened by clicking the "Long Range Decision Support" button on the Sidebar Menu. The module will then be loaded into the main screen of INFORM DSS v2.0.





The LRDS module contains several options arranged in a ribbon control. Some options are available upon opening the module, while other options only become available once a LRDS configuration has been opened.

The LRDS module can be closed by clicking on the "File" ribbon tab and selecting "Exit Module".

6.4 Managing LRDS Module Configurations

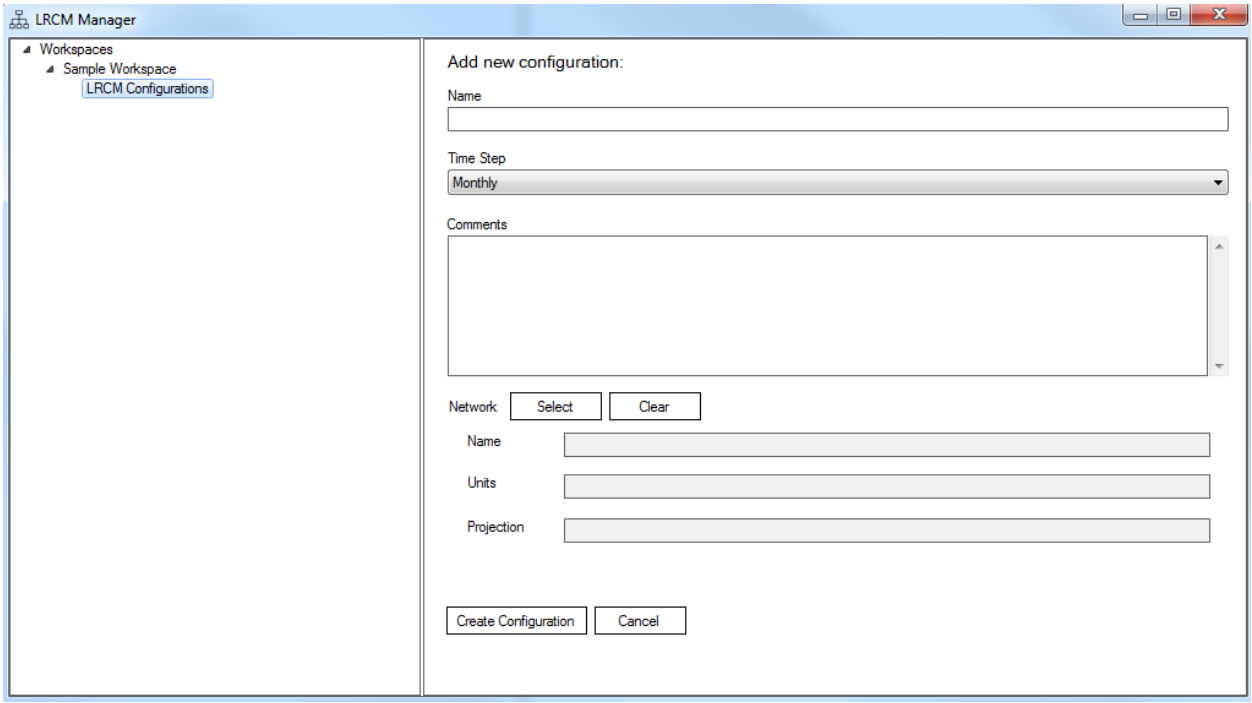
LRDS module Configurations can be created, re-opened, and deleted by clicking "Manage LRDS Configurations" on the "Project Tools" tab of the ribbon. This will open the LRDS Manager form.

6.4.1 LRDS Configuration List

The LRDS Manager form displays a tree of all existing Workspaces. A list of existing LRDS Configurations is displayed under each Workspace. If an LRDS Configuration List is blank, then no LRDS Configurations have been created yet.

6.4.2 Adding a New LRDS Configuration

New LRDS Configurations can be added under any of the available Workspaces. Identify the Workspace under which the LRDS Configuration is to be created, right-click "LRDS Configurations" immediately under the Workspace, and select "Add New LRDS Project".



Next, fill in the following information on the right side of the form:

Name: Enter the name of the LRDS Configuration.

Time Step: Select "Monthly".

Comments: Enter comments about the LRDS Configuration. This section can be left blank if desired.

Network: Click the "Select" button to open up a new form. Use the tree on the left side of the form to select the Network upon which the LRDS Configuration will be based, and click "Select". Fill in the Network Name, Units, and Projection fields on the LRDS Manager form.

Lastly, click Create Configuration. A new LRDS Configuration will be created, and any files associated with this LRDS Configuration are automatically saved under the Workspace path.

6.4.3 Selecting an Existing LRDS Configuration

An existing LRDS Configuration can be selected on the left side of the form by finding the Workspace under which it was created and left-clicking the LRDS Configuration name.

6.4.4 Deleting an Existing LRDS Configuration

Right click the LRDS Configuration to be removed from the left side of the form and select "Delete". Please note that deleting a LRDS Configuration will permanently remove all of its associated files from the Workspace.

6.4.5 Opening an Existing LRDS Configuration

Left-click the LRDS Configuration to be opened from the left side of the form. Select "Open Configuration" from the right side of the form.

6.5 LRDS User Interface

LRDS Configurations use the same GIS-based user interface as the Network module. The ribbon menu also displays additional items once an LRDS Configuration is created or opened.

The GIS Control is identical to the GIS control used in the Network module and displays the Network and User Layers. The elements displayed in the map are based on the Network that was selected when the LRDS Configuration was created. At this point, the Network is locked, new elements cannot be added, and existing elements cannot be removed. Note that the Network used in the LRDS Configuration is a *copy* of the original Network, meaning that edits to the LRDS Configuration Network will not affect the original Network. The Map Tools tab in the ribbon has the same functionalities as the one used in the Network module.

6.51 Module Tools Tab

The Module Tools tab in the ribbon contains several functionalities needed to define data for the LRDS Configuration. These functionalities are explained in the next few sections of the manual.

6.6 Developing a New LRDS Configuration

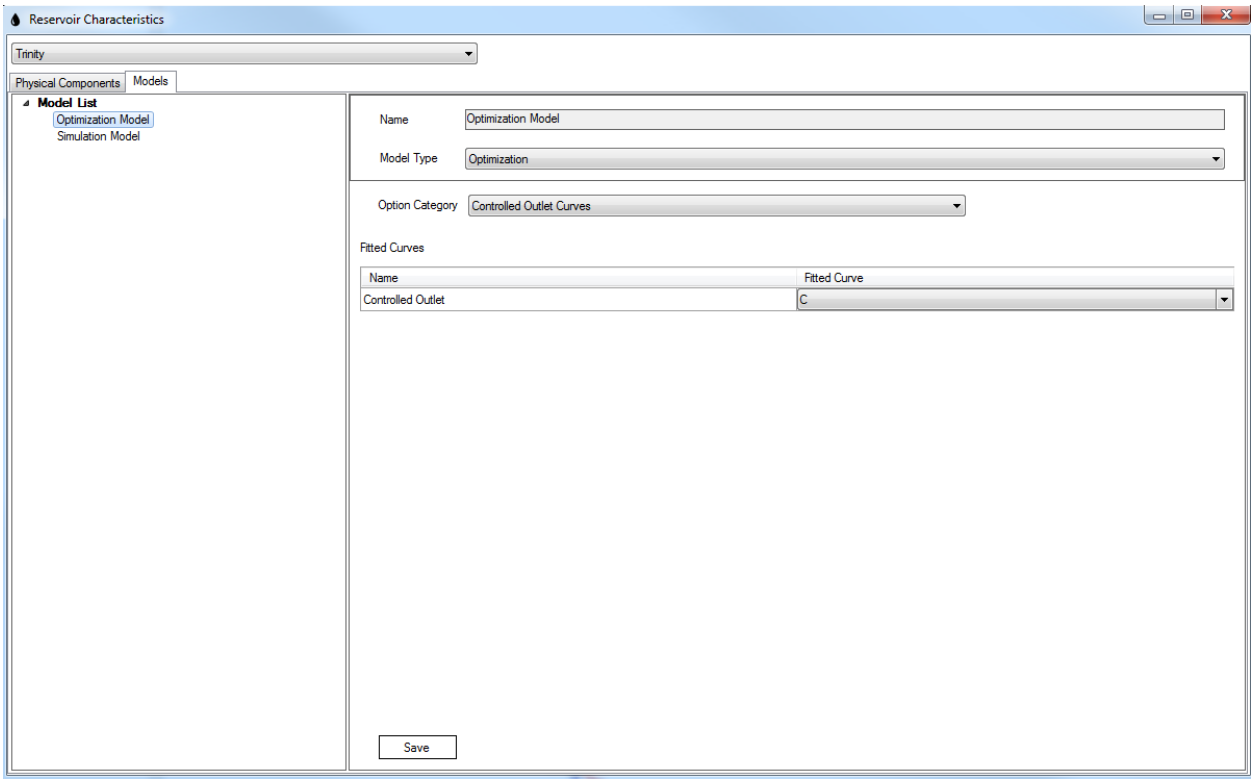
Developing an LRDS Configuration involves specifying how the operations of a reservoir system and the flow of water through it should be modelled. A Model is defined for each element to describe its behavior. A Model Set is then created by specifying which Model should be used for each element in the system. Two different types of Model Sets should be defined: the Optimization Model Set which contains the models used by the optimization model, and the Simulation Model Set which contains the models used by the simulation model. These Model sets are used to perform run for a specific forecast horizon and ensemble forecast. Additionally, the optimization model requires the user to specify Objective Functions and Constraints.

