



## A LEADING-EDGE IRRIGATION DEMAND MODEL FOR ASSESSING IRRIGATION EXPANSION WITH FINITE WATER SUPPLIES

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### ABSTRACT

Like many jurisdictions in North America, the irrigation industry in Alberta, Canada has found it necessary to intensively examine its future state of development, in view of substantially increased competition for a finite supply of available water. In order to do so, it was recognized that available technical science and assessment tools needed to be up-dated and expanded. Specifically, the opportunity and ability to utilize state-of-the-art computer modelling techniques could allow much more detailed and varied analyses to be carried out. As part of a broad scope basin water management planning review, the development of a complex irrigation demand model was undertaken. After several years of detailed and intensive software development, a suite of data input, irrigation simulation and analysis tools has been derived. The application of the irrigation demand model component provides for very detailed projections of daily water requirements, consumptive use, conveyance and application losses, as well as return flows. Annual and multi-year irrigation demands can be determined in conjunction with water supply conditions that reflect both the inter-relationship with the vagaries of climate as well as varying scenarios of development within the industry. In particular, output from the application of the whole suite of tools indicates both the projected level of water supply deficits as well as the potential impacts of those shortages.

### BACKGROUND

In the province of Alberta, Canada, with its current irrigated land base in excess of 600,000 hectares, the industry is assessing the opportunities and risks associated with expanding that base, within the confines of currently licensed water allocations. Irrigation efficiency is defined, for Alberta conditions, as the ratio between the net amount of diverted irrigation water available for plant consumption and the total amount of water diverted from a natural water source

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for irrigation use. It has been projected that the irrigation water use efficiency gains that have been made over the last 10 to 20 years have resulted in substantial reductions in water consumption per unit of irrigation area. This "freed-up" water has the potential to extend existing licensed volume allocations over an expanded irrigation area. The question then was, just how much of an irrigated area increase can be sustained by available water supplies, and variabilities thereof, and at what level of risk and impact to the irrigation farm economy?

The assessment carried out in this respect has been an extensive five-year partnership project, beginning in 1996, between the 13 local producer-owned irrigation districts, the Alberta Government and the Government of Canada. This multi-million dollar project not only developed the necessary simulation and analytical software but also carried-out detailed unit-by-unit inventories of irrigation systems, crops and distribution infrastructure. These inventories as well as a variety of complementary field research were all carried-out to calibrate and drive the modelling components. There were three primary objectives of the Irrigation Water Management Study (Irrigation Water Management Study Committee 2002), as it related to Alberta.

- Quantify the extent of improvement in irrigation water use efficiencies over the previous 10 to 20 years.
- Accurately determine current and future water requirements and water management operations for sustainable irrigation development.
- Quantify the potential opportunities for irrigation expansion, at reasonable risks to irrigation producers.

#### **Available Modelling Software**

Up until the mid-1990s, irrigation demands were modelled as a basic component within the Water Resources Management Model (WRMM), a long-standing river basin planning tool originally developed for application by the Alberta Government's Department of Environment, as a part of their water management, protection and regulation mandates. Previous irrigation demand modelling employed in this Alberta river basin planning did not fully recognize the large extent of variability in irrigation water requirements from irrigation block to irrigation block or from day-to-day or year-to-year. As a result, only a general regional demand input was generated, with no capability to also carry-out sensitivity analyses for projected future irrigation conditions. Further, the weekly time step process incorporated did not provide the level of time sequence detail required to fully recognize potential daily occurrences of moisture events that could affect how irrigations are managed or demands adjusted.

Consequently, it was recognized, early in the study process, that a new state-of-the-art irrigation demand model would be required to more effectively determine

irrigation opportunity potentials, yet retain the interface where demand output could be input to the basin planning model that controlled water supply conditions. A search was carried out to determine the availability of existing software that could satisfy the requirements of generating and managing irrigation demands throughout the complex networks of today's irrigation district systems. Despite a review of both North American and internationally recognized basin planning and water routing software, it was determined that what was available was designed to simulate hydrologic functions of "aggregating" tributary water from several sources into common collectors, the opposite direction from that required in deriving and meeting field-by-field irrigation demands.

