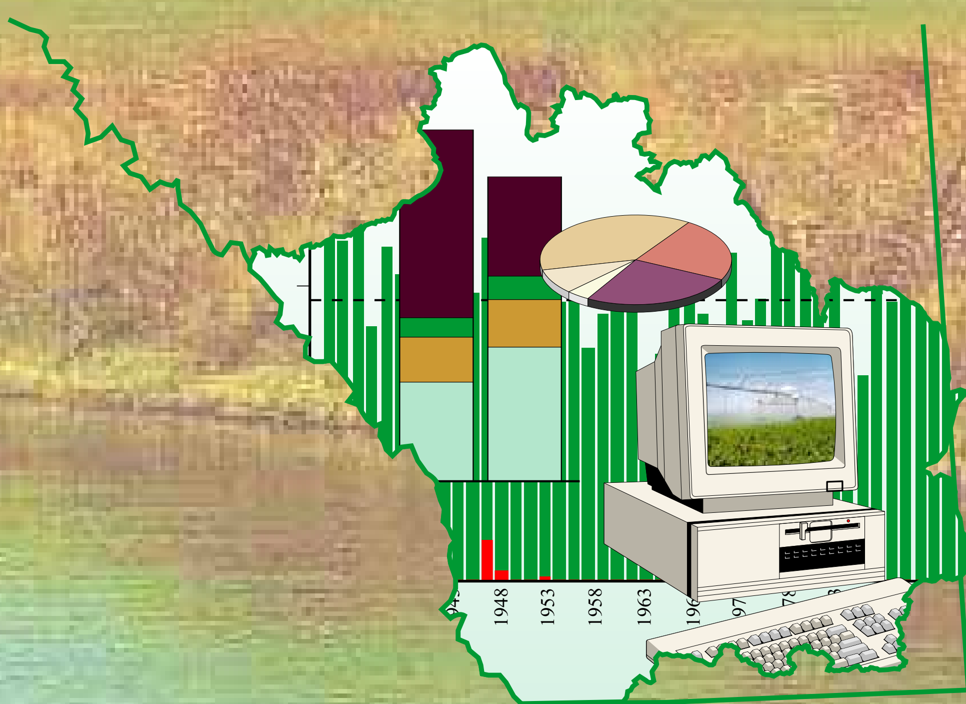
SOUTH SASKATCHEWAN RIVER BASIN

IRRIGATION in the 21st Century

Volume 4: Modelling Irrigation Water Management



SOUTH SASKATCHEWAN RIVER BASIN
IRRIGATION IN THE 21ST CENTURY

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South Saskatchewan River Basin
Irrigation in the 21st Century

Volume 4:
Modelling Irrigation Water Management

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Volume 4. Modelling Irrigation Water Management

I. Deriving Irrigation Water Demands Through the Irrigation District Model (IDM)

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EXECUTIVE SUMMARY

One of the major undertakings within the Irrigation Water Management Study, as reported in *Irrigation in the 21st Century,* involved the development of specialized irrigation water demand computer modelling and data handling tools. Volume 4 describes the modelling processes in detail and consists of two parts. Part I provides a description of the components developed and utilized for the determination of irrigation district demands and irrigation district flow solutions. These components, known as the Irrigation District Model (IDM) suite of tools were developed specifically for this project. The detailed description and associated information provided will be useful for reviewing both the programming and algorithm logic of the tools. Part II presents an overview of the Water Resources Management Model (WRMM) utilized for determining available irrigation district supply and deficits. Alberta Environment (AENV) developed the WRMM tool previously, as required for earlier studies for the purpose of modelling water use and water supply throughout entire river basins. Part II of this volume also presents the results of various calibrations and validations performed on the integration of the WRMM and the IDM suite of tools to validate the application of the algorithms and their implementation.

The Irrigation District Model (IDM) suite of tools was developed specifically for the study of irrigation requirements and basin supply within irrigation districts in southern Alberta. At the core is the Network Management Module (NMM) and the Irrigation Requirements Module (IRM). These modules were developed with the latest development tools available and were designed to model the physical reality of district operations. To achieve this goal Alberta Agriculture:

- Developed a database that detailed the land, crop and irrigation method of every irrigated parcel of land within each district. This database also included conveyance information of the districts and a weather database containing daily values from 1927 to 1995. The database was also integrated with a GIS layer to provide the capabilities of display and review of the elements contained in the districts.
- Developed or selected algorithms that were shown to provide the highest accuracy for determining irrigation demands, irrigation schedules and canal operations.
- Performed studies validating the algorithms and their implementation within the tools.

The IDM suite of tools was developed by Phoenix Engineering Inc. The algorithms are based on real-time demand and operations. This report details the algorithms of each module, its design and its implementation.

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INTRODUCTION

The Irrigation District Model, or IDM, consists of a suite of tools that are used to model an irrigation water distribution network. The IDM is comprised of the following components.

- IDM DB Convert, which is used to convert the Input Dataset into a format that can be used by the IDM
- Network Management Module (NMM), which is used to simulate an irrigation water distribution network
- Irrigation Requirements Module (IRM), which is used to model on-farm irrigation demands
- Local Operating Database (LOD), which is the central repository for IDM configuration data and base data
- Scenario Builder, which is used to create different modelling scenarios from a base case
- IDM Export, and IDM Import which are used to transfer an NMM District Version from one LOD to another
- Import IBDF and Import WRMM Output which are used to manage and analyse the input and output datasets for the Water Resources Management Model[2] (WRMM)
- Farm Financial Impact and Risk Model (FFIRM) that is used in the analysis of the results to assess the risk associated with various expansion scenarios[3].

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[2] The WRMM was developed by Alberta Environment and is not a component of the IDM.

[3] The FFIRM was developed by Alberta Agriculture and is not a directly interactive component within the IDM suite of tools. However, data files from IDM were created to facilitate their use within applications of the FFIRM.

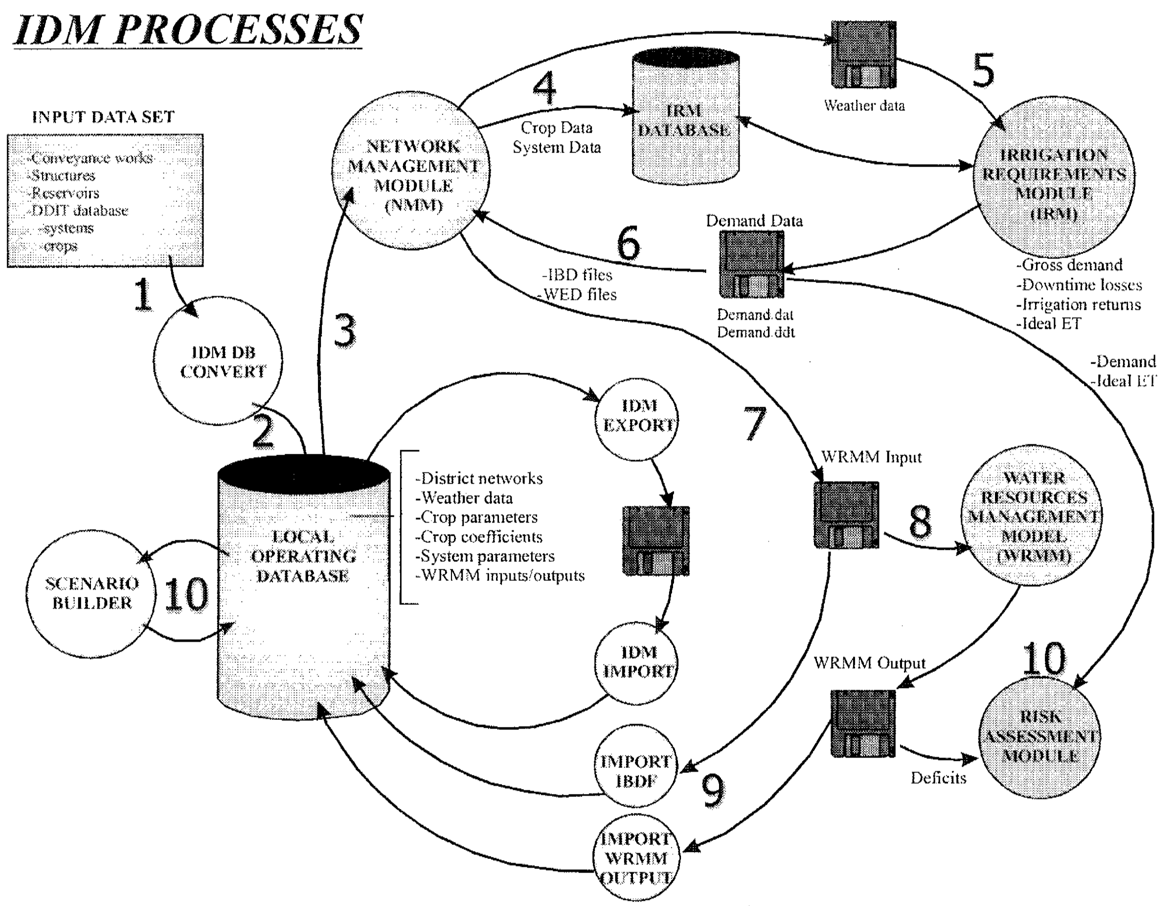

Figure 1. Schematic of the IDM Modelling Process.

Figure 1 shows how the various modules interact with each other. Starting with an Input Data Set (1), the IDM DB Convert is used to convert and store the data into the Local Operating Database (2). From there, the NMM is used to create a project (3) that consists of all or part of an irrigation water distribution network.

After the model has been initialized, the NMM is used to create an IRM database and an exported weather data set (4). The IRM is then run (5) to calculate the on-farm irrigation demands which are then imported back into the NMM (6).

At this point an NMM simulation is run and output is generated for use by the WRMM (7). Steps 1 through 7 are repeated for each of the irrigation districts in a river basin.

The WRMM is then run (8) to analyse the water use in the basin. Output is generated that contains information on water deficits (i.e., when the available supply is not able to meet the demand). Both the input to and output from the WRMM are imported into the LOD to support analysis of the data (9).

To analyse the impact of various expansion scenarios, the Scenario Builder is used to create alternate irrigation scenarios (10).

When a new scenario has been created, steps 3 through 9 are repeated and the deficits from the various scenarios are compared. Once all of the scenarios have been run, the Farm Financial Impact and Risk Module is used to assess the economic impact of any incurred water supply deficit conditions on farming operations and the risk of incurring those impacts (11).

IDM MODULES

IDM DB Convert

The IDM DB Convert is used to convert and store the data from an Import Data Set into the Local Operating Database (LOD). An Import Data Set is comprised of the following.

- A conveyance works ESRI Shape File that includes spatial data and attribute data for all conveyance works segments in the District.
- A structures ESRI Shape File that contains information about all of the irrigation works structures such as control structures, farm turnouts, spillways, etc.
- A reservoir ESRI Shape File which contains spatial data and attribute data for all of the reservoirs in the District.
- A DDIT (District Data Input Tool) database that contains information on the irrigation systems, field areas, and crop types for each irrigated field in the District.

A successful run of the IDM DB Convert results in the creation of a Network Version in the LOD. Each Network Version represents a snap shot of the state of an irrigation district as that relates to the make-up of its water supply infrastructure and its on-farm systems and crops. Each run of the IDM DB Convert results in a new and separate Network Version.

LOCAL Operating Database

The Local Operating Database (LOD) is a Microsoft SQL Server database that is the central repository for information used by the various components of the IDM suite of tools. The LOD contains the following information:

- District Network Version (created by the IDM DB Convert);
- Weather Data;
- Crop parameters (root depth, planting date, harvest date, irrigation threshold, etc.);
- Crop Coefficients (used in the calculation of evapotranspiration);
- Irrigation system parameters (water use rate, coverage rate, etc.); and
- WRMM inputs/outputs.

The following tools interact directly with the LOD.

- IDM DB Convert;
- IDM Export;
- IDM Import;
- Import IBDF;
- Import WRMM Output;
- Scenario Builder; and
- Network Management Module.

Network Management Module

The Network Management Module (NMM) models the flow of water in an irrigation water distribution network. It uses the network information obtained from the Input Data Set and demand data produced by the Irrigation Requirements Module, and calculates the following:

- Daily demand and flow rates at all points in the network;
- Conveyance losses; and
- Return flows.

The above data can be summarized and formatted by NMM to produce Irrigation Base Data (IBD) files that contain input data for the Water Resources Management Model (WRMM).

The following steps are involved in modelling a network.

- Data Preparation: an Input Data Set is assembled and imported into the LOD using the IDM DB Convert.
- Creating and configuring an NMM Project which involves opening a Network Version and selecting all or portions of it into the project.
- Initializing the model that uses the information in the LOD to create a simulation model of the network components in the project.
- Creating the Time Series Dataset. This determines the time period and number of time steps to be used in the simulation.
- Setting the base flow and other parameters.

- Creating an IRM database and weather files. In this step, the necessary information to run IRM is extracted from the NMM configuration and the LOD.
- Running the IRM to generate the demand data. The demand data is stored in two external files: Demand.dat, and Demand.ddt.
- Importing the demand data into the NMM.
- Running the NMM simulation.
- Creating the input files for WRMM (IBD and HBD files).

Irrigation Requirements Module

The Irrigation Requirements Module (IRM) is used to determine the on-farm irrigation water demand. It does this by modelling the crop water user, irrigation systems, and irrigation methods.

Crops. The IRM can model 58 different crop types. A crop parameters and a Crop Coefficient curve for each crop type is stored in the Local Operating Database (LOD). Using this information, weather data, and soil data, it is possible to determine the evapotranspiration (ET) from the crop during each day of the simulation. A water balance calculation is then performed to determine the change in soil resulting from the ET and to determine when the model will simulate an irrigation cycle.

Irrigation Systems. The IRM can model 21 difference types of irrigation methods. The parameters modelled include Water Usage Rate (the rate that water is taken from the irrigation network), Return Flow Factor (the portion of water not absorbed by the soil that is returned to the irrigation network), Application Efficiency (the portion of water taken from the irrigation network that is absorbed by the soil), Coverage Rate, and Downtime. Irrigation is modelled in Bands, which are portions of an irrigation field. A Band is the amount of field that is covered by the irrigation system in a single day. The Coverage Rate of the irrigation system determines the size of the bands.

Water Balance. The IRM maintains a soil moisture water balance and tracks the following water movements.

- Evapotranspiration (ET);
- Precipitation absorbed by the soil;
- Irrigation water absorbed by the soil; and
- Water lost to deep percolation.

The soil moisture water balance allows the IRM to determine the current level of soil moisture relative to the soil moisture holding capacity. This value is a factor in the calculation of ET and determines when the model irrigates the crop.

In addition to those for the soil moisture water balance, the following other water movements are tracked.

- Runoff from precipitation
- Irrigation returns
- Irrigation losses
- Downtime losses

Output. The results of the calculations are stored in a Microsoft Access database and can be displayed in a graphical or tabular format or can be exported into text files. Demand data are also written to a special pair of files, DEMAND.DAT and DEMAND.DDT, which are used to transfer the information to the NMM.

Import IBDF

The Import IBDF tool is used to import Irrigation Base Data (IBD) files and Hydrological Base Data (HBD) files into the Local Operating Database (LOD). These files are generated by the NMM and contain input data for the WRMM. Importing the data contained in these files makes it easily accessible to automated analysis tools used to compare the WRMM output to the input or to compare the output from multiple scenarios.

Import WRMM Output

The Import WRMM Output tool is used to import the output generated by the WRMM into the Local Operating Database (LOD). This output consists of Ideal (requested) water use and Actual water use with the difference being the deficit. Importing the data into the LOD makes it easily accessible for automated analysis such as comparison to the WRMM output from several scenarios.

IDM Export and IDM Import

NMM Network Versions can be moved between Local Operating Database instances with the IDM Export and IDM Import tools. IDM Export writes all of the information contained in a NMM Network version into a group of text files. These text files can then be transferred to other computers and imported into other instances of the LOD using the IDM Import tool. Network Versions may also be backed up and restored using these tools.

Scenario Builder

Scenario Builder is used to create a modified copy of an existing NMM Network Version. It is used to create different expansion scenarios so that the size and frequency of deficits can be compared to the base case. The following three types of scenarios can be created.

- Crop change where the irrigated area stays the same but the cropping pattern is changed.
- System change where the irrigated area stays the same but the irrigation method used changes.
- Area expansion where the cropping pattern and irrigation method used stays the same but the irrigated area is expanded.

It is possible to create scenarios that are combinations of the above by running the Scenario Builder multiple successive times.

NMM MODULE

The Network Management Module is a major component of the IDM; the following section presents a detailed discussion of the architecture, development and design.

Technology

The NMM is based on the following technologies:

- Microsoft Windows NT
- Microsoft COM and ActiveX
- ESRI MapObjects GIS front end
- Microsoft SQL Server
- COM Structured Storage

Each is described in detail below.

Windows NT Platform. Windows NT was selected as the platform for the following reasons.

- It supports large address spaces. Programs can have up to 2 gigabytes of data.
- Multi-processor systems are supported.
- Distributed application architectures are supported.
- It uses the NTFS file system that allows for large volumes (as large as 2 terabyte) and large files ($2^{44} - 1$ kilobytes).
- It runs on low cost, highly available hardware.
- It is widely used and well supported.

Microsoft COM and ActiveX. COM and ActiveX are both Microsoft technologies that address the development and use of software components.

Microsoft ActiveX controls (formerly known as OLE controls or OCX controls) are components (or objects) that can be inserted into applications. There are literally hundreds of ActiveX controls available today with functionality ranging from a timer control (which simply notifies its container at a particular time) to full-featured spreadsheets and word processors. By making use of these widely available and low-cost software components, NMM could be delivered more quickly and at a lower cost.
The Microsoft Component Object Model (COM) is a platform-independent, distributed, object-oriented system for creating binary software components that can interact. The

NMM model engine was developed as a COM server, which allows it to be controlled by a separate user interface program as well as by a script engine.

ESRI MapObjects. ESRI MapObjects software is a powerful collection of embeddable mapping and GIS components. It is used by the NMM to provide a map-centric interface and allows the user to interact with the model as a map rather than a more traditional table based user interface.

Microsoft SQL Server. Microsoft SQL Server is the relational database management product that is used to hold the base data and configuration data required by the IDM suite of tools.

COM Structured Storage. COM Structured Storage is used by the NMM to efficiently store multiple kinds of objects in one document. This allows the state of an NMM project to be captured in a single document and moved from one computer to another without the risk of losing information.

Modular Design

The NMM uses a modular design that utilizes component-based technologies. This design was selected to get maximum leverage from existing off-the-shelf software. For those components that had to be developed, modularisation made it possible to select the appropriate development environment for each component giving consideration to cost of development vs. performance.

The following commercially available components were used in the development of the NMM application: ESRI MapObjects (GIS control), ComponentOne True DBGrid Pro (grid control), and Microsoft ActiveX Data Objects (database access). These components provided extensive functionality at a very low cost relative to the cost of developing the functionality from scratch.

Two separate development environments were selected for the development of the NMM application. For the user interface, Microsoft Visual Basic (VB) was used; for the model engine, Microsoft Visual C++ (VC++) was used. VB is a Rapid Application Development (RAD) tool that makes it possible to develop a feature rich application in much less time that it would take using other tools such as Microsoft Visual C++ (VC++). VB was chosen for the user interface because of its RAD capabilities and its ability to easily make use of a wide variety of off-the-shelf components. For the model engine, VC++ was used because of the need for maximum performance and the ability to use features of the Win32 platform that are not accessible to VB (such as multithreading and COM Structured Storage).

The two components that comprise the NMM application, Nmm.exe and NmmCo.exe, are described below.

Nmm.exe. Nmm.exe is the main application. It contains the user interface, implements all of the functions, and generates most of the output. It makes extensive use of services offered by other components. For example:

- The main view of the NMM project consists of a map of the network. The ESRI MapObjects component acting under the control of the main application provides all the mapping functions.

- Data grids, which appear on various forms, are managed by the ComponentOne True DBGrid Pro control under the direction of the main application.

- The network simulation is provided by the NmmCo component. The main application configures the NmmCo as required to simulate the network and controls the execution of the simulation, saving/retrieving of the configuration and result.

NmmCo.exe. NmmCo.exe is a COM server component written in Microsoft Visual C++. It performs the network simulations for the NMM application. It serves a number of components, such as Canal Segment, Diversion, Reservoir, Irrigation Demand, etc., that can be connected together to simulate any irrigation water distribution network. Once the network has been configured, NmmCo simulates the operation of the network to determine the flow rates through the network for all time steps in the simulation period.

Local Operating Database

Microsoft SQL Server is used to implement the Local Operating Database (LOD) that stores all of the base data for the irrigation water distribution networks and irrigation systems. The data are loaded into the LOD by the IDM DB Convert application. NMM requires a connection to the LOD when a simulation is being configured. Once the simulation has been configured, the database connection is no longer required.

Model Engine

This section discusses in detail the NMM model engine.

Overview. The NMM simulates an irrigation water distribution network by assembling a number of simulation components. The currently available components are:

- Canal Segment

- Closed Pipe Segment

- Diversion

- Junction

- Control Gate
- Reservoir
- Irrigation Demand
- Runoff Collector
- Base Flow
- System Source
- System Sink

Each is described in detail below.

Checked Canal.

1) Overview

The Checked Canal component conveys water between two points in the network model. Checked Canals have a storage volume that must be filled at the start of the season and is drained at the end of the season. Seepage and evaporation (future) losses occur when the Checked Canal is full.

2) Connection Points

The Checked Canal has two connection points; an upstream connection and a downstream connection.

i) Upstream: The upstream connection of a Checked Canal can be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Control Gate
- Diversion
- Demand
- Collector

ii) Downstream: The downstream connection of a Checked Canal can be connected to the upstream connection of any of the following.

- Checked Canal

- Closed Pipe
- Diversion
- Demand
- Base Flow
- Reservoir

3) Configuration

Each Checked Canal is configured with the following information.

- WRMM Block Name – used in the process of discovering the extent of the WRMM Blocks.
- Length – specifies the length of the canal segment in metres. The model engine algorithms do not currently use this value.
- Seepage Rate – specifies the amount of water lost to seepage when the Checked Canal is full. Specified in m^3/s.
- Maximum Capacity – specifies the maximum flow rate, in m^3/s, that the Checked Canal can handle. If, during the forward simulation, the flow rate exceeds this number, a log entry will be generated in the NMM Exception Log.
- Volume – specifies the volume of the Checked Canal segment when it is full.
- Surface Area – specifies the surface area of water in the Checked Canal segment when full. This parameter will be used in the future in the canal evaporation calculation.
- Construction Type – specifies the type of construction. Not currently used in any algorithms.

4) State Data and Time Series Data

i) State Data: A checked Canal has current stored volume [m^3] as state data.

ii) Time Series Data: A Checked Canal has the following time series data:

- Inlet flow rate [m^3/s] (optional – is present only when the inlet of the Checked Canal is an inlet to the WRMM Block to which it belongs).
- Outlet flow rate [m^3/s] (optional – is present only when the outlet of the Checked Canal is an outlet from the WRMM Block to which it belongs).

5) Operation

During the flushing mode (described later), the Checked Canal generates a demand such that the storage volume of the canal is filled in the number of days specified by the model Filling Rate parameter.

Until the Checked Canal is full, a portion of the water that enters the segment is used to fill the segment. After it is full, all of the water entering the segment passes through except for the amount specified for seepage losses.

During the drain mode (described later), the Checked Canal releases its stored water at a rate of 25% of the maximum capacity per day.

On any forward time step, if the water flowing through the Checked Canal exceeds the maximum capacity, an entry is created in the Exception Log.

Closed Pipe.

1) Overview

The Closed Pipe component conveys water between two points in the model network. Closed Pipes have a storage volume that must be filled at the start of the season and is drained at the end of the season. Closed Pipes differ from the Checked Canal component because they do not have seepage or evaporation losses.

2) Connection Points

The Closed Pipe has two connection points: an upstream connection and a downstream connection.

i) *Upstream:* The upstream connection of a Closed Pipe can be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Control Gate
- Diversion
- Demand
- Collector

ii) *Downstream:* The downstream connection of a Closed Pipe can be connected to the upstream connection of any of the following.

- Checked Canal

- Closed Pipe
- Diversion
- Demand
- Base Flow
- Reservoir

3) Configuration

Each Closed Pipe is configured with the following information.

- WRMM Block Name – used in the process of discovering the extent of the WRMM Blocks.
- Length – specifies the length of the segment in metres. Used in the calculation of volume.
- Diameter – specifies the diameter of the pipe in metres. Used in the calculation of volume.
- Maximum Capacity – specifies the maximum flow rate, in m^3/s, that the Closed Pipe can handle. If during the forward simulation, the flow rate exceeds this number, a log entry will be generated in the Exception Log.

4) State Data and Time Series Data

i) State Data: A Closed Pipe has current stored volume [m^3] as state data.

ii) Time Series Data: A Closed Pipe has the following time series data:

- Inlet flow rate [m^3/s] (optional – is present only when the inlet of the Closed Pipe is an inlet to the WRMM Block to which it belongs).
- Outlet flow rate [m^3/s] (optional – is present only when the outlet of the Closed Pipe is an outlet from the WRMM Block to which it belongs).

5) Operation

During the flushing mode, the Closed Pipe generated a demand such that the storage volume of the pipe is filled in the number of days specified by the model Filling Rate parameter.

Until the Closed Pipe is full, a portion of the water that enters the segment is used to fill the segment. After it is full, all of the water entering the segment passes through. During the drain mode, the Closed Pipe releases its stored water at a rate of 25% of the maximum capacity per day.

On any forward time step, if the water flowing through the Checked Canal exceeds the maximum capacity, an entry is created in the Exception Log.

Diversion.

1) Overview

The Diversion component splits the stream of water entering the component and sends water to one or more of the following.

- an attached Demand;
- zero or more attached laterals; and
- the Diversion outlet.

2) Connection Points

The Diversion has four types of connection points: an upstream connection, a Demand connection, a downstream connection, and zero or more lateral connections.

i) Upstream: The upstream connection of a Diversion can be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Control Gate
- Diversion
- Junction
- Demand
- Collector

ii) Downstream: The downstream connection of a Diversion can be connected to the upstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Diversion
- Demand
- Base Flow

- Reservoir
- System Sink

iii) Demand: The Diversion may have a Demand attached. Demands are used to simulate irrigation demands on the network.

iv) Laterals: The Diversion may have zero or more laterals. Laterals are connected to Control Gates that control the amount of water sent down each lateral.

3) Configuration

Other than the connection information, Diversion components do not have any configurable parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A Diversion has the following time series data.

- Outlet flow rate [m^3/s] (optional – is present only when the outlet of the Diversion is an outlet from the WRMM Block to which it belongs).

5) Operation

In each time step, the Diversion does the following.

- Diverts the requested amount of water to the attached Demand, if there is one.
- Adds up the total demand requested by the Control Gate attached to each lateral.
- If there is sufficient remaining water to meet the total demand from all laterals, the requested amount of water is supplied to each lateral.
- If there is insufficient remaining water to meet the demand, the water is apportioned by equal percentage (i.e., each lateral gets an equal percentage of the water it requested) and then supplied to the laterals.
- Any and all remaining water is passed to the downstream component.

Junction.

1) Overview

The Junction component joins two streams into one. One stream is defined as the upstream segment of the main channel and the other is defined as a tributary.

2) Connection Points

The Junction has three connection points: an upstream connection, a downstream connection, and a single tributary connection.

i) Upstream: The upstream connection of a Junction can be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Control Gate
- Diversion
- Junction
- Demand
- Collector

ii) Downstream: The downstream connection of a Junction can be connected to the upstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Diversion
- Demand
- Base Flow
- Reservoir

iii) Tributaries: The Junction's tributary may be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Diversion
- Demand
- Base Flow
- Collector

3) Configuration

Other than the connection information, Junction components do not have any configurable parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A Junction has the following time series data:

- Inlet flow rate [m^3/s] (optional – is present only when the inlet of the Junction is an inlet to the WRMM Block to which it belongs).

5) Operation

In each forward time step, the Junction accepts water from the components attached to the upstream connection and the tributary connection and sends it to the component attached to the downstream connection.

For each reverse time step (when the demand is being calculated), the junction passes all of the demand at the downstream connection to the component attached to the upstream connection.

Reservoir.

1) Overview

The Reservoir accepts water from the upstream component and releases water to one or more downstream Control Gates. For the Irrigation Water Management Study, the storage function of the Reservoir has been disabled. (The Reservoir component would normally store water in anticipation of a demand that exceeds upstream conveyance capacity.)

2) Connection Points

The Reservoir has two or more connections: a single upstream connection and one or more downstream connections.

i) Upstream: The upstream connection of a Reservoir can be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Control Gate
- Diversion
- Junction

- Demand
- Collector

ii) Downstream: The downstream side of a Reservoir can be connected to one or more Control Gates through which water is released to downstream portions of the network.

3) Configuration

A Reservoir has the following parameters that can be configured:

- Surface area [m^2] – will be used in the future to calculate the evaporation.
- Elevation vs. Volume curve – used to convert the current volume to an elevation and vice versa.
- Current elevation [m] – used at the beginning of a simulation run to set the storage volume.

4) State Data and Time Series Data

i) State Data: A Reservoir has the following state data.

- Current stored volume [m^3]

ii) Time Series Data: A Reservoir has the following time series data.

- Lower Level Limit – specifies the lowest acceptable Reservoir storage volume for each time step.
- Upper Level Limit – specifies the highest acceptable Reservoir storage volume for each time step.

5) Operation

In each forward time step, the Reservoir accepts water from the attached upstream component and supplies the requested amount of water to each attached downstream Control Gate. Any difference between the incoming volume and the outgoing volume will result in a change in the storage volume. If the storage level is at the lower limit, then the water supplied to the Control Gates will be rationed with each Control Gate getting an equal percentage of the water requested. Alternately, if the storage level is at the maximum the water sent to each Control Gate will exceed the amount requested by an equal percentage in order to keep the reservoir level from exceeding the Upper Level Limit.

The storage level in the reservoir is determined during the reverse time steps as the demand is being summed up from the downstream components. If the demand exceeds the capacity of the upstream conveyance works, the Reservoir limits its demand in that time step to the capacity of the upstream conveyance works. When excess capacity exists in later time steps, the Reservoir increases its demand to account for the previously deferred demand. In the forward time steps, the Reservoir appears to anticipate the periods when the downstream demand exceeds the upstream capacity by increasing the Reservoir level ahead of time.

Control Gate.

1) Overview

The Control Gate is used at the head-works of the system, at the lateral connections on Diversions, and at the outlets of Reservoirs. It requests the amount of water necessary to meet the downstream demand at each time step

2) Connection Points

The Control Gate has a single upstream and downstream connection.

i) Upstream: The upstream connection of a Control Gate can be connected to the downstream connection of any of the following.

- System Source
- Diversion Lateral
- Reservoir

ii) Downstream: The downstream connection of a Control Gate can be connected to the upstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Diversion
- Demand
- Junction
- Reservoir
- Collector
- System Sink

3) Configuration

The Control Gate has no configuration parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A Control Gate has the following time series data.

- Downstream Demand – contains the flow rate, in m^3/s, required to meet the demand of the attached downstream components.

- Downstream Demand Delta – is used to alter the amount of water that is delivered to the attached downstream components.

- Actual Amount Delivered – records the amount of water actually delivered in each time step.

5) Operation

In each forward time step the Control Gate requests the amount of water from the upstream component that is required to meet the downstream demand. The Control Gate then passes the water received from the upstream component to the downstream component. The amount delivered can be different than the amount requested and is determined by logic in the upstream component. If Demand Delta data has been supplied the Control Gate will modify the amount requested by the values specified in the Demand Delta.

The amount of water requested in each time step is determined during the reverse time steps where the demand from the downstream components is summed up and recorded by the Control Gate.

Base Flow.

1) Overview

The Base Flow is used at any point in the network where a minimum flow rate must be maintained.

2) Connection Points

The Base Flow has a single upstream and downstream connection.

i) Upstream: The upstream connection of a Base Flow can be connected to the downstream connection of any of the following.

- Checked Canal

- Closed Pipe

- Diversion

- Demand

- Collector
- Control Gate

ii) Downstream: The downstream connection of a Base Flow can be connected to the upstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Diversion
- Demand
- Junction
- Reservoir
- Collector
- System Sink

3) Configuration

The Base Flow has no configuration parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A Base Flow has the following time series data.

- Base Flow – contains the minimum flow rate, in m^3/s, that should flow through the Base Flow component at each time step.
- Actual Flow – records the amount that actually flowed through the Base Flow component at each time step.

5) Operation

During reverse time steps, the Base Flow checks the demand from the downstream components and compares it to the minimum flow rate specified for the time step. If the demand from the downstream components is less than the specified minimum, the demand is increased to the specified minimum. Otherwise, the demand is passed to the upstream component unchanged.

In each forward time step the Base Flow passes all water received from the upstream component on to the downstream component and records the flow rate.

Collector.

1) Overview

The Collector component collects water from one or more upstream components and passes it on to a single downstream component.

2) Connection Points

The Collector has two or more connections: one or more upstream connections and a single downstream connection.

i) Upstream: The upstream connections of a Collector can be connected to the downstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Control Gate
- Diversion
- Junction
- Demand
- Collector

ii) Downstream: The downstream connection of a Collector can be connected to the upstream connection of any of the following.

- Checked Canal
- Closed Pipe
- Diversion
- Demand
- Base Flow
- Reservoir
- Junction
- Collector

3) Configuration

Other than the connection information, the Collector component does not have any configurable parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A Collector has the following time series data.

- Actual Flow – records the amount that actually flowed through the Collector component at each time step [m^3/s].

5) Operation

In each forward time step, the Collector accepts water from all of the attached upstream components and passes it on to the single attached downstream component. The amount of water that passes through the Collector at each time step is recorded.

Demand.

1) Overview

The Demand component represents an irrigation demand on the network.

2) Connection Points

The Demand has an upstream connection and a downstream connection.

i) Upstream: The upstream connections of a Demand can be connected only to a Diversion component.

ii) Downstream: The downstream connection of a Demand is used to pass Irrigation Returns to a downstream Collector. If no downstream connection is supplied, the Irrigation Returns are passed to the component downstream of the Diversion.

3) Configuration

Other than the connection information, Demand components do not have any configurable parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A Demand has the following time series data.

- Gross Demand – the rate that the irrigation system removes water from the conveyance works when it is "on".

- Down Time Losses – the amount of water (expressed as an average rate over the time step) that is not used by the Demand in each time step due to irrigation system down time.

- Irrigation Returns – the amount of water that returns to the network as irrigation runoff.

5) Operation

The behaviour of the Demand is determined by two factors; the type of conveyance works it is attached to, either a Checked Canal or a Closed Pipe, and whether a Collector is attached or not.

i) Demand Attached to Checked Canal: On each reverse time step the Demand requests the amount of water specified by the Gross Demand value for the time step. On the forward time step, the Demand takes only the Gross Demand less the Down Time Losses. The Down Time Losses flow to the outlet of the Diversion that the Demand is attached to. Irrigation Returns flow to the attached Collector. If a Collector is not attached, then the Irrigation Returns flow to the outlet of the Diversion that the Demand is attached to.

ii) Demand Attached to Closed Pipe: On each reverse time step the Demand requests the amount of water specified by the Gross Demand. On the forward time step, the Demand takes this amount of water, Down Time Losses and Irrigation Returns flow to the attached Collector. If a Collector is not attached, the Down Time Losses and Irrigation Returns flow to the system sink.