6.6.1 Element Models

Each LRDS Configuration is based on a Network that was previously created in the Network module. Networks define the water resources system as a collection of elements (arcs and nodes) and contain important physical information about each element. An LRDS Configuration builds on the Network by defining models that describe how water moves through each element. For instance, the Network module is used to define the physical characteristics of a reservoir, including the number and capacities of the outlets. The purpose of a reservoir model created under an LRDS Configuration is to specify how the outlets are to operate through rules that determine how much water should be released from the reservoir.

6.6.1.1 Creating a New Element Model

In order to create a new Model for a particular element (or view existing ones), open up the Element Characteristics form in the same way as describe in the Network section of the User Manual.



The tab "Physical Components" contains the description of the physical characteristics of the element developed under the Network module. However, an additional tab "Models" is now available to specify the element Models. A new Model can be added by right-clicking "Models" in the Item Tree. This will open up a new form to specify the name of the model and the type of model to be created. Once a new Model has been created, it will be added to the Item Tree and left-clicking it will make options available on the right side of the form. Depending on the type of form, you may need to specify and save several options. If there are options to be specified, a selectable box entitled "Option Category" will appear. Select the options you wish to include from this box, and they will be loaded into the main form.

6.6.1.2 Model Types

The different model types and their associated options are described next.

(1) ***Stream Models:*** Stream models specify how water is routed from the upstream to the downstream end of a stream arc. The following models are available in this software version.

No Routing: This model immediately translates the upstream flow to downstream flow, without any time lag or attenuation.

(2) ***Channel Models:*** Channel models specify how water is routed from the upstream to the downstream end of a channel arc. The following models are available in this software version.

No Routing: This model immediately translates the upstream flow to downstream flow. There is no time lag or attenuation.

(3) ***Diversion Models:*** Diversion models specify how water is routed from the upstream to the downstream end of a diversion arc. The following models are available in this software version.

No Routing: This model immediately translates the upstream flow to downstream flow, without any time lag or attenuation.

(4) ***Return Models:*** Return models specify how water is routed from the upstream to the downstream end of a return arc. The following models are available in this software version.

No Routing: This model immediately translates the upstream flow to downstream flow. There is no lag or attenuation.

(5) ***Reservoir Models:*** Reservoir models specify how reservoir outlets are operated. There are two available model types: An Optimization model should be defined for the Optimization Model and a Rule Based Simulation model should be defined for the Simulation Model.

As discussed in the Network module section, reservoir outlets can be uncontrolled and/or controlled. Uncontrolled outlets release at the exact amounts specified by the user in the Network module, and thus, no rules governing their operations are needed. Controlled outlets, on the other hand, are outlets the outflows of which can be regulated between zero and a maximum level (capacity) specified by the user. For these outlets, models are needed to specify the timing and magnitude of releases to be made. The following model options are available for controlled reservoir outlets:

(5.1) ***Optimization:*** In optimization models, the release at each timestep is determined from the results of the Optimization Model. Thus, no specific rules are needed to set the releases. Instead, the Optimization Model will automatically create a state variable representing the reservoir storage and a decision variable representing the total controlled reservoir outflow. These variables can be used to set constraints and objective function terms.

(5.1.1) *Controlled Outlet Curves:* Controlled outlet curves set the maximum outlet release capacity as a function of elevation. The Network module is used to import this information as a table with discrete elevation/release capacity data points. In order to use this information as part of the Optimization Model, the curves should be approximated with analytical functions and a function should be selected for each controlled outlet. If no functions are available, new functions can be developed by accessing the controlled outlet under the "Physical Components" tab, selecting "Fit Analytic Curve", and creating one or more analytic curves.

(5.1.2) *Uncontrolled Outlet Curves:* Setting uncontrolled outlet curves follows a similar process as described in the "Controlled Outlet Curves" section.

(5.1.3) *Storage/Area/Elevation Curves:* Setting storage/area/elevation curves follows a similar process as described in the "Controlled Outlet Curves" section. Two curves should be selected, one representing area as a function of storage, and another representing elevation as a function of storage.

(5.1.4) *Net Evaporation:* This option sets the net evaporation rate (evaporation minus precipitation) from the reservoir surface. Rates can be specified as constant, monthly varying, or a timeseries. Please note that the net evaporation rates can potentially be adjusted or overwritten in subsequent functionalities that use reservoir models.

(5.1.5) *Hydropower:* If a reservoir houses a power plant, a hydropower operations model can also be specified here. A hydropower operations model is based on the Aggregate Turbine described in the Network module. If a reservoir is associated with an Aggregate Turbine with one or more Energy Functions, then any desirable combination that determines how much energy is generated as water is released from the reservoir can be selected to become the hydropower operations model.

(5.2) ***Rule-Based Simulation:*** The Rule-Based Simulation model requires the user to create rules that specify how much water is released from each reservoir. All option categories are identical to those described in the previous section, except for the "Operating Rules" described next.

(5.2.1) *Operating Rules:* This category is used to define individual operating rules to represent different operational constraints and objectives. There are three fundamental types of rules: minimum, maximum, and exact. Minimum rules specify a minimum release from the reservoir; i.e., the release from the reservoir should equal or exceed the value set by the rule. Maximum rules specify a maximum release from the reservoir; i.e., the release from the reservoir should be less than or equal to the value set by the rule. Finally, exact rules specify the precise amount to be released.

A priority-based system is used to arrange the operating rules in order of importance. The rule with the highest priority is assessed first, the second highest priority rule is assessed next, and so on. A rule is implemented only if it does not conflict with a higher priority rule. For instance, if the highest priority rule is a minimum release rule, then the release from the reservoir should not be less than the value set by that rule, even if lower priority rules would prefer a lower release. On the other hand, it is acceptable for a lower priority rule to impose a stricter minimum flow (i.e., a higher minimum flow value), because doing so will still meet the minimum flow of the highest priority rule.
A final release quantity will be chosen if one of three circumstances occur:

(1) If an exact rule is evaluated, its value will be used and no further rules will be evaluated. If the value suggested by the exact rule violates the minimum or maximum release requirement associated with higher priority rules, then the final release will equal the minimum or maximum requirement, respectively.
(2) If a minimum or maximum requirement of a rule exceeds or is less than the maximum or minimum requirement of a higher priority rule, then the final release will equal the maximum or minimum requirement of the higher priority rule, respectively.
(3) If all rules have been evaluated and neither (1) nor (2) occurred, then the final release value will be set to the highest minimum release requirement.

Two rules are created by default and cannot be removed by the user. The Maximum Storage Limit rule ensures that the storage does not go above a maximum value. The Minimum Storage Limit rule ensures that the storage does not drop below a minimum value. Both rules are automatically assigned highest priority (that cannot be changed) and are highlighted in gray in the Operating Rule List. The priority of all remaining rules is set by

moving a rule up and down the Operating Rule List, with rules at the top of the list having higher priority than rules at the bottom. The only exception is the Minimum Storage Limit rule highlighted in gray at the bottom of the list, which has highest priority as described earlier. A description of different operating rules is provided next.

(5.2.2) *Release Constraints:* These rules set constraints on the minimum, maximum, or exact amount of water to be released. A Function Manager can be used to set the value of the constraint as a function of a constant, a month, an external monthly variable, or a computed variable.

(5.2.3) *Storage Constraints:* These rules set constraints on the minimum, maximum, or exact amount of storage in the reservoir. A Function Manager can be used to set the value of the constraint as a function of a constant, a month, an external monthly variable, or a computed variable. Storage constraints are converted by the model into release constraints. For instance, a minimum storage constraint is enforced by computing a maximum release constraint that ensures that storage does not fall below the minimum limit.

(5.2.4) *Downstream Flow Constraints:* These rules set constraints on the minimum, maximum, or exact amount of flow at downstream location. Users first select the downstream location and variable to control. A Function Manager can be used to set the value of the constraint as a function of a constant, a month, an external monthly variable, or a computed variable.

(5.2.5) *Global Operating Rule:* If a Global Operating Rule associated with a reservoir has been previously created, users can add that rule to the reservoir. Note that the parameters of the Global Operating Rule will be displayed, but cannot be edited without returning to the Global Operating Rule Manager.

(5.2.6) *Optimization Policy:* Specifies an exact release equal to the value suggested by the Optimization Model.

(5.3) ***Creating A New Rule:*** Right-click on an existing rule in the Operating Rule List (except for the rule at the bottom) and select "Add New Rule". In the command prompt, enter the name of the rule, select the type of rule to create, and click "Save". A new rule will be created and appear in the Operating Rule List.