### DEVELOPING THE MODELLING PROCESS

The principal objective of using modelling techniques was to derive variable irrigation demands on available, but limited water supplies, quantifying and qualifying any deficits that may occur, and then quantifying the impacts of those potential deficits on the financial viability of various types of farm enterprises. Although the primary focus for the discussion in this paper is on the development and application of the Irrigation District Model (IDM) software (Baker et al. 2000), the modelling process employed in the overall Irrigation Water Management Study actually involved several different simulation, data capture, data manipulation and analytical tools, most of which were new developments.

These tools included an on-farm irrigation demand generator, referred to as the Irrigation Requirements Module (IRM); a conveyance network demand quantifier and routing solver, referred to as the Network Management Module (NMM); the WRMM water supply manager; and an economic impact and risk assessment application, referred to as the Farm Financial Impact & Risk Model (FFIRM). Figure 1 illustrates this modelling and analysis cycle with the primary model components displayed within the assessment sequence. As can be seen, the IDM is actually made up of two distinct but integrated modules; the IRM and the NMM. Other support tools involved both the data capture and conversion processes, merging the required data into the Local Operating Database (LOD).

First and foremost in supporting any modelling application and the integrity of its output, is the data upon which a model executes its functions. In the case of this particular study and model development, an inordinate amount of data were collected in the field or extrapolated from existing databases. The primary data complex and GIS shape files driving the application of the suite of modelling tools were assembled with 1999 as the base reference year. The fundamental data components included daily agro-climatic data, on-farm crop mix and irrigation system information, as well as conveyance infrastructure component and network details.

The IDM suite of tools is designed to run on a Microsoft Windows NT Server platform, referencing MS Access database tables and a Microsoft SQL local operating database. The software is primarily developed in MS Visual Basic and

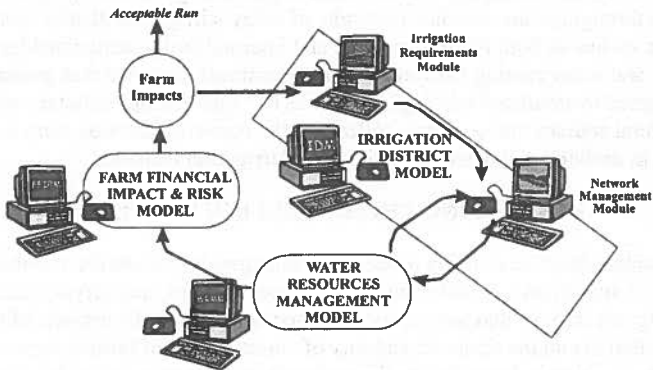


Figure 1. The irrigation demand, supply and impact modelling analysis cycle.

MS Visual C++, with a graphic user interface displaying simulated network components as a GIS map using ESRI MapObjects (AAFRD 2002).

### Data Collection and Warehousing

The agro-climate database, fundamental to driving irrigation demands, was developed on the architecture of the existing Gridded Prairie Climate Database (GRIPCD) (Riewe et al. 2001). The GRIPCD is a synthesized database of daily climate information, including such parameters as precipitation, maximum and minimum temperatures, relative humidity, wind and solar radiation. The database was developed to reference climate data on a 50-kilometre by 50-kilometre grid across the Canadian prairies, covering a period from 1920 through 1995. This extensive database was enhanced for the region covering the irrigated areas in Alberta by pre-determining daily potential evapotranspiration (PE) values for each of the associated climate grid points (Riewe et al. 2001).

Much of the required data collection was achieved through an intensive field-by-field inventory process, conducted by each irrigation district. In compiling this extensive database, each and every irrigation field within a district was catalogued as to the type of crop being grown and the type of in-field irrigation system that was used to apply irrigation water on to that field. A total of 56 different crop or crop production-types and 18 different irrigation systems or system configurations were identified for the inventory process. The final inventory consisted of more than 10,000 individual irrigation fields, each linked to individual infrastructure delivery points identified in a GIS shape file, with each being simulated on a daily basis for each day in an irrigation year, for as many years as were to be included in a model run.