System Source.

1) Overview

The System Source supplies water to all of the inlets into the network.

2) Connection Points

The System Source is connected to one or more Control Gates.

3) Configuration

Other than the connection information, the System Source does not have any configurable parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: None.

5) Operation

On forward time steps, the System Source delivers the requested amount of water to each attached Control Gate.

System Sink.

1) Overview

The System Sink receives water from all of the outlets from the network.

2) Connection Points

The System Sink is connected to the components at the end of all branches of the network.

3) Configuration

Other than the connection information, the System Sink does not have any configurable parameters.

4) State Data and Time Series Data

i) State Data: None.

ii) Time Series Data: A System Sink has the following time series data.

- Consumption – records the total amount of water consumed by all Demands (Gross Demand less Down Time Losses and Irrigation Returns).
- Deficit – records the total Demand Deficits.

5) Operation

Receives water from all unconnected outlets on the network.

Model Configuration

This section discusses how to configure the NMM to model an irrigation water distribution network.

Constructing a Network Model. The general steps that are followed to construct a NMM model of a network are as follows.

Instantiate (i.e. create an instance of) all of the components that will be used in the model. This will consist of a Source, Sink, Check Canals, Closed Pipes, Diversions, Control Gates, Junctions, Demands, Reservoirs, Collectors, and Base Flows.

Connect the components together. For example, a Checked Canal is connected to an upstream Control Gate by setting the Control Gate's downstream component reference to point to the Checked Canal and the Checked Canal's upstream component reference to point to the Control Gate.

Initialize the model. During this step, the NMM analyses the network and constructs the array required to hold the time-series data arrays. In this step, the WRMM blocks are also analysed and WRMM return flow collectors (Collector components) are added to the model.

Examples. In the following discussion, several simulation networks will be constructed, with each successive network building on the previous one. The figure below illustrates a schematic of a simple water distribution network.

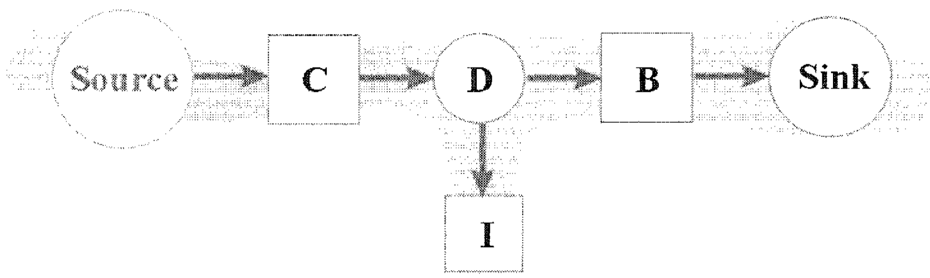

Figure 2. An example of a simple network configuration.

The components are describes as follows.

- One Control Gate component (the "C" on the diagram);
- A Diversion component (the "D" on the diagram);
- An Irrigation Demand component (the "I" on the diagram);
- A Base Flow component (the "B" on the diagram);
- Checked Canals components that connect the Control Gate to the Diversion and the Diversion to the Base Flow (the lines connecting the "C", "D" and "B" together);
- A Source that supplies the water to the network; and
- A Sink component that receives the water.

The Control Gate controls the flow of water into the network and will, by default, request just enough water from the Source component to satisfy all of the demand on the network. At the Diversion component, water is diverted from the Checked Canal to the Irrigation Demand to meet that demand. The remaining water flows down to the Base Flow component and finally to the Sink component.

The Base Flow component is used to simulate a tail out and will create an additional demand at the control gate so that there is left over water at the diversion.

The following steps are taken by the NMM when simulating this network.

1. The network is run backwards through the time steps and backward up through the network from the Sink component to the Source component. As the model engine progresses through the component it adds any new demands to the total. For example:

   - When the model encounters the Base Flow component, it adds the specified flow rate to the demand.

   - Upstream of the Base Flow component is a Checked Canal component. When the model encounters this, it adds on the amount of water that will be lost to seepage to the total demand.

   - Upstream of the Checked Canal is a Diversion component. The model will add on the gross demand (irrigation demand, plus down-time losses) from the Irrigation Demand component attached to the Diversion to the total demand.

   - Upstream of the Diversion component is another Check Canal component. The seepage from this segment is added to the total demand.

   - Upstream of that is the Control Gate component. This component stores the total demand for all components downstream of it in an array with one element for each time step in the simulation.

   - This process is repeated for all time steps from the last to the first.

2. At this point the model runs forward through the simulation from the first time step to the last. At each time step it performs the following:

   - The Control Gate is queried to determine how much water is required to meet the demand of the downstream component for the current time step.

   - The Source component delivers the requested amount of water to the Control Gate, which passes it through to the downstream components.

   - The Checked Canal downstream of the Control Gate removes water from the amount delivered by the Control Gate to account for seepage. It delivers the remainder of the water to the Diversion Component.

   - The Diversion Component queries the Irrigation Demand to determine its demand and delivers the requested amount of water. On a forward time step, the Demand requests only the amount of water required by the irrigation demand. The remaining water (i.e., the downtime losses) flow by into the Diversion outlet. Any water not used to service the demand is passed on the Checked Canal component downstream of the Diversion component.

   - The downstream Check Canal removes some of the water to account for seepage and passes the remainder to the Base Flow node.

- The Base Flow node passes all of the water it receives to the System Sink component.

It is possible, by exporting data from the NMM, to perform a water balance on the system. The water supplied by the Source component can be compared to the sum of the water delivered to the various demands plus any water that flows into the Sink component. In this case, the demand will consist of seepage from two Check Canal components plus the gross irrigation demand.

In Figure 3, a lateral branch has been added to the network using a Diversion component. The flow of water into the lateral is controlled with a Control Gate component (the "C" immediately downstream of the Diversion component). On the lateral are two additional Diversion components that divert water to Irrigation Demand components and a Base Flow component at the end of the lateral. Like the main channel, the end of the lateral is also connected to the System Sink component. Two Diversion components and two Demand components have also been added to the main channel downstream of the first Diversion component.

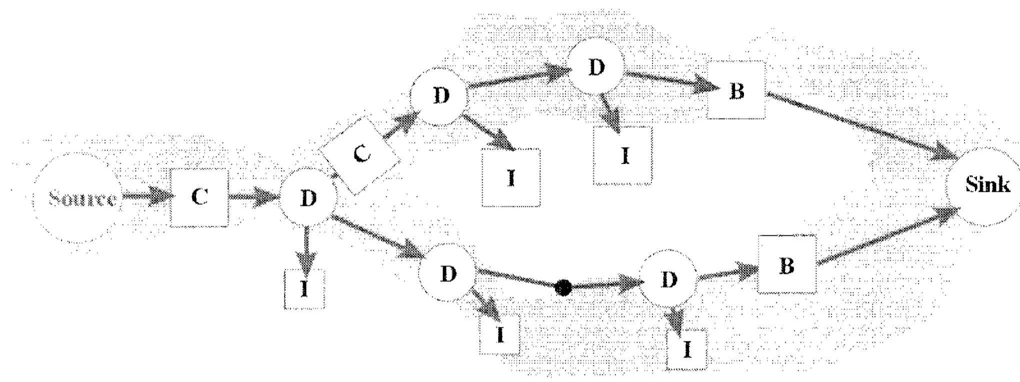

Figure 3. Lateral branch added to network configuration.

When simulating this network, the NMM must now determine how much water it must divert into the lateral to meets the demands on that lateral. It determines this in the same manner that it determines the demand on the main channel: it runs backwards through the time steps and backwards up through the lateral starting at the System Sink until it reaches the Diversion Component where water is diverted into the lateral. At this point, the demand is added to the demand that has been summed up for the main channel. The Control Gate component at the head of the lateral tracks the demand for the lateral for each time step and stores this information so that it can divert the required amount of water into the lateral when the model is running forward through the simulation.

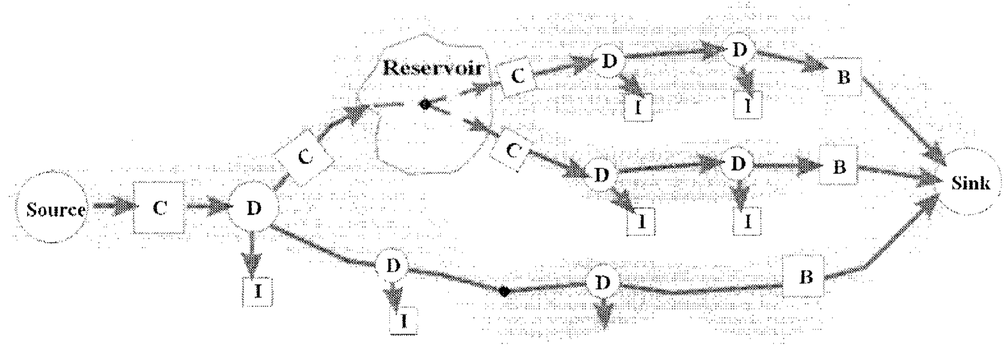

Figure 4. Reservoir added to the network configuration.

Figure 4 shows the network with the addition of a Reservoir Component. The Reservoir component has one inlet and two outlets (Reservoirs may have one or more outlets). The flow of water from each outlet on the Reservoir is controlled by a Control Gate component. If the flow of water into the Reservoir component exceeds that water released from the outlets, the Reservoir component will store the excess. Conversely, if the water being released from the Reservoir component exceeds the rate that water is flowing into the Reservoir component, it will take water from storage to make up for the shortfall in supply.

> *Note that for the Irrigation Water Management Study, the function of the Reservoir component was disabled. This was done to allow the Water Resources Management Model to control the reservoirs. In this circumstance, the Reservoir component is essentially the same as a Diversion Component.*

During the simulation, the Reservoir component is treated as follows:

- In the first phase of the simulation, when the model is running backwards through time and up the network, the demand on each branch connected to a Reservoir component outlet is summed up. At the Reservoir component, the demands for all outlets are summed and are passed on up through to the inlet. The Control Gate components, attached to each outlet, store the demand for each time step so that during the second, forward, phase they can release that amount of water into the branch.

- In the second phase of the simulation, when the model is running forward in time and down through the network, the Reservoir component divides up the water flowing in through the inlet and passes it on to each branch. The amount of water released into each branch is controlled by the Control Gate components, which were "programmed" to know how much water is required to meet the demands on the branch during the first phase of the simulation.

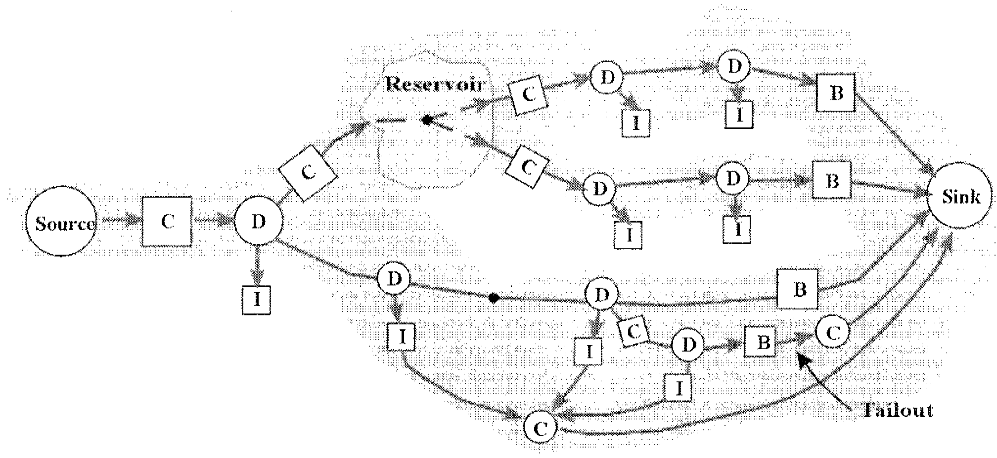

Figure 5. Irrigation Returns Collector added to network.

In Figure 5, an Irrigation Returns Collector component has been added. This component collects the runoff from an Irrigation Demand component. If an Irrigation Demand component is not connected to a Collector component, the runoff from the field is assumed to flow back into the canal that provides the irrigation water. The Collector component is used by the NMM to track irrigation water that flows back into the basin via means not included in the simulated network.

In the Irrigation Water Management Study simulations, the NMM automatically creates one Collector component for each WRMM Block, which is known as the WRMM Return Flow Collector, and connects all Irrigation Demand components within the WRMM Block to that Collector component. This makes it possible for the NMM to determine the amount of irrigation runoff that needs to be included in the WRMM return flow for each WRMM Block.

During the simulation, the Collector component is ignored in the first phase of the run. In the second phase, the irrigation returns from the Irrigation Demand component are passed to the Collector component. The Collector component sums up all of the water it receives and passes it on to the System Sink.

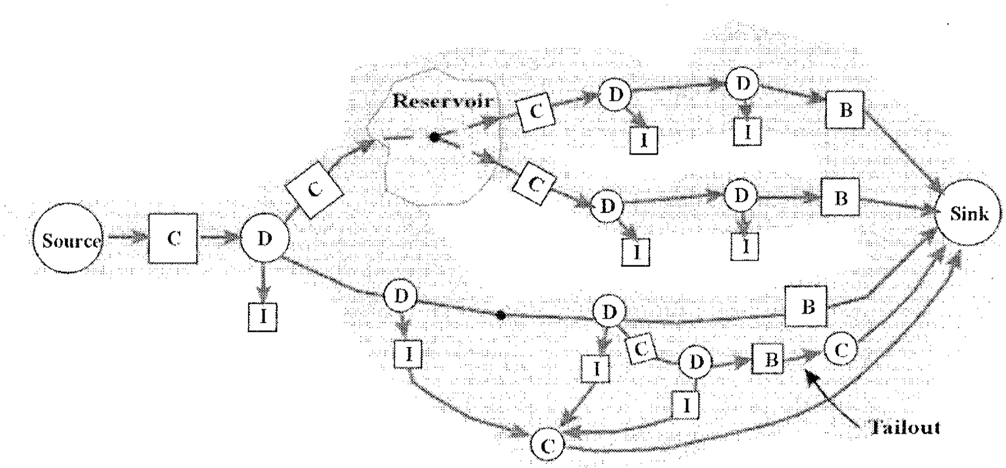

Figure 6. Return Flow Collector added to network configuration.

Figure 6 shows the addition of a Return Flow Collector component. In this case, the Collector component is attached to a canal segment or Base Flow component and collects the water flowing from that component. This configuration is used to track the amount of return flow making use of the fact that the Collector component tracks the flow rate through it for each time step. For the Irrigation Water Management Study, at least one Return Flow Collector is configured for each WRMM Block and is used to collect data about the return flows from the WRMM Block.

In Figure 7, a Junction component was added to the network. The Junction component joins two streams and outputs the combined flow to the attached downstream component. It can be used to join two canals or can be used to allow irrigation return flows to re-enter the network as is shown above.

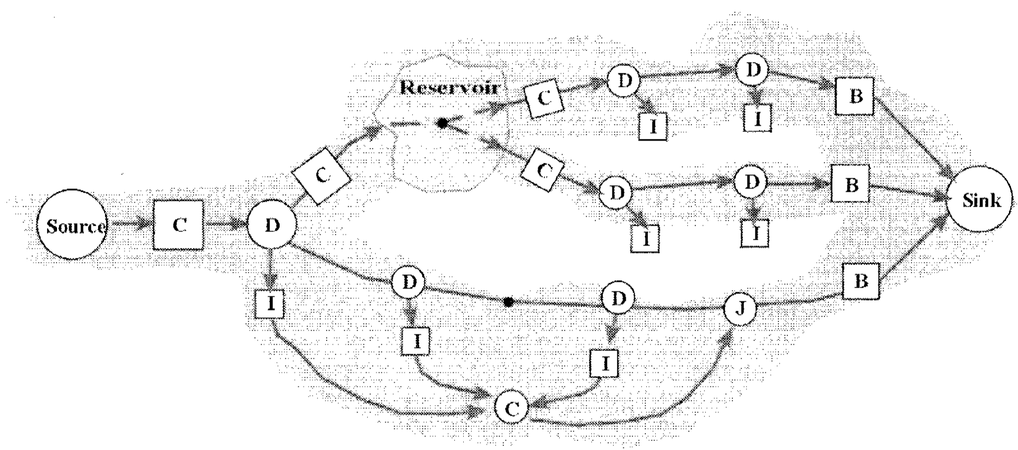

Figure 7. Junction added to network configuration.

Automatic Model Generation. Because of detail with which the irrigation districts were to be modelled, it was necessary to develop a means by which the configuration of the simulation network could be automated. The solution that was developed uses the data in the Alberta Agriculture Geographic Information System (GIS) as the basis for the simulation network. The advantage of this approach is that an existing base of data could be used thereby avoiding duplication of data and effort to collect and manage the data. It also provided a means for representing irrigation networks within the NMM by using the ESRI Map Objects GIS control.

The NMM uses the data from three layers in the GIS. They are:

- A Conveyance Works layer that contains all of the conveyance works segments;
- A Structures layer that contains all of the diversion, spill-way, and tail outs structures; and
- A Reservoir layer that contains all of the reservoirs.

Data from the Alberta Agriculture GIS system must be exported into ESRI Shape Files before it can be used by the NMM. The Shape Files contain both the geographic information (such as the length and path of a canal segment) and attribute data (such as the type of construction, capacity, seepage rate, etc.) as well as routing and connection information.

One of the key elements that enable the NMM to build the simulation network from the GIS data is the directedness and connectedness of the conveyance works shape file. The conveyance works layer consists of a number of nodes that are connected by arcs. Each arc has a direction of flow, a "from node", and a "to node". By analysing the nodes and arcs, it is possible for the NMM to determine how the network is constructed and the direction of flow in each segment.

Before the Shape Files and the data they contain can be used by the NMM they must be processed by the IDM DB Convert application which converts the data in the shape files into a format that is usable by the NMM and stores it in the IDM Local Operating Database. This process has the following steps.

1. The Conveyance Works shape file is processed as follows.

    - All the segments and nodes are identified as well as the connections between the segments and nodes.

    - An upstream trace is performed, starting from the nodes that have only flow into them, to find all of the inlets into the network. Loops are detected and identified so that they can be fixed.

    - A downstream trace is performed starting from nodes that have only flow out of them, to find all of the outlets from the network. Loops and unconnected nodes are detected and identified so that they can be fixed. Nodes with two inlets and no outlets are also identified as potential errors (i.e., water flows in but not out).

2. The Reservoir shape file is then processed.

    - This step requires additional input in the form of a table, called the CONV2RESV table, which identifies the conveyance works segments that are "pseudo segments". (Reservoir pseudo-segments are those segments that have been added to the conveyance works layer to join the segments at the inlet of the reservoir to the segments at the outlet of the reservoir. They don't physically exist but are required by the NMM so that it can process the network.) Using the network information from conveyance works layer, the reservoir layer and the table of reservoir pseudo segments, the nodes that are reservoirs are identified.

3. Junctions and Diversions in the network are then analysed.

    - Nodes with one outlet and more than one inlet are identified as Junctions. Junctions with more that two inlets are not allowed and are identified so that they can be fixed.

    - Nodes with one inlet and more than one outlet are identified as Diversions.

- If a node is found with multiple inlets and outlets, it is converted into two nodes joined by a zero length pipe of infinite capacity. This form is equivalent to the actual node but is one that the NMM can handle. The upstream node is treated as a Junction and the downstream node is treated as a Diversion.

4. The structures Shape File is processed. Different actions are taken for the different types of structures:

   - "LT" (lateral turnout) types are used to determine which segment at a diversion is the lateral. The segment referenced by the LT structure is determined to be a lateral.

   - "FT" (farm turnout) types are used to determine where the irrigation demands are located on the network. All of the farm turnouts on a canal or pipeline segment are aggregated together into a single demand and are placed at the downstream node of the segment.

   - "SW" (spill-way) and "TA" (tail-out) types indicate where an NMM Base Flow component should be located. Base Flow components may be connected to Collectors as dictated by the contents of the Sink Table.

5. After the structures have been processed the Sink table is processed. If Collector references a segment, the Collector outlet will flow back into the network upstream of the referenced segment; otherwise, the Collector outlet will flow into the System Sink.

6. Diversions and Junctions are now added to the model at the locations previously determined by analysing the inlets and outlets from the nodes. For Diversions, one segment is attached to the upstream connection, the segments that were referenced by an "LT" type structure are attached to the Diversion as laterals, and the remaining downstream segment (if there is one) is attached to the Diversion's downstream connection. Certain special conditions influence the decisions around how a Diversion is created and connected:

   - If the node does not have an upstream segment, a Diversion component is not created. Each segment leaving the node is connected to the downstream connection of a Control Gate. The upstream connection of the Control Gate is connected to the System Source.

   - If the node is a Reservoir (i.e., all segments coming into and leaving the node are Reservoir Pseudo-Segments) a Reservoir is created instead of a Diversion.

   For Junctions, one of the upstream segments is attached to the upstream connection while the other is attached to the tributary connection. The downstream segment is attached to the downstream connection. Currently, the BLAT Name is used to determine which of the two upstream segments should be treated as the tributary. If the BLAT Name of one of the upstream segments matches that of the downstream segment then both segments are considered to be the main channel and the other upstream segment is considered to be the tributary. If neither of the upstream segments have BLAT Names that match the downstream segment BLAT Name, the choice of which upstream segment will be the tributary is randomly selected.

At locations where a Collector outflow is to re-enter the network, a Junction component is inserted. In cases where this would result in a Junction immediately upstream of another Junction, a zero length segment of infinite capacity is added between the two Junctions.

7. Control Gates are then added to the network at the following locations:

    - On all lateral connections on all Diversions
    - At all Reservoir outlets
    - At all inlets to the network.

    Base Flows are added to the network at the tributary connection to all Junctions and at the end of each reach.

8. Lastly, Demands are added downstream of each segment that is referenced by one or more FT type structures. Since Demands can only be attached to Diversions, a Diversion is created if one does not already exist.

Local Operating Database

The NMM requires several types of data in order to perform a simulation of an irrigation water distribution network. These include:

- Project level data that describe what components are to be included in the simulation as well as other related information.
- Network configuration information that includes all of the components used to construct the model and how the components are connected.
- Spatial data (ESRI Shape Files) that are used to provide the data for the GIS interface.
- Time series data for certain components such as minimum and maximum levels for reservoirs, base flow rates for canals, irrigation demands, etc.
- Weather data, which are included in the data sets that are created for the Irrigation Requirements Module (IRM) runs.

As well, for the Irrigation Water Management Study, there was a need to store the output from the NMM so that it can be analysed. This information was stored in the IDM Local Operating Database (LOD), which is described in detail below.

Overview. Data in LOD can be placed in the following categories.

- Model Configuration Data
- Base Data
- Weather Data
- Shape Files
- Model Output
- WRMM Output

Model Configuration Data. The NMM uses model configuration data stored in the LOD to create the simulation models of the irrigation water distribution networks. The configuration data are organized into Network Versions. Each Network Version contains a description of an entire physical irrigation network along with ESRI Shape Files that allow NMM to display the network using its GIS interface. Specifically, a Network Version contains all of the following.

- Conveyance works segments (checked canals or closed pipes) and their attributes (such as length and capacity)
- Location of the diversions and junctions
- Location of the reservoirs, their attributes
- Locations of the control gates and base flow components
- Locations of the irrigation turnouts and which irrigation systems are supplied by the turnout
- Information on the irrigations systems (type of equipment, coverage rate, consumption rate, efficiency, etc.)
- Information on the irrigation fields (soil type, crop type, etc.)
- Information on how all of the above is connected together

For the Irrigation Water Management Study, Network Versions contain entire irrigation districts such as LNID, EID, etc., or super districts such as the Saint Mary's Project. Because each Network Version and all of its components are tagged with a unique identifier, it is possible to have multiple versions of the same irrigation district stored in the LOD.

Global Identifiers. Each component in an irrigation network that is to be imported into the LOD must be assigned a Global Identifier (GID). Once assigned, the GID for that irrigation network component never changes. This is done for the following reasons.

- It provides the necessary means of identifying a network component that may appear in several Network Versions. For example, there may be several versions of the LNID in the LOD but in each version a specific canal segment (the first segment downstream from the head-works, for example) will all have the same GID.

- It provides a convenient tag that can be used to describe how the network components are connected together.

- It is used to relate the network components to the GIS data and vice versa.

- It will assist in replicating changes to multiple copies of the LOD in the event that it is published and distributed to several locations.

- In combination with the Object Table and the Class Table in the LOD, it provides a means of identifying what type of component is referenced by the GID.

Figure 8 below shows an example of how the GID is used to establish the connections between the NMM components. In the figure, a Diversion component is connected to an upstream Checked Canal component and a downstream Checked Canal component. The upstream Checked Canal points to the Diversion component as the component that is downstream from it. The downstream Checked Canal points to the Diversion component as the component that is upstream from it. The other connections are not shown.

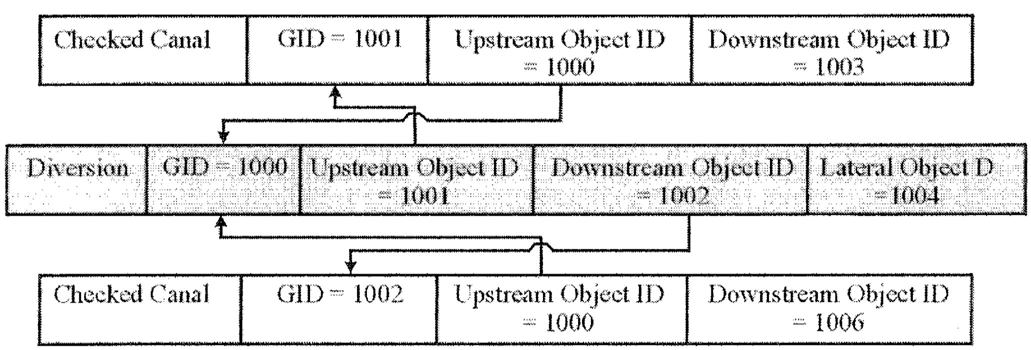

Figure 8. Global IDs used to make component connections.

Figure 9 shows how the model components relate to records in the Object Table via the GID. The Class ID, found in each record in the Object Table, references a record in the Class Table. The records in the Class Table provide the component type information as well as the component name, the database table that contains the component information, and a description of the component.

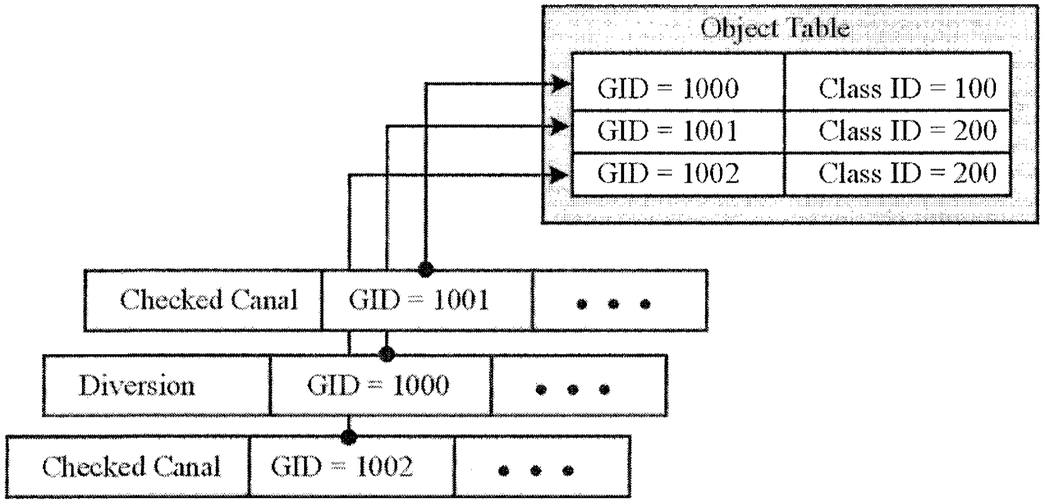

Figure 9. Global IDs contained in the Object Table.

Figure 10 shows how records in the Object Table relate to records in the Class Table and the GIS database. The links between the records in the Object Table and GIS database are required to allow the user interface to relate GIS features to the NMM component data.

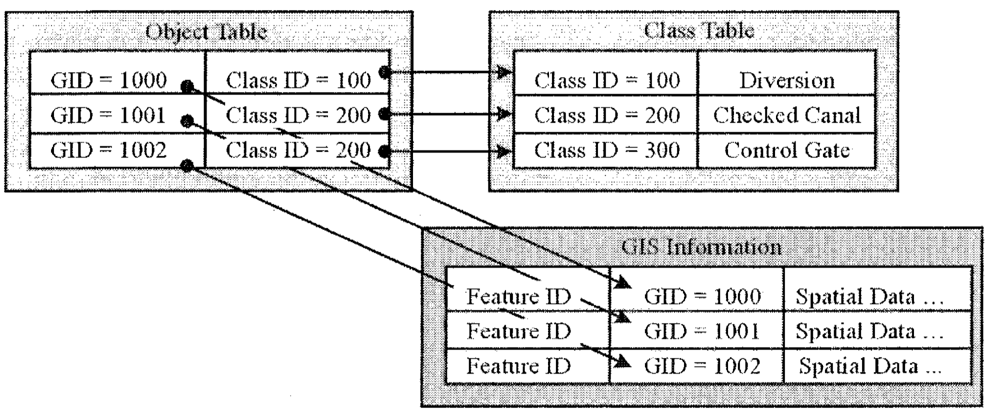

Figure 10. The Object Table provides a link to class information and GIS information.

Base Data. In addition to the Model Configuration Data, the LOD also contains base data such as:

- Weather data;
- Crop data; and
- Irrigation system performance and efficiency data.

1) Weather Data

The weather data stored in the LOD are organized by Weather Station location and are comprised of the daily values for the:

- Maximum Temperature
- Minimum Temperature
- Maximum Relative Humidity
- Minimum Relative Humidity
- Rainfall
- Wind Run
- Solar Radiation
- Evapotranspiration Potential
- Lake Evaporation

2) Crop Data

The base data includes information on the crops that can be simulated by the Irrigation Requirements Module (IRM). This includes such things as min/max root depth and the crop coefficients (which are used in the calculation of Evapotranspiration). The NMM does not use this data directly but does include it in data sets prepared for the IRM. Note that the configuration data includes the crop type for each field connected to the network.

3) Irrigation Systems and Performance Data

The base data also include information on the types of irrigation systems that can be simulated by the Irrigation Requirements Module (IRM). As with the Crop Data, the NMM does not use this data directly but includes it in the data sets it creates for the IRM.

Model Reference Tables. The NMM uses the following tables in the LOD.

- BaseFlow
- CheckedCanal
- Class
- ClosedPipe
- Collector

- CollectorConnection
- ControlGate
- Demand
- DemandConnection
- Diversion
- DiversionConnection
- Junction
- JunctionConnection
- Object
- Project
- ProjectObject
- Reservoir
- ReservoirConnection
- ShapeFile
- Version

Each is described below:

Object Table. The Object Table (Table 1) contains the complete catalogue of all NMM objects in all of the District Versions. If the ObjectID is known, the District Version it belongs to and its class can be determined.

Table 1. Contents of the Object Table.

Column	Type	Description
ObjectID	PK	Object ID of Object.
VersionID	FK	District version object belongs to.
GID	Number	Global ID.
ClassID	FK	ID of class that object belongs to.

Base Flow Table. The Base Flow Table contains the attributes and connection information for all of the NMM Base Flow components for all of the Network Versions

(Table 2). The Version Table and Project Object Table determine the particular Network Version and Project that a Base Flow component belongs to, respectively. The other attributes include:

- *SetBaseFlow*: If true, indicates that the base flow rate will be set to the specified value; otherwise the base flow rate is set to zero.

- *BaseFlowRate*: The flow rate [m^3/s] to set the base flow rate to. Note that the setting of the Base Flow Scaling Factor will affect this value.

Table 2. Contents of the Base Flow Table.

Column	Type	Description
ObjectID	FK	Object ID of BaseFlow object.
UpstreamCompOID	FK	Object ID of upstream component.
DownstreamCompOID	FK	Object ID of downstream component.
SetBaseFlow	Boolean	Flag indicates if base flow is to be set.
BaseFlowRate	Number	Rate of base flow [m^3/s].

Table 3. Contents of the Checked Canal Table.

Column	Type	Description
ObjectID	FK	Object ID of CheckedCanal object.
UpstreamCompOID	FK	Object ID of upstream component.
DownstreamCompOID	FK	Object ID of downstream component.
Name	String	Canal segment name.
Length	Number	Length of the canal [m].
MaximumCapacity	Number	Maximum capacity of the canal [m^3/s].
Volume	Number	Volume of water in canal when full [m^3].
Area	Number	Surface area of canal when full [m^2].
ConstructionTypeID	Number	Type of construction.
Seepage Rate	Number	Seepage rate when full [m^3/s].
FlowRateTimeSeries	Number	Determines if time series data is maintained.
WrmmBlock	String	Name of WRMM block canal is in.
DeadEnd	Boolean	Indicates if canal is dead-ended.

The Checked Canal Table contains the attributes and connection information for all of the NMM Checked Canal components for all of the Network Versions (Table 3). The Version Table and Project Object Table determine the particular Network Version and Project that a Checked Canal component belongs to, respectively. The other attributes include:

- *Name:* The name of the canal segment. This value is not used by NMM.

- *Length:* The length of the canal segment in metres.

- *Maximum Capacity:* The maximum capacity of the canal in m^3/s. If NMM must move water through the canal segment at a rate higher than this in order to meet the demand, an exception will be created in the exception log.

- *Volume:* The volume of the canal when full. This is used in the filling and draining phases of the run.

- *Area:* The surface area of the water in a full canal. This will be used in the future to calculate the evaporation from the canal segment.

- *Construction Type:* Originally used in the determination of the seepage. It is not currently used by NMM.

- *Seepage Rate:* The rate that water seeps from the canal when full in m^3/s.

- *Flow Rate Time Series Flag:* Indicates if time series data on the flow rate should be maintained. It is necessary in certain cases to know the flow rate through the canal at each time step in order to determine WRMM Block Consumptive Use and Return Flow.

- *WRMM Block:* The name of the WRMM Block that contains the canal.

- *Dead End Flag:* Indicates if the canal is dead-ended. If this flag is true then the flow rate at the outlet of the canal segment is forced to be zero.

Closed Pipe Table. The Closed Pipe Table contains the attributes and connection information for all of the NMM Closed Pipe components for all of the Network Versions. The Version Table and Project Object Table determine the particular Network Version and Project that a Closed Pipe component belongs to respectively. The other attributes include:

- *Name:* The name of the canal segment. This value is not used by NMM.

- *Length:* The length of the canal segment in metres.