(5.4) ***Enabling/Disabling a Rule:*** Rules can be disabled by right-clicking on an existing rule in the Operating Rule List (except for rules at the top and bottom) and selecting "Disable". This will change the font of the rule to italic and light gray. Disabled rules will not be considered during a simulation. A disabled rule can be enabled by right-clicking the rule and selecting "Enable". Newly created rules are enabled by default.

(5.5) ***Editing A Rule:*** Right-click on an existing rule in the Operating Rule List (except for the top and bottom rules) and select "Edit". This will open a new form where the rule parameters can be specified.

(5.6) ***Changing Rule Priorities:*** Right-click on an existing rule in the Operating Rule List and select "Increase Priority" or "Decrease Priority" to move the rule up or down in the Operating Rule List. The top and bottom rules in the list cannot be moved.

(6) ***Watershed Models:*** Watershed models specify the amount and timing of inflows entering the water resources system. Users can define the values as a function of a constant, a month, or an external monthly variable. Please note that these values can potentially be adjusted or overwritten in subsequent functionalities that use watershed models. Additionally, data import tags can be defined for each watershed to make bulk inflow forecast imports from external data files. This process is explained in more detail in Section 6.15.3.1. Data import tags are defined by clicking the "Set Data Import Tags" button and entering the tags into the text box. Multiple tags can be defined by separating each tag with a comma.

(7) ***Demand Node Models:*** Demand models specify demand node targets. Demand node targets represent the desired amount of water that is to be abstracted from the river basin network at the demand node. Users can define the values as a function of a constant, a month, and an external monthly variable. Please note that these values can potentially be adjusted or overwritten in subsequent functionalities that use demand node models.

(8) ***River Node Models:*** River node models specify how the water balance at river nodes is computed. There are four model types:

The Simulation model type is used as part of the Simulation Model and performs simple mass balance. The Optimization model type is used as part of the Optimization Model. This model automatically creates a state variable representing river flow which can be used to set constraints and objective function terms. Diversions (if present) are treated as being extracted automatically (assuming that there is enough flow) for both the Simulation and Optimization model types.

Two additional model types can be defined if a river node has lateral flows (either through a diversion or channel arc) leaving the node. The Controlled Lateral Outflow Optimization model type is used as part of the Optimization Model. It differs from the regular Optimization model type by defining an additional decision variable that is used to set the magnitude of the lateral flow. The Controlled Lateral Outflow Simulation model type is used as part of the Simulation Model. It differs from the regular Simulation model type by including operating rules that can be used to set the magnitude of the lateral flow. The operating rules and their implementation logic are similar to those associated with reservoirs. The following operating rules are available:

> (8.1) *Lateral Flow Constraints:* These rules set constraints on the minimum, maximum, or exact amount of lateral flow. A Function Manager can be used to set the value of the constraint as a function of a constant, a month, an external monthly variable, or a computed variable.
>
> (8.2) *Downstream Flow Constraints:* These rules set constraints on the minimum, maximum, or exact amount of flow at location downstream of the arc through which the lateral flow occurs. Users first select the downstream location and variable to control. A Function Manager can be used to set the value of the constraint as a function of a constant, a month, an external monthly variable, or a computed variable.
>
> (8.3) *Demand Target:* This sets an exact lateral flow constraint that equals the demand target of the demand node connected to the diversion. This option is not available for lateral flow occurring through channels.
>
> (8.4) *Optimization Policy:* Specifies an exact lateral flow equal to the value suggested by the Optimization Model.

If the river node has been defined to include an Aggregate Turbine, all model types can set energy generation characteristics by selecting “Hydropower” from the “Category Options” selectable box. An Energy Function would also need to be selected, along with the value of the constant elevation.

(9) ***Delta Node Models:*** Delta node models specify the operations and mass balance in the Sacramento–San Joaquin River Delta. There are two model types. The Rule Based Simulation option is used as part of the Simulation Model and the Delta Rule Optimization option is used as part of the Optimization Model. Both rules compute the following variables:

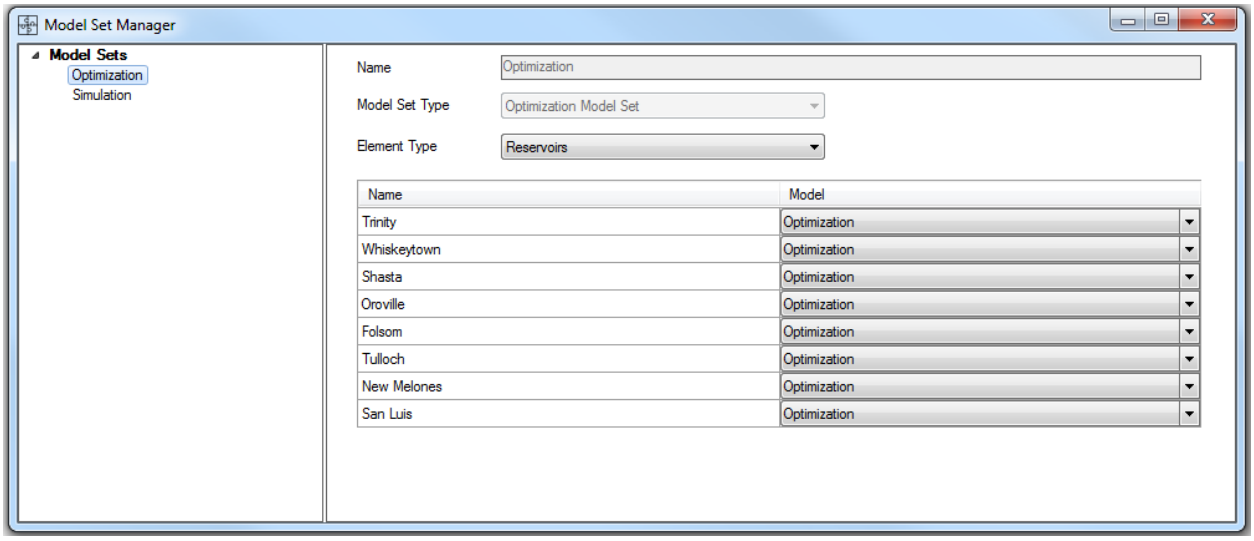
- *Total Delta Outflow:* Represents the total flow exiting the delta.
- *X2 Location*: Represents the location of the isohaline interface (X2) in kilometers from the Golden Gate Bridge.
- *Pumping:* Represents the pumping from the delta into a channel through the combined use of the Banks and Tracy pump stations.
- *Delta Outflow Requirement:* Represents the minimum desired value of the total delta outflow.

Both rules require the user to set a monthly varying delta outflow requirement. The Rule Based Simulation option also requires operating rules that specify how much water should be pumped from the delta. The operating rules and their implementation logic are similar to those associated with reservoirs and river nodes.

6.7 Model Set Definition

Model Sets are developed by selecting a model for each element in the river basin. As a result, a Model Set describes how the entire basin is being modelled. To model a water resources system, at least two different types of Model Sets have to be created: the Optimization Model Set which will be used by the system optimization process and the Simulation Model Set which will be used by the system simulation process.

Model Sets can be defined by clicking on the “Model Set Definition” button on the ribbon. This will open the Model Set Manager form.



A new Model Set can be added by right-clicking "Model Sets" in the Item Tree. This will open up a new form. Specify the name of the Model Set, select the type, and then use the right side of the form to select a Model for each element in the system. The "Element Collection" selectable box can be used to cycle through the different types of elements. Click "Save" after a Model has been selected for each element. The new Model Set will be added to the Item Tree. Selecting it will display all identified Models.

6.8 Global Operating Rules

Global Operating Rules are operating rules that do not apply to *individual* reservoirs, but they are used to make two or more reservoirs work together to meet a common operating objective. Global Operating Rules are established by first defining them under the Global Operating Rule Manager and then adding them to the individual reservoirs' local operating rules. Global Operating Rules are only defined as part of the Simulation Model; the rules generated by the Optimization Model are always global.

6.8.1 Global Downstream Constraint

The Global Downstream Constraint operating rule imposes a downstream flow constraint that two or more reservoirs have to meet. To create this rule, the user must first select the downstream variable to be controlled (either a flow or X2 variable), then specify the downstream target to be met, and finally, determine which upstream reservoirs would be required to work together to meet the constraint imposed at the downstream location.

If there is a violation of the downstream constraint, then the burden of meeting the constraint is placed on the upstream reservoir based on user-defined parameters as follows:

$$\text{Extra Release from Reservoir i} = (\text{Constraint Violation}) * (\text{Factor}_i)/(\text{Factor}_1+\text{Factor}_2+\ldots+\text{Factor}_R)$$

where R is the number of reservoirs included in the rule, and $\text{Factor}_i = \text{Numerator}_i$.

Note that the Factor can be time-varying.

6.9.1 Global Downstream Constraint – Storage Ratio

This operating rule is identical to the preceding rule, except for the way the Factor is calculated:

$$\text{Factor}_i = (\text{Numerator}_i) * (\text{Storage in Reservoir i} / \text{Denominator}_i)$$

6.9 Custom Variable Definition

Each element in the water resources network contains several default variables. For instance, a reservoir contains a storage variable that keeps track of the volume over time. Additionally, there are variables that represent reservoir elevation, surface area, the amount of water being released, the amount of power being generated, etc. Once you define a system (both through the Network module and the Models), these variables are automatically created and computed whenever runs

are executed. Custom Variables allow users to define and import additional variables that are not created by default.

