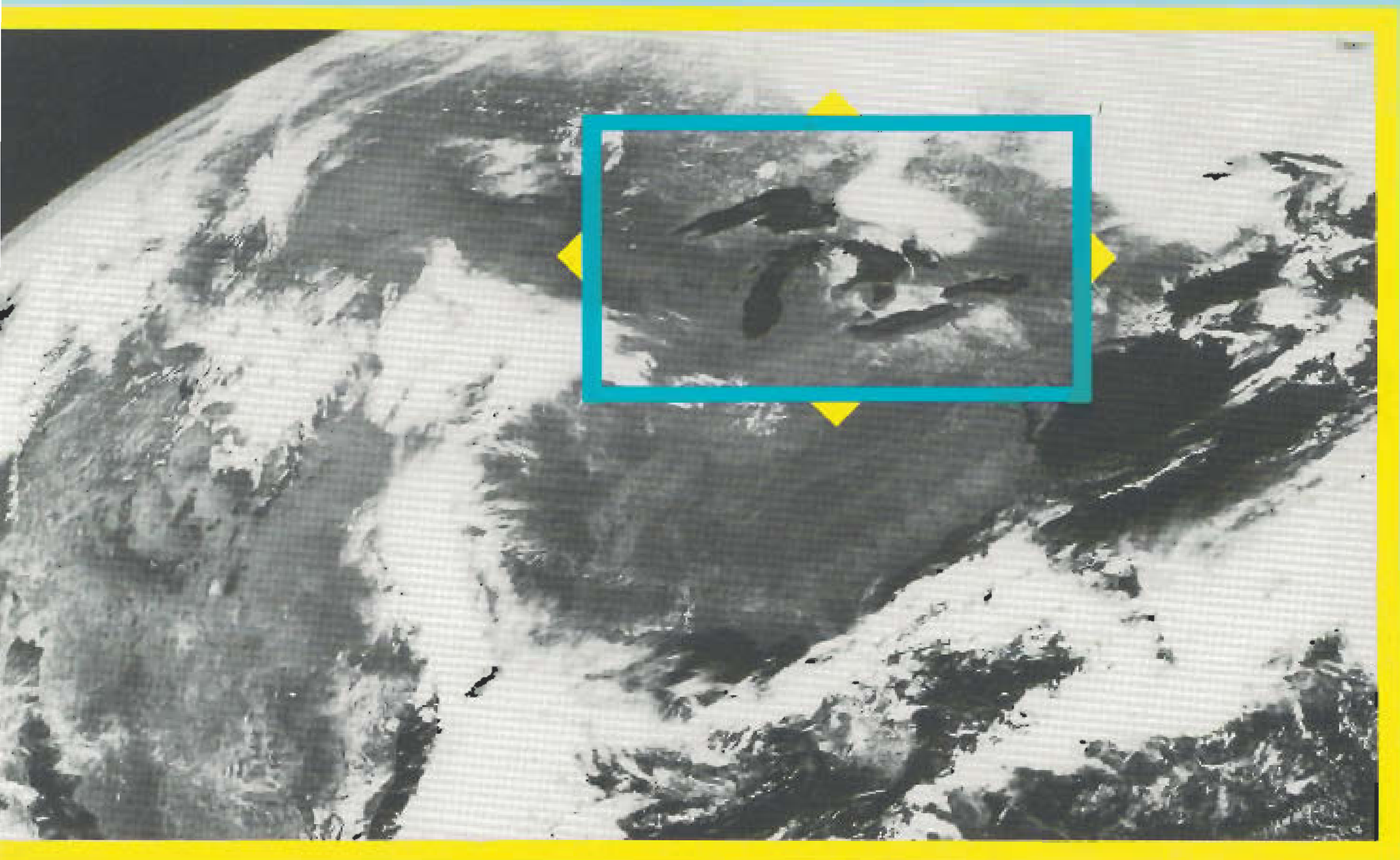
# Estimating Great Lakes Water Consumption: Analysis of Existing Models

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University of Wisconsin
Sea Grant Institute in cooperation with the Institute for Environmental Studies University of Wisconsin–Madison

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*IES Report 139*

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**University of Wisconsin Sea Grant Institute**
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# *Executive Summary*

## *Purpose*

Consumptive use estimates from the 1985 International Joint Commission (IJC) report on *Great Lakes Diversions and Consumptive Uses* have been extensively quoted and have significantly influenced Great Lakes water resources policy. Until now, however, the bases for those estimates of water withdrawn from but not returned to the Great Lakes hydrologic system lacked thorough, documented investigation.

Precurser to the IJC 1985 consumptive use estimates were 1981 findings of the International Great Lakes Diversions and Consumptive Uses (IDCU) Study Board. IJC had appointed IDCU to develop consumptive use estimates for seven sectors: municipal water use, rural domestic water use, manufacturing water use, mining water use, rural stock water use, irrigation water use and thermal power water use.

This *Analysis of Existing Models* summarizes the models, examines the assumptions, and discusses the techniques underpinning IDCU and IJC estimates of Great Lakes water consumption. Based on this investigation, we recommend more rigorous uncertainty analysis of the consumptive use estimates and sensitivity analysis of the models used.