Finally, in cooperation with the irrigation districts, a GIS database (ESRI ArcInfo) was developed that provided detailed linework and specific attributes for all of the irrigation district conveyance and drainage infrastructure, an estimated 8,000 kilometres or more, including reservoirs.

In order to examine the potential effect on irrigation demand through expanding the irrigation land base, or of on-going changes in on-farm irrigation technology, or of crop mix shifts, the Scenario Builder software application allows the user to modify any model dataset to reflect those types of changes, either as wholesale adjustments to a project or to specific component areas within a project.

### **The Irrigation Requirements Module (IRM)**

In essence, this module monitors, through its simulations, the soil moisture status of each irrigation field within any defined irrigation block or project, for each day of 365 days in each and every year of a simulation period. The layering and compounding of irrigation water demands and losses is illustrated in Figure 2. The diagram defines the progression of IDM (IRM + NMM) derivations down to integration with the WRMM. Some of the defining parameters are fixed or have default values, but many are variables that the user can set to depict a particular operating condition or else a projected situation for a sensitivity analysis. Variable settings can be critical in affecting the derived overall demand. The ultimate effect on demand derivations rests with the accuracy and functionality of the model algorithms, ones that have been developed, defined and incorporated, based on actual field research or long-time experience (AAFRD 2002).

Besides driving the daily crop consumptive use, the agro-meteorological data file also supports derivation of evaporation components, start date of plant growth each year, time periods for application of alternative out-of-season soil moisture accumulation or loss algorithms, as well as magnitude of rainfall intensities for run-off determinations.

The crop-type attributes provide an extensive level of detail to variable crop-type water use determinations. Such crop-specific parameters as maximum root zone depth, rate of root depth development, daily consumptive use coefficients, crop growing season and harvesting date(s), randomized irrigation threshold values and randomized eligibility for fall irrigation applications are some of the main attributes that extend the diversity of the modelling regime.

An identification of soil textures for each irrigation field was derived through the AGRASID (CAESA 1998) soils database for Alberta. From that soil texture information, a range of water holding capacities was defined for each texture group, values that then quantified available moisture and irrigation threshold values. In addition, through soil texture polygons overlaid on the GIS infrastructure base, channel seepage potentials were derived (Iqbal et al. 2000).

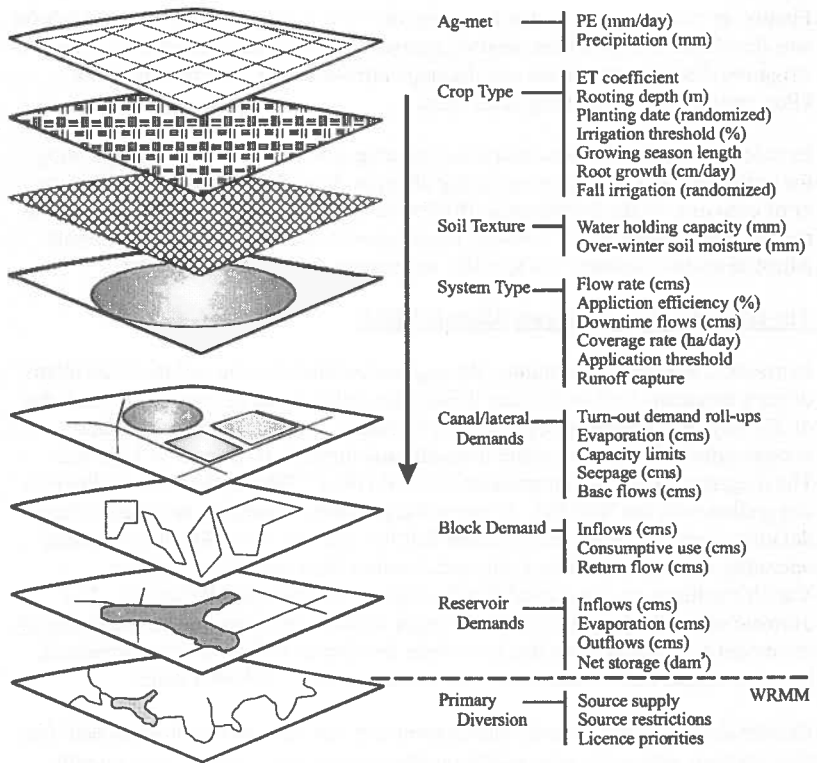


Figure 2. IDM "layers" of water demand and routing variables.