There are two types of Custom Variables. Derived Variables are defined as a function of one or more existing default variables. External Variables are data series that are imported by the user. Custom Variables are defined under a Model Set. Please note that only Custom Variables displayed under the Simulation Model Set will be available for display in later functionalities of the program.

6.9.1 Derived Variables

Derived Variables are functions of existing variables. To define them, you first need to specify which of the existing variables to use in this definition and which type of function to apply. Once they are defined, the program computes the Derived Variables whenever a model run is executed. At present, derived variables can be generated by summing/averaging over time or summing/averaging across multiple variables in the same time step.

6.9.1.1 Single Variable

Single Temporal Sum: This derived variable is computed by taking a single default variable and summing its values over time. Thus, at each time step, this derived variable represents the sum of the default variable over all previous time steps.

Single Temporal Average: This variable is similar to that of the Single Temporal Sum but *averages* (instead of summing) the values of the default variable over time.

6.9.1.2 Multiple Variables

Multiple Sum: This derived variable is computed by summing multiple default variables at *each* timestep (i.e., not over time).

Multiple Average: This variable is similar to the Multiple Sum, but averages all selected default variables at each time step.

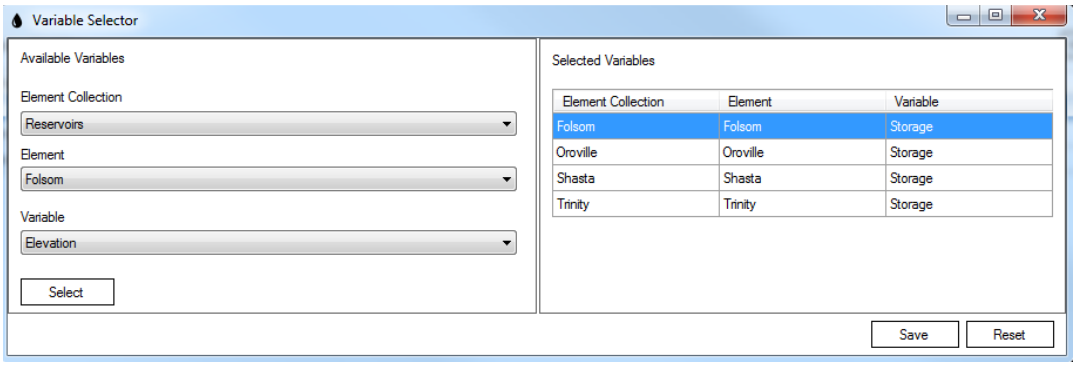
Multiple Sum & Temporal Sum: This derived variable is a combination of the Multiple Sum and Single Temporal Sum. First, the Multiple Sum algorithm is applied to the selected default variables. Then, the resulting variable is summed over time.

Multiple Sum & Temporal Average: This derived variable is similar to the Multiple Sum & Temporal Sum variable. However, the variable is averaged over time.

Multiple Average & Temporal Sum: This derived variable is similar to the Multiple Sum & Temporal Sum variable. However, the multiple variables are averaged at *each* timestep.

Multiple Average & Temporal Average: This derived variable is similar to the Multiple Sum & Temporal Sum variable. However, the multiple variables are averaged at each timestep and the result is averaged over time.

The variables used to define a Derived Variable can be selected by right-clicking a variable in the variable list and selecting “Edit” to open a Variable Selector form.



The left side of this form contains all of the default variables. A specific variable can be selected by first selecting its element type, then selecting the specific element, next selecting the variable itself, and lastly clicking "Select". This will add the variable to the "Selected Variables" list on the right side of the form. The selected variables can be saved by clicking "Save".

6.10 External Variable Definition

External Variables can be used to import data into the software. At present, two types of external variables can be defined: monthly and timeseries. Once created, their values can be set by right-clicking the variable in the variable list and selecting "Edit". This will open a new data entry screen that can then be used to import the variable values.

6.10.1 Monthly Data

This option defines a variable with 12 different monthly values.

6.10.2 Timeseries Data

This option defines a variable that consists of a timeseries. A timeseries is defined by set of dates and a corresponding set of variable values.

6.11 Objective Function

Objectives are a key input to the Optimization Model. Objectives characterize stakeholder interests and are quantitative metrics through which alternative management policies are evaluated.

6.11.1 Creating a New Objective Function

Click on the "Objective Function Definition" button on the ribbon to launch the Objective Function Manager form. The Item Tree on the left will display a list of all Model Sets. Right-click the Model Set under which the new Objective Function is to be created, select "Add a New Objective Function", and provide a name. A new Objective Function will be created and additional options will become available on the right side of the form.

Objective Functions are only used in conjunction with the optimization model, and they should be created under the Model Set that applies to that model.

6.11.2 Creating a New Group

Individual objective function terms can be organized logically by defining groups that hold one or more terms. Right-click on the "Groups" node in the tree and enter the name of the new group. Click "Save" and a new group should appear in the tree.

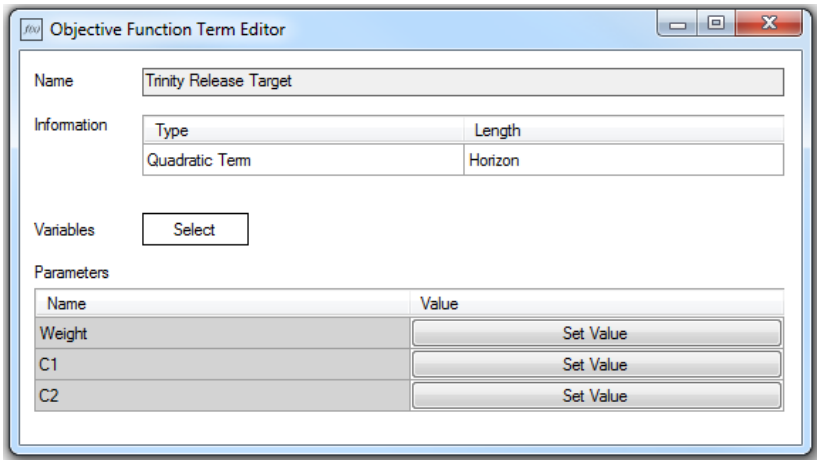
6.11.3 Adding a New Objective Function Term

Select a Group by right-clicking it and then click "Add Term". Enter the name of the new term, select the type of term to be added, selected the term length and click "Save". A new term will be added to the table on the right side of the form.

The Term Length refers to how many timesteps to include in the term. If "Horizon" is selected, then all timesteps are included. If "Terminal Stage" is selected, then only the last stage is selected. Note that this option is only available for terms that are based on non-flow state variables. "Horizon and Terminal Stage" is a combination of the previous two options.

6.11.4 Editing an Objective Function Term

Right-click the row containing the term in the objective function term table and select "Edit". This will open an Objective Function Term Editor that can be used to specify the term parameters.



Each Objective Function Term is a function of one or two state or decision variables. The variables to be used in the term can be selected by clicking the Select button. This opens a new form that lists all of the available state and decision variables. A variable can be selected by right-clicking it in the "Available Variables" table and then clicking "Select Variable". A selected variable will appear in the "Selected Variable" table. Previously selected variables can be removed by right-clicking them in the "Selected Variable" table and then clicking "Remove Variable".

Once a variable has been selected, the Objective Function Term Editor form will display a data table that can be used to input the term parameters. The different terms and their parameters are described in the following sections. For each term, variable k represents a time index, and variables x_1 and x_2 represent the selected state or decision variables.

Quadratic Term: This term is a function of a single variable (state or decision) and is represented by the following equation:

$$Value(k) = Weight(k) * \frac{(x_1(k) - C1(k))^2}{(C2(k))^2}$$

Linear Term: This term is a function of a single variable (state or decision) and is represented by the following equation:

$$Value(k) = Weight(k) * C1(k) * x_1(k)$$

Mixed Term: This term is a function of a two variables and is represented by the following equation:

$$Value(k) = Weight(k) * C1(k) * x_1(k) * x_2(k)$$

Above Single-sided Quadratic Term: This term is a function of a single variable (state or decision) and is represented by the following equation:

$$Value(k) = Weight(k) * \frac{(x_1(k) - Threshold(k))^2}{(C2(k))^2} \quad \text{if } x_1(k) > Threshold(k)$$

$$Value(k) = 0 \quad \text{if } x_1(k) \leq Threshold(k)$$

Below Single-sided Quadratic Term: This term is a function of a single variable (state or decision) and is represented by the following equation:

$$Value(k) = Weight(k) * \frac{(x_1(k) - Threshold(k))^2}{(C2(k))^2} \quad \text{if } x_1(k) < Threshold(k)$$

$$Value(k) = 0 \quad \text{if } x_1(k) \geq Threshold(k)$$

An individual term can be enabled/disabled by right clicking it and selected "Enable" or "Disable". Only enabled terms will be included during model runs. Entire groups can also be enabled/disabled.