## *Approach*

This report focuses on the 14 models IDCU developed to estimate water consumption for seven water use sectors in the United States and in Canada. These models often include subcategories within the sectors and geographic units for data aggregation. We discuss the methods, assumptions and implications of each model, and offer many sector-specific suggestions on how best to address inconsistencies and uncertainties.

We have constructed consumptive use equations for each water use sector from the disparate information available on past methods. These equations are fundamentally linear, with nonlinear and logarithmic functions embedded in certain variables. Our notation system assigns specific parameters to model variables and constants.

## *Major Issues and Findings*

- In general, the IDCU consumptive use estimates were obtained by multiplying a "drive" variable by a consumptive use coefficient for each of the seven water use sectors. The drive variable was usually population. Therefore:

  - U.S. consumptive use estimates, though seemingly based on various socioeconomic parameters, were driven by population estimates from the Bureau of the Census.

  - Canadian consumptive use estimates were similarly driven by population forecasts derived specifically for IDCU.

  Thus, consumptive use estimates are very sensitive to assumptions regarding population change.

- IDCU examined population changes in the Great Lakes basin only. However, population changes (and economic demand) outside basin boundaries could also affect consumptive use, and need to be considered.

- The general structure of IDCU models is consistent across sectors and regions, but some aspects of the models hinder direct comparison. Problems result from:

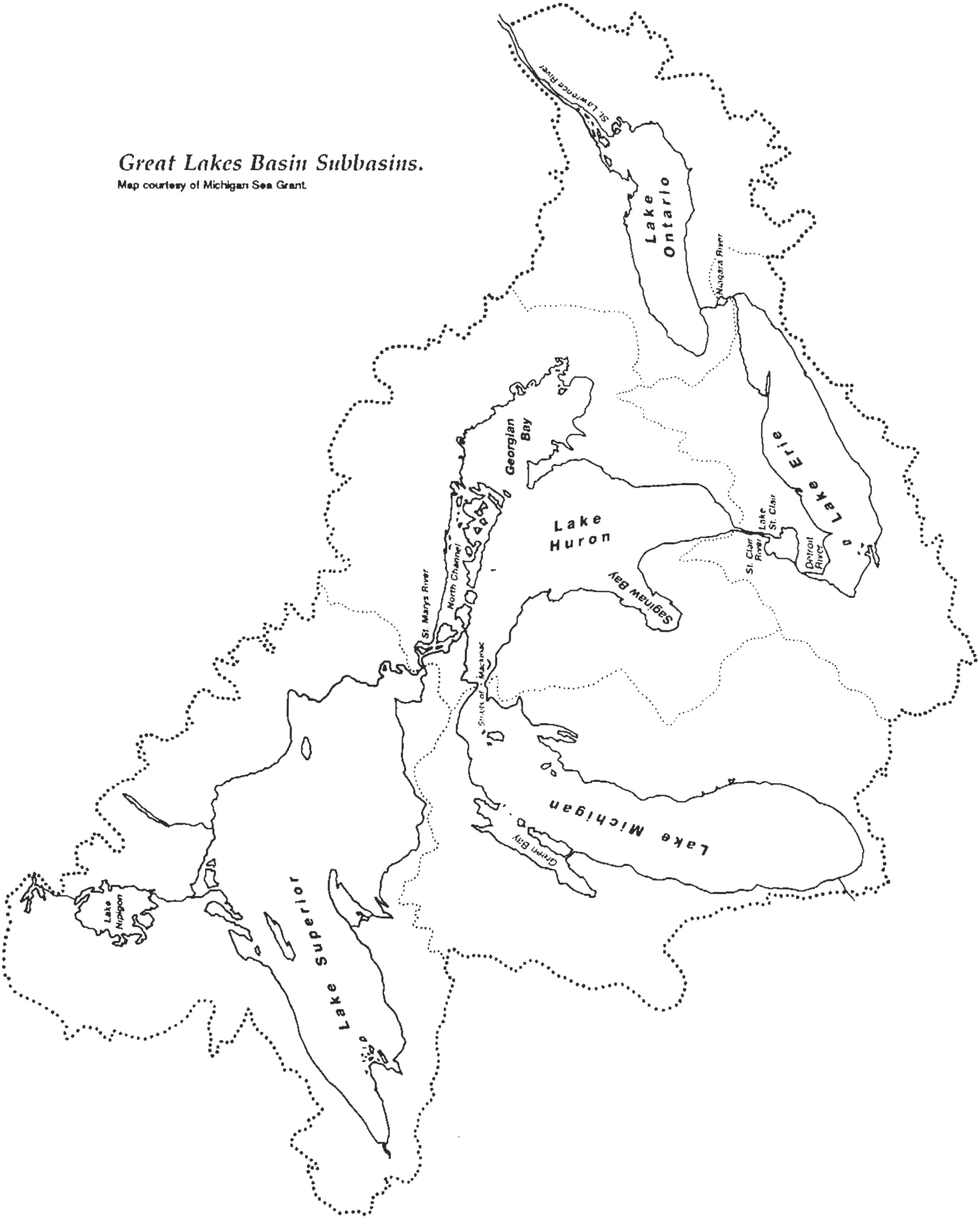
  - multiple and varying data sources, including data from different base years

  - assumptions that are not always specified or that are buried in data sources

- Accuracy of data, assumptions and forecasting methods that most influence the consumptive use estimates should be reevaluated, taking into account the effects of ongoing changes in technology and regulations on water use.