- *Maximum Capacity:* The maximum capacity of the canal in m^3/s. If NMM must move water through the canal segment at a rate higher than this in order to meet demand, an exception will be created in the exception log.

- *Diameter:* The internal diameter of the pipe. It is used to calculate the volume of water that the pipe segment contains when full and is used in the filling and draining phases of the run.

- *Flow Rate Time Series Flag:* Indicates if time series data on the flow rate should be maintained. It is necessary in certain cases to know the flow rate through the canal at each time step in order to determine WRMM Block Consumptive Use and Return Flow.

- *WRMM Block:* The name of the WRMM Block that contains the canal.

- *Dead End Flag:* Indicates if the canal is dead-ended. If this flag is true then the flow rate at the outlet of the canal segment is forced to be zero.

Table 4. Contents of the Closed Pipe Table.

Column	Type	Description
ObjectID	FK	Object ID of ClosedPipe object.
UpstreamCompOID	FK	Object ID of upstream component.
DownstreamCompOID	FK	Object ID of downstream component.
Name	String	Canal segment name.
Length	Number	Length of the canal [m].
MaximumCapacity	Number	Maximum capacity of the canal [m^3/s].
Diameter	Number	Diameter of the pipe [m].
FlowRateTimeSeries	Number	Determines if time series data is maintained.
WrmmBlock	String	Name of WRMM block canal is in.
DeadEnd	Boolean	Indicates if canal is dead-ended.

The Collector Table contains only the Object ID of the Diversion object since it has no attributes of its own (Table 5). The Version Table and Project Object Table determine the particular Network Version and Project that a Collector component belongs to respectively. The Collector Connection Table contains the connection information for the Collector.

Table 5. Contents of the Collector Table.

Column	Type	Description
ObjectID	FK	Object ID of collector.

- The Collector Connection Table contains the connection information for each Collector component (Table 6). There is one entry for each connected component that the Collector is connected to. The CompType column indicates the type of connection.

Table 6. Contents of the Collector Connection Table.

Column	Type	Description
CollectorOID	FK	Object ID of Collector object.
ConnectedCompOID	FK	Object ID of component connected to collector.
CompType	FK	Class ID of component connected to collector.

CompType may assume one of the following values.

- "1" if the component is connected on the upstream side of the Collector.
- "2" if the component is connected on the downstream side of the Collector.

The Control Gate Table contains the connection information for all of the NMM Control Gate components for all of the Network Versions (Table 7). The Version Table and Project Object Table determine the particular Network Version and Project that a Control Gate component belongs to, respectively.

Table 7. Contents of the Control Gate Table.

Column	Type	Description
ObjectID	FK	Object ID of ControlGate object.
UpstreamCompOID	FK	Object ID of connected upstream component.
DownstreamCompOID	FK	Object ID of connected downstream component.

The Demand Table contains the connection information for all of the NMM Demand components for all of the Network Versions (Table 8). The Version Table and Project Object Table determine the particular Network Version and Project that a Demand component belongs to, respectively. Each Demand component is connected to an upstream Diversion component and may optionally be connected to a Collector component. Demand components connect to one or more downstream demands such as an Irrigation Turnout.

Table 8. Contents of the Demand Table.

Column	Type	Description
ObjectID	FK	Object ID of Demand object.
DiversionCompOID	FK	Object ID of the Diversion component that the Demand is connected to.
CollectorCompOID	FK	Object ID of the Collector component that the Demand is connected to.

The Demand Connection Table contains the downstream connection information for each Demand component (Table 9). There is one entry for each downstream component that the Demand component is connected to. CompType indicates what type of component is connected. At the present time, CompType may only be a "1", which indicates an Irrigation Demand.

Table 9. Contents of the Demand Connection Table.

Column	Type	Description
DemandOID	FK	Object ID of Demand object.
ConnectedCompOID	FK	Object ID of component connected to Demand.
CompType	FK	Class ID of component connected to Demand.

The Diversion Table contains only the Object ID of the Diversion object since it has no attributes of its own and the connection information is stored in the Diversion Connection Table (Table 10). The Version Table and Project Object Table determine the particular Network Version and Project that a Diversion component belongs to, respectively.

Table 10. Contents of the Diversion Table.

Column	Type	Description
ObjectID	FK	Object ID of the Diversion object.

The Diversion Connection Table contains the connection information for each Diversion component (Table 11). The ObjectID of the connected component is specified as well as the type of connection indicated by the value stored in CompType. CompType can assume one of the following values.

- "1" if the connected component is upstream of the Diversion component.
- "2" if the connected component is downstream of the Diversion component.
- "3" if the connected component is a downstream lateral.
- "4" if the connected component is a demand.

Table 11. Contents of the Diversion Connection Table.

Column	Type	Description
DiversionOID	FK	Object ID of the Diversion object.
ConnectedCompOID	FK	Object ID of component connected to Diversion.
CompType	FK	Class ID of component connected to Diversion.

The Junction Table contains only the Object ID of the Junction object since it has no attributes of its own and the connection information is stored in the Junction Connection Table (Table 12). The Version Table and Project Object Table determine the particular Network Version and Project that a Junction component belongs to, respectively.

Table 12. Contents of the Junction Table.

Column	Type	Description
ObjectID	FK	Object ID of the Junction object.

The Junction Connection Table contains the connection information for each Junction component. The ObjectID of the connected component is specified as well as the type of connection indicated by the value stored in CompType. CompType can assume one of the following values.

- "1" if the connected component is upstream of the Junction component.
- "2" if the connected component is downstream of the Junction component.
- "3" if the connected component is a tributary to the Junction component.

Table 13. Contents of the Junction Connection Table.

Column	Type	Description
JunctionOID	FK	Object ID of the Junction object.
ConnectedCompOID	FK	Object ID of component connected to Junction.
CompType	FK	Class ID of component connected to Junction.

The Reservoir Table contains attribute information for a Reservoir component. The connection information is stored in the ReservoirConnection table. The Version Table and ProjectObject Table determine the particular Network Version and Project that a Reservoir component belongs to respectively. The Reservoir Table stores the following Reservoir component attributes.

- *Name:* the name of the reservoir.
- *Area:* the surface area of the reservoir. Used to calculate the surface evaporation.
- *VolumeEqType:* the form of the volume equation. The volume equation may take on one of several forms depending upon what fits the volume vs. elevation curve the best.

- *VolumeCoeffA-E:* the coefficients for the volume vs. elevation equation. Not all coefficients are used in all forms of the volume vs. elevation equations.

- *MinElevation:* the elevation of the water surface at the minimum service level of the reservoir expressed in metres.

- *MaxElevation:* the elevation of the water surface at the full service level of the reservoir expressed in metres.

Table 14. Contents of the Reservoir Table.

Column	Type	Description
ObjectID	FK	Object ID of the Reservoir object.
Name	String	Name of the Reservoir.
Area	Number	Surface of the area of the reservoir [m^2].
VolumeEqType	Number	Form of volume equation.
VolumeCoeffA	Number	Coefficient for volume equation.
VolumeCoeffB	Number	Coefficient for volume equation.
VolumeCoeffC	Number	Coefficient for volume equation.
VolumeCoeffD	Number	Coefficient for volume equation.
VolumeCoeffE	Number	Coefficient for volume equation.
MinElevation	Number	Minimum service level elevation [m].
MaxElevation	Number	Elevation as FSL [m].

The Reservoir Connection Table contains the connection information for each Reservoir component. The ObjectID of the connected component is specified as well as the type of connection indicated by the value stored in CompType. CompType can assume one of the following values.

- "1" if the connected component is upstream of the Reservoir component.

- "2" if the connected component is downstream of the Reservoir component.

Table 15. Contents of the Reservoir Connection Table.

Column	Type	Description
ReservoirOID	FK	Object ID of the Reservoir object.
ConnectedCompOID	FK	Object ID of component connected to Reservoir.
CompType	FK	Class ID of component connected to Reservoir.

The Class Table contains information about each of the classes of objects stored in the Local Operating Database (Table 16).

Table 16. Contents of the Class Table.

Column	Type	Description
ClassID	PK	Class ID.
ClassName	String	Name of class.
TableName	String	Name of table that stores the class objects.

The Version Table contains information about each of the Network Versions stored in the Local Operating Database (Table 17). The following attribute information is stored for each Network Version:

- *VersionID:* the ID of the Network Version. This ID is attached to each object that is created as part of the Version.
- *CreationDate:* the date that the Network Version was created in the Local Operating Database.
- *IsValid:* a flag that indicates if the Network Version is valid. Because of the process that is used to create the Network Version, it is possible to have a Version record for a Network Version that is not complete or is invalid. In these cases, the Version is not automatically deleted since it may contain information required to diagnose a problem with the input data set.
- *CreatedBy:* is the User ID of the user that created the Network Version.
- *Name:* the name assigned to the Network Version.
- *Description:* a description of the contents of the Network Version.
- *Notes:* additional notes regarding the Network Version.

Table 17. Contents of the Version Table.

Column	Type	Description
VersionID	PK	District Version ID
CreationDate	Date	Date the District Version was created.
IsValid	Boolean	Indicates if the District Version is valid.
CreatedBy	String	User ID of creator.
Name	String	Name of the District Version.
Description	String	Description of the District Version.
Notes	String	Additional notes.

The Project Table contains information about each NMM Project that is created (Table 18). A Project is created using a specific Network Version and is tagged with the creation date and the User ID of the user that created the project.

Table 18. Contents of the Project Table.

Column	Type	Description
ProjectID	PK	Project ID of an NMM Project.
VersionID	FK	District Version used in Project.
CreationDate	Date	Date Project was created.
CreatedBy	String	User ID of creator.

The Project Object contains a record for each object that is part of a Project (Table 19). This table is primarily used when the NMM Model is being initialized.

Table 19. Contents of the Project Object Table.

Column	Type	Description
ProjectID	PK	Project ID of an NMM Project.
ObjectID	FK	Object ID of objects in Project.

Entity Relationship Diagram. Figure 11 shows the Entity Relationship Diagram (ERD) for the tables in the LOD used by the NMM.

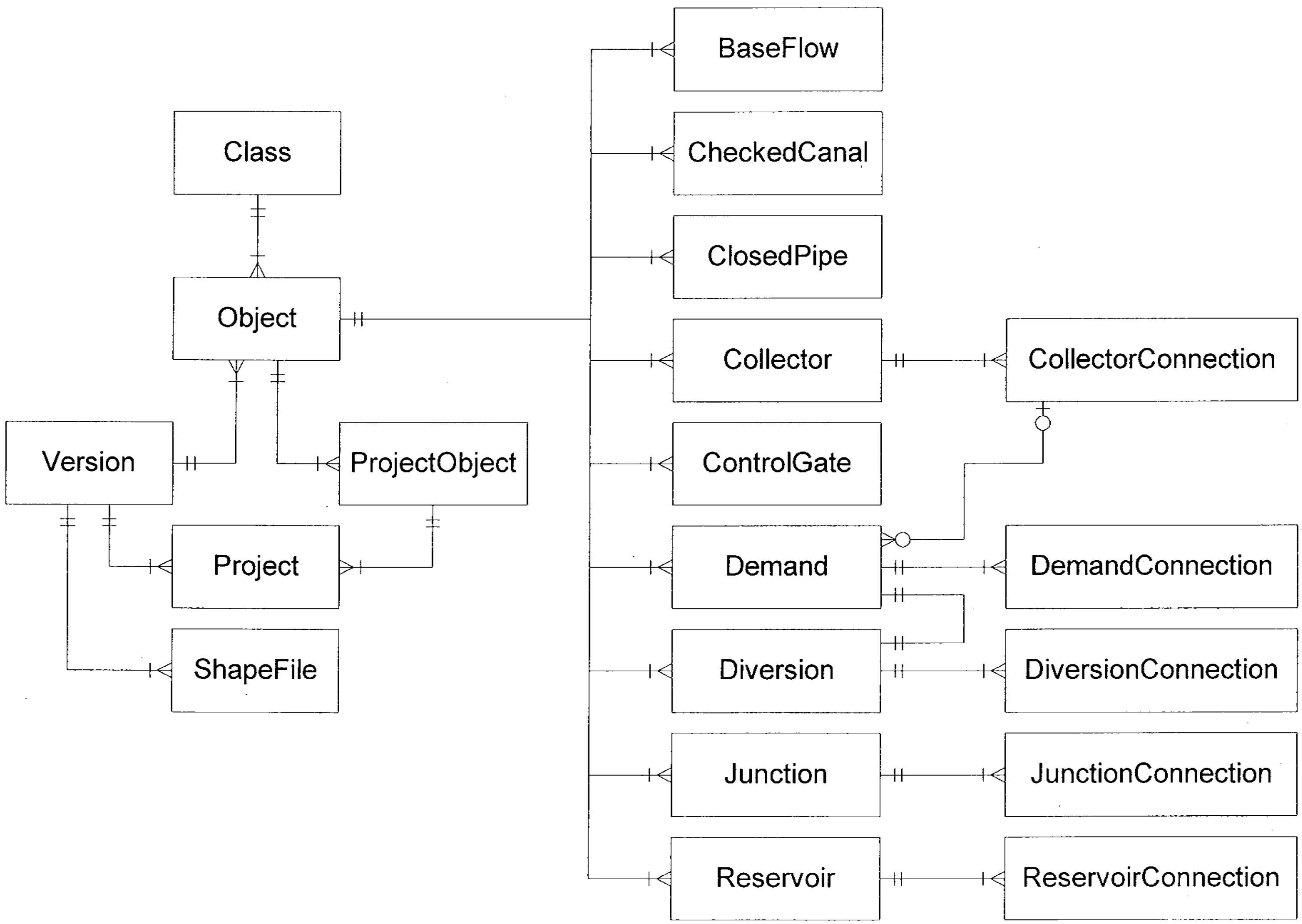

Figure 11. Local Operating Database entity relationship diagram

Interaction with the WRMM

Overview. For the Irrigation Water Management Study, the Water Resources Management Module (WRMM) was used to model the river basins that contain many irrigation districts. Each district was modelled as one or more Irrigation Blocks (WRMM Blocks), each with an inlet and an outlet. The water that flows into the inlet is the sum of the Consumptive Use for the block and the Return Flow. Consumptive Use is the aggregate of all types of consumption including irrigation demands, seepage, evaporation, and losses. Return Flow is any water that flows from the block back into the river basin.

In order to provide input data to the WRMM, the NMM has to be aware of the boundaries of the WRMM Blocks. This information is contained within the Conveyance Works layer in the GIS data sets (ESRI Shape Files). When NMM is initializing a model, it walks through the network to discover the boundaries of each WRMM Block contained within the model. If necessary, it adds additional data collection points at the interfaces of the blocks to enable the calculation of the net flow of water into and out of the blocks.

The WRMM Blocks tend to be an over simplification of the physical network because they have only one inlet and one outlet with the outlet being only for return flow. In reality, some or all of the water supplied to a block comes from another block and not from a supply channel in many cases. This causes some difficulties when generating data sets that are acceptable to WRMM, especially during the canal-draining phase of the simulation when it is possible to have negative (by definition) Consumptive Use resulting from stored water in one block draining into another block.

WRMM Block Extents. Figure 12 shows a simplified diagram of a simulation network with three WRMM Blocks. As the NMM is initializing the irrigation water distribution network model, it traces through the entire network looking for the boundaries of the WRMM Blocks.

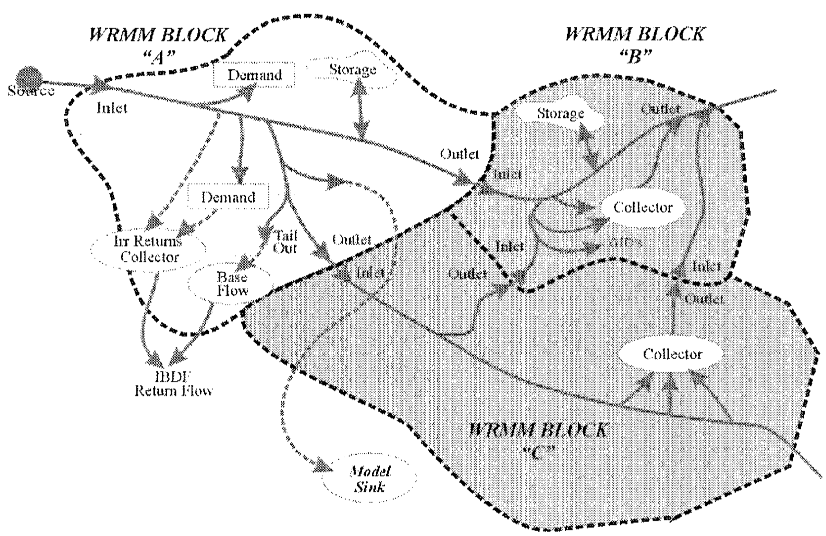

Figure 12. Extent and integration of WRMM Blocks.

The boundaries are the locations where the WRMM Block that a conveyance works segment is assigned to differs from the WRMM Block that a connecting conveyance works segment is attached to. The locations of the boundaries are saved.

At each boundary to a WRMM Block, the NMM must collect time series flow data. In some cases, these data are automatically collected by the component. In other cases, the component must be reconfigured to collect the data.

WRMM IBD and HBD Files. Figure 13 illustrates the equivalent WRMM version of the network shown in Figure 12. Since WRMM Blocks can have only one inlet and one outlet, special calculations must be made by the NMM to produce output acceptable to the WRMM. To produce a single net inflow into the block, the NMM sums all of the inlet flows and subtracts off the sum of all outlet flows. To produce a single return flow from the block, all of the return flow sources for the block are added together.

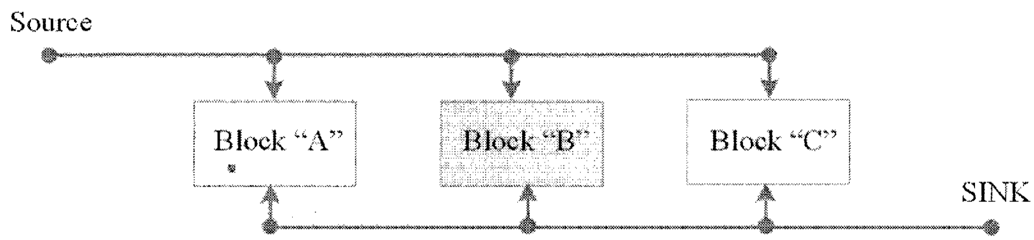

Figure 13. WRMM linking of network blocks.

The results of an NMM network simulation are passed on to the WRMM in Irrigation Base Data Files (IBDF) and Hydrological Base Data Files (HBDF). For each WRMM Block in the network, the NMM will produce one IBDF and one HBDF. The IBDF contains the Consumptive Use and the Return Flow. The HBDF contains Inflow data.

To calculate Consumptive Use, the sum of all Return Flows and Outlet Flows for the WRMM Block is subtracted from the sum of all Inlet Flows. This calculation must be modified when the irrigation distribution network is being drained at the end of the irrigation season since it can yield negative numbers that are unacceptable to the WRMM. Negative Consumptive Use occurs because the water draining from the conveyance works shows up as Outlet Flow and Return Flow, the sum of which is larger than the sum of the Inlet Flow. In order to provide output that the WRMM can use, in these cases an Inflow is added to the HBDF that matches the sum of the Outlet Flow and Return Flow. The Inflow in the HBDF file is treated by WRMM as a water source within the WRMM Block.

Model Operation

This section describes the operation of the NMM. It provides an overview of the steps that must be taken to prepare a model run, describes the generated output, and methods that may be used to validate the results.

Preparing For an NMM Simulation. Several steps are involved in preparing for an NMM Simulation. They include:

- Data Preparation
- Creating and configuring an NMM Project
- Initializing the model
- Creating the Time Series Dataset
- Setting the base flow and other parameters
- Creating an IRM database
- Running IRM to generate the demand data
- Importing the demand data

Each step is described below.

1) Data Preparation

Before an irrigation water distribution network can be simulated, a data set, known as a Network Version, must be prepared. This typically involves running the IDM DB Convert tool to convert data from a variety of sources into a format that can be stored in the Local Operating Database (LOD). The IDM DB Convert uses the following input:

- ESRI Shape Files for the Conveyance Works layer. These files contain spatial information (location and length of the conveyance works segments), network information (direction of flow and interconnection of the segments), and attribute data (capacity, seepage rate, surface area, etc.).
- ESRI Shape Files for the Reservoir layer. These files contain spatial and attribute information about the reservoirs.
- ESRI Shape Files for the Structures layer. These files contain the locations of structures and network information.
- DDIT data that contain information as to the type and location of irrigation demands on the network.

The above data items are processed by IDM DB Convert and placed into the LOD. These data then become the source of all input for the NMM. The datasets are known as Network Versions and typically contain an entire Irrigation District although this is not a requirement for either the NMM or LOD.

2) Creating and Configuring an NMM Project

Once a dataset, or Network Version, is available in the LOD, it is possible to create an NMM Project. An NMM Project is a collection of information required to run a simulation and includes a collection of model components, information on how they are connected, data arrays to hold the time series data and a number of model configuration parameters.

Creating an NMM Project involves selecting the Network Version that will form the basis of the simulation and setting the scope of the model by selecting the portion of the irrigation water distribution network to be simulated. As little as one segment or the entire network can be selected.

3) Initializing the Model

After the desired amount of the network has been selected into the NMM Project, the model must be initialized. The initialization process is where simulation components are created and connected together to represent the network that has been selected. This is a complex process that involves a number of steps. These steps are described above in the section titled *Automatic Model Generation.*

At the end of the initialization process, the NMM has constructed a simulated network and is nearly ready to run a simulation.

4) Creating the Time Series Dataset

Before the simulated network can be run, it is necessary to create a Time Series Dataset. This is essentially an array that contains one row for each time-step and one column for each value that is recorded during the simulation. To create the Time Series Dataset, the start and end dates must be specified along with the length of the time-step. The NMM will then allocate memory to hold the dataset and will initialize all elements to zero.

The NMM allows the creation and storage of multiple Time Series Datasets and provides tools for managing them. When the NMM Project is saved, the Time Series Datasets are stored along with it so that they will be available the next time the Project is opened.

5) Setting the Base Flow and Other Parameters

Once a Time Series Dataset has been created, the Base Flow flow rates can be set. This involves initializing certain columns in the Time Series Dataset that represent minimum flow rates at specific locations in the network. The Base Flow flow rates are set to a constant value throughout the simulated irrigation season. The starting date and ending date of canal operations are specified as part of the process for initializing the Base Flows.

6) Creating an IRM Database

For the NMM to do a useful simulation, it is necessary to know what the irrigation demands will be at each irrigation turnout for all time-steps. This information is obtained by running the Irrigation Requirements Module (IRM). The configuration information for an IRM run is contained within an IRM database. The NMM generates the database by extracting the required information from the LOD and inserting it into an empty IRM database template. In addition to the database, the NMM extracts the necessary weather information from the LOD and writes it to files that are read by the IRM when performing its simulation.

7) Importing IRM Generated Demand Data

The IRM generates demand data for the simulation network and places them into specially formatted files. The demand data are read from these files by the NMM and are placed in the appropriate time series data columns in the Time Series Datasets.

Some processing must be done on the demand data before they can be used by the NMM. NMM requires that all demands services along a conveyance works segment be aggregated into a single demand that is supplied by a Diversion Components at the downstream end of the segment. IRM, however, generated demand at a field level. Therefore, Field level demands must be aggregated into systems level demands (a system services one or more fields; system level demands are aggregated together with other systems that are serviced by the same irrigation turnout; and finally, turnout level demands that are serviced by the same conveyance works segment are aggregated together. Information on the association of fields, systems, turnouts, and conveyance works segments is contained within the LOD and is copied into the IRM database that is generated by NMM.

Running the Simulation. When the simulation model has been fully initialized and the IRM generated demand data has been imported, the simulation is ready to be run. The simulation is run in two phases: the Reverse Phase, and the Forward Phase. Each is described below.

1) Reverse Phase

In the reverse phase, the model runs through the simulation using reverse time steps and moves through the network from the outlets up to the inlets. This allows the model to determine the flow rates necessary at each point in the network in order to meet the demands. At the end of each time step, the flow rates at each Control Gate are recorded so that the necessary amount of water can be routed to all sections of the network during the forward phase.

2) Forward Phase

In the forward phase the required amount of water, as determined in the reverse phase, is released into the network and routed to the demands. In this mode, the down time losses and irrigation returns are analyzed so that the return flow from the network can be calculated.

3) System Filling and Flushing

The model simulates the filling and flushing of the system by creating a pseudo demand at each canal and pipeline segment that is equal to the volume divided by the number of days that are to be taken to fill the entire system. The demands from base flows are added in so that at the end of the filling period all canals and pipelines are full and the specified flow rates exist at the base flow locations. These calculations occur in the reverse phase. In the forward phase, water enters the network at the flow rate determined in the reverse phase. As water enters each canal or pipeline segment, a portion of it is used to fill the canal or pipeline with the rest being passed on to the downstream segments.

4) Normal Operation

After the filling and flushing are complete, the model is switched into a normal operations mode. In this mode, the demand from return flows, irrigation, and seepage are all accounted for and serviced. When summing up the demands in reverse phase the Gross Irrigation Demand is used as the demand. In the forward phase, demands that are serviced by Checked Canals take the Gross Irrigation Demand less the Downtime Losses. The Downtime Losses flow through the canals and either show up as return flow or are lost (i.e. flow to the System Sink). Demands that are serviced by Closed Pipes take the amount specified by the Gross Irrigation Demand and route the Downtime Losses to a Collector. In both cases, Irrigation Returns are routed to a Collector and show up as return flow from the network.

5) System Draining

The model simulates the draining of the system at the end of the irrigation system by releasing the stored water in the canals and pipelines at a controlled rate of 25% per day.

Output. After the simulation is complete, the results can be output in several different formats depending on the requirements. For the Irrigation Water Management Study, IBDF (Irrigation Base Data File) and HBDF (Hydrological Base Data File) files are generated for use with the WRMM. Any data in the Time Series Dataset can be exported to CSV files. Several pre-packaged sets can be exported and include the following:

- Deficits
- Demands
- Source Outflow
- Sink Inflow
- Water Balance

An additional feature is provided that allows a specified list of Time Series Dataset columns to be exported. Tools are provided to create and manage these lists.

Model Validation and Testing. The NMM supports running portions of an irrigation water distribution network. Projects can be as small as one segment or may encompass the entire network or anything in between. This allows the model operation to be validated by analyzing smaller networks that are more manageable in terms of the numbers of data points. Also, if historical data has been gathered from a branch of the system, it is possible to model that branch in the NMM and compare it to the actual operation of the irrigation network.

The NMM also performs the following consistency checks.

- The network connections are validated to ensure that components are connected to other components in a manner that is valid. Unconnected components are identified so that they may be properly configured.

- The network is checked for loops (i.e., water re-entering the network at a point that is upstream of the branch inlet).

- A water balance is performed in each time step to ensure that no water is being lost or manufactured by the model.

Scripting the Operation of the NMM. The operation of the NMM can be automated through the use of the scripting feature built into the NMM. The scripts are text files that contain a series of instructions to be carried out by the NMM. They can encompass an entire simulation from the creation of an NMM Project to the generation of output and allow the simulation run to be carried out unattended. This feature was used extensively to automate the hundreds of simulations that were carried out for the Irrigation Water Management Study.

NMM Output

NMM produces a variety of output that falls into the following categories.

- Model configuration (.NMM files)

- Diagnostic output

- Time series data exports

- WRMM inputs (IBD files and HBD files)

.NMM Files. The NMM stores a project in a file with the extension "NMM". These files contain all of the configuration and Time Series Datasets information contained within a project. This allows an NMM project to be saved and later restored.

Diagnostic Outputs. The following diagnostic files are created by NMM during the various phases of initialization and simulation.

- *Init.log* is generated during the initialization of the model. The file contains diagnostic information and error messages if problems are encountered. It is written to the application directory.

- *Connect.txt* is also generated during the initialization of the model. The file contains diagnostic and error messages with respect to the connections between the components used in the simulated network. It is written to the application directory.

- *Wrmm.txt* is generated while NMM is analyzing the WRMM Blocks. The file contains a list of the WRMM Blocks that were found, the inlets, the outlets, and the returns flows for the block. It can be found in the application directory.

- *Demand.log* is generated when NMM imports the demand data generated by IRM. The file contains diagnostic, warning, and error messages regarding the loading of the demand data. It is written to the application directory.

- *Demand.csv* is a diagnostic file that is used to verify the demands that are loaded into a Demand component. It contains the Gross Demand, Down Time Losses, and Irrigation Returns for the last Demand component processed. It can be found in the application directory.

- *Scrip.log* is generated when NMM is run in batch mode using a script. The file contains information, diagnostic, warning, and error messages regarding the operation of NMM and the execution of the script. It is written to the application directory.

Data Export. The following time series data can be exported from NMM for further analysis.

- *Deficit.csv* contains the Sink.Deficit column from the time series data. This column indicates the total demand deficit (i.e., the amount of water that was requested by the Demands but was not supplied) for each time step.

- *Demands.csv* contains the total amount of water that was consumed for irrigation in each time step. It is equal to the sum of Gross Irrigation Demand minus the Down Time Losses and Irrigation Returns.

- *SinkInputs.csv* contains a column for each stream that returns water to the System Sink.

- *SourceOutputs.csv* contains a column for each stream that inputs water into the network.

- *WaterBalance.csv* contains the information required to perform a water balance on NMM. It consists of all of the inputs into the network, the total seepage, the total return flow to the System Sink, total irrigation consumption, and the total deficit.

Component Data. Many of the components maintain time series data that can be exported. Those that do are listed below with a brief description of what data they maintain.

Base Flow: Tracks requested and actual base flow rates.
Checked Canal: Tracks inlet or outlet flow rates when at the border of a WRMM Block.
Closed Pipe: Tracks inlet or outlet flow rates when at the border of a WRMM Block.
Collector: Tracks actual flow rate through the Collector.
Control Gate: Tracks demand (i.e., the amount of water required downstream to meet all demands) and actual flow rate.
Demand: Stores Gross Demand, Down Time Losses, Irrigation Returns. These values are obtained from IRM.
Diversion: Tracks the outlet flow rate when the Diversion outlet is at the border of a WRMM Block.

Reservoir: Tracks water level, upper water level limit, and lower water level limit.
Seepage: Tracks seepage rate.
Sink: Tracks returns, consumption, and deficit.

WRMM IBD and HBD Files. NMM can generate IBD and HBD files that are used for WRMM input. When the IBD/HBD files are generated, NMM also generates the following additional files that can be used to verify the contents of the IBD/HBD data:

Inlets.csv: Contains the flow rates for all of the time steps for each inlet into the WRMM Block.
Outlets.csv: Contains the flow rates for all of the time steps for each outlet from the WRMM Block.
Returns.csv: Contains the return flows from the WRMM Block (irrigation returns and return flows from tail outs and spill-ways).
Consumption.csv: Contains the calculated consumption for each time step (sum of the inlets minus the sum of the outlets minus the sum of the return flows).
Averages.csv: Contains the year, week number, Julian Day, and the weekly averages for consumption, and return flow.
Weekly.csv: Contains the year, week number, and the weekly averages for consumption and return flow.
CSV File (with the same name as the IBD/HBD file): Contains the same weekly average data that is written to the IBD/HBD files except that it is in columnar format.

Exception Log. During the forward phase of the simulation, NMM compares the flow rate through segment and compares it to the segment maximum capacity at each time step. If the flow rate exceeds the capacity, a log entry is created. These entries are kept in an exception log file, called "Exception.log". This file can be found in the application directory.

Demand Data

The NMM required data on the irrigation demands and their locations on the irrigation system network. These data are generated by the IRM and is placed in a pair of files, ***Demand.dat*** and ***Demand.ddt***, from which the NMM reads the demand data. The reading and writing to this file is controlled by a software component, called DemandCo, that is common to both the NMM and IRM.

The following describes how the demand data files are generated by the IRM.

- During the IRM initialization, a DemandCo Field is created for each IRM Field in each IRM Block.

- After the initialization is complete, each DemandCo Field is associated with a DemandCo Turnout and a DemandCo Demand. These associations are later used by NMM to determine the demand at Turnouts and Demands. It is also used to verify that the mappings are complete by summing all of the demand from the Fields attached to a Demand and comparing it to the sum of all of the demand from the Fields attached to the

Turnouts. If the results are equal then the mapping is consistent.

- During the IRM simulation, the irrigation demand, return flow, and downtime losses are recorded into the Demand.ddt file for each field during each time step.

The NMM uses the demand data files as follows.

- The NMM opens the demand data file via the DemandCo component.

- The NMM requests the demand at each Turnout. The DemandCo component, using the associations created by the IRM between Fields and Turnouts, sums the demand for each Field that is associated with the Turnout and returns the result to the NMM.

Additional data are also available from the demand data files that are intended to support the Risk Assessment Model. These data include:

- WRMM Block information that makes it possible to sum the demand for a WRMM block.

- Ideal ET for each Field for each time-step that is used in conjunction with the actual ET to determine actual yield vs. ideal yield.

IRM MODULE

The Irrigation Requirements Module (IRM) is a component of the Irrigation District Model (IDM) suite of tools. It is designed to assist the irrigation districts and regulating/review agencies with the process of determining current on-farm irrigation requirements and potential on-farm irrigation requirements. The IRM utilises field-based information to predict on-farm crop water requirements. In general terms, the field-based information consists of the following:

- Soil Type (fine, coarse, medium).
- Crops grown (a single parcel of land can be broken down into any number of cropped fields).
- Method of irrigation (which can be tied to each cropped field).

The individual fields can be referenced to blocks that fit the overall network of each of the irrigation districts. The IRM can perform its calculations for a single field, a specific group of fields, for blocks of fields, or entire irrigation districts. The IRM performs all of the calculations based on a daily time step, and allows for drill-down validation of the results. The module will run in near real time, i.e. a day-to-day basis, for a single year or for multiple year simulations. Results are provided in daily or weekly formats. In addition, a complete range of what-if scenarios is supported. For example, adjustments in irrigation method or crop mix can be tried without having to change core data.

The software was developed in Microsoft Visual Basic and Microsoft Visual C++ and stores its data in a Microsoft Access database. When operated within the IDM Suite of tools, its Access database is generated from the Network Management Module (NMM). NMM uses irrigation district data maintained in the Microsoft SQL Local Operating Database (LOD). The result of an NMM-generated IRM project can then be imported back into NMM for the calculation of flow solutions.

IRM Information Components

The IRM program is comprised of a number of components. During operation in IDM, these components will be populated by NMM. These components are (in sequence that you will utilize/configure the components):

1. Definitions of various soils, irrigation methods and blocks. These definitions describe the characteristics of each item (e.g. soil type) within a group (e.g. soil). The definitions are linked to the field data at the time of modelling a project. The irrigation methods definitions are used as defaults when inputting specific field data. Fields are organized into blocks that are characteristically located within proximity of one another utilising similar canal reaches.
2. Field data that describe the characteristics of the land on each quarter section. The data include plant types, soil types, irrigation methods, farmed area and usage of fall irrigation. The data

from these fields are stored in a database and are available to all projects. The field data also maintain a link to user defined blocks.