6.12 Constraint Set

Constraints are a key input to the optimization model. Their purpose is to delineate the feasible (permissible) domains of state and/or decision variables.

6.12.1 Creating a New Constraint Set

Click on the "Constraint Set Manager" button on the ribbon to launch the Objective Function Manager form. The Items Tree on the left will display a list of all Model Sets. Right-click the Model Set under which the new Constraint Set should be created, select "Add a New Constraint Set", and provide a name. A new Constraint Set will be created and additional options will become available on the right side of the form.

Note that Constraint Sets are only used in conjunction with the optimization model. As a result, Constraint Sets should be created under the Model Set that will be used with the optimization model.

6.12.2 Creating a New Group

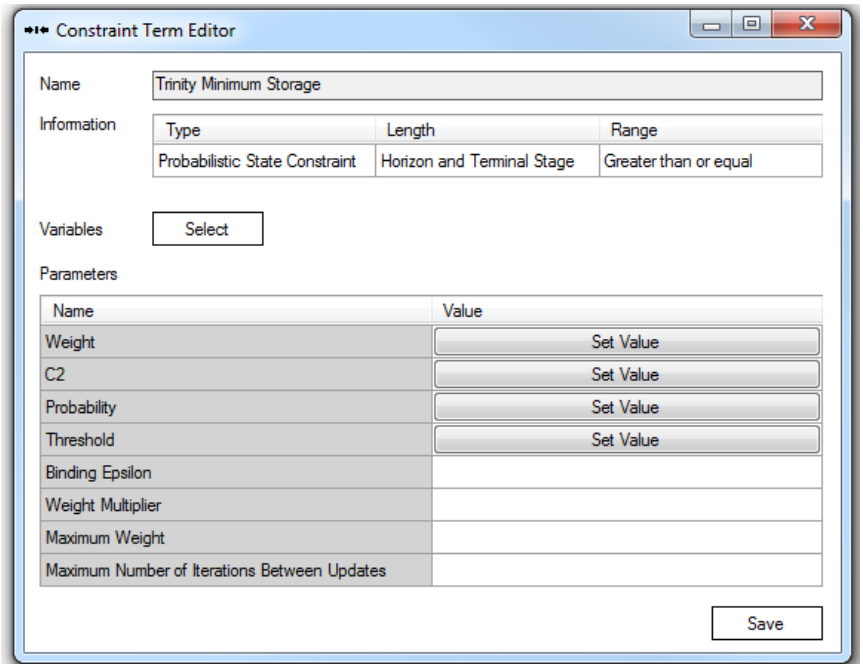
Individual constraint terms can be organized logically by defining groups that hold one or more terms. Right-click on the "Groups" node in the tree and enter the name of the new group. Click "Save" and a new group should appear in the tree.

6.12.3 Adding a New Constraint

Select a Group by right-clicking it and then click "Add Term". Enter the name of the new term, select the type of constraint to be added, select the term length, choose the constraint directional range (i.e., >= or <=), and click "Save". A new term will be added to the table on the right side of the form.

6.12.4 Editing a Constraint

Right-click the row containing the term in the "Individual Constraints" table and select "Edit". This will open a Constraint Term Editor that can be used to specify the term parameters.



Each Constraint is a function of one state or decision variable. The variables to be used in the constraint can be selected in the same way that the variables for Objective Function Terms are selected.

Once a variable has been selected, the Constraint Term Editor form will display a data table that can be used to input the term parameters. The different constraints and their parameters are described in the following sections. For each term, the variable k represents a time index, and the variable x_1 represents the selected state or decision variable.

Single Decision Constraint: This term is a function of a single decision variable and is represented by the following equation:

$x_1(k) \geq Threshold\ (k)$, for a "Greater than or equal" constraint;

$x_1(k) \leq Threshold\ (k)$, for a "Less than or equal" constraint.

Probabilistic State Constraint: This term is a function of a single state variable and is represented by the following equation (where P[] denotes probability in %):

$P[x_1(k) \geq Threshold(k)] \leq Probability[k]$, for a "Greater than or equal" constraint,
$P[x_1(k) \leq Threshold\ (k)] \leq Probability[k]$, for a "Less than or equal" constraint.

Probabilistic State Constraints are handled internally as one-sided Objective Function terms that become active when the constraint is violated. The Optimization Model will attempt to find solutions that keep the associated Objective Function terms as small as possible, thereby also meeting the original state constraints. The parameter Penalty Weight specifies the weight of the term in the objective function. In addition to setting these variables, several scalar parameters can be set. If none of these parameters are defined, then the constraint is treated as a fixed penalty constraint, and the weight remains constant. On the other hand, specifying values for the additional parameters allows the weight to become variable. The idea is to start with a small weight and then gradually increase it only if the constraint is violated. The following scalar parameters can be set:

1. Binding Epsilon: This parameter represents an amount by which the constraint is allowed to be violated. It is recommended that a small positive number be used.
2. Weight Multiplier: This parameter specifies how to increase the weight if the constraint is violated. The increase takes place as follows: New Weight = Old Weight * Weight Multiplier.
3. Maximum Weight: This parameter limits the maximum value of the weight.
4. Maximum Number of Iterations Between Updates: Weight increases occur automatically whenever the Optimization model has converged and a constraint has been found to be violated. Additionally, weight increases can also be specified to occur after a fixed number of iterations, as defined by this parameter.

6.13 Horizons

A Horizon defines the future timespan over which the LRDS module will optimize the water resources system. A Horizon is defined by a start time and a horizon length which specifies the number of time steps from the start time until the end of the horizon.

6.13.1 Creating a New Horizon

Click on the "Horizons" button on the ribbon to launch the Horizon Manager form. Right-click "Horizons" in the Item Tree and select "Add a New Horizon" in the Item Tree. Fill in the following information:

Name: Name of the horizon.

Start Time: Start date of the horizon. A horizon should start on the first day of the month.

Horizon Length: The number of time steps constituting the Horizon.

Click "Save" and a new Horizon will be created. Its characteristics will be shown on the right side of the form.

6.14 Setup Manager

A Setup is a particular combination of a Horizon, the Model Sets used to define the optimization and simulation models, and the number of traces to be included in the inflow ensembles. A Setup essentially defines how a system is modelled. Once a Setup is defined, additional options become available to set other input parameters, such as initial conditions and forecast ensembles. Finally, a Setup can be used to define different Runs that will allow users to employ the Optimization and Simulation Models to assess how the system will perform over the forecast/management horizon.

6.14.1 Creating a Setup

Click on the "Setup Manager" button on the ribbon to launch the Setup Manager form. The Item Tree on the right side of the form will contain a list of all Horizons. A Setup can be added under each horizon by right-click "Setups" in the Item Tree and selecting "Add a New Setup". Fill in the following information:

Name: Name of the Setup.

Optimization Model Set: The model set to be used by the Optimization Model.

Simulation Model Set: The model set to be used by the Simulation Model.

Number of Traces: The number of traces to be included in the inflow forecast ensemble.

Click "Save" and a new Setup will be created. Its characteristics will be shown on the right side of the form.

Each new Setup creates a *copy* of the selected Model Sets (and their underlying element Models). As a result, users can edit the element Models under a Setup without affecting the original element models. The same is true for Objective Functions, Constraints, and Custom Variables.

6.15 Setup Tools

Once a new Setup is created (or an existing Setup is opened), the ribbon displays a list of Setup Tools. The tools are organized into five main categories. The "System Model" group allows the users to fine-tune some of the parameter sets before creating the Setup. The "Ensemble Definition" group allows users to define the ensemble forecasts. The "Initial Conditions" group is used to define the initial conditions of the water resources system at the beginning of the horizon. The "Runs" group allows the user to perform run. Finally, the "Results Analysis" group provides functionalities to view the results.

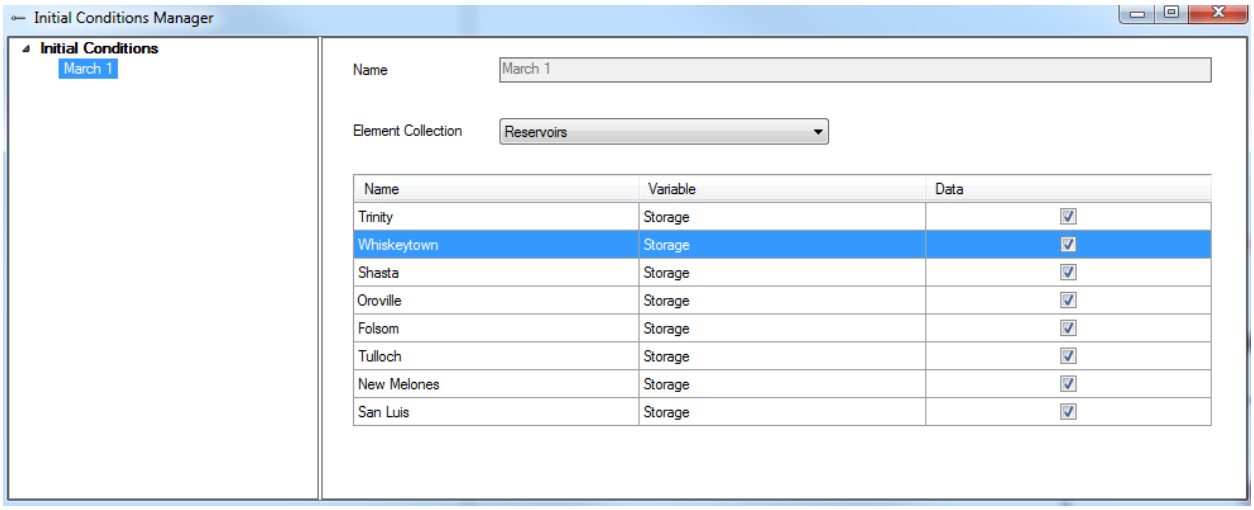
6.15.1 System Model Group

This group can be used to launch the Custom Variable Definition, External Variable Definition, Objective Function, and Constraint Set forms. These forms are identical to the ones described in previous sections.