*Great Lakes Basin Subbasins.*

Map courtesy of Michigan Sea Grant.



# 1

*Chapter*

# *Purpose*

The waters of the Great Lakes basin — which comprises five subbasins draining to Lakes Superior, Huron, Michigan, Erie and Ontario — provide myriad benefits.

Although large quantities of water are withdrawn from the Great Lakes hydrologic system to sustain various human activities (approximately 75,000 cubic feet per second, cfs, in 1975), an estimated 95% is returned (International Joint Commission, IJC, 1985). Water not returned and assumed "lost" from the system (largely due to evapotranspiration) is consumptive use.

This report evaluates the methods used in IJC's 1985 report *Great Lakes Diversions and Consumptive Uses* to estimate and forecast consumptive use. The purpose here is to constructively examine the data bases and underlying assumptions that affect the development of consumptive use simulation models. Some background on IJC and how it has evaluated consumptive use in the Great Lakes basin is appended.

The methods used to estimate consumptive use for IJC's 1985 report were developed by the IJC–appointed International Great Lakes Diversions and Consumptive Uses Study Board (IDCU) in response to increasing U.S. and Canadian concern over water use issues in the Great Lakes basin. For its 1985 report to the governments, IJC also incorporated estimate modifications based on public input and additional studies. This report focuses on the IDCU models but does not compare these models with other consumptive use models. Detailed analyses of alternative models and cross-comparisons among models could further refine consumptive use forecasting.

The IDCU study covered seven water use sectors in the Great Lakes basin — the municipal, rural domestic, manufacturing, mining, rural stock, irrigation and thermal power generation sectors — with separate analyses for U.S. and Canadian portions of the basin. This report parallels the format of IDCU's report (1981) to IJC. Information on how the separate sectors function in the Great Lakes region as a whole can be found in Institute for Environmental Studies Report 131 (David et al. 1988).

IDCU completed and submitted estimates and forecasts of consumptive use in the Great Lakes basin to IJC for review in 1981. Upon review of the report, IJC altered certain IDCU consumptive use estimates and forecasts based on revised assumptions pertaining to the manufacturing and thermal power sectors. These (aggregated) estimates are shown in Table 1. This document evaluates *initial IDCU methods*, which lead to their 1981 figures, but the withdrawal and consumptive use estimates displayed and discussed in this document are those that appear as *final estimates published by IJC in 1985* and, thus, they reflect the alterations made in the manufacturing and thermal power sectors.

**TABLE 1: Estimated Consumptive Use of Great Lakes Water and Average Annual Change**

| | Manufacturing | Municipal | Thermal Power | Irrigation | Rural Domestic | Mining | Rural Stock | Total |
|---|---|---|---|---|---|---|---|---|
| **USA** | | | | | | | | |
| 1975(cfs) | 2,270(53%) | 680(16%) | 420(10%) | 260(6%) | 300(7%) | 250(6%) | 130(3%) | 4,310 |
| 2000(cfs) | 4,050(48%) | 870(10%) | 2,260(27%) | 500(6%) | 330(4%) | 320(4%) | 130(2%) | 8,460 |
| Avg.Annual Change | 2.34% | 1.00% | 6.96% | 2.65% | 0.38% | 0.99% | 0.00% | 2.73% |
| **CANADA** | | | | | | | | |
| 1975(cfs) | 220(34%) | 150(23%) | 60(9%) | 100(16%) | 30(5%) | 0 | 80(13%) | 640 |
| 2000(cfs) | 600(42%) | 200(14%) | 310(22%) | 130(9%) | 60(4%) | 10(1%) | 120(8%) | 1,430 |
| Avg.Annual Change | 3.27% | 1.16% | 6.79% | 1.05% | 2.81% | – | 1.63% | 3.27% |
| **BASIN** | | | | | | | | |
| 1975(cfs) | 2,490(50%) | 830(17%) | 480(10%) | 360(7%) | 330(7%) | 250(5%) | 210(4%) | 4,950 |
| 2000(cfs) | 4,650(47%) | 1,070(11%) | 2,570(26%) | 630(6%) | 390(4%) | 330(3%) | 250(4%) | 9,890 |
| Avg.Annual Change | 2.53% | 1.02% | 6.94% | 2.26% | 0.67% | 1.11% | 0.70% | 2.81% |

Source: IJC 1985

Each section of this document is intended to accomplish the following goals:

- Summarize clearly the methods used to determine current and future withdrawal and consumptive use rates;
- Identify the assumptions on which these methods were founded;
- Discuss the methods and assumptions in terms of clarity, defensibility and accuracy;
- Identify options for further study that would update and potentially enhance the reliability of the estimates and forecasts.