3. Project data that describe the parameters and land areas to be modelled for a specific project.

4. Environmental data that contain daily values utilized in modelling soil moisture fluctuations, plant growth and irrigation requirements. The data are stored in a separate text file and are selected by the user as part of the project definition.

5. Results data that are stored in the IRM database and are available for graphing and exporting. The results data contain daily values of the model calculations. Users of Microsoft Access can develop custom reports/queries from this database.

6. Components 3, 4 and 5 are also available in macro-projects such that what-if scenarios can be analysed for groups of field data (blocks).

Based on the above components, IRM provides two levels of input. The first level of input is for those components that are not project-specific. These general inputs include the definitions (soil types, irrigation methods and block parameters) and the field data. Also, at this level of input you have the ability to modify the colour levels used to indicate the area of farmed land per quarter section. This modification is performed with the legend window.

The second level of input is for those project or macro-project specific parameters. This involves selecting the quarter sections of land (or Blocks, in the case of Macro-Projects) to be used in the calculations and providing basic data to be used in that project's model run. Also at this level of input you select which environmental data file(s) are to be used in the model calculations.

The output of IRM is available as exported data and as printed graphs.

IRM Reference

Water Balance Component Definitions. The Gross On-Farm Demand for irrigation is divided into many subsequent components, which can be tracked and associated to derive an accurate picture of the total water balance. These components are described in more detail in Figure 14, in the following discussion, as well as in Appendix A of this report.

Gross On-Farm Demand- the total amount of water entering the canal.

Gross Irrigation Demand- the gross amount of water use by the irrigation system (i.e., the sum of the amount of water taken from the canal system by each on-farm irrigation system). Includes down time losses.

DownTime Losses - the total amount of water that flows through the canal unused because of irrigation system down time.

Gross Irrigation Application - the gross amount of water actually pumped from the canal by the irrigation system. Does not include down time losses.

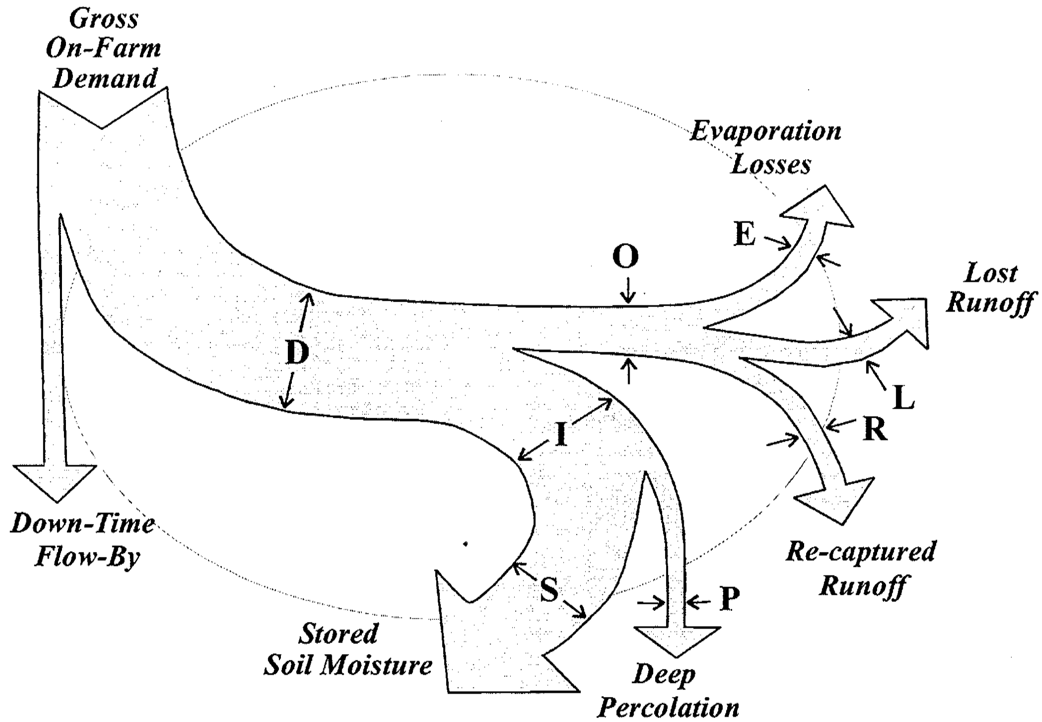

Figure 14. Components of the on-farm water balance.

Irrigation Returns - the fraction of the gross irrigation application that runs off and returns to the canal.

Irrigation Losses - the fraction of the gross irrigation application that is lost due to run off that does not return to the canal, evaporation during irrigation or farm spills.

Net Irrigation Application - the net amount of moisture that is actually added to the soil.

Rain - the amount of rain that falls onto a field.

Runoff - the amount of rain that is not absorbed by the soil.

Evapotranspiration - the amount of water that is pulled from the soil by the plant and evaporated.

Percolation Losses - the amount of water lost due to percolation out of the lower zone.

Increase in root zone moisture - the amount by which the root zone moisture increased during the day.

Increase in lower zone moisture - the amount by which the lower zone moisture increased during the day.

Return Flow - the amount of water that returns.

Component Equations. The above quantities are related through the following equations.

- Gross Demand = Gross Irrigation Demand + Canal System Demands (See NMM Module)

- Gross Irrigation Demand = Down Time Losses + Gross Irrigation Application
- Gross Irrigation Applications = Irrigation Returns + Irrigation Losses + Net Irrigation Application
- Net Irrigation Application + Rain - Runoff = Evapotranspiration + Percolation Losses + Increase in root zone soil moisture + Increase in lower zone soil moisture
- Lost = Irrigation Losses + Evapotranspiration + Percolation Losses
- Return Flow = Down Time Losses + Irrigation Returns + Rain Runoff

Equation Variables and Units

The following variables are presented within the equations of this section. They are described more fully with each equation. However, they are presented here as a means of identifying the units utilized for each variable.

Table 20. Equation variables and their units.

Variable Names	Equations	Units
RootZoneMoisture	2, 7, 8, 9, 10, 11	mm
RootDepth	2	mm
SoilMoistureCapacity	2, 9, 10	mm/mm
ActualET	3, 7	mm
ETPotential	3, 4, 5, 6	mm
Radiation	4, 5, 6	Langley/Day
TempMax	4, 5, 6	deg. C
TempMin	4, 5, 6	deg. C
Wind	4, 5	km/Day
Slope	5, 6	kPa/deg. C
NetRad	5, 6	MJ/m^2
PsychConst	5, 6	kPa/deg. C
AbsTemp	5, 6	deg. K
WindSpeed	5	m/s
VpDeficit	5	kPa
AtmPress	5, 6	kPa
Elevation	5, 6	m
HeatVap	5, 6	MJ/kg
SatVp	5	kPa
RHMean	5	%
G	5, 6	$MJ/m^2/day$
Rain	8, 10, 11	mm
Runoff	9, 10, 11	mm
Rain	9	Inches
LowerZoneMoisture	9, 10	mm
SoilDepth	9, 10	mm

Component Model Overview

As discussed previously, the IRM model is constructed from a number of component objects. The object hierarchy is shown in the figure below:

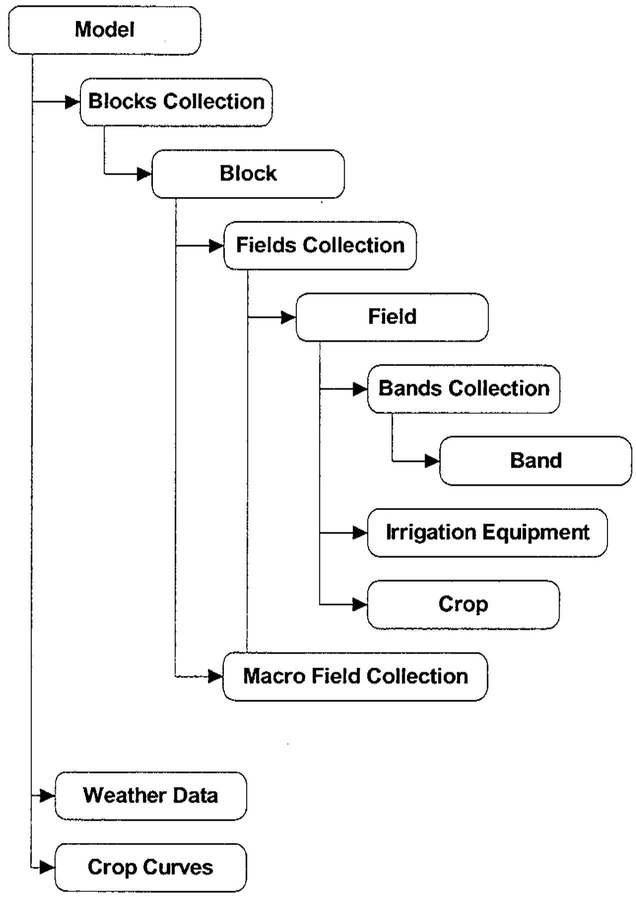

Figure 15. The inter-relationships of model components.

Model Component. The Model component is the highest-level object and encapsulates all of the other objects used to model the irrigated lands. Two types of models are provided: Standard and Macro. The Macro version uses Macro fields, which are an aggregated version of the Standard field.

Model Initialization. The following parameters are passed to the Model component during initialization.

- ET Equation to be used.

- Starting date for canal operations. The *starting date for canal operations* is the first day that water is flowing through the irrigation system. The first few days of operation are used for canal flushing. In the Model, water is available for irrigation 5 days after the start date for canal operations.

- Ending date for canal operations. The *ending date for canal operations* is the last day that water in the system is useable for irrigation.

- Randomized Irrigation Threshold Flag. The *irrigation threshold* is the level of soil moisture in the root zone (relative to the maximum) at which the Model will begin irrigating. In order to achieve a more realistic simulation, some randomness may be introduced into the threshold by turning the *Random Irrigation Threshold* flag on.

- Randomized Seeding Date Flag. The date at which a particular crop type is seeded is specified in the Plant (crop) Table in the IRM database. In order to achieve a more realistic simulation, some randomness may be introduced into the seeding date by turning on the *Random Seeding Date* flag.

- Use Field Level Irrigation Flag. The Model supports two modes for fall irrigation. In the first mode, whether a field is fall irrigated depends on the setting of a flag in the Field Table in the IRM database. In the second mode, Fields are selected at random to achieve a specified Block area. The *Use Field Level Irrig Flag* controls which mode the Model operates in. When set the former mode is used; when not set the latter mode is used.

The following initialization processing is performed.

- The crop coefficients for all crop types are loaded.

- The weather data are loaded and validated. A check is made to ensure that the data necessary to perform the specified ET calculation are present in the data file.

- The Block objects are created and initialized. (See Block Initialization)

After all of the Blocks objects have been created, the total area for all irrigated lands in all Blocks is calculated. This value is used in the calculation of some of the area weighted average values.

Model Calculations. Following a successful initialization of the model, the simulation calculations are performed. Figure 16 shows the calculation cycle that is performed by the Block object.

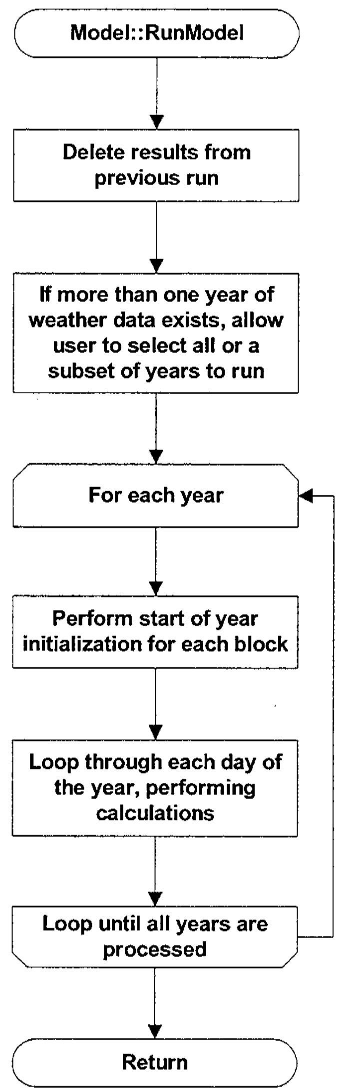

Figure 16. Calculation cycle performed by the Block Object.

Model Daily Processing Details. Figure 17 details the processing that the Model object performs for each day of the year.

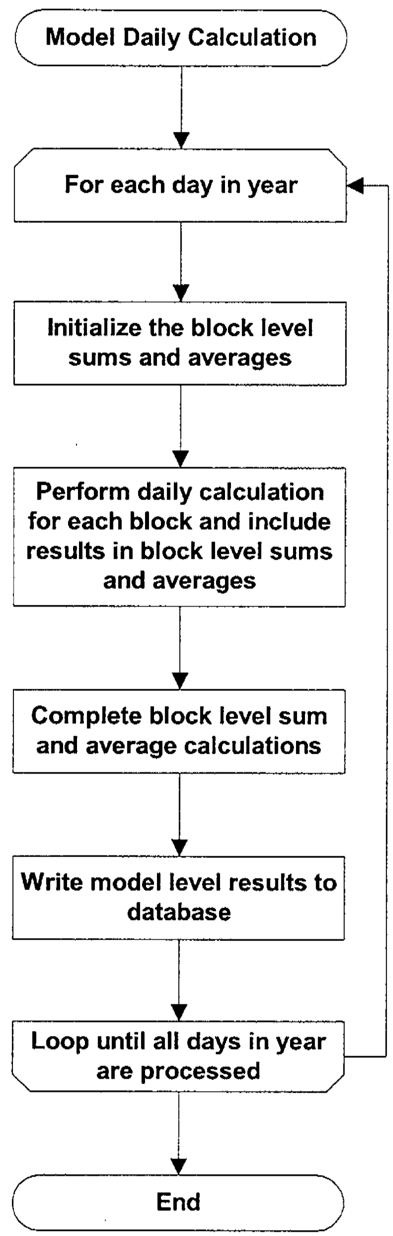

Figure 17. Processing cycle of Model Object for each day of the year.

Model Results. The results from each Block are aggregated into Model level results as follows.

- *Radiation, Temperature, Wind* and *ET Potential* are block-area-weighted averaged. The *ET Potential* may be a calculated value or one that is supplied in a weather file. *Radiation, Temperature* and *Wind* are obtained from the weather files.

- A large number of accumulators are summed, including: *Gross Irrigation Demand, Down Time Losses, Gross Irrigation Application, Irrigation Returns, Irrigation Losses, Net Application, Fall Irrigation Application, Rain, Runoff, Evapotranspiration, Delta Soil Moisture, and Percolation Losses.*

- Return Flow is calculated as the sum of *Runoff, Irrigation Returns, and Down Time Losses.*

Block Component

The Block component of the Model represents a collection of Fields. It is typically used to represent the organization units of an irrigation system. The Block component of the IRM consists of a collection of Fields that share some common attributes. These attributes include the following.

- Weather data.

- Percentage of fields which are fall irrigated.

- Wheat Planting Date Offset. The *Wheat Planting Date Offset* is used to move the planting dates for the crops in the Block forward or backward in time. The offset, in days, is added to the crop Relative Planting Date, Relative Cover Date, and Relative Harvest Date (see Crop Component).

- Randomized Seeding Date Flag (see Model Initialization).

- Evapotranspiration Scaling Factor. The *ET Scaling Factor* is applied to ET calculated by the model prior to performing the soil moisture balance calculations and is used to calibrate the Model.

- Soil Moisture Holding Capacity. The *Soil Moisture Holding Capacity* is the total amount of water, expressed as a depth that a unit depth of soil can hold.

- Initial Soil Moisture Fraction. The *Initial Soil Moisture Fraction* is used to set the initial level of soil moisture in the Fields and is expressed as a fraction of the soil moisture holding capacity.

- Soil Depth. The *Soil Depth* defines the depth of the soil in the Block and is the total depth of both the Root Zone and the Lower Zone. Root depths for the crops are not allowed to exceed the Soil Depth.

- Location specific constants used in the calculation of Evapotranspiration Potential (i.e., CTR, TXR, and Elevation).

The following parameters are passed to the Block component from the Model component (i.e., they are common to all Blocks).

- Evapotranspiration Potential calculation method.
- Starting date for canal operations.
- Ending date for canal operations.
- Crop Coefficient Curves.

Block Initialization. The following is performed during the initialization of a Block object.

- The *Irrigation On Day* (i.e., the first day of the year which water is available to be applied to fields) is calculated by adding 5 days to the start day for canal operations.
- The *Irrigation Off Day* (i.e., the last day of the year which water is available to be applied to fields) is set equal to the end day for canal operations.
- *Fall irrigation* is initialized.
- The *Field objects* are created.

The following are performed for each Field object that is created.

- An Irrigation Equipment object is created and initialized. On initialization, the Gross UsageRate, Application Efficiency, Return Flow Factor, Days to Cover Field, Down Time Per Day and Field Area are passed to the Irrigation Equipment object. These parameters are obtained from the record in the Field Table in the IRM database.
- A Plant (crop) object is created and initialized. On initialization, the Irrigation Threshold, Minimum Root Depth, Maximum Root Depth, Forage Flag, Relative Planting Date, Relative Cover Date, Relative Harvest Date, Wheat Planting Date Offset, Random Seeding Range, and Randomized Seeding Date Flag are passed to the Plant object. Except for the Wheat Planting Date Offset, Random Seeding Range and Randomized Seeding Date Flag, all parameters are obtained from the Plant Table in the IRM database.
- A reference to the crop's *Coefficient Curve* is passed to the initialized Plant object.

The *Field object* is created and initialized. On initialization, the *Elevation, ET Scaling Factor, Initial Soil Moisture Fraction, Soil Depth, Soil Moisture Capacity, Randomised Irrigation Threshold Flag, Fall Irrigation Flag, Fall Irrigation Model (i.e. Cereal/Silage/None), and Area* are passed to the Field object along with a reference to the Irrigation Equipment object and Plant object previously created.

Block Start of Year Initialization. At the start of each year's processing, the Block objects are re-initialized. During this initialization, the following are carried out.

- The Reference Day for the year is calculated. The *Reference Day* is defined as the first day in which the average daily temperature has been above 5°C for five consecutive days. The Reference Day is not allowed to be sooner than Julian Day 105.

- The Start of Winter is determined. *Winter* is defined as the first day of the year that the maximum daily temperature is below 5°C for five consecutive days. Note that if the criteria are not met, Winter Mode will start on Julian Day 365. For the first year of a simulation, Winter Mode starts on Julian Day 1. Once winter has started, it remains winter until the Reference Day is reached.

- Irrigation is disabled. (It is re-enabled 5 days after canal operations begin).

- Each Field object is initialized for the start of the year.

Fall Irrigation Initialization. Special processing is required to initialize the fall irrigation algorithm for Fields with silage or cereal crops. The objective of the algorithm is to select a subset of these Fields so that the percentage (by area) of fall-irrigated fields matches the number specified for the Block. The same percentages of silage and cereal crops are selected.

Note that because the exact percentage by area of Fields that are fall irrigated will tend to exceed the value specified for the block due the to fact that entire Fields must be selected. Fields are selected on a random basis until the sum of the selected Fields exceeds the specified Block percentage. Fields with forage crops are always eligible for fall irrigation.

The Field selection may be run in two modes. In the first mode, a different group of fields is selected for each run. In the second mode, the same groups of fields are selected for fall irrigation for each run. This behaviour is controlled by turning the Random Field Selection on or off on the Block tab of the Project form. The "Random Field Selection" may be turned on or off on a Block-by-Block basis. If it is turned on, a new sequence of random numbers will be generated each time the model is run. This is because the random number generator is seeded from the system clock. The effect of this is to select different groups of fields to receive fall irrigation each time the Model is run. If off, the sequence of random numbers will not change from run to run and, if the Fields in the Block are not changed, the same Fields will be selected for each run. This is because in this case the initial value used for the random number generator seed is saved so that an identical sequence of random numbers is generated.

Note that the "Use Field Level Irrig Flag" option will cause the random field selection to be ignored. Instead, a field level fall irrigation flag will be used to determine whether a field received fall irrigation or not. Figure 18 illustrates the algorithm for selecting the fields to be fall irrigated.

A Field is not eligible for fall irrigation unless fall irrigation for that Field has been enabled. Fall irrigation may be enabled in one of two ways: on a field by field basis via the "Modify Field Info" form, or by setting the percentage of fields to be fall irrigated in the Block to a number greater than zero. Note that in the latter case, whether a particular Field is enabled for fall irrigation depends on random chance.

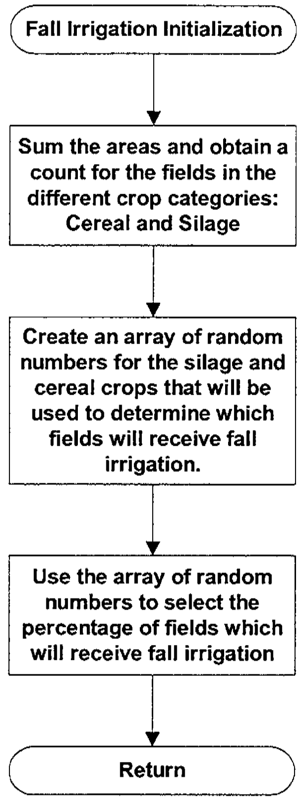

Figure 18. Algorithm for selecting the fields to be fall irrigated.

In order for a Field selected for irrigation via the "Modify Field Info" to be irrigated in the fall, the "Use Field Level Irrig Flag" option on the Project form must be checked. If this box is not checked, the Field may be selected as part of a group of fields that receive fall irrigation.

Generating the Random Number for Fall Irrigation. Figure 19 illustrates the algorithm for generating a sequence of random numbers that are used to select the fields that will receive fall irrigation.

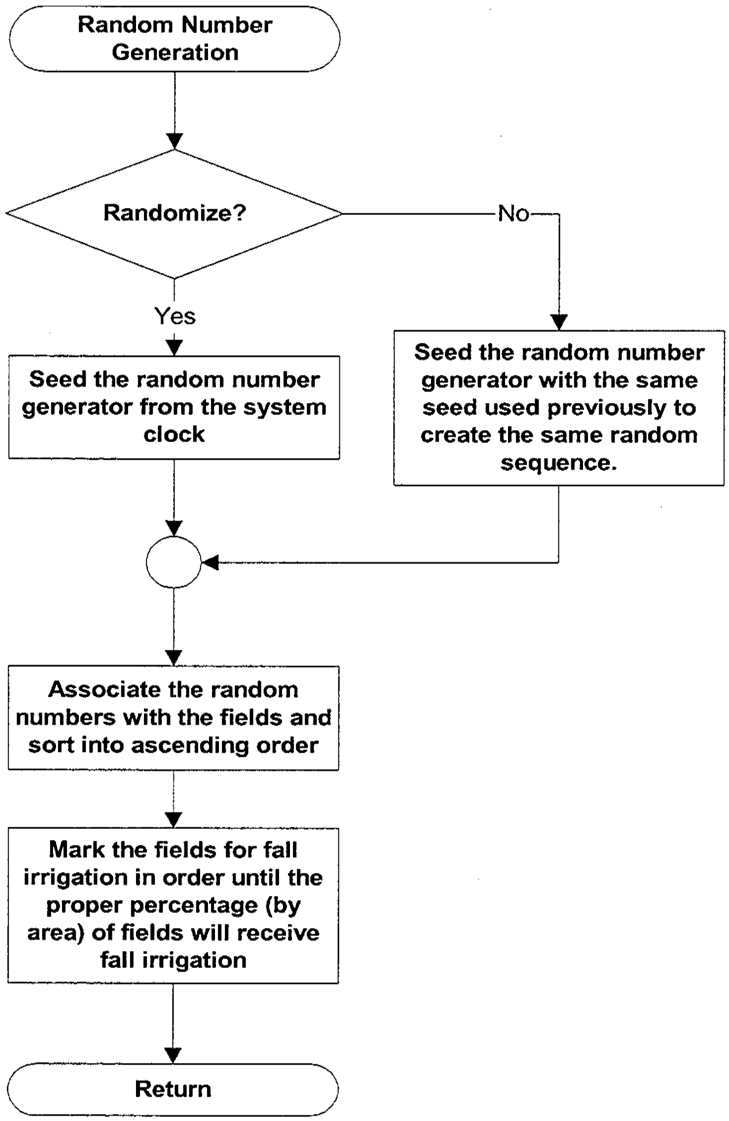

Figure 19. Algorithm for generating a sequence of random numbers for fall irrigation.

Block Calculations. The Block object calculations occur in two phases. In the first phase, the blocks are initialized for another yearly cycle (see Block Start of Year Initialization). In the second phase, the irrigation requirements are determined for each day of the year.

The irrigation requirements calculations are carried out as depicted in Figure 20.

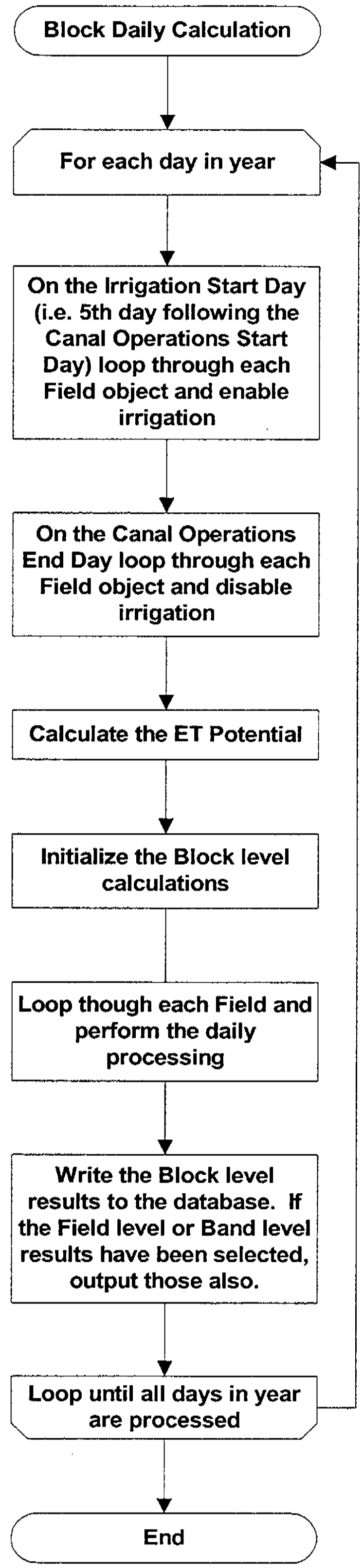

Figure 20. The process of irrigation requirements calculations

Block Results. The following are aggregated into Block-level results by summing the results from each Field in the block.

- Gross Irrigation Demand. *Gross Irrigation Demand* is the total amount of water required to meet the demands of the irrigation systems on the irrigated Fields and includes down time losses.

- Down Time Losses. *Down Time Losses* is the total amount of water that flows through the irrigation system unused because of irrigation system downtime.

- Gross Irrigation Application. *Gross Irrigation Application* is the total amount of water that is taken from the irrigation network by the irrigation systems. It is the sum of Net Application, Irrigation Losses and Irrigation Returns.

- Irrigation Returns. *Irrigation Returns* is the total amount of run off that was collected from irrigated fields resulting from water applied by irrigation but not absorbed.

- Irrigation Losses. *Irrigation Losses* is the total amount of water that was removed from the irrigation network by the irrigation systems but was lost before it could be absorbed by the soil. It represents water that evaporated before it reached the soil or run-off that did not return.

- Net Application. *Net Application* is the total amount of water that was absorbed by the soil.

- Fall Irrigation Application. *Fall Irrigation Application* is the total amount of water that was applied as fall irrigation that was absorbed into the soil.

- Runoff. *Runoff* is the total amount of water that fell on irrigated Fields but was not absorbed.

- Evapotranspiration. *Evapotranspiration* is the total amount of water that was lost due to Evapotranspiration from the crops on the irrigated fields.

- Delta Soil Moisture. *Delta Soil Moisture* is the total change of soil moisture (expressed as a volume) for all Fields. When this value is negative, there was a net loss in soil moisture during the day.

- Percolation Losses. *Percolation Losses* is the total amount of water that was lost due to percolation out of the lower zone.

Other results are expressed in terms of an average depth based on an area-weighted average of the values obtained from each field. These are:

- Average Rain. *Average Rain* is the same as the Rain value in the weather file.

- Average Evapotranspiration. See Band Component.

- Average Delta Soil Moisture. Average of Root Zone and Lower Zone moisture calculations detailed in the Field Component.

- Average Percolation Losses See Band Component.

The Model results file also includes the daily weather data (i.e., *Maximum Daily Temperature, Minimum Daily Temperature, Wind Run, Rain, Maximum Daily Relative Humidity, Minimum Daily Relative Humidity, and Solar Radiation*).

Field Component

The Field component consists of a collection of Band objects, an Irrigation object and a Plant (crop) object. Field objects are created by a Block object and share a number of attributes in common with all Fields in a Block or in a Model. The attribute that are common to all Field objects in the Model is:

- The Randomized Irrigation Threshold Flag

The attributes that are common to all Field objects in the Block are:

- The Elevation (from Location Table in IRM Database);

- The Evapotranspiration Scaling Factor;

- The Wheat Planting Date Offset (passed to each Plant object created by the Block object);

- The Initial Soil Moisture Fraction

- The Soil Depth; and

- The Soil Moisture Holding Capacity.

The following attributes are set on a Field object by Field object basis.

- A reference to a Plant (crop) object.

- A reference to an Irrigation Equipment object.

- Fall Irrigation Flag. The *Fall Irrigation Flag* is used to indicate that the Field object is to perform fall irrigation.

- Fall Irrigation Model (i.e. silage or cereal), which is dependent on the Plant (crop) object. Non-forage crops can use one of two fall irrigation algorithms: Silage or cereal. There are minor differences between the two, which is explained in detail in the Field Irrigation Logic topic. The Fall Irrigation Model is used to select the fall irrigation modelling process to be used by the Field object.

The Fall Irrigation Flag may originate either with the Field Table in the IRM database or from the computations performed by the Block object. Selecting the "Use Field Level Irrig Flag" on the Project Parameters tab of the Project form will cause the Fall Irrigation Flag to be set according to the value in the Field Table; otherwise, the Block object will set this flag according to the algorithms used for random fall irrigation. See the documentation on the Block Component for more details.

Field Initialization. The following is performed during the initialization of a Field object.

- The Band objects are created and initialized. On initialization, the Elevation, Evapotranspiration Scaling Factor, Initial Soil Moisture Fraction, Soil Depth, Soil Moisture Holding Capacity, and the Band Area are passed to the Band object along with a reference to the Plant (crop) object. The Band Area is the area of one of the bands that the Field is divided into. The number of bands in the field is determined by the number of days the irrigation system takes to cover the field; one band is created for each day.

Field Start of Year Initialization. At the start of each year's processing, the Field objects are re-initialized. During this initialization, the following is carried out.

- The Reference Day is updated. (See Block Start of Year Initialization.)

- The Start of Winter is updated. (See Block Start of Year Initialization.)

- Each Band object is initialized for the start of the year. A *band* is the portion of a field that gets irrigated during a one-day period. Several bands may be required to irrigate a single field.

- A new random Irrigation Threshold is obtained if the Randomized Irrigation Threshold Flag was set in the model initialization.

- The current Band (for irrigation purposes) is reset to the first Band in the Field.

Field Calculations. Figures 21 and 22 detail the processing that the Field object performs for each day of the year.

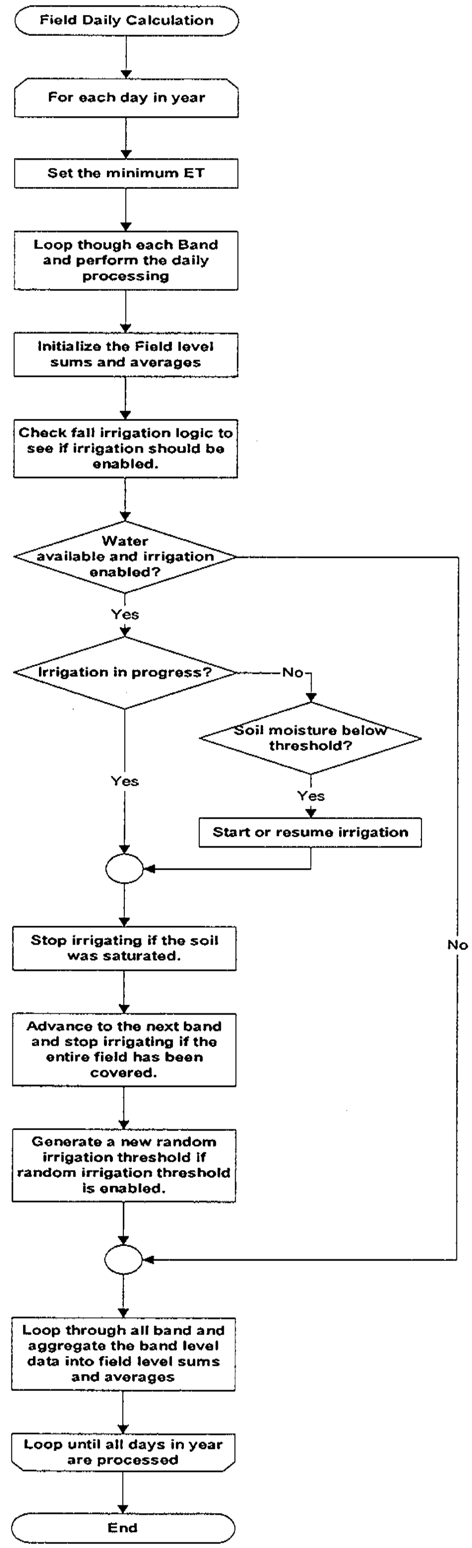

Figure 21. Processing that the Field Object performs for each day of the year.