6.15.2 Initial Conditions

Initial conditions refer to the values of certain variables at the start of the horizon. For instance, the storage in the reservoirs needs to be specified before any model can determine how that storage varies over time.

Click on the "Initial Conditions" button on the ribbon to launch the Initial Conditions Manager. The Item Tree on the right side of the form will contain a list of all Initial Conditions. Initial Conditions can be added by right-clicking "Initial Conditions" in the Item Tree and selecting "Add new Initial Conditions". This will create a new item in the Item Tree and open new data entry options on the right side of the screen.



The data table on the right side of the screen displays a list of elements and variables for which initial conditions have to be set. Each data table lists all of the initial conditions associated with a particular element type (e.g., reservoirs). The "Element Collection" selectable box can be used to access initial conditions for different element types. To set an initial condition, right-click a row in the data table and click "Edit". This will open a new data entry screen where the value of the initial condition can be entered and saved.

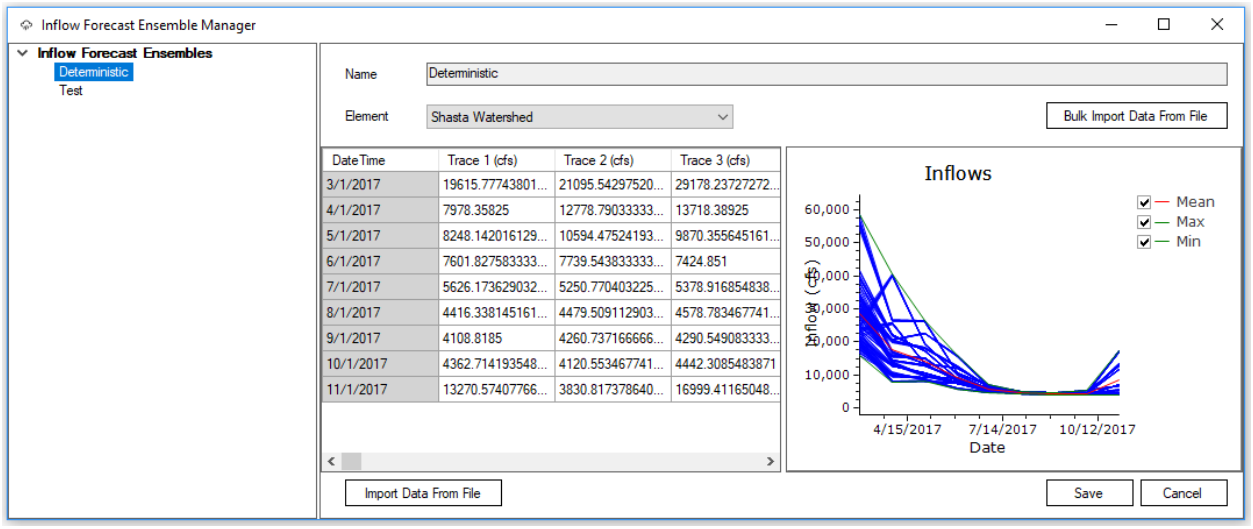
6.15.3 Ensemble Definition Group

The ensemble definition group is used to define the values of the inflow forecast ensemble. Additionally, two other variables, net evaporation and demand targets, are treated as ensembles. Each ensemble consists of several traces, the number of which was specified when the user created the Run, and each trace is a timeseries of values spanning the horizon. The ensembles of different variables are related in that the first trace of the inflow forecast ensemble is used in conjunction with the first trace of the net evaporation and demand target ensembles. The same applies to the 2nd, 3rd, and all remaining traces.

6.15.3.1 Creating a New Inflow Forecast Ensemble

Click on the "Inflows" button on the ribbon to launch the Inflow Forecast Manager form. The Item Tree on the right side of the form will contain a list of all Inflow Forecasts. Inflow Forecasts can be added by right-clicking "Inflow Forecasts" in the Item Tree and selecting "Add new Inflow

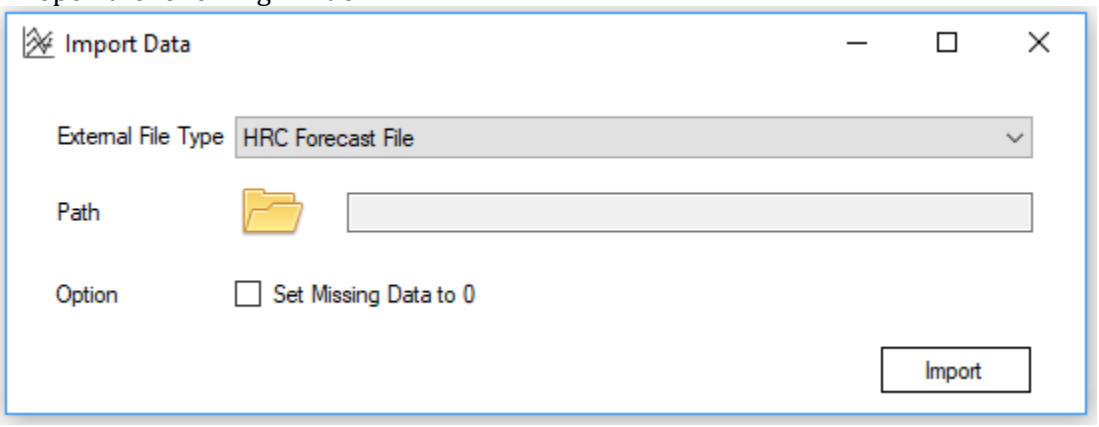
Forecasts". This will create a new item in the Item Tree and open data entry options on the right side of the screen.



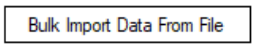
The data table on the right side of the screen displays the Inflow Forecast Ensemble. The first column contains the dates corresponding to the time steps in the horizon, and the remaining columns represent the different traces. The "Watershed" selectable box can be used to access forecast ensembles for different watersheds.

When an Inflow Forecast Ensemble is first created, values might automatically be copied into the trace columns depending on which type of inflow model was used as part of the Model Sets upon which the run is based. If a "Constant" model has been selected, the constant value will be pasted into each time step and each trace. If a "Monthly" model has been selected, the monthly values will be used.

Data can also be imported from an external data file by clicking on the Import Data From File button. This will open the following window:



Users should specify the file type and path to the file to be imported. Users can also decide how missing data is to be handled. If the check box is selected, then missing data will be set to zero values. Otherwise, missing data will be set to the values specified by the inflow model that was used to automatically generate values when the scenario was first created. Clicking "Import" will then import data for an individual watershed (the one selected in the selectable box).

Bulk imports for multiple data files can be made by pressing the 

button. This opens the same window as the "Import Data From File" button. However, users should now navigate to a specific folder path instead of a specific file path. The data tags defined for each watershed model (see Section 5.9.6) are then used to select the right files to be imported from the user-selected folder. The import routine will use the data import tag to identify the file that should be imported by selecting the file whose name starts with the characters contained in the data tag. Consequently, it's important to choose the file names to start with unique characters so that they can be turned into data import tags. If a watershed model has multiple tags (separated by commas), the data in each individual file will be summed to create one final ensemble for the watershed. A summary screen provides an overview of which files were found and imported after the bulk import has been completed.

Inflow forecasts should be specified for each watershed. Each watershed should be saved individually by using the "Save" button.

6.15.3.2 Creating a New Net Evaporation Ensemble

The process for creating a new Net Evaporation Ensemble is similar to the one used to create Inflow Forecast Ensembles. Net evaporation is specified for each reservoir in the system.