For the purpose of illustration, equations have been developed and are provided for each of the 14 model methods used to complete the IDCU study. These equations help to identify the driving components of the model, the variables that are highly sensitive to changes in underlying assumptions and the comparability among models. For a detailed orientation to the format of the equations, see Chapter 3.

Each model is discussed in five categories: methods, assumptions, results, general critique or discussion, and options for further study. It should be noted that the options for further study proposed in this document are of a preliminary nature and are not necessarily *recommendations* for future study. The suggested options range widely from requesting simple clarifications to proposing large-scale research and monitoring programs. Often the suggestions simply call for updating IDCU-employed statistics. However, several options involve revising IDCU analytical assumptions and methods.

It is again emphasized that the options for further study should be considered by policymakers but should not be viewed as recommendations to "correct" the estimates and forecasts adopted by IJC. First, there is no *correct* prediction for the future, as social, economic, technological and climatic trends that appear likely now could not be realized 10 years from now.

Second, it is uncertain how significantly the consumptive use estimates might change as a result of the suggested options for further study. Although the suggestions are intended to increase the reliability of the consumptive use estimates, in certain sectors the change would be too small (especially with respect to total consumptive use) to justify the effort. Analysis of sensitivity and uncertainty should help show which options deserve attention with respect to the relative amounts of water use involved.

Chapter 2 will discuss the concept of consumptive use in detail and will further outline the importance of assessing the role of consumptive use in the Great Lakes basin.

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2

*Chapter*

# Consumptive Water Use

Consumptive water use occurs in several ways. Water is consumed as it becomes part of a manufactured product, such as canned vegetables, or as it becomes resident in living plant or animal tissues.

Most consumptive use, however, results from evaporation. Increased evaporation potential is normally associated with increased withdrawals to supply water for cooling in thermal power plants, food processing, households, irrigation and other widely varying uses. Increased evaporation often occurs with increased withdrawals because larger water surface areas are exposed to the atmosphere (irrigated cropland, evaporation ponds) than if the water remained in lakes and rivers.

Consumptive use is very difficult to measure and quantify, mostly because of its nonpoint or dispersed nature. In irrigation, for example, there is a great deal of uncertainty in estimating evapotranspiration over large geographic areas. In contrast, the intake and outfall of one particular water system is often monitored to estimate manufacturing and consumptive use. Interpretation of the measurements is problematic because multiple sources or extractions of water for different purposes can occur in one main system. In addition, because consumption generally constitutes a small percentage of withdrawal, consumptive use estimates could be on the same order of magnitude as the measurement error associated with estimating water withdrawals.

In spite of these difficulties, it is important that efforts continue toward achieving an understanding of consumptive use so that we can better predict the impact of human activity on water supplies. As a first step, it is critical to define accurately the purposes and magnitude of water withdrawals. However, certain types of consumptive use are defined and estimated more easily than others.

For example, the physical processes of thermal cooling (which removes water) are fairly well defined by the laws of thermodynamics and plant efficiencies. Other water uses occur under widely varying conditions such as climate, population density and so on. The uncertainty associated with estimating water use should be approached using explicit procedures for error analysis and statistical methods to help determine probable ranges of consumptive use for each sector of concern.

In the International Joint Commission (IJC) report, *Great Lakes Diversions and Consumptive Use* (1985), consumptive use is defined as "that portion of water withdrawn or withheld from the Great Lakes and assumed to be lost to them due to evaporation during use, transpiration from irrigated crops, leakage, incorporation into manufactured products, or similar occurrences during use." Total consumptive use in 1975 was estimated at about 4,950 cubic feet per second (cfs). As a portion of withdrawal, consumptive use estimates among the five Great Lakes subbasins ranged from 4.8 to 10.4% with approximately 75% of total consumptive use occurring in the subbasins of Lakes Michigan and Erie (International Great Lakes Diversions and Consumptive Uses Study Board, IDCU, 1981). The United States is responsible for 87% and Canada 13% of total consumptive use in the Great Lakes basin.

In terms of overall water budget, consumptive use is no different from deliberate water transfers out of the lakes. Artificial transfers can also *add* water to the system. The principal diversions, as these transfers into *and* out of the Great Lakes are termed, include Long Lac, Ogoki, Chicago, Welland and New York State barge canals, as well as two small diversions from Lake Huron and Lake St. Lawrence (Loucks et al. 1987). Long Lac and Ogoki diversions increase the supply of water to the lakes and have resulted in increased lake levels of about 0.25 ft for each lake (IJC 1985). The Chicago diversion draws from Lake Michigan, and water is diverted from Lake Erie to Lake Ontario via the Welland Canal. These withdrawals have caused lake levels to fall an average of 0.07 and 0.06 ft, respectively. According to IDCU, the effects of these diversions on Great Lakes mean water levels have been minimal compared with natural fluctuations of the lakes. To date, total consumptive use caused by human activity has not significantly influenced the Great Lakes basin water supply.