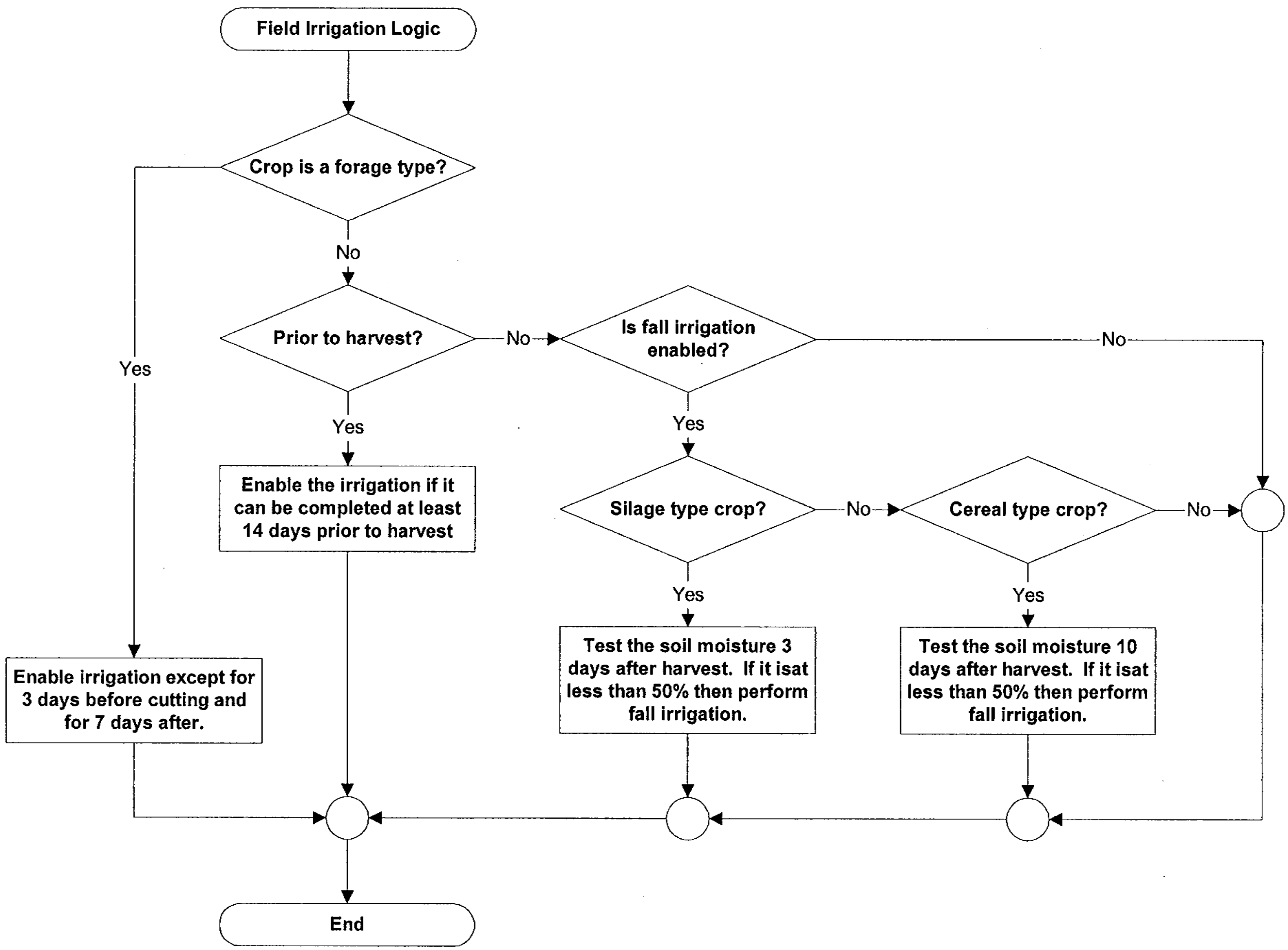

Figure 22. The logic sequence of the Fall Irrigation Algorithm.

Figures 21 and 22 can be summarized as follows.

Water is available for irrigation 5 days after canal operations start up to the day that canal operations stop (i.e., the end of the irrigation season). If water is available and the irrigation logic determines that a field may be irrigated, the Field object is free to irrigate if required.

Once an irrigation event has been started it will run until completion (i.e., cover all of the Bands that comprise the Field). An irrigation event may be suspended temporarily if a rain fall event increases the soil moisture in the current band to a point where the remaining capacity of the soil to hold moisture is less than the amount of water that will be applied by the irrigation system.

A rainfall event may raise the soil moisture to a sufficient level that there is no longer enough moisture holding capacity to hold the water that is applied by the irrigation system. In this case,the irrigation is suspended until the soil moisture falls below the irrigation threshold as a result of evapotranspiration. At this point the irrigation will resume where it left off.

Irrigation occurs in complete cycles. It starts with the first Band and ends with the last Band of a Field. Once the entire field has been covered, the irrigation stops until the soil moisture in the first band falls below the irrigation threshold.

If the "Random Irrigation Threshold" option has been selected on the Project form, the irrigation threshold will be set to a random number that has a flat distribution in a range of +/- 10% cantered around the irrigation threshold specified in the IRM Plant table. Before irrigation of a Field can start or resume, the soil moisture level in the root zone must fall below the irrigation threshold.

Except for forage crops, Fields may be irrigated any time after the irrigation system is available to deliver water, provided that the irrigation can be completed at least 14 days before harvest. (The irrigation system is available 5 days after canal operations start.). The following test is used to determine if irrigation can be enabled (Equation 1).

$$JulianDay < (HarvestDate - (14 + NumBands - CurrentIrrigBand + 1)) \tag{1}$$

If the equation evaluates to "True" then irrigation is enabled; otherwise, it is not. Note that all dates are expressed as Julian dates.

Irrigation is enabled at all times for forage crops except during a 10-day period that extends from 3 days prior to cutting until 7 days after cutting.

The soil moisture in Fields with silage crops is tested on the third day following harvest. If the soil moisture is less than 50% then the Field will be fall irrigated unless the soil moisture capacity is at 100% of capacity at the time the fall irrigation is to start. The fall irrigation starts with just enough days left in the irrigation season to complete the irrigation.

The soil moisture in Fields with cereal crops is tested 10 days after harvest. If the soil moisture is less than 50% then the Field will be fall irrigated if the soil moisture is less than 80% of capacity when it is time to start the fall irrigation. The fall irrigation starts with just enough days left in the irrigation season to complete the irrigation.

Field Results. The following data is written to the Field Results file for each day.

- Weather data that include *Maximum Daily Temperature, Minimum Daily Temperature, Wind Run, Rain (expressed as a depth), Maximum Daily Relative Humidity, Minimum Daily Relative Humidity, Daily Solar Radiation*
- Gross Irrigation Demand
- Down Time Losses
- Gross Irrigation Application
- Irrigation Returns
- Irrigation Losses
- Net Application
- Fall Irrigation Application
- Runoff (on a volume basis)
- Evapotranspiration (on a volume basis)
- Delta Root Zone Moisture (on a volume basis)
- Delta Lower Zone Moisture (on a volume basis)
- Percolation Losses (on a volume basis)
- Average Rain
- Average Evapotranspiration
- Average Delta Root Zone Moisture
- Average Delta Lower Zone Moisture
- Average Percolation Losses

Band Component

The Band is the lowest level component in the IRM Model. It represents a portion of a Field that is irrigated in one day. Band objects are created by a Field object and share a number of attributes in common with all Bands in a Field and Block. The attributes that are common to all Band objects in the Block are:

- Elevation (from the Location Table in IRM Database);
- Evapotranspiration Scaling Factor;
- Initial Soil Moisture Fraction;
- Soil Depth; and
- Initial Soil Moisture Fraction.

The attribute that is common to all Band objects in the Field is:

- A reference to a Plant (crop) object

Band Initialization. All of the band initialization is done at the start of the yearly processing cycle.

Band Start of Year Initialization. At the start of each year's processing, the Band objects are re-initialized. During this initialization, the following are performed.

- The Reference Day is updated.
- The Start of Winter is updated.
- Winter mode (used for the handling of precipitation) is turned on.
- The soil moisture is set to the Initial Soil Moisture value passed to the Band object by the Field object if this is the first year of processing. For subsequent years, the soil moisture at the start of the year is determined from the soil moisture at the end of the previous year.
- The root depth is reset to the minimum.

Starting with the second year, when the root depth is reset from the maximum back to the minimum, the moisture that was part of the root zone becomes part of the lower zone moisture, This process is the opposite to that which occurs when the roots grow into the lower zone.

Band Calculations. Figure 23 illustrates the Band calculation process.

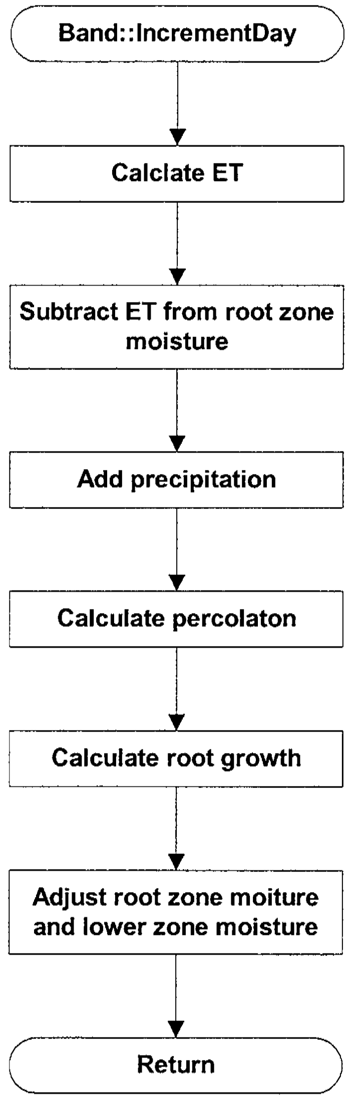

Figure 23. Calculations that are performed for each band on a daily basis.

Calculating the Actual Evapotranspiration. The evapotranspiration (mm/day) is dependent on whether the crop is growing or not. Figure 24 illustrates the process to determine either the ET value or the adjusted crop coefficient.

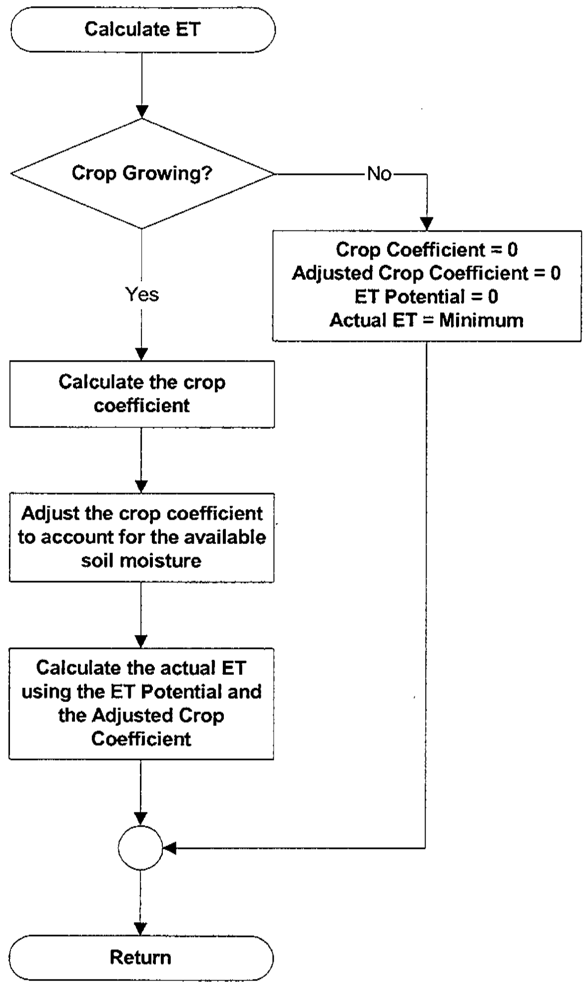

Figure 24. Calculating the actual evapotranspiration.

Is the Crop Growing? A forage crop is considered to always be growing for the purposes of the model. This makes it possible for the Field object to irrigate the crop at any time during the irrigation season.

For other crop types, the crop is considered to be growing between the planting date and the harvest date. Note that the Wheat Planting Date adjusts the planting date and harvest date for the Block and possibly by a Random Seeding Offset. The Ransom Seeding Offset randomises the dates at which crops are planted and is re-calculated at the beginning of each year.

The Crop Is Not Growing. If the crop is not growing (see the explanation for a growing crop for more details) the actual evapotranspiration will be set to the minimum.

Except for silage crops that have been recently fall irrigated, the minimum daily evapotranspiration is 0.25 mm per day. For fall-irrigated silage crops, the minimum is increased to 1.0 mm per day for 10 days following the completion of fall irrigation.

Calculating the Crop Coefficient. The crop coefficient is obtained from the CropCoeff Table in the IRM database based on the crop type and the Julian Day. The actual Julian Day used in the lookup is adjusted to account for the Wheat Planting Date offset and the Random Seeding offset. The effect of this is to shift the crop curve forward or backward in time.

Adjusting the Crop Coefficient. The crop coefficient must be adjusted to take into account the available soil moisture. The evapotranspiration is reduced when the soil moisture level is not at capacity. Equation 2 is used to adjust the crop coefficient.

$$AdjustedCropCoeff = CropCoefficient \times \left[\frac{\ln\left(\frac{RootZoneMoisture}{RootDepth * SoilMoistCapacity} \times 100 + 1 \right)}{\ln(101)} \right] \qquad (2)$$

With the crop growth question and the adjusted crop coefficient determined, the actual ET can be calculated. This value is calculated from the potential evapotranspiration, the adjusted crop coefficient, and the ET Scaling Factor using the following equation:

$$ActualET = ETScalingFactor \times AdjustedCropCoeff \times ETPotential \qquad (3)$$

The ET Scaling Factor (ETSF) is intended to be used as a calibration factor to represent actual irrigation management practices in the field, and is set on a block by block basis on the Block tab of the Project form.

The ET Potential used in the above equation is either calculated from the weather data or is taken from the value supplied in the weather file. The minimum ET is normally set to 0.25 mm per day. This value is used when the crop is not actively growing (i.e., prior to seeding or after harvest). For silage crops, the minimum ET is set to 1 mm per day for the 10 days following fall irrigation.

If calculated from the weather data, one of three equations may be used.

- Jensen-Haise
- Modified Penman

- Priestley-Taylor

Each is described in detail below.

1) Jensen-Haise (Equation 4):

$$ETPotential = 0.0004085 \times Radiation \times CTR \times \left[\frac{(TempMax + TempMin)}{2} - TXR \right] + Wind \times 0.00304$$

(4)

2) Modified Penman (Equation 5):

CTR and *TXR* are constants that are location specific. The location is specified on the Blocks tab on the Project form. *Radiation, TempMin, TempMax, and Wind* are obtained from the weather file.

$$ETPotential = \frac{0.408 \times Slope \times (NetRad - G) + PsychConst \times (1700/Tk) \times WindSpeed \times VpDeficit}{Slope + PsychConst \times (1 + 0.4 \times WindSpeed)}$$

(5)

Where:

$$Temperature = (TempMax + TempMin)/2$$

$$AbsTemp = Temperature + 273.16$$

$$AtmPress = 101.3 \times \left[\frac{(AbsTemp - (0.0065 \times Elevation))}{AbsTemp} \right]^{5.256}$$

$$Slope = 0.2 \times (0.00738 \times Temperature + 0.8072)^7 - 0.000116$$

$$HeatVap = 2.501 - (0.002361 \times Temperature)$$

$$PsychConst = Cp \times \frac{AtmPress}{(0.622 \times HeatVap)}$$

$$NetRad = \left[\frac{(0.63 \times Radiation \times 1000)}{43200} - 40 \right] \times \left[\frac{43200}{1000000} \right]$$

$$SatVp = \exp\left[52.58 - \frac{6790.5}{AbsTemp} - 5.03 * \ln(AbsTemp) \right]$$

$$RhMean = (RhMax + RhMin)/2$$

$$DailyVp = \frac{SatVp \times RhMean}{100}$$

$$VpDeficit = SatVp - DailyVp$$

$$G = 0$$

$$WindSpeed = Wind \times 0.01157407$$

Radiation, Rhmin, Rhmax, TempMin, TempMax, and Wind are obtained from the weather file.

3) Priestley-Taylor (Equation 6)

$$ETPotential = 1.7 \times \left[\frac{Slope}{Slope + PsychConst}\right] \times \left[\frac{NetRad\text{-}G}{HeatVap}\right] \tag{6}$$

Where:

$$Temperature = (TempMax + TempMin)/2$$

$$AbsTemp = Temperature + 273.16$$

$$AtmPress = 101.3 \times \left[\frac{AbsTemp - (0.0065 \times Elevation)}{AbsTemp}\right]^{5.256}$$

$$Slope = 0.2 \times (0.00738 \times Temperature + 0.8072)^7 - 0.000116$$

$$HeatVap = 2.501 - (0.002361 \times Temperature)$$

$$PsychConst = \frac{Cp \times AtmPress}{0.622 \times HeatVap}$$

$$NetRad = \left[\frac{0.63 \times Radiation * 1000.0}{43200} - 40\right] \times \left[\frac{43200.0}{1000000}\right]$$

$$G = 0$$

Radiation, TempMin, TempMax are obtained from the weather file. The Evapotranspiration Equation (ET Equation) calculates the Potential ET from meteorological parameters supplied in the weather file. Optionally, the ET Potential value supplied in the weather file may also be used.

Subtract ET from Root Zone Moisture. Once the Actual ET has been calculated, it is subtracted from the moisture in the root zone (Equation 7).

$$RootZoneMoisture = RootZoneMoisture - ActualET \tag{7}$$

The root zone moisture is constrained so that it can never be negative (i.e., if the above equation yields a negative root zone moisture, the latter is set to zero).

Add Precipitation Moisture to Band. Moisture is added to each band using the algorithm shown in Figure 25.

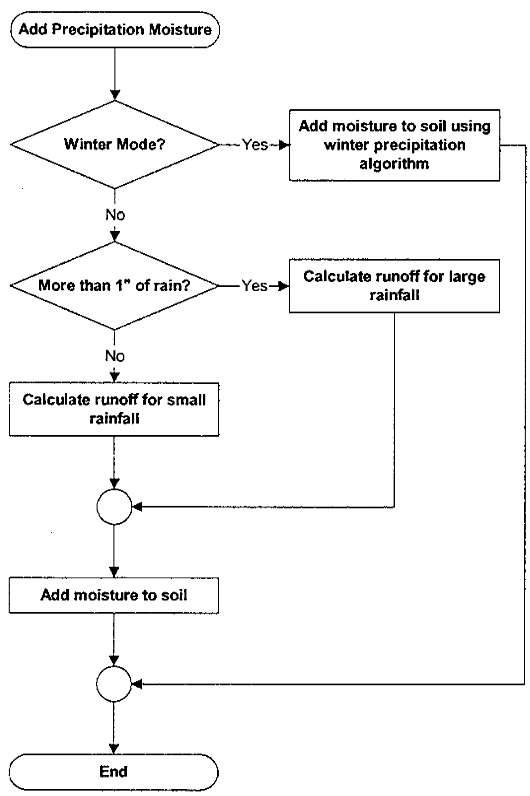

Figure 25. How moisture from precipitation is added to the soil for the Band.

When in "Winter Mode", only a fraction of the precipitation moisture is added to the soil, according to Equation 8.

$$RootZoneMoisture = RootZoneMoisture + 0.177 \times Rain \tag{8}$$

Note that the remainder of the moisture is not accounted for by the model (i.e. does not appear as return flow).

Equation 9 is used to determine how much runoff occurs for rainfalls of more than 25 millimetres in a single day.

$$Runoff = Rain - \left[0.9177 + 1.811 \times \ln(Rain) - 0.0097 \times \ln(Rain) \times \left[\frac{RZM + LZM}{SoilDepth \times SoilMoistCapacity} \right] \times 100 \right] \tag{9}$$

Where:

$RZM = RootZoneMoisture$
$LZM = LowerZoneMoisture$
$Rain = InchesOfRain$

Note that in order to apply the above equation, the rainfall amount is first converted to inches through this portion of the model calculation routine. The result (i.e., Runoff) is also expressed in inches of depth (per unit area in the Block) and therefore is converted to millimetres before it is used within other Model processes.

Small rainfalls are defined as those that drop less than 25 millimetres of water during the day. For these rainfalls, the soil moisture is allowed to reach 110% of field capacity before there is any runoff. Therefore, the runoff is calculated by the following equation.

$$Runoff = RootZoneMoisture + LowerZoneMoisture + Rain - 1.1 \times (SoilDepth \times SoilMoistCapacity) \tag{10}$$

If the runoff calculated by this equation is negative, it is set to zero.

After the runoff is calculated, the remaining rainfall moisture is added to the root zone as per the following equation.

$$RootZoneMoisture = RootZoneMoisture + Rain - Runoff \tag{11}$$

Note that this may increase the soil moisture in the root zone above 100% of capacity. This excess moisture will be percolated down into the lower zone during application of the percolation calculations, which follow.

Calculating Percolation. Percolation is calculated in two phases. In the first phase, the percolation of water from the root zone into the lower zone is calculated. In the second phase, percolation out of the lower zone is calculated.

Water percolation occurs when more water is present in the zone than the soil is capable of holding. The excess water moves down under the influence of gravity to a lower zone. In IRM, water can move from the root zone into the lower zone and out from the lower zone. Water that percolates out of the lower zone is considered lost from the system and is accounted for as a percolation loss.

The percolation calculations are performed as follows.

- Calculate the amount by which the moisture in the root zone exceeds the soil moisture holding capacity.
- If the amount is greater than zero, add that amount of moisture to the lower zone and subtract it from the root zone. This leaves the root zone moisture at 100% of capacity and will increase the moisture in the lower zone, possibly above its capacity.
- Calculate the amount by which the moisture in the lower zone exceeds the soil moisture holding capacity.
- If the amount is greater than zero, subtract it from the lower zone moisture and increase the percolation losses by that amount.

Calculating Root Growth. If the date is prior to the planting date the root depth is set to the minimum root depth as specified in the Crop Table. After the cover date, the root depth is set to the maximum specified in the Crop Table. In between the planting date and the cover date, the root depth is calculated according to Equation 12.

$$RootDepth = MaxRootDepth * (0.5 + 0.5 * \sin(Arc)) \quad (12)$$

Where:

$$MaturityRatio = \frac{DaysAfterPlanting}{DaysToMaturity}$$

$$Arc = 3.03 * MaturityRatio - 1.47$$

The root depth is constrained to be between the specified minimum root depth and the soil depth.

Adjusting the Soil Moisture to Account for Root Growth. When the roots grow, the root zone is extended into part of the lower zone. The water that was in the lower zone that then becomes part of the root zone as a result of root growth must now be accounted for as root zone soil moisture instead of lower zone moisture. This is accomplished as follows.

- The amount of water that was contained in the portion of the lower zone that became the root zone. A uniform distribution of moisture in the lower zone is assumed.
- The amount of water calculated above is subtracted from the lower zone moisture and is added to the root zone moisture.

Following this calculation, the depth of both the root zone and lower zone are recalculated to account for root growth.

Band Results. The Bands generates a number of values for each day. Some of these values refer to a depth of water such as the number of mm of rainfall, the number of mm of irrigation water applied, the number of mm of water in the root zone, etc. These values are converted into volumes of water by multiplying by the area. In some cases, the volumes are converted back into depths by dividing by the entire field area. This yields a result, which represents an average depth across the entire field.

Data, which represent field averages, include:

- Average Rain: *Average Rain* is the same as the Rain value in the weather file.

- Average Evapotranspiration: *Average Evapotranspiration* is the actual ET expressed as an average depth. Summing the ET volume for each Band and dividing by the Field area obtain it. During any day, some Bands will have an ET that is less than the Average Evapotranspiration and others will have an ET that is more. The reason for this is that the actual ET depends on the ET Potential (which is the same for all bands) and the soil moisture level (which will be different for all bands after first irrigation event begins).

- Average Delta Root Zone Moisture: *Delta Root Zone Moisture* is the change in the soil moisture level, positive or negative, during the day. For a Field object, it may be expressed as either a volume or as an average depth of water. A rainfall event, irrigation event, or root growth will increase the root zone moisture and will tend to create a positive Delta Root Zone Moisture (provided ET for the day is a lower number). Evapotranspiration will reduce the root zone moisture and will tend to result in negative Delta Root Zone Moisture.

- Average Delta Lower Zone Moisture: *Delta Lower Zone Moisture* is the change in the soil moisture level, positive or negative, during the day. For a Field object, it may be expressed as either a volume or as an average depth of water. Percolation from the root zone into the lower zone (as a result of a rainfall event or an irrigation event) will result in positive Delta Lower Zone Moisture. Root growth into the lower zone will result in negative Delta Lower Zone Moisture.

- Average Percolation Losses: *Average Percolation Losses* are the percolation losses expressed as an average depth. Summing the percolation losses for each Band and dividing by the Field area obtain it.

The following non-field average data are output to the Band Results table for each day.

- Weather data which includes Maximum Daily Temperature, Minimum Daily Temperature, Wind Run, Rain (expressed as a depth), Maximum Daily Relative

Humidity, Minimum Daily Relative Humidity, and Daily Solar Radiation

- Runoff resulting from rain fall events. The *Runoff* is the amount of water, expressed as a depth that has run off the Band as a result of a rainfall event.

- ET Potential. The *ET Potential* is either calculated using one of the ET equations or is a pre-calculated value supplied in the weather file.

- Crop Coefficient. The *Crop Coefficient* is obtained from the Crop Coefficient Curve. The Julian Day used to look up the Crop Coefficient is adjusted to account for the Wheat Planting Date Offset, the Random Seeding Offset or, in the case of forage crops, the Reference Date.

- Adjusted Crop Coefficient. The *Adjusted Crop Coefficient* is the Crop Coefficient that has been adjusted for available soil moisture.

- Actual Evapotranspiration. The *Actual Evapotranspiration* is the amount of water, expressed as a depth, which is removed from the root zone and evaporated away by the crop.

- Root Depth. The *Root Depth* is the depth of the roots on the particular Julian Day. For forage crops, this value does not change. For the remaining types of crops, this value will start out at the minimum root depth, as specified in the Plant Table of the IRM database, and will increase until it reaches the maximum root depth.

- Root Zone Moisture. The *Root Zone Moisture* is the amount of water, expressed as a depth, which exists in the root zone of the Band. Rainfall, irrigation, and root growth will increase this value; ET will decrease it.

- Root Zone Moisture Fraction. The *Root Zone Moisture Fraction* is the amount of water, expressed as a fraction of the maximum root zone moisture that exists in the root zone.

- Irrigation Threshold. The *Irrigation Threshold* is the current irrigation threshold. If the Random Irrigation Threshold Flag is set then this value will change each time the irrigation of the Field stops.

- Lower Zone Moisture. The *Lower Zone Moisture* is the amount of water, expressed as a depth that exists in the lower zone of the Band. Percolation from the root zone will increase this value; root growth will decrease this value.

- Lower Zone Moisture Fraction. The *Lower Zone Moisture Fraction* is the amount of water, expressed as a fraction of the maximum lower zone moisture that exists in the lower zone.

- Net Application. The *Net Application* is the amount of water, expressed as a depth that was absorbed by the root zone during an irrigation event.

- Percolation Losses. The *Percolation Losses* is the amount of water, expressed as a depth that percolated out of the lower zone and was lost.

- Fall Irrigation Flag. The *Fall Irrigation Flag* indicates if the irrigation is operating in the fall irrigation mode.

Irrigation Equipment Component

The Irrigation Equipment Component supplies the operating characteristics of the irrigation system or equipment to the Field and Band calculations. This component is described in detail in Appendix A. The following is an overview of the components that are supplied by the Irrigation Equipment Table.

The ***Gross Usage Rate*** is the rate at which the specific on-farm irrigation system removes water from the irrigation distribution system.

The ***Return Flow Factor*** is the portion of the water that is removed from the irrigation network by the on-farm irrigation system that is not absorbed by the soil but which returns to the irrigation system or river basin. The following equation shows how the Return Flow Factor is used in the calculation of Return Flow.

$$\mathrm{Re}\,turnFlow = GrossUsageRate \times \left(\frac{1 - ApplicationEfficiency}{100} \right) \times \mathrm{Re}\,turnFlowFactor - \quad (13)$$

The ***Application Efficiency*** indicates the percentage of the water that is removed from the irrigation distribution system that is actually absorbed by the soil in the irrigated Field.

The ***Days to Cover Field*** is the number of days it takes the irrigation system to cover the field. The Field object creates the same number of Bands as the Days to Cover Field.

The ***Down Time Per Day*** represents the amount of time, expressed in minutes per day, that the irrigation system is not taking water from the irrigation network. This results in flow-by and return flow since the water that has been allocated to the Field for irrigation is not being used.

The ***Precipitation Cut-off*** indicates the accumulated precipitation that must occur before an irrigation event would be turned off.

The ***System Type*** indicates a modelling classification for each equipment or method type. Full details on this parameter can be found in Appendix A.

Crop Component

The ***Forage Flag*** is used to indicate that the crop is a forage type. For this crop type the Crop Curve is shifted in time from year to year to correspond to the Reference Day is updated.

The ***Minimum Root Depth*** is the initial root depth for the crop. This depth also defines the root zone depth. For forage crops, the root depth does not change so the Minimum Root Depth is set equal to the Maximum Root Depth.

The ***Maximum Root Depth*** is the final root depth reached by the crop. This depth also defines the root zone depth.

The ***Relative Planting Date*** is an offset, positive or negative, that is added to Julian Day 120 to get the Julian Day on which crop is normally planted.

The ***Relative Cover Date*** is an offset, positive or negative, that is added to Julian Day 120 to get the Julian Day of the normal cover date.
The ***Relative Harvest Date*** is an offset, positive or negative, that is added to Julian Day 120 to get the Julian Day on which the crop is normally harvested.

The ***Irrigation Threshold*** is the soil moisture level relative to the maximum soil moisture that will trigger the Field object to irrigate the field.

The ***Random Seeding Range*** is the number of days that the planting date of the crop can lead or lag the normal planting date. If the Random Seeding Flag is set then the planting date will follow a uniform distribution around the crops normal planting date.

The ***Crop Coefficient Curves*** are sets of coefficients, one set per crop type, that are used to adjust the Potential ET to account for the stage of growth of the crop.

he ***Soil Moisture Capacity*** is the amount of water that the soil can hold, expressed as a ratio of water depth to soil depth. Water added to the soil in excess of this value will result in percolation or runoff.

Overview of Database Structure

The IRM dataset, with the exception of the weather file, is stored in a Microsoft Access 97 database. The database contains both queries and tables. Some of the queries are executed from the IRM program. They may be viewed from the database where long names have been used to document the purpose of each query.

Structure of Database. The IRM database is a Microsoft Access 97 database. The database holds 23 tables as well as several additional tables temporarily established during the software operation. Nine of the tables are universal to all (macro)-projects. These are:

- Soil
- Irrigation Equipment
- BlockID
- EvapoTransEq
- LegendColor
- Plant
- CropCoeff
- Field
- Location

Five tables hold the results of (macro-) project runs. These include:

- ProjectResult
- FieldResult
- BandResult
- BlockResult
- SelectedResults

The remaining five tables contain the (macro-) project specific data, namely:

- MacroProject
- MacroProjectBlock
- Project
- ProjectBlocks
- ProjectFields.

Further documentation of the contents of each table is stored in the database. You may view the tables' design and contents by logging in the database as ***"irmuser"*** when opening the database.

Overview of the Environment File. Each IRM (macro-) project is run with one or more environment (weather) files that are external to the database. Prior to running a (macro-) project you must select a file for each block contained in the project.

Structure of the Environment File. IRM weather files consist of a header line prior to a contiguous set of daily weather. The header is not read by the software but is useful in notifying potential users of the structure of the weather file. A typical header line would be:

YEAR,MONTH,DAY,TMAXC,TMINC,WINDKMD,PRECMM,RHMAX,RHMIN,SRKJD.

This header line shows the correct structure of an IRM weather file, which consists of a year value (four digits), month (0 to 12), day (of the month), maximum temperature (Centigrade), minimum temperature (Centigrade), wind run per day (kilometres), precipitation (millimetres), maximum relative humidity (%), minimum relative humidity (%), daily solar radiation (kilojoules per day). All weather files must have this structure. The weather file parameters are to be comma-separated values. If a user is missing any parameters the field can simple be left as a null (i.e. this will result in two adjacent commas). For projects that use the Jensen-Haise Equation, the relative humidity component is not required. For projects that use the Priestly Taylor Equation, neither wind speed nor relative humidity are required. Projects that use the Modified Penman Equation require all variables.

Weather files can span multiple years but must begin January 1 of the first year and end December 31 of the final year and be contiguous throughout. When multiple blocks are part of a (macro-) project, you may assign each block the same or a different weather file. Prior to running the model, the software will determine the periods that are common in each weather file and will prompt the user to select the start and end date for the analysis.

IRM Glossary

Application efficiency
The fraction of the water consumed by the irrigation system that is absorbed by the soil. The remaining fraction is either returned to the canal (see Return flow percentage) or lost by some other mechanism (evaporation, etc.).

Band
A band is the portion of a field that gets irrigated during the course of one full day. Several bands may be required to irrigate a single field.

Block Name
Block Name is the name of the block that represents a logical grouping of fields as defined by the User.

Coverage rate
The amount of area that the irrigation system can cover per day.

Crop coefficient (AKC1)
A dimensionless number that when multiplied by the evapotranspiration potential indicates the maximum amount of moisture that the crop will extract from the soil on a daily basis.

Default ET Scaling Factor
The Default ET Scaling Factor is the initial ET Scaling Factor that is loaded to the project and macro-project parameters when the specific block is selected. The scaling factor is applied to the results of the ET equation. The default value may be adjusted on a (macro-) project by (macro-) project basis.

Default %Fields Fall Irrigated
The Default %Fields Fall Irrigated is the initial percentage of fields fall irrigated which is loaded to the project and macro-project parameters when the specific block is selected. For standard projects, this is only used when the Use Field Level Irrig. Flag is not checked on the Project Parameters screen. A description of the fall irrigation algorithm can be found in the Project Parameters help topic. The default value may be changed on a (macro-)project by (macro-)project basis.

Default Location
Default Location is the initial Location that is loaded to the project and macro-project parameters when the specific block is selected. The location provides elevation and CTR and TXR coefficients that are used in the ET calculations of some models. The default location may be changed on a (macro-)project by (macro-)project basis. If additional locations are desired contact the software administrator.

Default Soil Depth

Default Soil Depth for a block is the initial soil depth that is loaded to the project and macro-project parameters when the specific block is selected. The default value may be changed on a (macro-)project by (macro-)project basis.

Default Wheat Planting Date Offset

The Default Wheat Planting Date Offset is the initial value that is loaded to the project and macro-project parameters when the specific block is selected. This is the adjustment for the Wheat planting date (and hence, all seed crops) for each block within the (macro-) project. Positive numbers indicate the planting date is performed later than the standard dates specified in the database. The default value may be changed on a (macro-) project by (macro-)project basis.

Down time

The number of minutes per day that the irrigation system is not pumping water from the canal. For side roll irrigation equipment, the down time represents the amount of time spent each day moving the equipment to the next band.

Fall irrigation

Fall irrigation results in the field being irrigated after the harvest. Two models are used. The model descriptions can be found in the Project Parameters help topic.

Forage crop

A crop that is harvested more than once per year. Examples include hay and alfalfa. The model assumes that these crops have been previously established.

IBDF output file

An IBDF file is a required input file for Alberta Environment's Water Resources Management Model (WRMM).

Irrigation threshold

A soil moisture level against which the current soil moisture is compared to determine if it is time to start irrigation. Irrigation is started when the soil moisture falls below the irrigation threshold that is expressed as a fraction of the soil moisture capacity. For example, a threshold of 0 results in no irrigation, a threshold of 0.8 results in irrigation when only 20% of the soil's moisture capacity has been removed.

Lot ID

Some Irrigation Districts use "Lot ID" to define parcels of irrigated land. The convention for assigning the Lot ID to a quarter section will be based on the location of the main turnout for the Lot. A quarter section may have multiple fields for multiple Irrigation Lots but a specific Irrigation Lot may not be entered in multiple quarter sections. This will ensure no double accounting of Irrigation Lots.

Macro-field

A logical field that is created by combining all fields with matching soil type, plant type and irrigation methods within a Block.