6.15.3.3 Creating a New Net Demand Target Ensemble

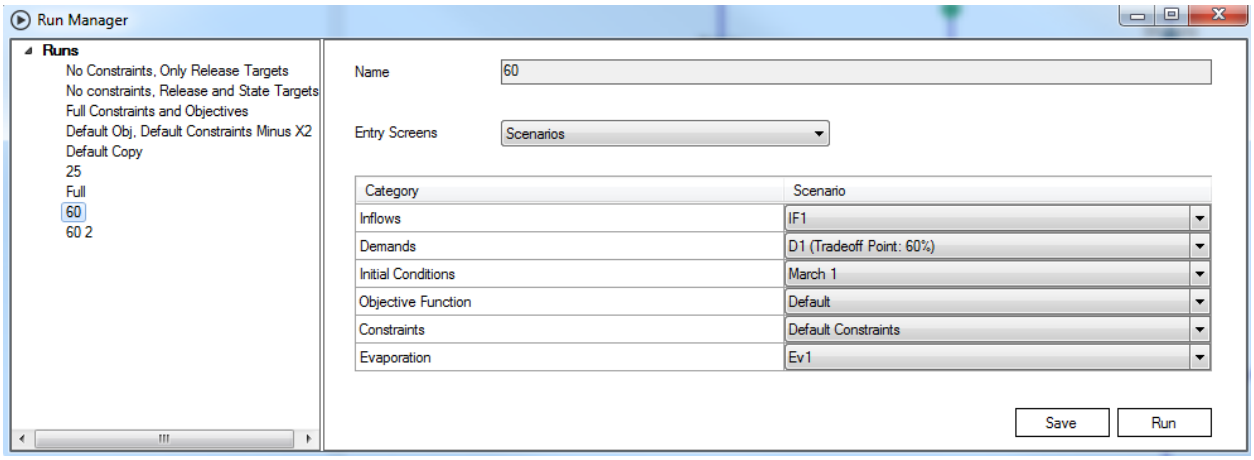
The process for creating a new Demand Target Ensemble is similar to the one used to create Inflow Forecast Ensembles. Demand targets are specified at each demand node in the system.

6.16 Run

Runs incorporate the last pieces of information that need to be defined before the optimization and simulation models are activated. Run collect all the relevant information needed to perform quantitative computations for the water resources system. Once this information has been defined, a Run can be computed to determine the water resources system response over the forecast/management horizon.

6.16.1 Creating a New Run

Click on the "Single Run" button on the ribbon to launch the Run Manager form. The Item Tree on the right side of the form will contain a list of all Runs. Run scan be added by right-clicking "Runs" in the Item Tree and selecting "Add new Run". This will create a new item in the Item Tree and open new data entry options on the right side of the screen.



There are two main entry screens which can be toggled using the "Entry Screens" selectable box. The "Scenarios" screen is used to select different user-created scenarios. Scenarios should be selected for the following categories:

Inflows: Select one Inflow Forecast Ensemble containing an inflow ensemble.

Demands: Select one Demand Target Ensemble containing a demand target ensemble.

Evaporation: Select one Net Evaporation Ensemble containing a net evaporation ensemble.

Constraints: Select one Constraint Set containing constraints for the optimization model.

Objective Function: Select one Objective Function containing objective function terms for the optimization model.

Initial Conditions: Select an Initial Condition containing the initial conditions for the water resources system elements.

The "Optimizations Options" and "Simulation Options" screens are used to specify options for the optimization and simulation models, respectively. A set of suggested default options is automatically created. It is recommended that users keep these options unless they have a strong understanding of the internal workings of the optimization and simulation algorithms.

6.16.1 Computing a Run

A Run can be computed once all of its parameters have been specified by clicking the Run button. This will sequentially invoke the optimization and simulation models and will create results that are stored in the database. During this process, a screen is displayed to report on the progress.

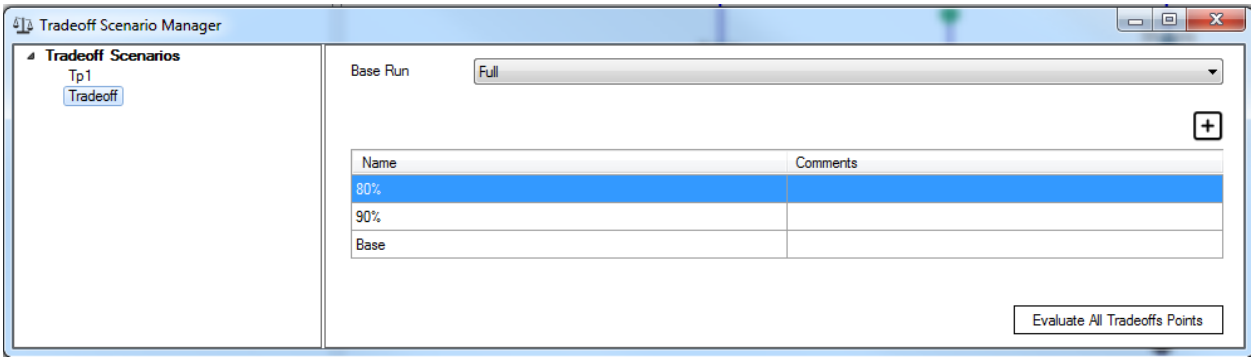
6.17 Tradeoff Generation

A Run uses a Demand Target Scenario that specifies the demand targets to be met. Tradeoffs between different demand target levels can be derived by generating Tradeoff Scenarios that use

the same Run (i.e., the same inflows, initial conditions, objectives, etc.) except for systematically varying demand targets.

6.17.1 Creating Tradeoff Scenarios

Click on the "Tradeoff Generation" button on the ribbon to launch the Tradeoff Manager form. The Item Tree on the right side of the form will contain a list of all Tradeoff Scenarios. Tradeoff Scenarios can be added by right-clicking "Tradeoff Scenarios" in the Item Tree and selecting "Add new Tradeoff Scenario". Each Tradeoff Scenario is based on a previously created Computation that is selected by the user. A new item will be created in the Item Tree and open data entry options on the right side of the screen.



6.17.2 Creating a New Tradeoff Point

Each Tradeoff Scenario contains a default Tradeoff Point named "Base". This point represents a Run that is an identical copy of the Run upon which the Tradeoff Scenario is based. Additional Tradeoff Points can be added by clicking the ⊞ button.

6.17.3 Editing a Tradeoff Point

Tradeoff Points can be edited by right-clicking them on the data table, and selecting "Edit". This will open a new form that allows the user to specify how the demand targets corresponding to the tradeoff point should be changed from the base demand targets. A percentage multiplier (which can be positive or zero) can be specified for each demand node and to multiply (scale) the base demand targets.

6.17.4 Generating Tradeoffs

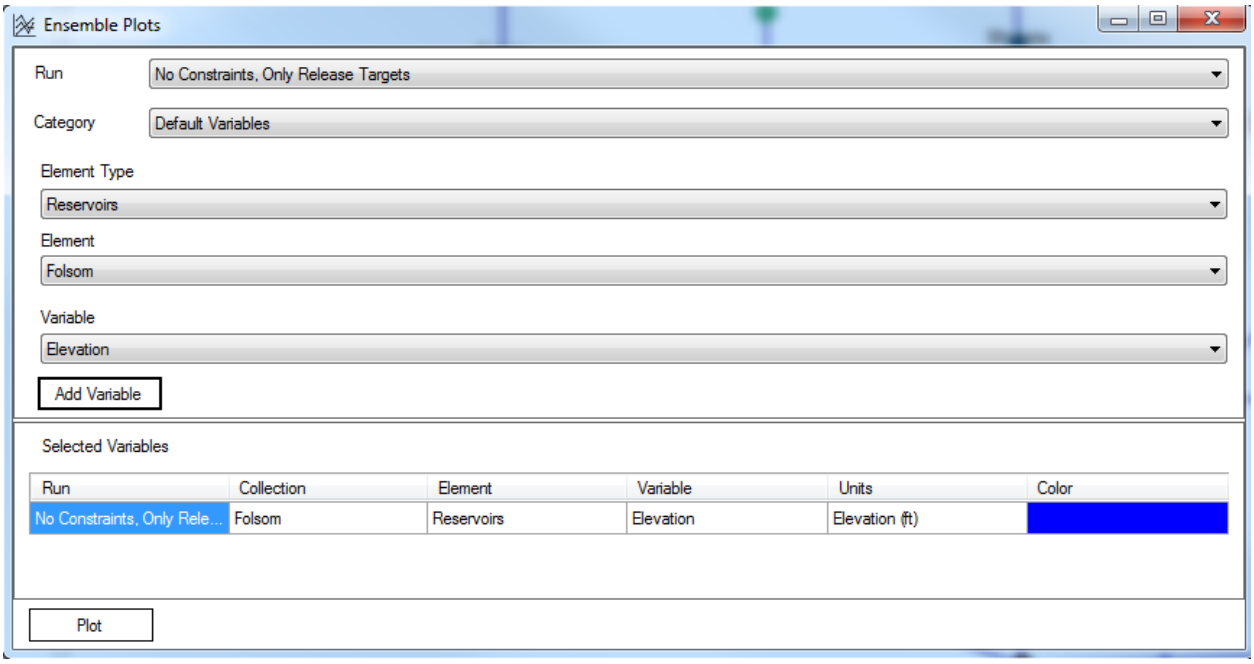
Once the Tradeoff Points have been specified, they can be computed by clicking the Run All Tradeoffs button. Each tradeoff point will be computed by running the Run in conjunction with the demand targets specified for it. A screen is displayed indicating the progress.