In similar fashion to the crops detail, the diversity of on-farm system types and various operating parameters provided considerable variability in how water was demanded, in how much by-passed through system shut-down or set moves, in how it was applied, by rate and by amount, in how much of a field was covered each day, and in how much was lost through the application process. Several additional system-specific operating criteria were also attached, such as reduced application depths at the beginning of the year when crop rooting was in its early stages.

### The Network Management Module (NNM)

This module accumulates all system demands for respective turn-out deliveries into respective conveyance works, routing those demands back through the network to up-stream reservoirs and initial diversion points off of the basin water

supply system. The NMM is component object based (Baker et al. 2000) and is built to conform to the Microsoft Component Object Model (COM). The NMM requires few algorithms or parameter settings, as it is basically an arithmetic accumulator of downstream demands as it moves "up" the network. ILOG CPLEX linear programming has been incorporated into NMM to solve for optimal routing of water distribution.

The conveyance and drainage network of each and every irrigation block has been inventoried in detail and captured within a GIS shape file. This defines, on a reach-by-reach basis, the type of works in place, the design capacity thereof, the seepage and evaporation rate potentials, as well as the projected base flow. The latter, for example, is derived for each network, based on previously recorded return flows and is tagged at the most downstream end of associated return flow channels as a Base Flow Object. These shape files and associated attributes are merged with IRM demands into the LOD, linked by individual delivery turnouts.

As specified by each district's operational pattern, NMM initiates the start-up date for each district, including a time period for canal flushing. All canal and lateral demands are rolled up to produce required block inflows and resulting block outflows. Outflows can, in part or in whole, become inflows to adjacent blocks or can simply be directed out of the block as return flow or to an outflow sink.

As block demands are rolled-up, outflow requirements from storage facilities react according to reservoir operating rules. These in turn roll-up demand requirements in successive fashion to the primary point(s) of water source diversion.

### MODEL CALIBRATION AND VALIDATION

To achieve confidence in the modelling output, it was mandatory that validation of results with actual recorded events be performed. To that end several individual validation projects were undertaken, where accurate historical recorded data were available, or where water audits had been previously carried out.

On average, for the test cases analyzed, simulated total water demand for the season, as compared to actual demand, was within  $\pm 1.5\%$ . Figure 3, for the Lethbridge Northern Irrigation District (LNID) (67,000 hectares), illustrates a comparative graphical plot of time-series IDM simulated demand and return flow for 1999 (an average year), in comparison with actual recorded inflows and outflows. Simulations were found to be within 1.7% for inflow volumes, within 3.2% for return flows and within 3.1% for total consumptive use. One notable irregularity between the two profiles is at system start-up in the spring. Due to early spring conditions that were drier than normal, particularly on perennial forages, an irrigation demand threshold was triggered within the IDM, whereas in reality, irrigators were slower to react, for various cultural reasons.

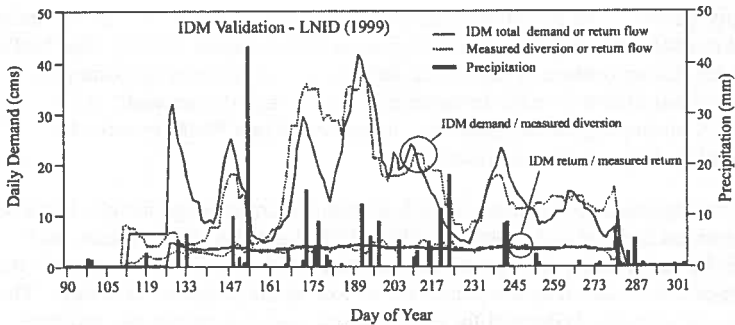


Figure 3. Comparison of profiles of modelled and actual water demand and return flows.