Macro-project

Macro-projects are created by consolidating the common field configurations (plant type, soil and irrigation systems) within each block. This speeds the modeling process and provides the ability to model a variety of "What if" scenarios by modifying the macro-field composition without modifying the database's field data.

Maximum root depth

The maximum depth to which the plant's roots will grow.

Minimum root depth

The minimum root depth of the plant.

Moisture capacity

The amount of water that the soil can hold.

Project

A Project is a user-selected set of quarter sections that are modeled based on specific weather, canal and other model parameters.

Reference date

The first day after the average daily temperature has been above 5 degrees C for five consecutive days.

Relative cover date

The date relative to Julian day 120 (May 1) that the plant achieves full coverage. This may be further adjusted by the Wheat Planting Date Offset.

Randomized seeding range

The actual seeding date for each field may be randomized within a range of dates of the actual seeding date as follows: Actual Seeding Date = (Seeding Date - x days) + 2x*Random; where Random is a uniformly distributed number between 0 and 1. The x variable can be found in the plant table as "RandSeedingRange" and is typically five days (i.e. Seeding occurs +/- five days from the plant's seeding date).

Relative cut date

The number of days of growth before the crop is cut down. Applies to forage crops.

Relative harvest date

The date relative to Julian day 120 (May 1) that the plant is harvested. . This may be further adjusted by the Wheat Planting Date Offset.

Relative planting date

The date relative to Julian day 120 (May 1) that the plant begins to demand moisture. This may be further adjusted by the Wheat Planting Date Offset.

Return flow percentage

The return flow percentage is the percentage of water that does not enter the soil that returns to the canal as run-off. The percentage of water that does not enter the soil is calculated from the application efficiency.

Water usage rate

The consumption rate of the on-farm irrigation systems.

APPENDIX A

Details of the Irrigation Methods Component

IRM On-Farm Irrigation System Modelling Parameters
("Irrigation Methods Table")

Background

The Irrigation Requirements Module (IRM) is the on-farm irrigation water demand component of the Irrigation District Model (IDM). It is designed not only to determine the moisture demand by crops, but also to determine the required amount of water to be diverted through various types of on-farm irrigation systems for field applications. With there being many types of irrigation systems utilized in southern Alberta, there are just as many varying factors impacting the total demand for water back at the diversion point to each type of system. Operational characteristics such as timing of use, depths of application, general water application efficiency factors, as well as system downtime losses, all come into play when the IRM determines a daily water demand to each individual field in an irrigation block.

When making its calculations, the IRM looks at the soil moisture condition in each and every field for each day in the irrigation season. As crops from one field to the next vary and as climate varies from day-to-day, week-to-week and month-to-month, the net water demand to each field will also vary across those time frames. Then, when the particular irrigation system covering each field is integrated into the situation, an additional order of variability is added to the water demand determinations. For example, while some types of systems apply large amounts or depths of water per set or irrigation pass, with a limited number of irrigations per year, others put on small amounts of water to a cropped area many times during the irrigation season. This may also affect the amount of time that a system takes to complete full coverage of a given field. For some systems, applying a limited amount of water during each irrigation means that the coverage time may be a matter of only a few days. For other systems, it may take considerably longer to complete one full irrigation of a field. Some systems will have an associated higher amount of downtime due to required set change periods, while others may only incur downtime due to some form of unscheduled mechanical failure. As a result, these types of variabilities affect how irrigations are managed within the IRM and the resulting demand for water, usually expressed in litres per second.

Effect of Irrigation Application Efficiency

One of the greatest variables affecting overall water demand into an irrigated field is the application efficiency of the particular type of irrigation system being used. Irrigation application efficiency is defined as:

$$E_a = \frac{\text{Net amount of applied water available for crop use}}{\text{Total amount of water diverted to the irrigation system}} \times 100\%$$

There are several components of water loss that can occur within the application process. These are illustrated in Figure A-1. The nature of operation and water application of different types of systems will have different effects on the extent to which application water is lost from use by crops. Uncontrolled water applications typically have high amounts of water loss due to field run-off, poor application uniformity and resulting deep percolation. Similarly, systems that apply large amounts of water at a time on an infrequent basis can have similar types of loss effects. Systems that put on small amounts of water often usually will have less water loss, but are much more sensitive to the effects of aerial spraying and evaporative losses. Overall, the operator management of systems in terms of timing of applications, lengths of sets, etc. can have significant effect on the net application efficiency of any system.

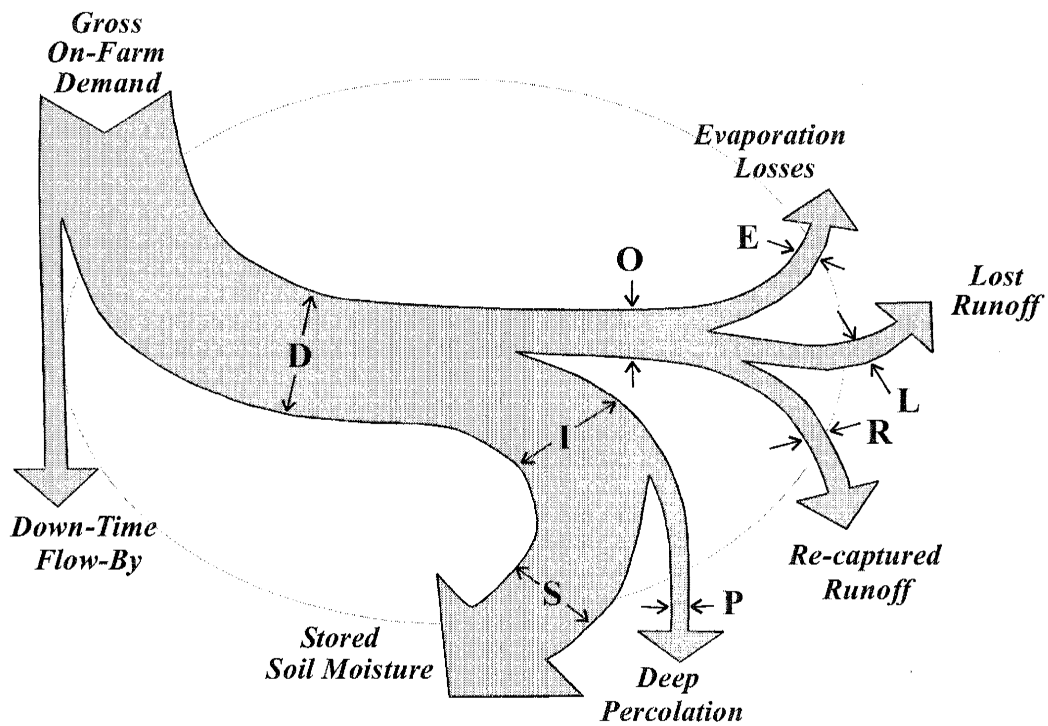

Figure A-1. Components of on-farm irrigation water supply, loss and net availability to the irrigated crop.

Types of Irrigation Systems

For the purposes of modelling irrigation in Alberta, 18 different types or configurations of systems are assumed to represent the extent of variability commonly encountered. These can be grouped into four distinct groups, differing by the very nature of their operations.

1) Sub-Surface Irrigation
2) Gravity or Surface Irrigation (commonly referred to as “flood” irrigation)
3) Sprinkler Irrigation
4) Micro Irrigation

Each of the above brings their own unique attributes to the determinations of required flow capacity.

a) Sub-surface systems utilize shallow-buried drainage pipe in reverse mode, where water is directed into the tubing to be dispersed into the soil profile, much as could be the case with a shallow perched water table. These are closed systems where most water loss is as a result of deep percolation.

b) Gravity or surface irrigation systems are unconfined water application systems that involve directing a sheet of water across and infiltrating into a soil surface, with either no or little mechanical water application control. Water control in these types of systems is usually directly proportional to three factors.

   - The extent that field slopes are moderated to more or less uniform gradients that provide consistent water distribution.
   - The availability of a sufficient supply (flow rate) of water to effectively cover the land in a reasonable timeframe but with minimized tail-water run-off from the end of the field.
   - The amount or extent of water control structures or devices, such as shallow earth dykes, proportionally spaced and running down the field, or head-ditch water diversion equipment such as siphon tubes, or the use of gated pipe with or without surge control valves.

   One of the most unique aspects of surface irrigation systems is that they generally require a relatively high flow rate for a relatively short period of time, regardless of field size. The flow characteristics distributing the applied water is more a function of the physical hydraulics of moving the sheet of water over a soil surface that contains specific side and downfield slopes, as opposed to the size of the area being irrigated. Increased water application efficiencies are often the outcome of utilizing devices, as mentioned above, that provide much more uniform control of the rate of diversion to an irrigated area

c) Sprinkler systems are much more "mechanically" controlled, confining water to application in specific areas at specific rates as dictated by the design and configuration of the equipment used. In sprinkler systems, the required diversion rate to a field has a direct proportionality to the field area being irrigated by the particular equipment in question. However, their actual application efficiencies can be somewhat affected by how they are operated in terms of their water application management by the operator.

d) Micro systems are, as the name implies, generally used in smaller field areas where very good water control is most advantageous and where the higher capital investment is more justifiable due to the usually high value of the crops grown with the help of these types of systems. Here, flow rates are usually relatively low, due both to the precise watering nature of the application systems and the usually smaller areas being irrigated. Nevertheless, required flow rates are generally still proportional to the area of coverage.

The general concept in deriving specific system operation parameter values is that each system-type is referenced to operating conditions and configurations based on standard or commonly observed coverages of a quarter-section-size field, or a commonly divided segment of such a parcel (e.g. 16 hectares or 32 hectares). The different types of systems, recognized for modelling purposes, are defined as follows:

a) **Gravity – Undeveloped – Sub-surface (Code = GUS):** Sub-Surface drainage tubing installed in a grid pattern such that water injected into the tubing will infiltrate from the tubing into the soil profile. This is the one case of a so-called "gravity" system which is not what is traditionally referred to as "surface" irrigation, and where the required system flow rate is generally directly proportional to the area of the field being irrigated. However, water flow into and through the system is influenced primarily under the force of gravity. Application efficiencies can be moderate to high.

b) **Gravity – Undeveloped – Flood < 40 acres (Code = GUF<40):** These systems typically have no land-forming included in their field development. As a result, water control is quite erratic, resulting in low water application uniformities and efficiencies. These types of systems would typically include contour-ditch and wild-flooding conditions. The system notation applies to field coverage equal to or less than 16 hectares (40 acres) in area, with an associated lower and fixed diversion rate to the field (60 litres per second). Application efficiencies are generally low.

c) **Gravity – Undeveloped – Flood > 40 acres (Code = GUF>40):):** These systems typically have no land-forming included in their field development. As a result, water control is quite erratic, resulting in low water application uniformities and efficiencies. These types of systems would typically include contour-ditch and wild-flooding conditions. The system notation applies to field coverage greater than 16 hectares (40 acres) in area, with an associated fixed diversion rate to the field (160 litres per second). Application efficiencies are generally low.

d) **Gravity – Developed – No control < 40 acres (Code = GDN<40):** These systems operate within field areas that have been land-formed through machine levelling to achieve specific field slope conditions for better water application control, uniformity and efficiency. These types of systems would typically include border-dyke and furrow-irrigated fields. However, few water control devices are used to control diversions to the irrigated area. The system notation applies to field coverage equal to or less than 16 hectares (40 acres) in area, with an associated lower and fixed diversion rate to the field (60 litres per second). Application efficiencies are generally low to moderate.

e) **Gravity – Developed – No control > 40 acres (Code = GDN>40):** These systems operate within field areas that have been land-formed through machine levelling to achieve specific field slope conditions for better water application control, uniformity and efficiency. These types of systems would typically include border-dyke and furrow-irrigated fields. However, few water control devices are used to control diversions to the irrigated area. The system notation applies to field coverage greater than 16 hectares (40 acres) in area, with an associated fixed diversion rate to the field (160 litres per second). Application efficiencies are generally low to moderate.

f) **Gravity – Developed – Controlled < 40 acres (Code = GDC<40):** These systems operate within field areas that have been land-formed through machine levelling to achieve specific field slope conditions for much better water application control, uniformity and efficiency. These types of systems would typically include border-dyke and furrow-irrigated fields. Nonetheless, in these systems, more sophisticated water control devices are used to control diversions to the irrigated area. The system notation applies to field coverage equal to or less than 16 hectares (40 acres) in area, with an associated lower and fixed diversion rate to the field (60 litres per second). Application efficiencies are generally moderate to high.

g) **Gravity – Developed – Controlled > 40 acres (Code = GDC>40):** These systems operate within field areas that have been land-formed through machine levelling to achieve specific field slope conditions for much better water application control, uniformity and efficiency. These types of systems would typically include border-dyke and furrow-irrigated fields. Nonetheless, in these systems, more sophisticated water control devices are used to control diversions to the irrigated area. The system notation applies to field coverage greater than 16 hectares (40 acres) in area, with an associated fixed diversion rate to the field (160 litres per second). Application efficiencies are generally moderate to high.

h) **Sprinkler – Solid Set (Code = SSS):** These are sprinkler irrigation systems which remain fixed in position within an irrigated field area, not requiring any labour to re-locate equipment between irrigation sets. Such systems are typically either pipeline distribution systems laid on the surface of the ground or buried beneath the fieldwork area, with sprinkler head risers extending above and between the crop canopy. The associated system flow rate is proportional to the field area covered. These systems are conducive to automated control and, because there is no equipment to be moved, can allow for higher diversion and coverage rates that support variable periods of operation each day. These systems also tend to be managed for moderate depths of application, having moderate to high application efficiencies. The associated system flow rate is directly proportional to the field area covered

i) **Sprinkler – Hand-Move (Code – SHM):** These are sprinkler irrigation systems which are laid out on the surface of an irrigated field but only cover a portion of the field during any irrigation set. Consequently, equipment must be moved between sets, requiring the system, in whole or in part, to be turned off for short intervals to allow for equipment re-location in the field. These systems are generally operated almost continuously through a day, applying relatively large applications of water with moderate application efficiencies. The associated system flow rate is directly proportional to the field area covered

j) **Sprinkler – Wheel-move – 2 laterals (Code – SW2):** These are sprinkler irrigation systems that irrigate only portions of an irrigation field during any irrigation set. Consequently, equipment must be moved (rolled) between sets, requiring the system, in whole or in part, to be turned off for short intervals, to allow for equipment re-location in the field. The typical configuration of these types of systems is such that two 400-metre laterals are operated to cover one quarter-section of land, or some equivalent thereof (one 400-metre lateral per 30 hectares). System capacity and field coverage rates are limited by this equipment configuration, thereby potentially limiting the system capability to adequately meet crop water demands. These systems are generally operated almost continuously through a day, applying relatively large applications of water with moderate application efficiencies. The associated system flow rate is directly proportional to the field area covered.

k) **Sprinkler – Wheel-move – 4 Laterals (Code – SW4):** These are sprinkler irrigation systems that irrigate only portions of an irrigation field during any irrigation set. Consequently, equipment must be moved (rolled) between sets, requiring the system, in whole or in part, to be turned off for short intervals, to allow for equipment re-location in the field. The typical configuration of these types of systems is such that four 400-metre laterals are operated to cover one quarter-section of land, or some equivalent thereof (one 400-metre lateral per 15 hectares). System capacity and field coverage rates are not normally limited by this equipment configuration, thereby adequately meeting crop water demands. These systems are generally operated almost continuously through a day, applying relatively large applications of water with moderate application efficiencies. The associated system flow rate is directly proportional to the field area covered.

l) **Sprinkler – Pivot – High pressure (Code = SPH):** These are advanced mechanically driven sprinkler irrigation systems that continuously rotate around the irrigated area while irrigating. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Under high pressure operating conditions, where impact sprinklers spray the water high above the crop, water application efficiencies are generally moderate. Applications are generally small and frequent, but system capacities are normally adequate to meet crop water demands. The associated system flow rate is directly proportional to the field area covered.

m) **Sprinkler – Pivot – High pressure – Corner (Code = SPHC):** These are advanced mechanically driven sprinkler irrigation systems that continuously rotate around the irrigated area while irrigating, and are adapted with additional equipment to irrigate field corner areas beyond the normal circular field. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Under high pressure operating conditions, where impact sprinklers spray the water high above the crop, water application efficiencies are generally moderate to high. Because corner systems require intermittent high flows and higher application rates, application efficiencies could be negatively impacted to a slight degree. Applications are generally small and frequent, but system capacities are normally adequate to meet crop water demands. The associated system flow rate is directly proportional to the field area covered.

n) **Sprinkler – Pivot – Low pressure (Code = SPL):** These are advanced mechanically driven sprinkler irrigation systems that continuously rotate around the irrigated area while irrigating. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Under low pressure operating conditions, where drop-tube nozzles distribute the water just above the crop canopy, water application efficiencies are good. Applications are generally small and frequent, but system capacities are normally adequate to meet crop water demands. Application efficiencies are generally high. The associated system flow rate is directly proportional to the field area covered.

o) **Sprinkler – Pivot – Low pressure - Corner (Code = SPHC):** These are advanced mechanically driven sprinkler irrigation systems that continuously rotate around the irrigated area while irrigating, and are adapted with additional equipment to irrigate field corner areas beyond the normal circular field. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Under low pressure operating conditions, where drop-tube nozzles distribute the water just above the crop canopy, water application efficiencies are good. Because corner systems require intermittent high flows and higher application rates, application efficiencies could be negatively impacted to a slight degree. Applications are generally small and frequent, but system capacities are normally adequate to meet crop water demands. Application efficiencies are generally high. The associated system flow rate is directly proportional to the field area covered.

p) **Sprinkler – Linear – High pressure (Code = SLH):** These are advanced mechanically driven sprinkler irrigation systems that continuously move laterally across the irrigated area while irrigating. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Under high pressure operating conditions, where impact sprinklers distribute the water high above the crop, water application efficiencies are moderate at best. Applications are generally small and frequent, but system capacities are normally adequate to meet crop water demands. Application efficiencies are generally moderate to high. The associated system flow rate is directly proportional to the field area covered.

q) **Sprinkler – Linear – Low pressure (Code = SLL):** These are advanced mechanically driven sprinkler irrigation systems that continuously move laterally across the irrigated area while irrigating. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Under low pressure operating conditions, where drop-tube nozzles distribute the water just above the crop canopy, water application efficiencies are good. Applications are generally small and frequent, but system capacities are normally adequate to meet crop water demands. Application efficiencies are generally high. The associated system flow rate is directly proportional to the field area covered.

r) **Sprinkler – Volume gun – Stationary (Code = SVS):** These sprinkler irrigation systems rely on a single large nozzle sprinkler to cover a broad irrigated area. Individual or multiple units can be used to cover a field, but usually multiple sets are necessary, requiring the system, in whole or in part, to be shut-down for short intervals to allow for equipment re-location in the field. Coverage by these types of systems is limited, and due to the high volume and single stream of water that is sprayed into the air, application uniformity and efficiency declines. Application depths are generally small to moderate, with low to moderate application efficiencies. These systems are generally operated almost continuously through a day. The associated system flow rate is directly proportional to the field area covered.

s) **Sprinkler – Volume gun – Traveller (Code = SVT):** These sprinkler irrigation systems rely on a single large nozzle sprinkler to cover a broad irrigated area. However, these are advanced mechanically driven sprinkler irrigation systems that continuously move across the irrigated area while irrigating. The automation of these systems allows for full continuous operation, except where intermittent mechanical breakdowns may occur. Coverage by these types of systems is limited, and due to the high volume and single stream of water that is sprayed into the air, application uniformity and efficiency declines. These systems are generally operated almost continuously through a day, with applications generally being small but frequent. Application efficiencies are in the moderate range, with the associated system flow rate being directly proportional to the field area covered.

t) **Micro – Spray - Sprinkler (Code = MSS):** These types of systems are very specialized sprinklers or spray systems, connected through extensive lines of small diameter tubing. They have a low capacity and apply water in close proximity to the crop, minimizing surface area coverage and thereby achieving higher water application efficiencies. These systems, being more or less permanently placed within a field, lend themselves well to automation and to variable water application periods. Applications are generally small, but frequent, with high application efficiencies. The associated system flow rate is directly proportional to the field area covered.

u) **Micro – Drip - Trickle (Code = MDT):** These types of systems are very specialized water emitting systems, connected through extensive lines of small diameter tubing. They have a very low capacity and apply water in close proximity to the crop, minimizing surface area coverage and thereby achieving higher water application efficiencies. These systems, being more or less permanently placed within a field, lend themselves well to automation and to variable water application periods. Applications are generally small, but frequent, with high application efficiencies. The associated system flow rate is directly proportional to the field area covered.

Determining System/Equipment Parameter Values - Modelling Process Inputs

Table A-1 lists all of the system types and their respective water demand and application parameter values. However, the values listed are, for the most part, dependent upon certain assumptions or standards that are applied for Alberta conditions. Many of the parameters are exclusive to the IDM computer modelling application, as reasonable attempts are made to try and represent actual field practices. As any of the reference values are changed, as local situations may dictate, many of the parameter values could change, either slightly or significantly. For example, when different operator management levels are considered, the net result could be either higher or lower application efficiencies for the respective systems. In addition, some values presented in Table A-1 are provided as comparative information only, as the IRM calculates many of these values directly on a field-by-field basis during selected modelling runs.

The following provides some description of each of the variables listed in Table A-1 (by Column letter), preceded by two over-arching variables that are referenced in calculation routines deriving system-specific parameter values (1 and 2 below). In addition, some general information is included on how respective values are used within the IRM derivations:

1) ***Agro-Climatic Factor ("A"):*** Climatic influences vary across the irrigated regions such that some areas receive more days of warmer and drier conditions, while other areas are cooler and receive more precipitation. As a result, the requirement rate for moisture replacement is greater in some areas than in others. Consequently, in the warmer and drier areas, in-field irrigation systems will need to have greater capacities than systems operating in the cooler and more moist areas, particularly those where irrigation may be more supplemental in nature. As a result, a unique "Agro-Climatic Factor" has been derived for individual climate regions across the irrigated areas. This factor is linked as an attribute within each climate reference station and is applied in the calculation of system capacities in respective regions, pro-rating required replacement rates based on local climate conditions. The distribution of agro-climatic factor values is depicted by the isobaric lines within Figure A-2.

2) ***"Design" Consumptive Use ("CU"):*** This is the rate (mm/day) at which irrigation systems are designed to meet crop moisture demands. It does not reflect the maximum moisture consumption rate by a crop but has been accepted as the effective "design" rate at which, if soil moisture levels are managed properly, a high water use crop will have access to adequate moisture through high consumptive use periods. This is based on a 90% exceedence level, which means that in nine years out of ten, this design capacity of an on-farm system should be sufficient, under good irrigation management, to sustain required moisture levels for high water use crops. Designing a system capacity to provide 100% assurance of meeting crop moisture needs throughout any crop year usually demands such high capacities that associated system design is usually not economic to try and achieve.

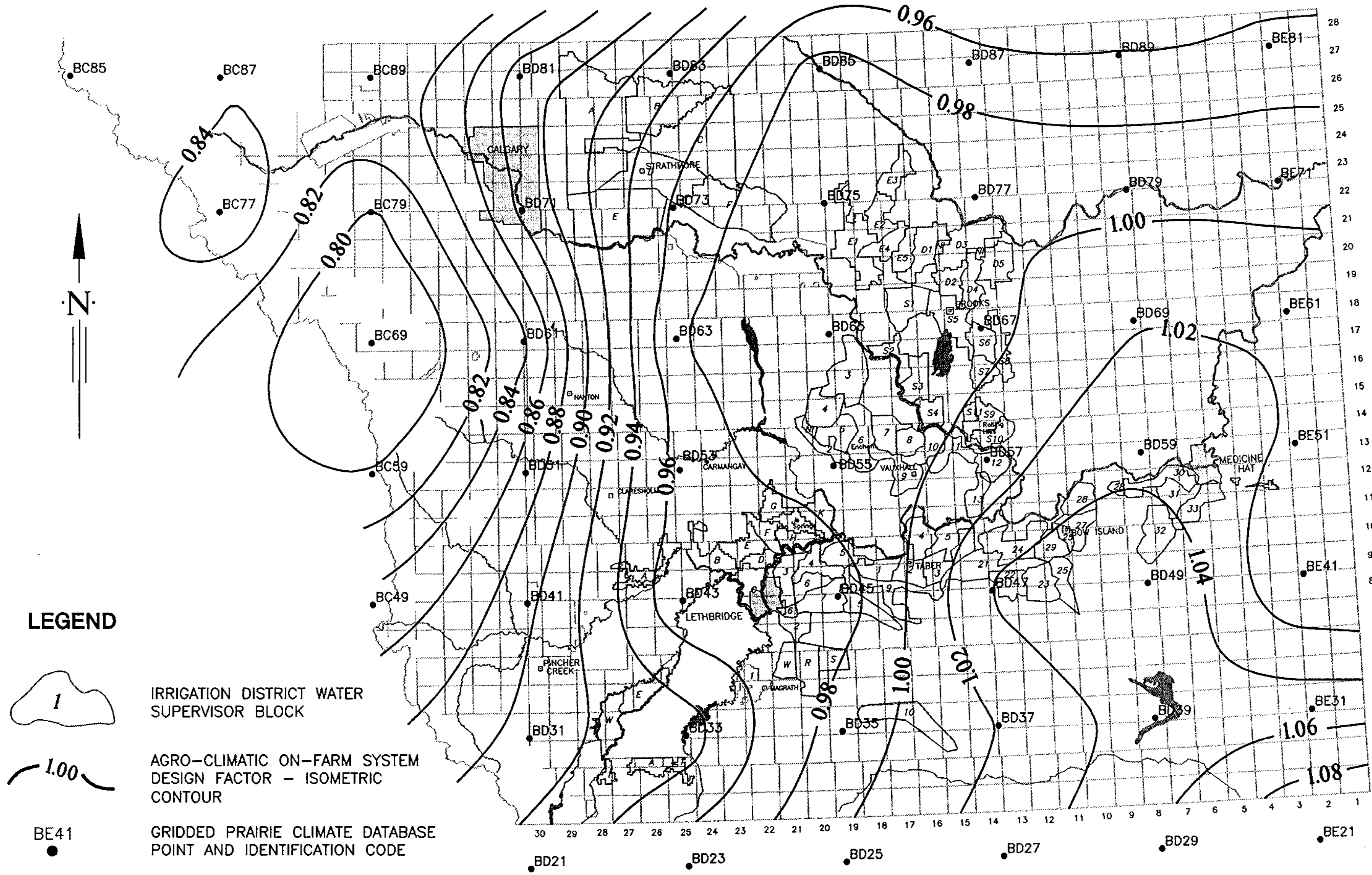

Figure A-2. On-Farm Irrigation Systems Design Agro-Climatic Factors.

A) ***System-Type Code:*** As defined above under Types of Irrigation Systems.

B) ***System Capacity-Type:*** Defines whether the system flow rate is fixed (F) or is a variable (V) function proportional to the size of the area being irrigated.

C) ***Time to Irrigate ("T"):*** Defines the time (days) it takes for a given system to complete a full irrigation across an irrigated field. It is dependent upon normal set times and application amounts and references a normal field size. It defines the time period required between successive field irrigation events. This does not apply to most of the gravity systems that have assigned coverage rates.

D) ***Irrigation Coverage ("C"):*** Defines the irrigation area that can be covered in one day, based on the fixed rate of flow of irrigation water into the field. This applies to gravity systems only.

E) ***Seasonal Irrigation Factor ("t"):*** Controls the amount or depth of application of a given irrigation system per set or pass, to restrict those application depths as they may apply to early season irrigations when crops are just germinating and moisture use is low and shallow within the soil profile. The Seasonal Irrigation Factor proportionately reduces the Time to Irrigate factor which reduces set times and corresponding application depths. In many respects, this allows for the simulation of "irrigation for germination" applications.

F) ***Precipitation Threshold ("Pc"):*** When an irrigation event is occurring in any given field and a precipitation event occurs such that soil moisture levels may increase beyond the crop-specific irrigation threshold trigger, this factor sets the accumulated precipitation level that must occur before an irrigation event would be turned off.

G) ***Operational Downtime Ratio ("Dt):*** This represents the expected proportion of each operation day that a given irrigation system would be shut-down, in whole or in part, due either to scheduled set changes or unforeseen system breakdowns.

H) ***Flow-By Downtime ("Fd):*** This represents the expected time (minutes per day) that a given irrigation system would be shut-down, in whole or in part, due either to scheduled set changes or unforeseen system breakdowns. During this period, water conveyed to a field point of delivery would not be able to be diverted and so flows by unused, accumulating at some downstream point as either water for re-use or return flow.

J) ***Evaporation Losses Factor ("E"):*** Defines the average proportion of system-conveyed and applied water that is lost to evaporation on average through an irrigation season.

K) ***Field Outflow Factor ("O"):*** Defines the proportion of applied water that would be expected to run-off from an irrigation field, resulting from applied water that does not infiltrate into the soil profile and moves off of the field due to land slope conditions.

L) ***Outflow Re-Capture Factor ("R"):*** Defines the average projected proportion of the Outflow water that accumulates and that potentially could be re-captured for re-use in a downstream irrigation block catchment.

M) ***"IRM" Return Flow Factor ("Rf"):*** Defines the average projected proportion of the overall water conveyed and applied through the irrigation system that could potentially be captured within the downstream conveyance system and accumulate as part of the Return Flow volume from the network. It is a function of the Outflow Recapture Factor and is used specifically within the IRM moisture calculations only.

N) ***"Effective" Application Portion ("I"):*** Defines the average proportion of the overall water delivered to and through a given irrigation system that actually infiltrates into the soil profile.

P) ***Deep Percolation Factor ("P"):*** Defines the average projected proportion of the overall water delivered to and through a given irrigation system that infiltrates through the soil profile to depths below the root zone, making it unavailable for crop use. (The IRM calculates deep percolation losses directly and independent of this factor.)

Q) ***Application Efficiency (Net – "Ea"):*** Defines the overall net application efficiency, as per definition, with all water loss factors taken into account.

R) ***Capacity Sizing Factor ("k"):*** Defines the proportion to which system design capacities equate to normally expected crop water use rates, as set within the "Design Consumptive Use" value. Although required system capacities are fundamentally designed to match or exceed required soil-crop moisture replacement rates, some equipment configurations or operating conditions either do not provide the capability to convey such capacities or, on the other hand, may provide additional capacity beyond replacement rates.

S) ***Unit Capacity ("q"):*** Based on all of the crop water requirements, the irrigation system coverage rates or irrigation periods, as well as all of the application loss factors, this is the computed capacity of a given irrigation system required to satisfy the specified demands and limitations. This value is expressed in units of flow rate per unit of area irrigated for those systems defined to have a variable capacity rate, proportional to the field area being irrigated, or in units of flow rate only for those systems that have a fixed system capacity. It is this value that the IRM uses when configuring irrigation applications through a given system in a given field.

T) ***Gross Application Depth ("D"):*** Based on the Unit Capacity, the time to irrigate and the area of an irrigated field, this is the computed value of the depth of water applied to a field. (This value is calculated independently by the IRM.)

U) ***Net Application Depth ("d"):*** Based on the Gross Application Depth and the accumulated Net Application Efficiency, this is the computed value of depth of applied water that is available for crop use within the available root zone. (This value is calculated independently by the IRM.)

Table A-1 provides a sample of typical values of the above parameters and factors that may be applied in a given geographical zone of the irrigation region. This Table incorporates values that represent expected conditions under "***good***" on-farm irrigation management.

The Effect of Operator Management on On-Farm System Performance

As much as any type of irrigation system will have its advantages and disadvantages, its ability to achieve its projected application efficiency can be significantly impacted by how an operator manages that system. For example, a system that was designed to provide a full irrigation application through an eight-hour set, but is operated under 12-hour sets, is bound to lose a much higher proportion of the applied water through deep percolation and surface run-off. On the other hand, a system that is designed to apply light applications of water but is operated through an irrigation pass in a much shorter period than designed, will find a much greater proportion of the applied water being lost to evaporation.

As a result, a series of application efficiency values have been derived for each on-farm system type that pertain to four different levels of on-farm system management. "Standard" management is understood to mean management capabilities as practiced into the 1990s. "Good" management is what is projected to be the level of management developing at the beginning of the 21st century. Therefore, as the IRM is run, the user can set the management level which may apply to a specific scenario condition. A summary of these values for the four management levels is listed within Table A-2.

Table A-2. Variable IRM On-Farm System Application Efficiency Input Values.

System Type Code	"Low" Management Portion	"Standard" Management Portion	"Good" Management Portion	"Optimum" Management Portion
GUS	80%	90%	95%	95%
GUF<40	40%	50%	60%	60%
GUF>40	40%	50%	60%	60%
GDN<40	60%	70%	78%	80%
GDN>40	60%	70%	78%	80%
GDC<40	70%	75%	85%	90%
GDC>40	70%	75%	85%	90%
SSS	70%	75%	76%	80%
SHM	63%	68%	73%	75%
SW2	65%	70%	74%	76%
SW4	67%	72%	75%	77%
SPH	68%	74%	76%	78%
SPHC	67%	72%	75%	78%
SPL	70%	77%	82%	90%
SPLC	68%	76%	81%	88%
SLH	69%	74%	77%	80%
SLL	72%	78%	82%	90%
SVS	60%	65%	68%	70%
SVT	64%	67%	69%	72%
MSS	75%	80%	0.84%	88%
MDT	80%	85%	0.88%	94%

Volume 4. Modelling Irrigation Water Management

II. Determining Water Supply Availability to Meet Irrigation Demands

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EXECUTIVE SUMMARY

Part II presents an overview of the Water Resources Management Model (WRMM) tool utilized for determining available irrigation district supply and deficits. Alberta Environment developed the WRMM tool for previous studies for the purpose of modelling of the entire river basin. This overview was performed by Phoenix Engineering Inc. for the purpose of providing Alberta Agriculture with a broad overall assessment of the model, its documentation, algorithms and numerical methods. A data flow diagram of the system and a high level flow chart of the Model Simulation Program were also produced.

The analysis of the WRMM model was based on a review of the manual, a general review of the Model Simulation Program (MSP), and a detailed review of portions of the MSP. Comparisons were made between the algorithms and data flows that exist in the code to those documented in the manual.

The results of the review indicated the following.

- The model is, by necessity, a complex piece of software.
- The algorithms and numerical methods used are appropriate for the task.
- Very good external documentation exists (i.e. the WRMM manual) that is consistent with the actual FORTRAN code.

With respect to the sensitivity of the model output to the various inputs, the following conclusions were reached.

- The impact of a demand (e.g. irrigation demand) on the response of the model is directly related to the magnitude of the demand relative to the supply and the relative priority of the various demands.
- How the model deals with surpluses and shortages is determined by the configuration of the penalties (i.e. the priorities assigned to them).

This report also presents the results of various calibrations performed on WRMM and on the Irrigation District Model (IDM) suite of tools to validate the algorithms and their implementation. It was found that on an overall district level, the IDM inflow demands and outflows matched those simulated by the WRMM. However, the two models did not provide consistent flows at the WRMM block level. This was attributed to the macro simplification of the WRMM operations as compared to the actual physical representation of the irrigation distribution network referenced in the IDM tools. Validation was also performed for the Network Management Model to ensure a water balance was strictly enforced. Finally, a validation of the Irrigation Requirements Module (IRM) predicted demands was compared with measured demands to validate the algorithms presented in Part I of this volume.