Nevertheless, the impacts of withdrawals and consumptive use on the Great Lakes hydrologic system remain an issue of concern for two reasons. First, water availability is becoming increasingly important in regions outside the Great Lakes basin where current and/or projected water demands far exceed sustainable supplies. In many arid and semiarid regions of the United States, surface water is over-allocated and ground water is pumped at far greater rates than aquifers can naturally recharge. In spite of political, environmental and economic obstacles, large-scale water transfers from the Great Lakes could be perceived as necessary in times of regional or national water shortage.

Second, human activity has a direct and indirect impact on water quality, which in turn affects water supply and the valuable resources that depend on constant supplies of high-quality water. Chemical and nutrient pollution have had detrimental effects on fisheries and other biota supported by the lakes. The level and distribution of consumptive use influence water quality by reducing the system capacity to dilute or flush contaminants. The adoption and enforcement of water quality regulations could result in an effective loss of water supplies where contamination is a problem. Water users could be forced to obtain supplies from other sources or to pay for increasingly costly treatment and cleanup of contaminated surface and ground water in the Great Lakes region.

It is also advisable to consider the potential effects of global climatic change on human activities and water supply in the Great Lakes basin. Although the consequences of increased $CO_2$ in the atmosphere are currently subject to debate, it is conceivable that total net basin water supply could be significantly reduced by dramatic increases in evapotranspiration. If this occurs, then the absolute and relative influence of human consumptive use on basin water supply could change substantially (as a result of increased cropland irrigation).

It is not the purpose of this report to resolve these concerns or to recompute IJC estimates and forecasts of water use in the Great Lakes basin. Rather, the report attempts to analyze the existing consumptive use models and identify the underlying assumptions. With further clarifications, future research can be designed specifically to provide the most important information and to avoid costly duplication of research efforts.

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# 3

*Chapter*

# *Introduction to IJC Consumptive Use Models*

Consumptive use models for the seven water use sectors in both the United States and Canada were developed by the International Great Lakes Diversions and Consumptive Uses Study Board (IDCU 1981) and subsequently adopted by the International Joint Commission (IJC 1985). In this report, the models are represented by equations given early in each chapter. In general, the models consist of a "drive" variable (population, gross product value, energy production, acreage) and a water use factor (a constant value of withdrawal rates and/or consumptive use rates or ratios). The drive variable (current or future) is multiplied by the water use constant to derive the consumptive use (CU) estimate.

Below are the basic relationships for the models in each sector:

| | | |
|---|---|---|
| Municipal CU | = | (population) • (water withdrawal / unit population) • (% withdrawal water consumed) |
| Rural Domestic CU | = | (population) • (water withdrawal / unit population) • (% withdrawal water consumed) |
| Manufacturing CU | = | (Gross Product Value, GPV) • (water consumption / GPV) |
| Mining CU | = | (GPV) • (water consumption / GPV) |
| Rural Stock CU | = | (animal population) • (water withdrawal / animal) • (% withdrawal water consumed) |
| Cropland Irrigation CU | = | (irrigated cropland acres) • (water withdrawal / acre) • (% withdrawal water consumed) |
| Golf Course Irrigation CU | = | (golf course acres) • (water withdrawal / acre) • (% withdrawal water consumed) |

The remaining sectors received different treatment in the United States and Canada. The U.S. analysis included a consumptive use estimate for public lands irrigation; the Canadian analysis did not. Also, calculations for estimating consumptive use by the thermal power industry differed for the two nations. These differences are listed below:

| | | |
|---|---|---|
| Public Lands Irrigation CU (U.S. only) | = | (population) • (water withdrawal / unit population) • (% withdrawal water consumed) |
| Power CU (U.S.) | = | (plant capacity in energy production) • (% water consumptive use / unit energy production) |
| Power CU (Canada) | = | (plant capacity in energy production) • (water withdrawal / unit energy production) • (% withdrawal water consumed) |

These basic equations were applied over the entire Great Lakes basin to estimate consumptive use. Many assumptions were made to obtain the estimates, in part due to the lack of necessary data. The chapters covering each sector discuss these assumptions and include a more detailed analysis of the equations used. It is important to note that the value of *intermediate* variables and constants is not known in all cases. Therefore, the discussion of each model cannot always follow item by item with the equations as listed. The known parameter values are stated in the chapter discussion of each specific model.

Throughout this report the use of "US" in a variable name denotes United States and "CN" denotes Canada. For example, $CUUS(t)_2$ represents the consumptive use estimate for sector 2 in the time period t in the United States. $CUCN(t)_2$ would represent the same variable but as applied to Canada.

The variables and constants in the equations used are subscripted by up to three letters. In the first space following the variable, the subscript letter "i" represents a water use sector as defined by IJC (1985). Following "i" in the second space is the letter a, b, ..., g, denoting a particular water use sector parameter that varies among the seven primary water use sectors. The third subscript, j, describes the geographic unit of data aggregation for a particular variable (or constant) used in a model. Listed below are the various subscripts.