6.18 Result Analysis

The results generated by a Run or a Tradeoff Scenario can be viewed by using different plotting functionalities. The Ensemble Plots form can be used to view the ensembles associated with individual Runs. The Tradeoff Plots and Frequency Plot forms can be used to view the results associated with Tradeoff Scenarios.

6.18.1 Ensemble Plots

The system variable ensembles associated with each Run can be viewed by clicking the "Ensemble Plots" button on the ribbon. This will open a new Ensemble Plots form.



Different Runs and variables can be plotted by using the following selectable boxes on the form.

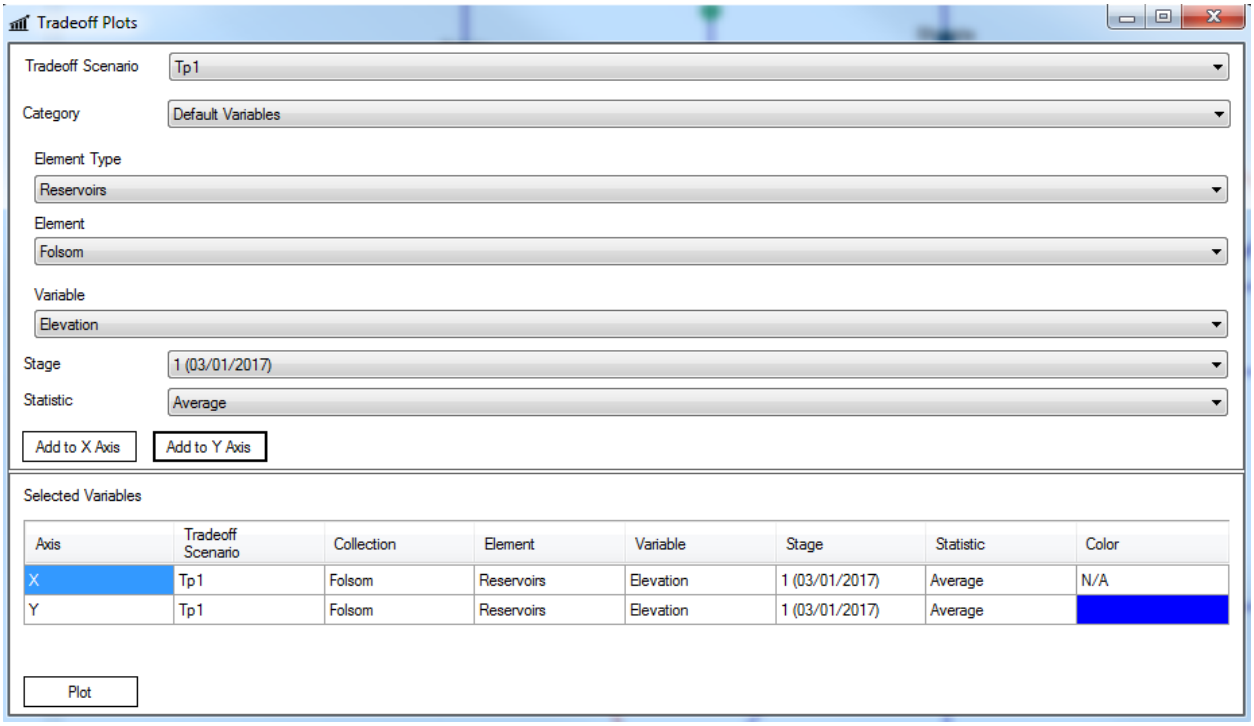
Computation: Selects from which Run to plot data.

Category: Specifies which types of variable categories to select. Recall that "Default Variables" are automatically created by the software. If this option is selected, additional selectable boxes are made available to enable the user to select different elements and ultimately the variables to be plotted. Selecting "Custom Variables" will enable the user to select user-defined Custom Variables (previously created with the Custom Variable Definition form). Selecting "External Variables" will enable the user to select user-defined External Variables (previously created with the External Variable Definition form). Once the user has chosen a variable, the Add Variable button can be clicked to add the variable to the "Selected Variable" list at the bottom of the screen. Multiple variables can be selected as long as they have the same units.
The "Selected Variable" list displays all selected variables to be plotted. The color that will be used to plot a variable can be edited by right-clicking a selected variable and clicking "Change Color". Pressing the Plot button will open a new form with the result plots.

6.18.2 Tradeoff Plots

The Tradeoff Plot screen can be used to illustrate tradeoffs between different variables. Users can select an X axis variable and one or more Y axis variables (as long as all Y axis variables have the same units) to plot against each other. Unlike the Ensemble Plot, the Tradeoff Plot does not plot the entire ensemble of each variable. Instead, the user must define a horizon stage and a statistic of the variable ensemble (at the selected stage) to compute and plot.

Click the "Tradeoff Plot" button on the ribbon to open a new Tradeoff Plot form.



Different Tradeoff Scenarios and variables can be plotted by using the following selectable boxes on the form.

Tradeoff Scenarios: Selects from which Tradeoff Scenario to plot data.

Category: Specifies which types of variable categories to select. As before, "Default Variables" are created automatically. Selecting this option opens additional selectable boxes which enable the user to select different elements and eventually the variables to be plotted. Selecting "Custom Variables" enables the user to select user-defined Custom Variables (previously created with the Custom Variable Definition form).

Stage: Selects the time step of the horizon for which to extract data for the Tradeoff Plot.

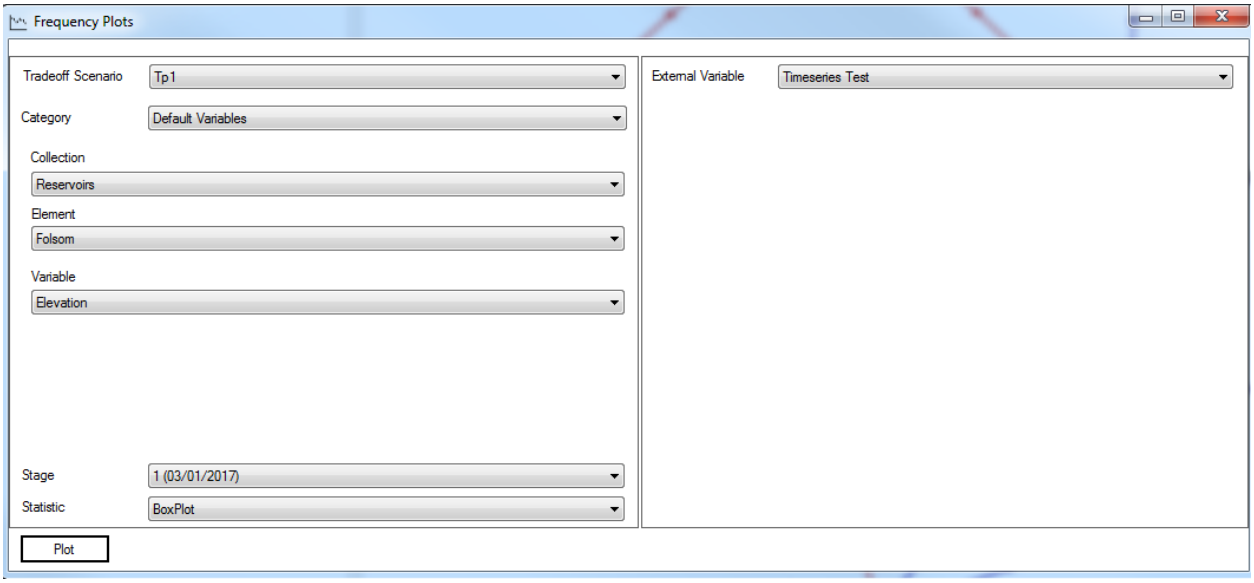
Statistic: Selects the statistic of the variable ensemble to be computed and used for the Tradeoff Plot.

Once the user has chosen a variable, the [Add to X Axis] button or the [Add to Y Axis] can be clicked to add the variable to the "Selected Variable" list at the bottom of the screen. Multiple variables can be added to the Y axis as long as they have the same units. Only one variable can be added to the X axis. X and Y axis variables do not need to have the same units. The "Selected Variable" list displays all selected variables to be plotted. The color that will be used to plot a variable can be edited by right-clicking a selected variable and clicking "Change Color".

Pressing the [Plot] button will open a new form with the plotted results.

6.18.3 Frequency Plots

The Frequency Plot screen can be used to compare the values of different Tradeoff Points to the frequency curves of External Variables imported by the user. One use of this functionality is to allow comparison of model results to the frequency curves of historical measurements recorded for the same variable. Click the "Frequency Plot" button on the ribbon. This will open up a new Frequency Plot form.



The left side of the form enables the user to select the Tradeoff Scenarios and variables. This selection mechanism is similar to the one used for the Tradeoff Plot form. The right side of the form is used to select the External Variable upon which the frequency distribution is based. The External Variable should be a timeseries with the same units as the variable selected on the left side of the screen. A frequency curve of the external variable will be created for the start date of the horizon and the date corresponding to the stage selected when the variable on the left side of the form was chosen.

Pressing the [Plot] button will open a new form with the result plots.