Overall, the IDM simulations were found to very closely match actual recorded diversions and component demands. However, as the IDM itself does not handle the calculations associated with reservoir management and operations, a task imbedded within the WRMM, calculated and recorded values of net changes in reservoir storage and reservoir evaporation need to be added to the IDM simulation demand in order to provide an equitable comparison between modelled and recorded volumes of water.

In summary, IDM predictions of overall demand were generally within ± 5% of recorded values, with simulated return flow amounts within less than 3% of recorded volumes. It was quite evident that irrigation demand values were quite sensitive to the value set for the ET Scaling Factor (ETSF), the factor intended to reflect irrigation operator management with respect to meeting optimum crop moisture requirements. Quite clearly, a shift of two or three percentage points in the ETSF can virtually eliminate any discrepancy between modelled demand and recorded diversions. Similarly, return flow volumes generated are very sensitive to the Base Flow Scaling Factor (BFSF) setting. Each of these two factors is also subject to some variance, depending upon the climatic or irrigation demand conditions in effect from one year to the next.

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WRMM REVIEW

This section contains the results of a software review of the Water Resources Management Model (WRMM), which was commissioned by the Alberta Irrigation Projects Association (AIPA). The scope of the work included the following.

- Provide a broad overall assessment of the Water Resources Management Model (WRMM) to determine the scope of its documentation and complexity of its algorithms and analytical processes.

- Analyze the WRMM and develop a data flow diagram to illustrate the mechanisms and processes whereby data are used in the WRMM.

- Provide a qualitative analysis of the sensitivity and/or importance of the data items that are included in the analytical process of the WRMM.

- Complete the conversion of portions of the existing documentation manual to "layman's" terms as a means of documenting the numerical methods and computations performed by the WRMM.

- Provide a simplified flow chart of the program along with a "layman's" description to illustrate the operation of the WRMM.

Disclaimer

The analysis presented in this report does not represent an endorsement of the Water Resources Management Model and does not in any manner warrant the correctness of the model.

Methodology

The information contained within this report and the assessments of various aspects of the WRMM are the result of the following activities.

- An in depth review of the external documentation (i.e., WRMM manual);

- A general high level review of the FORTRAN code;

- A detailed, in-depth review of portions of the FORTRAN code;

- Flow charting of the FORTRAN code;

- Comparisons of documented program structure to the actual program structure;

- Comparisons of the equations in the documentation to those used in the program; and

- Comparisons of the documented data flows and the actual data flows.

Overall Summary

A summary of the WRMM model is broken down into the following categories:

- Model and Numerical Methods;
- FORTRAN Code and Documentation; and
- User Interface.

Model and Numerical Methods. The external model is composed of a number of components that emulate the physical structures found in an actual river basin. A river basin is modeled by adding the components to the simulation and connecting them together.

Linear programming (a type of numerical method) is used to obtain a solution. Prior to solving for the solution, the external model must be put into a format that lends itself to solving by linear programming techniques. This conversion involves converting all components and their properties into arcs, nodes and flow rates. With the addition of a penalty system, or cost for using a particular arc, the model is able to solve for an optimal solution in each time step.

Although this model can operate in monthly time steps, weekly time steps are commonly used since these provide better representation of the flow variability that can occur within a month.

Fortran Code and Documentation. The model simulation program consists of more than 8000 lines of code. Aside from some brief comments at the beginning of the file, comments explaining the operation of the program are sparse. The coding uses a mix of more recent FORTRAN structures such as the IF-ELSE-ENDIF blocks and earlier unstructured GOTO statements, which is a reflection of the heritage and origins of the model. Common blocks are extensively used as well as some very large subroutine parameter lists.

The external documentation (the WRMM manual) is complete and includes information on the program structure, data flow, input requirements, algorithms, reference information and background.

User Interface. The user interface (i.e., the method by which the user provides configuration and simulation data) is based on formatted data files. These data files contain text blocks that store the data parameters and job control information. Generating correct data files requires careful attention by the user to ensure that the order of the data blocks is correct and that the data are placed in the correct fields within the block. Compared to today's standards, generating user input in this fashion is difficult and time consuming.

WRMM Data Flow Diagrams. Figure 1 shows a simplified schematic of the data flow for the WRMM system. The components of the system are:

- Model Simulation Program (MSP). This is the main FORTRAN program that performs the simulation of the river basin.

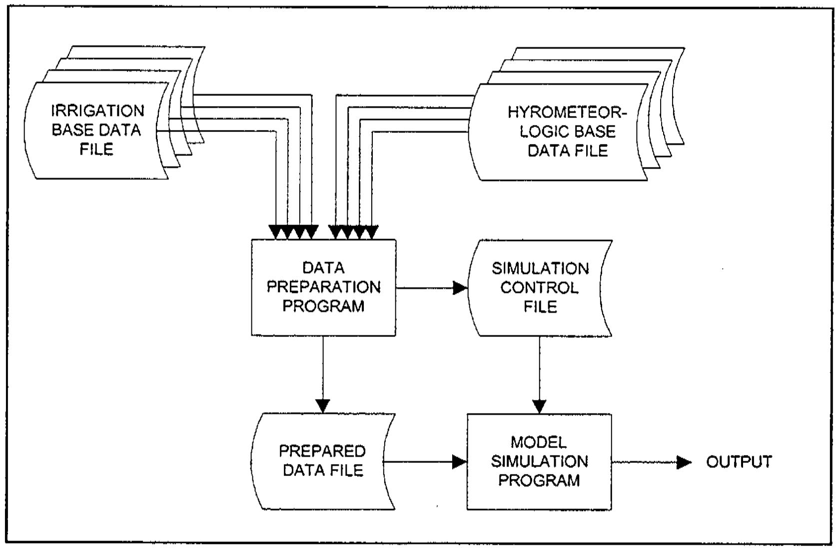

Figure 1. A system schematic of the WRMM.

- Data Preparation Program (DPP). This FORTRAN program extracts water supply and demand data from the Hydrometeorlogic Base Data Files for the components and the time periods specified in the Simulation Control File. Use of the DPP is optional.
- Hydrometeorologic Base Data Files (HBDF). This database contains water supply and demand data for approximately 75 years and more than 500 components.
- Irrigation Base Data File (IBDF). This data file is generated by the IRM and contains consumptive use and return flow data for an irrigation block. Use of the IBDF files is optional.
- Simulation Control File (SCF). This file contains all the data that are required to run the MSP (i.e., river basin components, supply and demand data, penalties, etc.). For multi-year runs, the DPP program must be used to prepare the input.
- Prepared Data File (PDF). This file is generated by the DPP and contains supply and demand data that are extracted from the HBDF and IBDF files.

Simulation Control File. The Simulation Control File (SCF) contains the physical components and some data for running the WRMM. Each SCF is comprised of the following sub-files:

- Identification;
- Simulation Control;
- Physical System;
- Penalty System;

- Water Demand;
- Water Supply; and
- Lag Data.

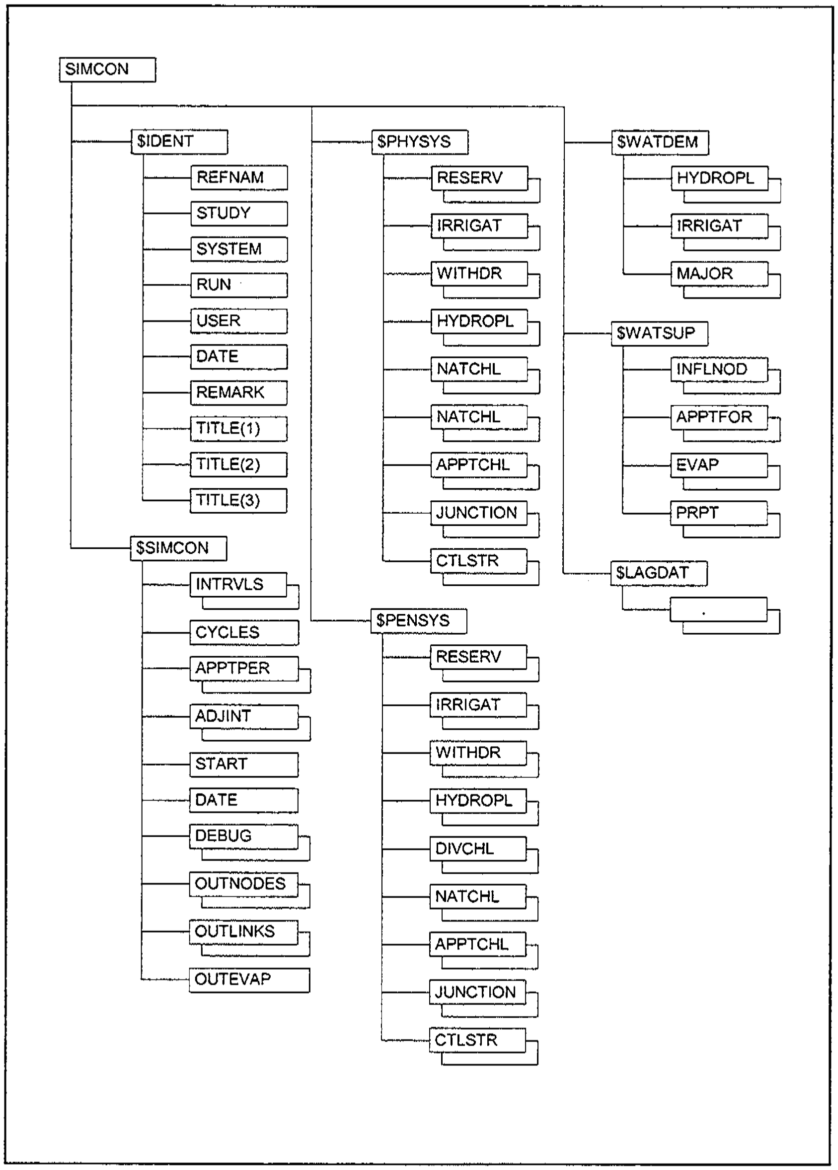

Figure 2. Schematic of the Simulation Control Files with the records found in each sub-file.

$IDENT Sub-File: This sub-file contains identification for the SCF file and simulation run. It does not influence the output of the simulation other than the output identification.

$SIMCON Sub-File: This sub-file controls the simulation and specifies the number of calculation time intervals, number of apportionment periods, number of adjustment time intervals and the start date of the simulation. Data in this sub-file also determine the range and type of data that are extracted from the HBDF and IBDF by the Data Preparation Program (DPP).

$PHYSYS Sub-File: This sub-file determines the number of components in the physical model and their relationship to each other. Data in this sub-file are also used by the DPP to determine the data it should extract from the HBDF and IBDF. Specifically, this sub-file contains the following data.

- Reservoir nodes, elevations vs. storage curves, precipitation and evaporation references;
- Irrigation withdrawal nodes, canal losses, areas, land use factors, return flow channel(s) and fractions;
- Major withdrawal nodes, return flow channels and fractions;
- Hydropower plant flow lines, rated head and capacity, efficiencies, head losses, headwater and tail-water elevations;
- Natural channel flow links;
- Apportionment channel flow links, apportionment agreement factors, minimum flows;
- Diversion channel flow links, maximum flow capacity;
- Junction nodes; and
- Outlet structures for referenced reservoirs, types of structures, control constants.

$PENSYS Sub-File: This sub-file is used to specify the operating policy for the river basin. The policy is determined by the relative magnitude of the penalties associated with operating above or below the reservoir rule curves and ideal zones for irrigation demands, hydro demands, apportionment channels, etc. Specifically, this sub-file contains the following data:

- Reservoir operating zones and penalties;
- Irrigation zones and penalties;
- Major withdrawal zones and penalties;
- Hydropower zones and penalties;
- Natural channel zones and penalties;
- Apportionment channel zones and penalties; and

- Diversion channel zones plus a limit on volume diverted in a cycle.

$WATDEM Sub-File: This sub-file specifies the ideal water demands for the various demand type components. Irrigation demand data in this sub-file may be supplied by DPP using the output from the IRM. Specifically, this sub-file contains the following data:

- Minor withdrawal demands;
- Hydropower demands;
- Irrigation demands, return flow constants and delivery efficiencies; and
- Major withdrawal demands.

$WATSUP Sub-File: This sub-file specifies the water supply data for the supply type components (i.e., inflow nodes, apportionment forecast flows). Specifically, this sub-file contains the following data:

- Initial storage in reservoirs;
- Apportionment forecast flows;
- Inflows; and
- Precipitation and evaporation values.

$LAGDAT Sub-File: This sub-file contains the lagging data for natural and diversion channels. It is used only if the model performs a time lagged run. Specifically, this sub-file contains the following data:

- Channel time lagging coefficients;
- Minimum channel flow for which time lagging is applied; and
- Cross-connect designations.

Hydrometeorlogic Base Data File. The Hydrometeorlogic Base Data File (HBDF) contains historical supply and demand data from approximately 75 years and for more than 500 components. Weekly or monthly intervals are contained in the database as required. Data for the desired components and intervals are extracted from the HBDF by the Data Preparation Program (DPP) under the control of the Simulation Control File (SCF).

Irrigation Base Data File. The Irrigation Base Data File (IBDF) is an output file that is generated by the Irrigation Requirements Module (IRM). The IBDF format is similar to the HBDF and contains irrigation demands, return flows and canal losses on a weekly or monthly time increment.

Aggregation of Irrigation Data. The Model Simulation Program (MSP) allows several irrigation blocks to be aggregated together into one irrigation demand. This simplifies the model input, reduces processing time and has no effect on the output of the model. From the WRMM manual:

The aggregation feature is used to combine a number of irrigation blocks in the IRM simulation run into a single block in the MSP run. Losses for canals internal to IRM irrigation blocks can also be included in the MSB block. Each IRM irrigation block is limited to one return flow channel (or none) and these channels may also be aggregated into a single MSP return flow channel.

Prepared Data File. The Prepared Data File (PDF) is generated by the Data Preparation Program (PDF) under the control of the Simulation Control File (SCF). Data in the PDF originate from the HBDF and IBDF and may include the following:

- Natural flows for the headwater and incremental inflows;
- Apportionment channel flow requirements;
- Irrigation demand and return flows;
- Municipal and industrial demands;
- Hydropower demands; and
- Evaporation and precipitation.

Irrigation Demand

Irrigation demands represent one of the major withdrawals that may occur in a river basin model. The demand data used by the model can come from one of three sources: A constant demand within the SCF; a variable demand within the HBDF; or the output of the Irrigation Requirements Module.

Constant Annual Demand Data within the SCF or Variable Demand within the HBDF. If either of these sources is used, the major withdrawal associated with the irrigation demand is calculated using the following input.

- Irrigated area;
- Irrigation depth;
- Return flow factors;
- Return flow constants; and

- Delivery efficiency.

The withdrawal (Gross Demand) is calculated in the following manner.

$$\text{Gross Demand} = \text{Consumptive Use} + \text{Return Flow} \tag{1}$$

where:

$$\text{Consumptive Use} = \frac{\text{Irrigation Depth} \bullet \text{Irrigated acres}}{\text{Delivery Efficiency}}$$

$$\text{Return Flow} = \frac{\text{Return Flow Factor} \bullet \text{Consumptive Use} + \text{Constant Return Flow}}{1 - \text{Return Flow Factor}}$$

A new irrigation depth, return flow factor, return flow constant and delivery efficiency may be supplied for each interval.

Irrigation Requirements Module. Output from the Irrigation Requirements Module (IRM) may be used by the MSP. The processing and simplified model described above is still used but the inputs are calculated by the Data Preparation Program (DPP) so that the results of the calculations (i.e., consumptive use and return flow) calculated by the MSP match the output from the IRM. Specifically:

- Delivery efficiency is set to 1.0.

- If consumptive use is greater than 0 then the return flow factor is calculated as per the following equation:

$$\text{Return Flow Factor}_{MSP} = \frac{\text{Return Flow}_{IRM}}{\text{Consumptive Use}_{IRM} + \text{Return Flow}_{IRM}} \tag{2}$$

- If the consumptive use is zero then the return flow factor is set to zero and the return flow constant is set to the return flow specified by the output of the IRM.

Influence and Sensitivity Analysis. The Model Simulation Program (MSP) is a deterministic algorithm that will generate the same outputs if given the same inputs. Conversely, changes to any of the following will result in different outputs.

- Physical model

- Water demands

- Water supply

- Penalties (priorities)

The influence of each of the above and the sensitivity of the model to changes in them are discussed below.

Physical Model. The physical model itself is the primary influence on the MSP. The addition or deletion of components will affect the output to varying degrees. Components that represent the large flows will have the most influence and those that represent minimal flow will have only a small influence. The relative influence of different component types, such as an irrigation demand or reservoir are determined on the basis of flow. All model data are converted to flow rates.

Supply/Demand Data and the Penalty System. Given a specific physical model, the exact output will depend on a complex interaction between the supply/demand data and the penalty system. The relative importance of the three factors is determined by the water management system the model is simulating. These systems will either be in balance, short of water or will have a surplus of supply. The behavior of the model under these conditions will be as follows.

- If the supply is sufficient to meet the demand (i.e., balanced), the penalties will have little influence on the output of the model since there will be little flow in the penalty zones.

- If the supply is not sufficient to meet the demand, the penalty system will influence how the model copes with the shortage. Changing the penalty system or the severity of the shortage will influence the model the most in this mode.

- If there is an over-supply, the penalty system will influence how the model copes with the excess. Changing the penalty system or the severity of the over-supply will influence the model the most in this mode.

Penalty System. The penalty system is what is used to "steer" the MSP. When the supply and demand cannot be balanced in the ideal zone of the components, the MSP must move into the non-ideal zone or one or more components. The action that the MSP takes is determined by the penalty system with the MSP always looking for the solution with the minimum total penalty.

The objective of the penalty system is two fold.

- To provide a mechanism whereby the MSP can choose between alternate solutions.

- To allow for the user to implement a "water usage policy" for the river basin.

From the WRMM manual:

An operating policy aims to achieve ideal states under normal conditions, i.e. ideal reservoir levels and channel flows, and fully satisfying all water demands. During periods of water scarcity or surplus, deviations from the ideal conditions are necessary. The operating policy specifies how these deviations are distributed throughout the system. This is achieved by a list of priorities defining the order in which deviations from ideal water demands, reservoir storage and channel flow requirements take place, so as to minimize the overall effect caused by the scarcity or surplus of water within the system. The user defines the operating policy by assigning penalty values for the operating zones of all components.

As indicated above, a system of penalties is used to control the behavior of the model under non-ideal conditions. The penalties, in essence, are the cost associated with flow through an arc on the internal model. The model will search for a solution that satisfies the constraints and that has a minimum total penalty or cost. Therefore, it is possible to influence the manner in which the model deviates from the ideal during periods of water shortage or surplus. This is done by assigning higher penalties to those deviations that are more undesirable and lower penalties to those deviations that are more easily tolerated.

The penalties assigned to the various deviations from the ideal that the model may make are what determines how closely the model simulates the manner in which the river basin is operated.

Irrigation Demand. The influence that irrigation demands have on the model output depend on a number of factors. These factors include:

- The relative magnitude of the irrigation demand compared to the water supply.
- The water resource management policy as implemented via the penalty system.
- The water management system the model is simulating (i.e., excess supply, balanced or water shortage).

The irrigation demand will have the most influence on the model when the penalty system puts a high priority on meeting the irrigation demand and there is a shortage of water in the system. In this case, the model will emphasize meeting the irrigation demands at the expense of other major demands (minor demands are always met).

Other Influences. There are two other factors that can influence the output of the model given a certain set of inputs. These are:

- The time intervals used (i.e., weekly or monthly).
- Whether the model is run in steady state or time-lagged mode.

The influence of both of these factors should be relatively minor.

Numerical Methods

Appendix A of the WRMM manual contains a very good description of the theory behind the Out-of-Kilter algorithm used to solve for the optional solution of the system of equations that represent the modeled system.

The Out-of-Kilter algorithm is based on linear programming techniques, which are often used to solve transportation and pipeline network problems. These problems involve a number of alternate paths that may be used. Each path has associated with it a cost or penalty for use. The goal of the numerical technique is to find the solution (i.e., the routes to be used) that has the lowest cost or penalty associated with it.

Before linear programming techniques can be used on the external network that simulates the river basin it must be transformed into an internal network of nodes and arcs that conform to the following rules.

- The flow must flow in only one direction;
- Each node in the network must have at least one incoming arc and one outgoing arc;
- Each arc has a lower and upper bound on the flow;
- The sum of the flow into a node must equal the sum of the flow out of the node; and
- There is a cost or penalty associated with the flow in each arc.

The external network, which is the one represented by the model input, does not meet these conditions. It is necessary, therefore, to transform the network into one that does. This new network is referred to as the internal network. The differences between the external network and the internal network include the following.

- The addition of several additional arcs between nodes to allow for one or more relaxation zones above and/or below the ideal and to maintain the continuity constraints;
- The associations of penalties with each arc to provide a criteria by which the model can find the optimal solution among the many possible solutions that satisfy the constraints; and
- The conversion of model parameters, such as reservoir storage or hydro-electric demand, into flows. In the case of reservoir storage, this is accomplished by adding several internal arcs, which connect the reservoir node with the system balance node in both a forward and reverse direction. Reservoir levels above and below the rule curve require flows in these arcs in order to maintain the balance at the reservoir node. Penalties for deviations from the rule curve level result from the penalties associated with the flows in these additional arcs.

Before the results are output, the model converts the flows on the internal network back into flows, reservoir levels, hydro-electric generation, etc., for the components found in the external network.

Model Simulation Program Flow Chart

A high level flow chart of the Model Simulation Chart was prepared as part of this report and printed as a separate document. This flow chart agrees with the basic structure described in the WRMM manual. That is:

The external network conditions obtained for the previous time step and the external targets for the current time step are converted into the internal network are initial flow allocations and flow bounds. The Out-of-Kilter Algorithm (OKA) is then used to derive the optimal solution for the internal network for the current time step. This solution is partially converted to external network values and checked against external network convergence requirements. These comprise the consistencies of:

- reservoir outflows with average reservoir elevation over the timestep and constraints of outlet structures;
- hydropower plant flows/powers with average head and tail-water values over the timestep;
- return flows with gross diversion.

The external requirements are achieved by convergence, i.e. re-setting flow bound, re-applying the OKA to find a new optimal solution for the internal network, then partially converting to external conditions to check for convergence.

Finally when a converged solution is found, all arc flows are summed and then converted to the external network values for the time step...

IDM/WRMM VERIFICATION

Two calibration studies were performed on the calibration and verification of the Irrigation District Model and of the Water Resources Management Model. These studies were designed to test the complete operation of the models used in the South Saskatchewan River Basin - Irrigation in the 21st Century study. The studies were based on determining the irrigation requirements through IDM's Irrigation Requirements Module, coupled with the determination of the distribution of these demands and expected return flows based on IDM's Network Management Module. Finally, the actual deliveries were calculated by the Water Resources Management Model based on the demands calculated in IDM. The results were then compared to measured values to provide an overall validation of the tools utilized in this study.

The first study was performed in March 2001 by Optimal Solutions Ltd. (Calgary, AB) under contract to Alberta Environment. The report "Development of WRMM Verification Scenario for 1988 of the Southern Tributaries Modelling System" focused on verification with flow monitoring locations. The process involved tests of water balances throughout a district, including the reservoirs. Significant balance errors were found within the districts, but after additional study, these were attributed to WRMM's simplification of the district's physical operation, along with errors in flow and rainfall measurement, reservoir evaporation calculations, and estimates of evaporation, seepage and return flow. When utilizing WRMM Blocks as the measurement reference, these errors were also attributed to the NMM consumption statistics within the WRMM blocks. However, once the physical overlays with the measurement stations were applied to the WRMM block reports it became clear that the primary ability of this study was to verify the district consumption values and not the consumption within the WRMM blocks. Table 1 summarizes the consumption values for the SMRID as measured by the District and as modeled by IDM for 1988.

Table 1. Comparison of measured and predicted diversions at SMRID in 1988.

Measured Diversion (dam^3)	Predicted Diversion (dam^3)	Percent Difference (%)
977,881	923,938	-5.52

A second calibration study was performed with Eastern Irrigation District-measured data from 1994 to 1999. This study was more elaborate due to its multi-year analysis and treatment of irrigation area changes during the monitoring period. The study enabled the Eastern Irrigation district to tune the configuration settings of the WRMM and to determine the farmer's operation characteristics as predicted by the IDM suite of tools. The analysis reviewed both the gross diversion and the net consumption (equal to gross minus return flow) for each year. To enable the treatment of changes in irrigation area the results were converted to volume amounts (dam^3). The results shown in Table 2 indicate that during the six-year period the predicted gross diversion was 4.33% less than the measured value and the predicted net diversion was 0.53% less than the measured value. The fluctuation in errors from year to year was studied in detail by the Eastern Irrigation District and Phoenix Engineering

Inc. It was determined that these fluctuations were caused by the IDM suite of tools not incorporating reservoir management and thus not reflecting carry forwards of reservoir deficits or reservoir draining. Thus, for longer periods, the reservoir errors will cancel out. Finally, the overall gross diversion error may be the result of incorrect establishment of base flow requirements. The operator sets this component, as it cannot be predicted by the model.

Table 2. Comparison of measured and predicted diversions at EID for 1994 to 1999.

Year	Measured Gross Diversion (dam^3)	Measured Net Diversion (dam^3)	IDM Predicted Gross Diversion (dam^3)	IDM Predicted Net Diversion (dam^3)	Percent Difference in Gross Diversion (%)	Percent Difference in Net Diversion (%)
1994	2.65	1.97	2.54	1.94	-4.19	-1.88
1995	2.81	2.01	2.17	1.63	-22.81	-19.02
1996	2.80	2.08	2.74	2.10	-2.20	0.59
1997	2.66	1.87	2.91	2.24	9.26	19.74
1998	2.85	2.17	2.89	2.22	1.30	2.27
1999	1.86	1.33	1.74	1.25	-6.62	-6.48
All	2.60	1.91	2.49	1.90	-4.27	-0.65

IDM VALIDATION

An additional validation study was performed, that utilized only measured results for the districts and those calculated by the Irrigation District Model. This study was designed to ensure the Irrigation District Model properly accounted for all water volumes delivered through the system. In other words, this study ensured that water was neither created nor destroyed during the modelling process. The results were then compared with the irrigation district measurements to partially assess the model's accuracy. As with the Eastern Irrigation Study, full validation was not possible due to IDM's limitation of not modelling reservoir management functions. This study was performed from measurements recorded in 1999.

IDM Water Balance

To understand the water balance portion of this validation, the reader is referred to Part I of this volume that presents the various components of the model and their interaction with the WRMM. Specifically, the reader is referred to the sections on "Model Configuration" and "Interaction with the WRMM". In reference to the latter section, Part I, Figure 12 "WRMM Block Extents" is reproduced here for a single WRMM block (Part II, Figure 3). This figure was used as the basis of the water balance study.

As shown in Figure 3, the water balance components within a model run consisted of :

IDM Source: The total water volume diverted.

Canal Storage: The portion of water delivered to fill the canals at the start of the season that is recovered during the drainage period at the end of the season.

Gross Demand: The irrigation demands determined by the Irrigation Requirements Module. This includes the net application volume, the irrigation losses, the irrigation returns and, in the case of open canal systems, the down-time losses. These components are presented in detail in Part I, of this Volume, in the "IRM Reference" section.

Evaporation: Due to the IDM being limited to canal operations exclusive of reservoirs, the evaporation component became insignificant. This variable will be added in the future when the management of reservoirs is also enabled within IDM.

Base Flow amounts: This is the base required flow in various canal reaches regardless of current irrigation demands.

Seepage: This represents the portion of water that is lost during an irrigation season due to seepage from the canal linings.

Collector: This model object represents assimilators of the water portions that are returned to the canal system from irrigation returns and base flow recoveries.

Model Sink: This model object represents the accumulation of all collectors in the model run.

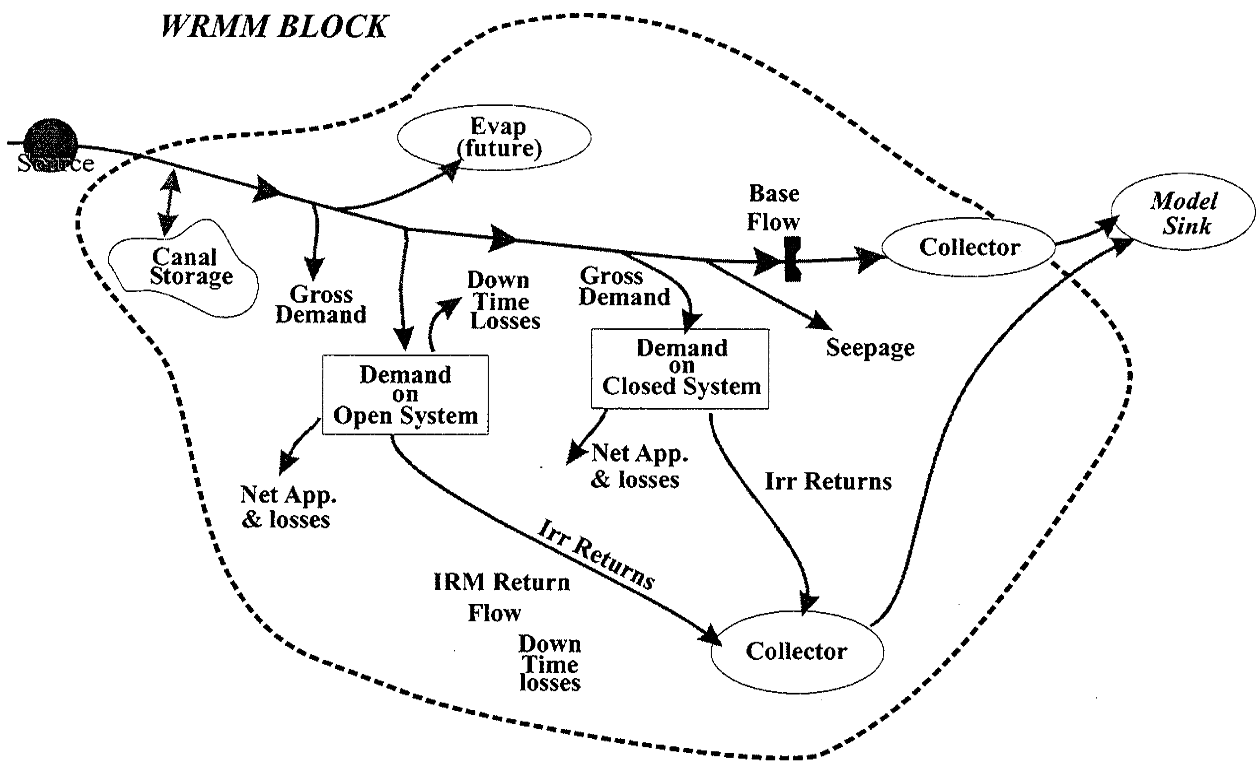

Figure 3. Water balance components within a WRMM block.

The water balance compared the Irrigation Requirements Module components along with the calculated model components to determine if they matched the values reported at the IDM Source. If the total of the demand components matched that of the IDM source then a water balance had been achieved. This process was completed for the Lethbridge Northern Irrigation District (LNID), the Bow River Irrigation District (BRID), the Magrath Irrigation District (MID) and the St. Mary's Project (SMP), representing the collection of the St. Mary River Irrigation District (SMRID), the Raymond Irrigation District (RID) and the Taber Irrigation District (TID). Table 3 compares the water balance components for each of these model runs. In each of the runs, the IDM Source matched the sum of the component listed below it.

Table 3. Water balance results from assessing component demands in four districts.

Component of Water Demand	Water Volumes by District (dam^3)			
	LNID	BRID	MID	SMP
IDM Source	**270,248**	**379,816**	**39,551**	**725,532**
IRM Gross Irrigation Application	190,196	230,570	16,751	566,531
Down-time Losses for Closed Systems	2,075	1,790	285	9,964
Down-time Losses of Open Systems	3,876	2,130	323	16,693
Seepage	8,725	16,582	635	26,221
Return Flow Collectors	57,815	128,135	15,853	85,000
Canal Filling Volume	7,561	609	5,704	21,124
Total of Components	**270,248**	**379,816**	**39,551**	**725,532**
Difference to Source	0	0	0	0

DISTRICT VERIFICATION

The method used to validate the Network Management Module (NMM) of the Irrigation District Model (IDM) was to review the diversions to several districts and to compare the water balance to the water requirements calculated by the IRM. The 1999 season was selected to validate the model. Actual return flow values measured in 1999 for all the irrigation districts were used in the validation process.

Actual diversion volumes were recorded or compiled by the irrigation districts. The diversions for the four districts used in the validation were recorded at the locations illustrated in Figure 4. Within this figure, the "St. Mary Project" (SMP) diversion compiles the overall diversions to Raymond Irrigation District (RID), the St. Mary River Irrigation District (SMRID) and the Taber Irrigation District (TID). Although these recordings are generally accepted as being satisfactory for routine water management operations, they do not necessarily represent higher levels of accuracy as flow measurement is concerned. Therefore, recorded values are to be considered in any comparisons as relative quantities only and not necessarily precise.

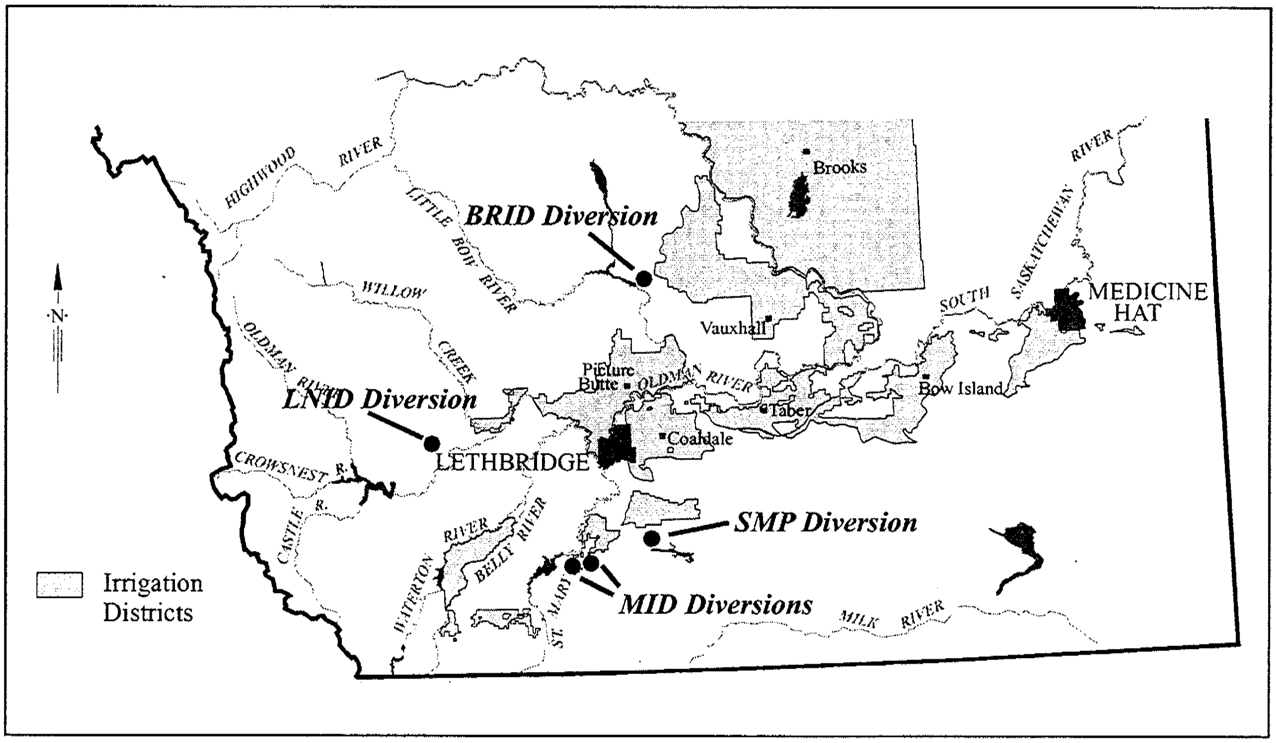

Figure 4. Irrigation district diversion locations referenced in the IDM validation process.