Subscript #1 ... i = water use sectors (i applies to both U.S. and Canadian models),
where i = 1, 2, ..., 7,
1 = municipal
2 = rural domestic
3 = manufacturing
4 = mining
5 = rural stock
6 = irrigation
7 = thermal power

Subscript #2 ... a-g = water use parameter (a, b, c, ..., g):

- a = supply source/use (used only in sector 1), where a = 1, 2, ..., 4,
  - 1 = lake-supplied domestic
  - 2 = lake-supplied commercial
  - 3 = nonlake-supplied domestic
  - 4 = nonlake-supplied commercial
- b = types of private water systems (used only in sector 2), where b = 1 and 2,
  - 1 = households with pressurized private water systems
  - 2 = households with nonpressurized private water systems
- c = industry groups (used only in sector 3), where c = 1, 2, 3, ..., 6,
  - 1 = primary metal
  - 2 = food and kindred
  - 3 = paper and allied products
  - 4 = chemical products
  - 5 = petroleum and coal
  - 6 = others
- d = mining industry groups (used only in sector 4), where d = 1, 2 and 3,
  - 1 = metal
  - 2 = nonmetal
  - 3 = fuels
- e = livestock types (used only in sector 5), where e = 1, 2, 3, ..., 6,
  (Note that the number of livestock type in U.S sector is unspecified.)
- f = irrigated land use (used only in sector 6), where f = 1, 2 and 3,
  - 1 = irrigated cropland
  - 2 = irrigated golf course
  - 3 = irrigated public land
- g = power plant type (used only in sector 7), where g = 1, 2, 3, ..., 5,
  - 1 = nuclear once through
  - 2 = nuclear closed
  - 3 = coal once through
  - 4 = coal closed
  - 5 = hydroelectric

Subscript #3 ... j = geographic units for data aggregation, where j = 1, 2, 3 and 4,

- 1 = U.S. Water Resources Council (WRC 1978) assessment sub-areas (United States)
- 2 = 42 counties (Canada)
- 3 = Ontario province (Canada)
- 4 = lake subbasins (United States and Canada) — Superior, Michigan, Ontario, Erie and St. Lawrence River basin

Although the equations are dimensionally consistent, conversions of measurement units (such as from gallons to cubic feet) are not explicitly indicated.

We begin our discussion of the models with the municipal water use sector.

# 4

*Chapter*

# *Municipal Water Use*

The International Joint Commission (IJC) report (1985) refers to municipal water use as "all water uses supplied by centralized water distribution systems throughout the Great Lakes basin except for manufacturing uses." These municipal systems supply water to sustain residential, commercial, institutional and certain recreational uses.

According to the IJC report (1985), for the Great Lakes basin as a whole, the municipal sector ranks third in terms of water withdrawal (10% of the total) and second in terms of consumptive use (16% of the total) for 1975. By 2000, this sector is projected to rank third in terms of both withdrawal (7% of the total) and consumptive use (11% of the total).

Municipal water use estimates include withdrawals from the Great Lakes, as well as ground water and upland surface water sources within basin boundaries. In 1975, the portion of municipal water supplied by the Great Lakes ranged from 40% in the Lake Ontario subbasin to 85% in the Lake Erie subbasin, with an average of 80% throughout the region. According to the IJC report (1985) the portion of municipal supply from the Great Lakes is expected to remain constant or increase slightly over the forecast period for all but the Lake Michigan subbasin.

The commercial portion of total municipal consumptive use in 1975 ranged from a low of 11% in the Lake Ontario subbasin, to a high of 54% in the subbasins of Lakes Michigan and Huron. Municipal water use estimates consist of the sum of domestic and commercial water use subsectors.

## *Municipal Water Use — United States*

### *Methods*

1. The most likely projection (MLP) of total consumptive use in the municipal water use sector is the sum of four individual supply source and/or end use projections of

consumptive use as shown by the equation below. For two source/use projections ($CU(t)_1$: lake-supplied domestic, $CU_2$: nonlake-supplied domestic), specific details were published in the International Great Lakes Diversions and Consumptive Uses Study Board (IDCU) report (1981), and those results are summarized by equations in this section. For two other source/use projections ($CU_3$: lake-supplied commercial, $CU_4$: nonlake-supplied commercial), IDCU did not publish specific methods, which therefore are not covered in this report. The four supply source and/or end use projections are described separately in sections 1.1–4, which follow. Estimates are summed over eight assessment sub-areas (ASAs) from the U.S. Water Resources Council (WRC) 1978.

$$CUUS(t)_1 = CU(t)_1 + CU_2 + CU_3 + CU_4 \qquad (4.1)$$

where:

$CUUS(t)_1$ — total municipal consumptive use (cubic feet per second, cfs) at time t = 1975, 1985 and 2000 in the U.S. municipal sector (i = 1)

1.1 Consumptive use (cfs) for the *domestic* subsector of the *lake-supplied* population at time t:

$$CU(t)_1 = \{WUS(t)_{1j} \cdot P_j \cdot [1+r(t)_j] \cdot MLSP(t)_j \cdot CURUS_1\} + \{P_j \cdot [1+r(t)_j] \cdot MLSP(t)_j \cdot NLL\} \qquad (4.2)$$

The variables are explained in turn:

$WUS(t)_{1j}$ — per capita withdrawal rate (gallons per capita daily, gpcd) for the domestic subsector of lake-supplied municipal water systems, where j = 1 (IDCU modified the WRC rate by assuming a 10% increase, WRC had predicted a 27% increase nationwide, by the year 2000.)