### MODEL OUTPUT AND RESULTS ANALYSIS

The IDM provides a considerable amount of water demand detail, whether it is examining individual parcel demands, rolled-up block demands or overall project diversion requirements. Output, at whatever desired level, can be displayed in both volume amounts or in a depth equivalent per irrigation unit area, for the quantifiers summarized below.

- Gross diversion demand.
- Total consumption at the farm gate.
- Net irrigation application as that amount of water available to crop roots.
- Total consumption at the farm gate and through the distribution system.
- Total return flow.
- On-farm losses.
- Distribution system losses.
- Reservoir evaporation losses.
- Other system losses not returned to the basin hydrology.

More extensive analysis of the output data can be extracted or derived. For example, conveyance works' design capacity is not used to restrict flow routing. Rather, an "exceptions log" is produced by NMM through each model run that allows the user to determine where, in the network, demands exceed current capacities, by how much those capacities are exceeded and over how many days these exceptional demands occur. This helps the user to verify whether limitations in meeting demands are a function of a water supply deficiency or a conveyance restriction.

With the demand data output having been entered into the WRMM process, output from the latter provides a direct weekly roll-up comparison between the ideal IDM demand and the WRMM simulated supply, including quantified



potential supply deficit conditions. These include when and where in the system operation deficits can occur. With both IDM and WRMM output, further analysis of the frequency, magnitude and duration of deficits can be carried-out to determine the potential financial impact of water supply shortfalls on the agriculture sector, or where alternative operational strategies could be employed.

Figure 4 illustrates the variable area-weighted-average irrigation demands and projected water supply deficits for a typical expansion scenario modelled for nine irrigation districts diverting their water from the Oldman River Basin. The scenario conditions applied include:

- 68 years of variable climate, 1928 to 1995 (with 1927 as a seed year);
- a 20% expansion in irrigation area beyond 1999 levels;
- a shift in crop mix to higher value, higher water-demand crops;
- a shift to more efficient on-farm systems;
- a higher level of farm water management with irrigators meeting 90% of optimum crop water requirements, and
- on-going improvements to distribution works and water control systems.

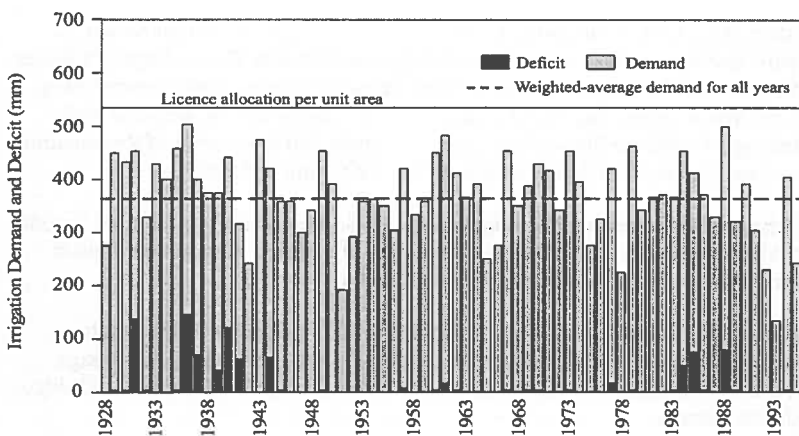


Figure 4. IDM-modelled variable irrigation demands and projected deficits.

Despite the 20% expansion and higher levels of crop irrigation requirements, the results in Figure 4 still indicate water demands each year being within licensed water allocations. Subsequent economic analyses through the FFIRM software indicated that the revealed deficits were manageable, for the most part, particularly as they appeared to any extent on a 40 to 50-year cycle.

## CONCLUSIONS

As reported in the conclusions of the Irrigation Water Management Study, "The simulation models in this study are excellent tools for evaluating the effects of changing water management variables on water demand and supply within irrigation districts." The extensive detail within the modelling output allows for very specific and concentrated analyses that can examine a variety of localized effects and impacts.

With the data structure in place to characterize the physical works of the irrigation industry in Alberta, and with the suite of data processing and decision-making tools developed, water managers, planners, and operations personnel are now much better equipped to implement critical irrigation water management and development initiatives that utilize and impact a finite resource.

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