The districts' actual diversions were plotted against the IDM simulated ideal demand at the source to determine if the approximate volumes of diversion and the profile of the seasonal diversion curve matched the demand predicted by the model. The demand, predicted by the IDM, was dependant on the input data specific for that year. This included such parameters as the daily climate conditions, precipitation events, crop distribution, and the location and type of irrigation systems in place.

The climate data comparison referenced 1999 data from Agriculture and Agri-Food Canada (AAFC) and Alberta Agriculture, Food and Rural Development (AAFRD) meteorological data acquisition sites. The irrigation district conveyance and drainage network configurations were set-up as they existed in 1999.

The output demand profile curves, for each of the districts used in the validation process, are shown in Figures 5 through 8. Some discussion is provided for each of the conditions evaluated, regarding the comparison of the predicted or modelled IDM demand and the recorded measured diversion. Some differences can be attributed to factors such as delayed seeding and chemical spraying operations that would offset the actual start-up of some systems to a slightly later date than predicted by the model. Occasionally, the realities of in-field use of some types of irrigation systems may have extended the irrigation of some types of crops during pre-harvest periods, just to complete a full-irrigation coverage, whereas the IDM may have otherwise determined an earlier irrigation "shut-down". Net reservoir storage gains through the irrigation season were not directly accounted for in the IDM calculations as those functions are attached to the WRMM. However, recorded changes in overall reservoir storage as well as computed evaporation losses off the reservoirs were included in the final validation processes.

The IDM demand and recorded district diversion curves for the SMP, which includes the RID, SMRID and TID, tracked reasonably well (Figure 5). Precipitation events in the beginning of June resulted in decreases in IDM demand that were reflected as well in actual recorded diversions. Differences in the last week of June and the first week of July balance can be attributed to operational patterns, both at the farm level and by the irrigation district. A dip in the IDM demand in mid August reflects both an increased soil moisture level and forage-cutting operations. Operationally, water likely continued to be diverted into the system either to bolster reservoir levels or in anticipation of irrigation start-up after forage harvest. Simulated fall irrigation matched diversion rates. IDM simulated demand exceeded actual measured diversions by almost 15%. However, when net gain in overall system reservoir storage and reservoir evaporation were taken into account, it was found that the IDM was in fact predicting a demand that was approximately only 6.5% lower than actual recorded gross diversion. Once again, variations here may be, in part, due to the 80% ETSF slightly under-estimating the irrigation management practice conditions in the 1999 simulation year. The IDM was also found to predict a return flow that was approximately 5.9% higher than what was actually recorded. This is usually an indication that distribution system water management is improving beyond the Base Flow Scaling Factor (BFSF) set points.

Within the Lethbridge Northern Irrigation District (LNID) in 1999 (Figure 6), low soil moisture in the early spring would have triggered an immediate IDM demand when the model commenced the irrigation season, whereas operationally, farmers were likely still seeding and did not start irrigating until later in May. A large rain in the first part of June decreased demand both in the IDM and at the actual diversion. The difference in the last week of June, between actual diversion and the IDM demand, would suggest irrigation continued although several smaller rainfalls would have decreased the demand in the model. The rest of the season and fall irrigation tracked well. Again, because the LNID has very little reservoir storage capacity within its own system, lack of reservoir storage gain information was of little consequence in the validation analysis. In fact , the recorded LNID gross diversion for 1999 and IDM-simulated diversion were within less than 1.7% of each other. Further, comparisons between modelled and recorded return flow volumes were within less than 3.1%.

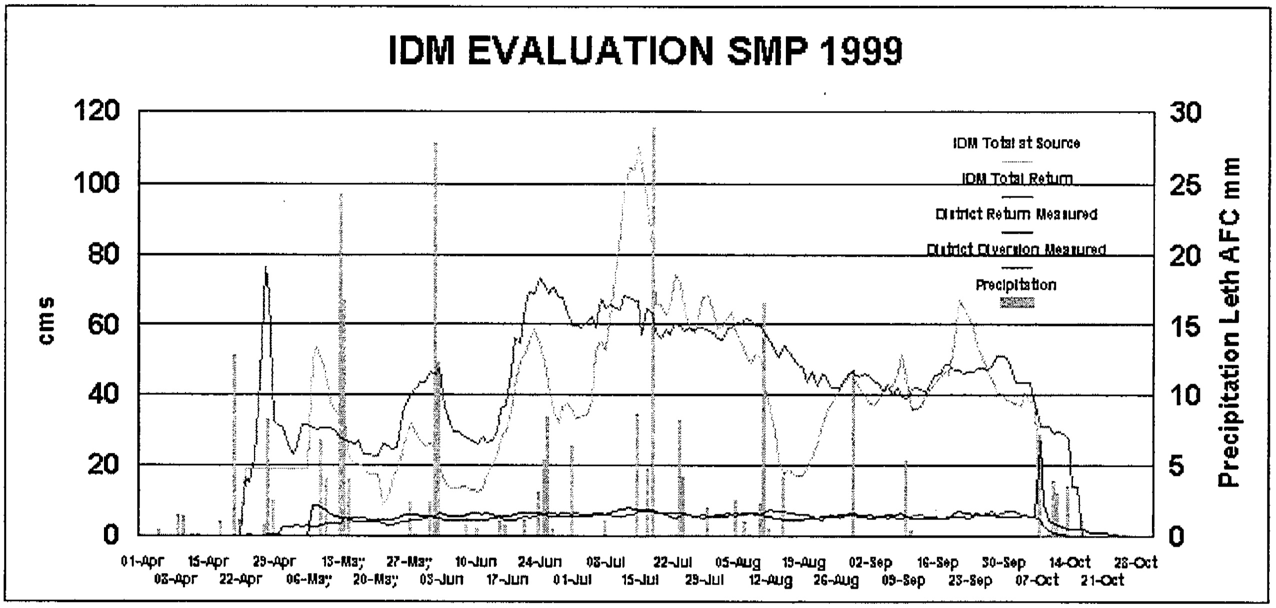

Figure 5. Comparison of the IDM demand and return flow vs. actual diversions and return flow records – SMP, 1999.

The comparison for the Bow River Irrigation District (BRID) between IDM demand and the actual diversion at the outlet from the Little Bow Reservoir tracked fairly well in 1999 (Figure 7). A rainfall at the beginning of June decreased the IDM demand as well as the actual diversion. A measured diversion larger than the calculated IDM demand in the middle of June could be a result of irrigation during the scheduled period even though soil moisture levels may have been above the trigger. An IDM demand larger than the measured diversion in the fall might suggest a lower rate of fall irrigation than assumed within the model. Overall IDM demand was found to be approximately 9.7% less than that which was actually measured. However, when net reservoir storage gain and reservoir evaporation were added into the demand, the IDM simulations were just 6.2% less than the recorded diversions. Once again, this difference can certainly be linked to a slight under-estimation of the ET scaling Factor, where, if the latter were set a few percentage points higher, the correlation between modelled and recorded would be almost equivalent. Other management variations beyond the assumed set points in the IDM may contribute to any residual minor discrepancies, as may minor inaccuracies in actual inflow measurements. Return flow values were found to be within less than 1.9% of recorded.

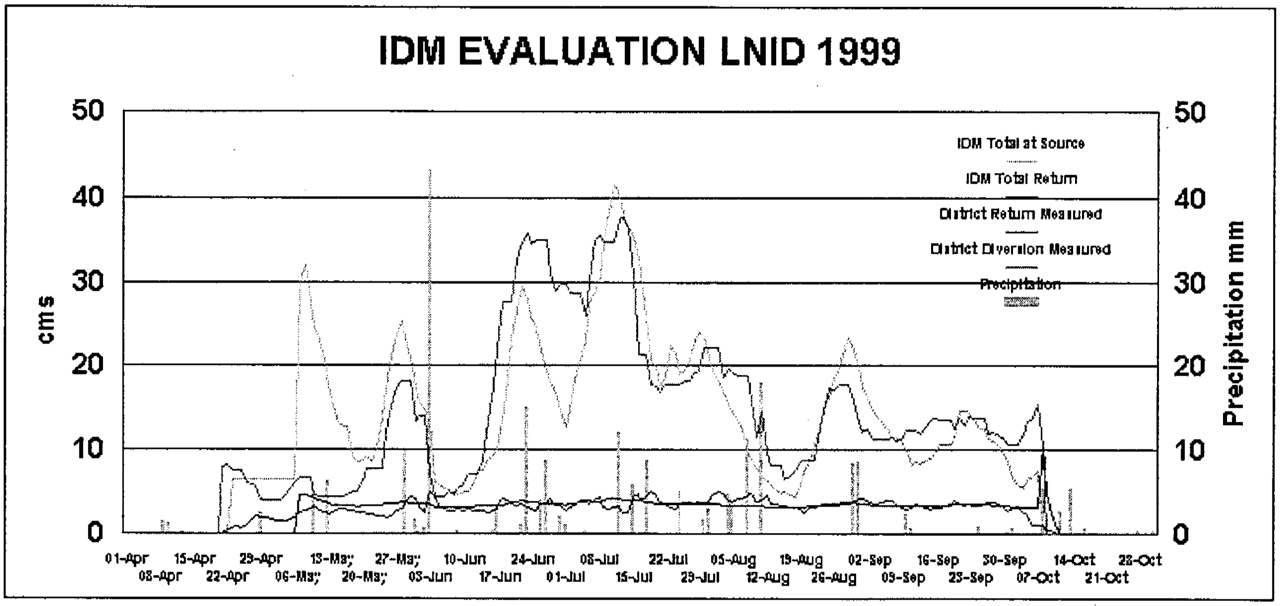

Figure 6. Comparison of the IDM demand and return flow vs. actual diversions and return flow records – LNID, 1999.

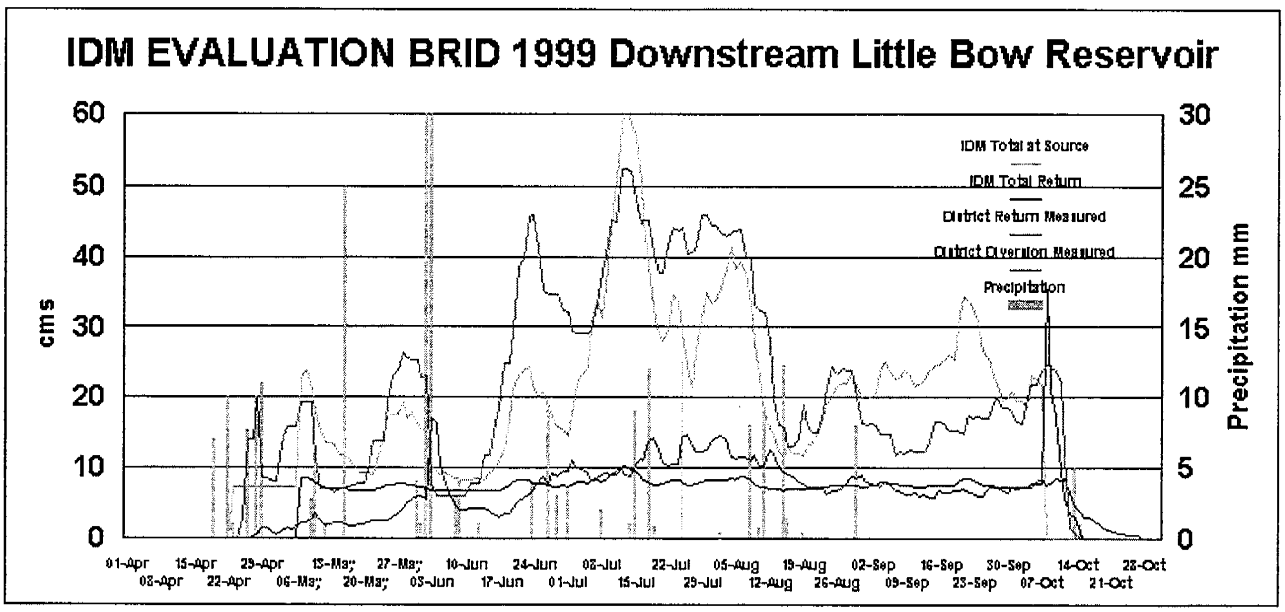

Figure 7. Comparison of the IDM demand and return flow vs. actual diversions and return flow records – BRID, 1999 – downstream of Little Bow Reservoir.

The 1999 IDM demand values for the MID were compared to the Waterton - St. Mary headworks diversions (Figure 8) at the two locations into the district (Figure 4). The large initial IDM demand at the beginning of the season can partially be explained by filling attributed to the main canal. Rainfall events in the beginning of June and the middle of July reduced the IDM demand as well as the diversion measured. The total gross diversion, as derived by the IDM, was found to be about 11% higher than what was actually recorded. The discrepancy between the two values can partially be explained by recognizing that the diversion measurements in these locations do lack some rigour. In addition, it is quite possible that water users in the MID irrigated at some level well-below meeting optimum crop moisture requirements and certainly below the 80% level assumed within the model. This would explain at last part of the higher demand predicted by the IDM. On the other hand, modelled return flow volumes were found to be within a 1.6% of recorded, which testifies to a reasonable correlation and calibration of the IDM for that component.

In summary, considering the four independent case studies examined, the total gross diversion volume, as modelled, was within ± 10% of the actual measured diversions. It needs to be remembered that For districtsSimilarly, the total modelled volume of annual return flow was within ± Y% of the total return flow actually measured.

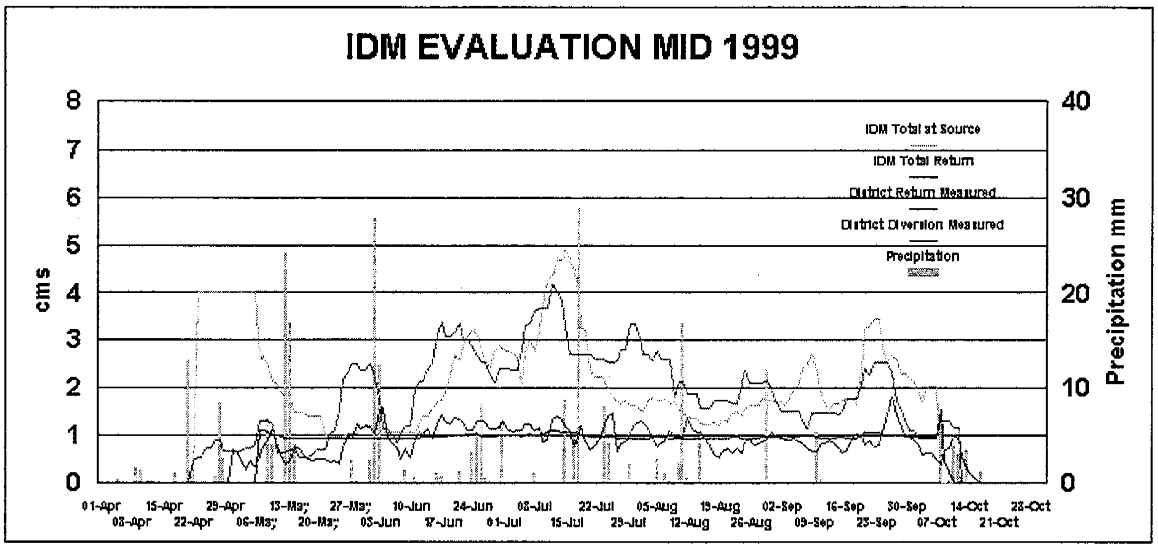

Figure 8. Comparison of the IDM demand and return flow vs. actual diversions and return flow records – MID, 1999 – AENV headworks diversion locations (2).

IRM VALIDATION

CIMP Project Validation

Although the above validations implicitly validate the Irrigation Requirements Module, selected field studies were performed such that this specific component could also be validated. This process was carried out to check the IRM's ability to track soil moisture, irrigation amounts, and irrigation timing. This was based on utilization of field data obtained from AAFRD's multi-year field research study entitled *Current Irrigation Management Practices (CIMP) Project.* For this validation comparison, the CIMP results from several different fields monitored in the Bow Island area were compared with the output generated through IRM simulation runs of those fields. Five fields monitored in 1998, 5 fields tracked in 1999, and 1 field evaluated in 2000 made up the sampling for comparison. All fields were sprinkler irrigated (centre pivot or side-wheel-roll). Within the CIMP project, records were kept that documented the amounts of irrigation applied, date of water application, weekly soil moisture levels, and rainfall amounts. Fields monitored contained crops of alfalfa (2 and 3-cut), sugar beets, canola, barley, and durum.

Three simple exercises were carried out to see whether or not improvements could be made in the IRM's ability to track soil moisture and the timing of irrigations.

1. Use current IRM settings and compare the results to measured data.
2. Adjust irrigation threshold values to measured soil moisture values.
3. Adjust ET Scaling Factor (ETSF) to match measured net irrigation amounts.

Figure 9 provides one sample of over 30 comparative visual assessments carried out to evaluate the correlation of module simulation predictions with actual field measurements. Within Figure 9, several variables are graphed for comparison purposes and are identified as:

- The soil water holding capacity or Field Capacity as actually measured from field sampling (Meas. FC) and as characterized by the IRM (Model FC) based on standard soil texture reference tables.
- Precipitation or Rainfall events as actually recorded in the field.
- Irrigation events (timing and magnitude) as recorded in the field (Meas. Irr.) and as predicted by the model (Model Irr.).
- Soil moisture levels as measured in the field (Meas. SM) and as predicted by the model simulations (Model SM).

As evident n Figure 9, there was generally a good correlation between the model simulation and field monitoring. However, the difficulty in using raw field data as opposed to controlled research plot data is that farm management strategies (frequency and timing of irrigation) can vary throughout the season and the values measured in the field may not be comprehensive enough to achieve a desirable level of accuracy. This, inevitably, can cause differences between modelled and measured results. Actual field parameter values such as irrigation amounts, timing of applications, cultural

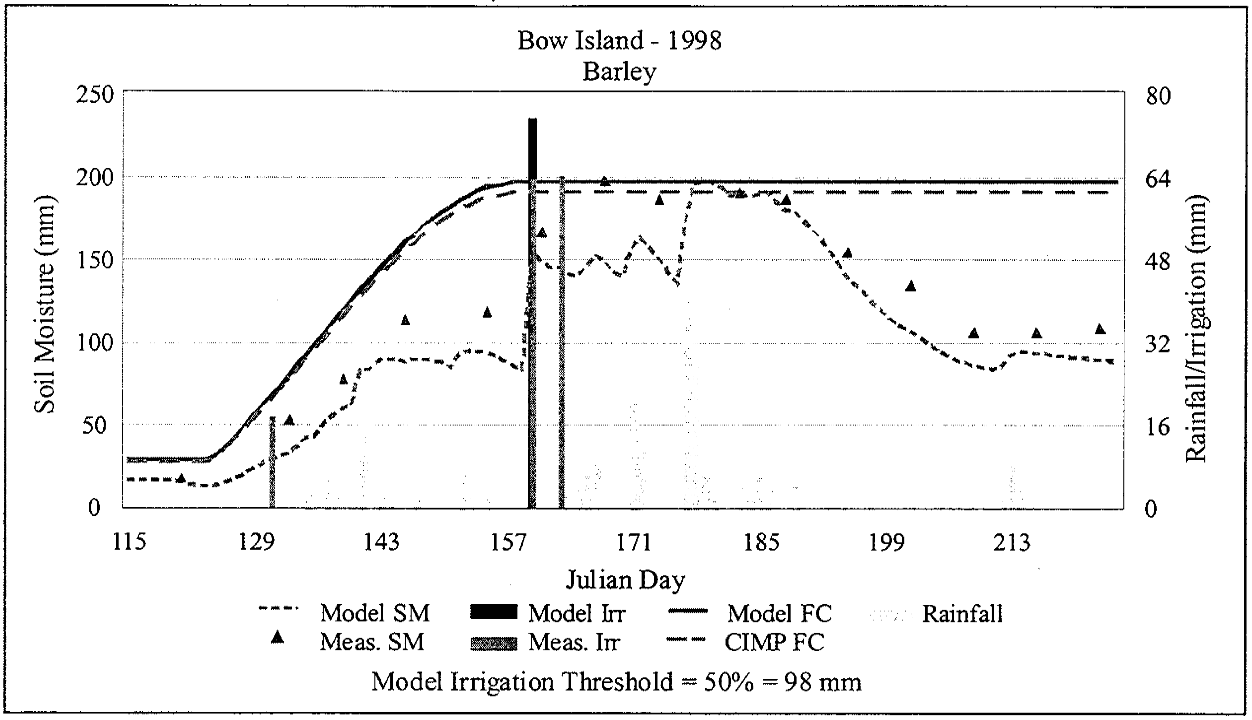

Figure 9. Example of comparison between IRM predictions and actual field measurements.

practices and true length of growing season also have an impact on the differences that may occur between model simulation and field results. One of the most significant factors that can distinguish actual field values from model predictions is operator management decisions or choices. This is the most difficult variable to rationalize and apply in such a computer modelling process. Like most computer models, the IRM uses pre-defined variables that make it somewhat rigid in its decision making process. Adjusting default values within the IRM can sometimes improve the accuracy of the model for an individual field.

The user of the model needs to be cautious when using the ET Scaling Factor (ETSF) to adjust crop water use. The tendency is to use this correction factor for either increasing or deceasing irrigation water applied. In some respects it accomplishes this desired outcome well, but in other respects it may distort other predictive outcomes. For example, as seen in some of the test comparisons, changing the ET scaling factor improved estimation of irrigation demand but did not improve the tracking of soil moisture. However, changing the irrigation threshold value improved both the estimation of irrigation demand and the tracking of soil moisture. In other cases, changing the ETSF improved irrigation demand from the default settings, but not the ability to track soil moisture. In those situations, changing the irrigation threshold level improved the soil moisture tracking but not the IRM's ability to calculate irrigation demand. The higher demand predicted by the IRM was often found to be the case when associated with fields where the actual crop in the field was under-irrigated throughout the season. This usually results in having a diminished crop stand that then demands less water. The model always assumes that crop water demands are met as best they can with the type of irrigation equipment in place.

Since there was only one field brought into the comparison for the 2000 crop season, it was difficult to conclude how the model reacts to years with lower rainfall (which was the case in 2000). Using only the default settings, the estimation of irrigation demand by the model was similar to that of the actual irrigation applied and the tracking of soil moisture by the model was also similar to field results.

Block Studies Validation

The next comparison for the IRM was to use measured flow data, for various years, from two irrigation blocks. In the Bow River Irrigation District (BRID), B – block was the focus of the data gathering and analysis. In the Lethbridge Northern Irrigation District (LNID), K - block, was used as the study area. The period of study was from 1994 through 1997. (The Block Study projects are described further in Volume 3 Part III.)

Actual crop areas, soil type and methods of irrigation were modelled. Weather data for each site were collected. Weather data consisted of maximum temperature, minimum temperature, rainfall, maximum relative humidity, minimum relative humidity, incoming solar radiation, and wind travel. These two blocks were originally selected due to the differences in the irrigation systems used. The LNID block was made up primarily of sprinkler irrigated fields (centre pivots and side-wheel-roll), whereas approximately one third of the irrigation area was covered by gravity or surface-type systems in the BRID.

IRM allows for the setting of various factors that are used in the calculation of irrigation demand. Settings for each model run remained constant. The following is a listing of the settings used for the comparison (the description of each can be found in Part I of this volume).

- *Random Threshold* – "On"
- *Random Seeding* – "On"
- *ET calculator* - Modified Penman
- *Irrigation Day* - this varied with Irrigation Districts
- *Weather file* - local data
- *Wheat Planting Date* = 0 (= no offset from standard seeding date)
- *ET Scaling Factor* - this was used to adjust model irrigation demand values to better match measured values. A setting of 1 was used to determine the amount of variation between model and measured irrigation demand values.
- *Agro-Climatic Factor* = 1. This would be used if the weather data were from a different location.
- *Initial Soil Moisture* - based on average soil moisture data obtained from smaller irrigation blocks (LNID – 1,295 hectares and BRID 1,457 hectares) within the larger blocks used in the comparison.
- *Soil depth* = 1.2 metres

The objectives of the comparison were two-fold.

1. To determine how well the model tracked measured irrigation demand (using model default values).

2. To compare measured irrigation demand to model values (changing ET scaling factor).

Results of the volume comparison are found in Table 4. Calculated demand volumes could be made to match measured values by changing the ET Scaling Factor.

Rainfall and length of growing season are the two largest factors that influence when irrigations occur. For water demands in 1994 and 1995, the model deviated in shape from the measured demand in June due to the large rainfall events in the latter part of May and early part of June. This occurred in both blocks. The model, being soil moisture based, predicted that sufficient soil moisture existed in the root zone to sustain adequate crop growth. On the other hand, irrigation farmers may have continued to irrigate beyond accepted levels for the fear of getting behind on their irrigation and possibly not being able to catch up later in the season.

In 1996, the increase in irrigation demand by the model in both blocks was related mostly to the limited amount of rainfall that occurred during the month of May. The model predicted irrigations to start sooner and last longer than was found to be the actual situation monitored in the field. Delay of measured demand may be related to current farming practices (e.g. spraying of herbicide, habit). In 1997, the large rainfall events that occurred in the last part of May delayed irrigation demand by the model. This was similar to what happened in 1995.

The tracking of measured demand in the B-block was somewhat poorer due to the high amount of surface-irrigated fields present in that study block. Timing of the application of water becomes somewhat more complicated when dealing with gravity irrigated fields. Traditionally, surface irrigation farmers apply one or possibly two applications of water during the season. Crop height and soil erosion are the two biggest factors affecting the timing of irrigation applications. Limits on volume of water diverted and long lengths of run are secondary factors that influence how gravity irrigation fields are managed.

Table 4. Adjusting the ETSF to modify modelled demands to match actual field demands.

Year	Block	ETSF	IRM (dam^3)	Measured (dam^3)	Variation in Volume
1994	B-Blk	1.0	32,044	26,045	23%
	B-Blk	0.85	25,959	26,045	0%
1995	B-Blk	1.0	17,116	16,837	2%
1996	B-Blk	1.0	33,150	25,426	30%
	B-Blk	0.8	25,530	25,426	0%
1997	B-Blk	1.0	29,614	32,694	-9%
	B-Blk	1.1	32,448	32,694	-1%
1995	K-Blk	1.0	7,845	8,351	-6%
	K-Blk	1.05	8,390	8,351	-1%
1996	K-Blk	1.0	29,780	19,552	52%
	K-Blk	0.76	19,352	19,552	-1%
1997	K-Blk	1.0	17,138	19,204	-11%
	K-Blk	1.15	19,167	19,204	-1%

NMM VALIDATION

Introduction

The Network Management Module (NMM) basically represents the conveyance and drainage network functions within the IDM. The most significant factors attached to this component of the simulations are the base flow parameters and the return flow generated throughout each system. Base flow is required to operate the conveyance system to overcome losses by seepage and evaporation, and to provide a margin of safety to ensure that sufficient water is available to sustain flows and meet demands at the end of the system. The amount of base flow plus contributions to the downstream flow within any block in the network, have a direct effect on the amount of return flow that is released from the distribution system. The base flow is one of the most difficult parameters to quantify and correlate into some form of algorithm because the level of base flow is so management-affected, dependant upon the individual operational philosophies or requirements of a given system or given water supervisor.

Base Flow Scaling Factor

The effect of varying the setting of a base flow within a system was found to be detectable and correlated to associated changes in the return flows from that system. Therefore, the Base Flow Scaling Factor (BFSF) was established to adjust the model determinations of return flow to match actual recorded flows at specific sites within the districts' designated return flow channels or pipelines. The BFSF was developed for each district, based on their respective return flow data that had been collected most recently. The BFSF takes into account on-farm return flows, downtime losses due to system set changes and, particularly, the necessary base flow required to maintain an acceptable "charge" of water within the system to sustain basic conveyance operations.

When a network is configured for any specific district, a return flow quantity (cubic metres per second) is "tagged" to the end point of each return flow drain. This sets the base operating flows for the network. The Base Flow Scaling Factor is used in the NMM to reduce the daily average return flow at each site by a factor that makes it equivalent to what has been determined to be the actual average base flow. This is all handled within the model. The NMM then produces the return flow value very much equal to that "tagged" as a daily average flow because it adds the down-time and irrigation return losses that are generated up-stream by the IRM to the base flow. This is true if the average daily flow or base flow is the average only for the normal operating period of the irrigation system (e.g. May 7 to October 7).

The Process of Establishing the BFSF. The daily average return flow component for the whole period is included in the conveyance works table and is used by the model to generate return flow. If the BFSF is set as unity, then the return flow "generated" by the model is higher than the actual return flow because of the addition of the down-time and field run-off losses. If the Model is run again with the scaling factor set at 0, then only these losses will be generated as return flow. The total of these losses must then be subtracted from the model-generated flows of the first run, netting-out as the base flow value (call it "X"). These losses should also be subtracted from the measured return flow for the period of the run (i.e. May 7 to October 7) to arrive at a net base flow based on recorded data (call it "Y"). The ratio of the model-generated base flow value and the net-recorded base flow value (X / Y) is defined as the Base Flow Scaling Factor. If the Model is run again using the scaling factor derived, the generated return flow should be equal to the actual return flow recorded for that period.

The BFSF is somewhat different for each district as their respective operational characteristics and distribution system make-up are also different. The individual district BFSF values vary generally from 0.8 to 0.9. However, in some situations where recorded return flow measurements from individual return drains were significantly deficient in a few districts, the BFSF had to be increased to as much as 4.1 in order for the model to accurately represent published return flow quantities. As more monitoring is developed and as system operations improve, the BFSF will continue to decrease as return flows are better managed and limited.

Return Flows

When the distribution and drainage networks were defined for the NMM application, return flow sites were established for each of the 13 irrigation districts. These sites were identified at the end of segments delineated in the distribution system spatial shape files and were labeled as *tail-outs* for operation of the model. The relative volume associated with each tail-out was evaluated and only sites with notable return flows were used to calculate a given district's total return flow.

The measured return flow values came from flow monitoring sites established by the Irrigation Branch of AAFRD, the Water Survey of Canada (WSC), as well as from those installed by the irrigation districts. Some measuring sites only included facilities that allowed for single-value flow estimates on a daily basis. Data from sites that used estimated values were obtained directly from the irrigation districts' records and were verified wherever and a much as possible as to their validity when compared with other flow system flow records. An average daily flow rate (m^3/s) was calculated for the period May 7 to October 7 for all the sites requiring a return flow value that corresponded with the default dates for which the model was run. All the irrigation districts were evaluated and the total volume of return flow was compiled for the 1999 irrigation season.

Once the value of the average daily flow (m^3/s) was established for each tail-out, the value was attached to the reference database for the model and was used for each model run for the period selected. The average return flow was calibrated using 1999 data as the base reference and was limited to the operations default period of May 7 to October 7 (Julian days 127 to 280). Changing the run period in IDM will change the total return flow volume.

As indicated in the previous section, the NMM references these return flow values in its process of deriving base flow amounts and in the user's setting of BFSF values. As the development, calibration and validation of the BFSF and return flows are so inter-dependent, the validation process described in the previous section is understood to also accomplish the validation requirements associated with determining return flows.

CONCLUSIONS

As a result of the analysis of the Water Resources Management Model (WRMM), the following conclusions were reached.

- The model is, by necessity, a complex piece of software.
- The algorithms and numerical methods used are appropriate for the task.
- Very good external documentation exists (i.e. the WRMM manual).
- The internal documentation of the model is poor.
- The FORTRAN coding syntax and style are dated. This tends to make the code more difficult to read and comprehend.

With respect to the sensitivity of the WRMM output to the various inputs, the following conclusions were reached.

- The impact of a demand (e.g. irrigation demand) on the response of the model is directly related to the magnitude of the demand relative to the supply and the relative priority of the various demands.
- How the model deals with surpluses and shortages is determined by the configuration of the penalties (i.e. the priorities assigned to them). This requires the configuration of the penalties to reflect actual operations to ensure results that match actual operations.

The Irrigation Requirements Module (IRM) was found to be quite accurate in predicting in-field irrigation demands compared with actual field results. Variations from the model predictions were often related to actual operator management that varied from assumed operating parameters set within the module.

The establishment of factor values that represent base flow operating conditions within the Network Management Module (NMM) was a difficult process to attempt to quantify within the module. Each operator and each distribution system network have their own unique characteristics that can have a significant effect on base flow and return flow conditions. As more of the return flow sites within any network are measured in more detail and with more precision, a more accurate representation of the base flows and return flows could be derived. Nonetheless, results from the calibration and validation assessments indicate that the NMM does a satisfactory job of accruing these flow volumes through the conveyance and drainage networks.

The Irrigation District Model (IDM) does an acceptable job of representing the gross irrigation demands and determining individual component water demands, in terms of both timing and overall volumes. However, because of the extensive number of variables that interact within the model, and the corresponding assumptions that are inevitably made in setting specific values to these variables, the IDM-user must be very familiar with the specific conditions that are being modelled so that predictive output will realistically simulate actual or expected field conditions. The effectiveness of future modelling will be dependent on continued field data collection, to keep modelling current with actual field conditions, and on increased flow monitoring capabilities to verify modelling output.

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Alberta Environment (AENV). 2000. Computer Program Description – Water Resources Management Model. Bow Region, Environmental Management Branch. Calgary, Alberta.

Unit Conversion Factors

	SI Units		Imperial Units
Area:	1.0 hectare (ha)	=	2.471 acres
Length:	1.0 millimetre (mm)	=	0.0394 inches
	1.0 metre (m)	=	3.281 feet
	1.0 kilometre (km)	=	0.621 miles
Volume:	1.0 cubic metre (m^3)	=	35.315 cubic feet
	1.0 cubic decametre (dam^3)	=	0.811 acre feet
Rate of Flow:			
	1.0 cubic metre per second (m^3/s)	=	35.315 cubic feet per second
Yield:			
	1.0 kilogram per hectare (kg/ha)	=	0.893 pounds per acre
	1.0 tonne per hectare (t/ha)	=	0.446 tons per acre