$P_j$ — population estimate, where j = 1 (U.S. Department of Agriculture, USDA, 1975)

$[1+r(t)_j]$ — growth multiplier (dimensionless) for population at time t = 1975, 1985 and 2000; where $r = [P(t+n)_j - P(t)_j]/P(t)_j$, where j = 1 (USDA 1975)

$MLSP(t)_j$ — municipal lake-served population as a fraction of total population at time t, where j = 1 (USDA 1975)

$CURUS_1$ — U.S. municipal water use sector consumptive use ratio (dimensionless) of consumptive use rate / withdrawal rate (WRC 1978)

NLL — net leakage loss assumed to be 2 gpcd (IDCU 1981)

1.2 Consumptive use for the *commercial* subsector of *lake-supplied* population (constant over projection period) (WRC 1978):

$$CU_2 = \text{rate of commercial consumptive use (cfs)} \qquad (4.3)$$

1.3 Constant consumptive use rate (cfs) for the *domestic* subsector of *nonlake-served* population with assumed conservation:

$$CU_3 = \{CURUS_1 \cdot WUS(t)_{3j} \cdot P_j \cdot [1+r(t)_j] \cdot (1-MLSP(t)_j)\} - CON(t) \qquad (4.4)$$

$WUS(t)_{3j}$ — per capita withdrawal rate (gpcd) for the nonlake-supplied domestic subsector (WRC 1978)

CON(t) — unspecified conservation rate (cfs) that varies in an unknown way so the consumptive use in this subsector is constant through time (IDCU 1981)

The remaining factors of the equation have been defined previously.

1.4 Constant consumptive use for the *commercial* subsector of the *nonlake-served* population (WRC 1978):

$$CU_3 = \text{rate of commercial consumptive use (cfs)} \qquad (4.5)$$

2. IDCU developed four alternative scenarios to the MLPs chosen:

Projection 2 — Great Lakes Basin Commission (GLBC 1974) Framework Study (high projection)

Projection 3 — unmodified WRC (1978) estimates developed for the Second National Water Assessment Study (NAS)

Projection 4 — calculated using state census rather than USDA (1975) Series E population projections

Projection 5 — modified MLP with conservation as a 10% reduction in withdrawals

## *Assumptions*

- MLP chosen by IDCU (1981) incorporates the assumptions made by WRC (1978) with two exceptions:

  1. WRC (1978) expected that future increases in municipal water use would be equally offset by increased conservation. IDCU (1981) assumed different water use trends for lake- and nonlake-supplied municipal systems for the domestic subsectors; no conservation was assumed for lake-supplied systems, which results in a 10% increase in withdrawal and consumptive use rates between 1975 and 2000.

  2. WRC (1978) assumed no net leakage loss from municipal systems while IDCU (1981) assumed a net leakage loss of 2 gpcd from lake-supplied municipal systems in the domestic water use subsector.

- IDCU (1981) assumed that 100% of net leakage was lost to the hydrologic system.

- Withdrawal and consumptive use rates for commercial users are expected to remain constant throughout the forecast period.

## *Results*

**TABLE 2: U.S. MLP of Municipal Withdrawal and Consumptive Use**

| | 1975 | 1985 | 2000 |
|---|---|---|---|
| **Estimated Service Population (millions)** | 25.3 | 28.0 | 32.0 |
| **Withdrawal (cfs)** | | | |
| Lake | 4890 | 5500 | 6420 |
| Nonlake | 1240 | 1400 | 1630 |
| Total | 6130 | 6900 | 8050 |
| **Consumption (cfs)** | | | |
| Lake | 550 | 600 | 720 |
| Nonlake | 130 | 150 | 160 |
| Total | 680 | 750 | 880 |

Source: IJC 1985

## *Discussion*

Although the U.S. model for municipal water use is straightforward in concept, the presentation is unclear and no reasoning is provided for several assumptions.

First, while population projections and withdrawal rates could be well known, the consumptive use ratio is not. The consumptive use ratio will have an important effect on final consumptive use projections, and it should be explicitly stated along with the assumptions on which it is based. For completeness, all withdrawal and consumptive use rates should be published even where there are no deviations from WRC (1978) report assumptions. The labeling of tables in the text is also not clear. For example, Table 5 on page F-13 is labeled as "MLP PER CAPITA WITHDRAWAL RATES" when, based on the text, what is really meant is per capita withdrawal rates for the domestic fraction of lake-supplied population. This can be determined from the text, but for clarity, the table should be distinctly labeled.

Second, it appears that municipal per capita demand is assumed constant *within* each of the five subbasins, while it varies among subbasins. According to the report, a city of 100,000 residents in the Lake Huron subbasin would demand only about 60% of the water that a city of the same size would demand in the Lake Michigan subbasin. The reasons for different per capita demand among subbasins were not specified in the IDCU report (1981).

Third, there is no discussion or substantiation of the assumed 2 gpcd leakage factor. It is not certain why the leakage factor was applied only to lake-supplied municipal systems. Perhaps it is assumed that conservation is a more important concern where the water source does not possess the perceived infinite quantity provided by the Great Lakes. The cost of obtaining and treating water could also vary between lake and nonlake sources.

## *Options for Further Study*

Where available, recent information on municipal water use in the U.S. portion of the Great Lakes basin could be collected and compared with trends projected in the IDCU report (1981). In particular, given the significance of the consumptive use ratio, a more detailed analysis based on current water use trends within the basin could be useful.

Further review could provide substantiation and discussion of the per capita leakage coefficient. The development and implementation of a leakage monitoring program in Great Lakes regional municipal areas could contribute to better quantification of leakage from centralized water systems.

## Municipal Water Use — Canada

### Methods

1. The Canadian model focuses on estimating residential and commercial-institutional water uses. Population forecasts were obtained from the province of Ontario, and two population growth projections were developed based on low and medium fertility rates and a constant level of migration.

A demographics-based model consisting of a rolling three-period average was constructed to compute the following for any year within the forecast period:

- the population of 42 Ontario counties located partly or entirely within one or more of the five Great Lakes subbasins
- the proportion of each county's population residing in a particular subbasin
- the proportion of each county's population served by municipal water supply systems

The Canadian model made no distinction between lake- and nonlake-supplied municipal systems. Also, all necessary model parameters were published in the IDCU report (1981). Therefore, the methods used to derive MLP of consumptive use in the Canadian report can be written as one equation as contrasted with the U.S. report where not all of the model parameters were published. The methods employed in the municipal sector consisted of multiplying a per capita withdrawal rate times a population projection times a consumptive use ratio as summarized by the equation below:

$$CUCN(t)_1 = CURCN_1 \cdot WCN(t)_{2a} \cdot P(t)_j \cdot M(t)_j \qquad (4.6)$$

where:

$CUCN(t)_1$ — total municipal consumptive use at time t = 1975, 1980, ..., 2000 in the municipal sector (i = 1), Canadian portion of the Great Lakes basin (cfs)

$CURCN_1$ — consumptive use ratio (dimensionless) : (consumptive use rate / withdrawal rate), assumed to be 20% of municipal withdrawal

$WCN(t)_{2a}$ — per capita withdrawal rate (gpcd) for the domestic (combined a = 1 and a = 3 U.S. sector parameters) and commercial (combined a = 2 and a = 4 U.S. sector parameters): these represent the mean water use coefficients at the county level for a given subsector in each basin as calculated in Table 14 of the IDCU report (1981)

$P(t)_j$ — population of each county residing in each basin at time t (IDCU 1981)

$M(t)_j$ — fraction of county population served by a municipal system (IDCU 1981)

2. Information on municipal water demand was obtained primarily from the 1975 *Inventory of Municipal Waterworks and Waste Treatment Systems* (IDCU 1981). The inventory consists of survey responses from individual municipalities throughout the province of Ontario. The data from this report were used to develop per capita water use coefficients.

3. The 42 counties are aggregated into 11 groups containing at least 15 municipalities each. This step was deemed necessary to reduce the influence of variation and inconsistencies in individual survey responses. Water use coefficients for domestic and commercial-institutional subsectors were then derived for each of the 11 groups by excluding values above the 90th percentile and below the 10th percentile. Mean and median coefficient values were derived for use in the regional forecast.

4. System losses are estimated at 10% of the residential and commercial water use coefficients. Although the IDCU report (1981) does not define "loss," presumably this term refers to loss from leakage. Consumptive use is defined as a percentage of residential plus commercial water use plus "estimated losses" and is estimated to constitute 15% of total municipal withdrawals.

5. MLP was computed using the mean water use coefficient with the medium population forecast. A high projection was developed using a water use coefficient value two standard deviations above the mean and the medium population forecast. A low projection was developed using a water use coefficient two standard deviations below the mean and the low population forecast.

## *Assumptions*

- Per capita rates of withdrawal are assumed to remain constant throughout the forecast period with separate estimates for MLP, high and low projections.
- The migration rate into Ontario is assumed constant at 50,000 persons per year. Geographic distribution is assumed to be directly proportional to existing population distribution.
- Projected trends related to the ratio of municipal to rural domestic water users are assumed to reflect 1951-71 trends.

## *Results*

**TABLE 3: Canadian Municipal Withdrawal and Consumptive Use**

| | 1975 | 1985 | 2000 |
|---|---|---|---|
| **Estimated Service Population (millions)** | 6.1 | 7.2 | 8.6 |
| **Withdrawal (cfs)** | | | |
| Lake | 720 | 840 | 1030 |
| Nonlake | 210 | 250 | 320 |
| Total | 930 | 1090 | 1350 |
| **Consumption (cfs)** | | | |
| Lake | 110 | 130 | 160 |
| Nonlake | 40 | 40 | 40 |
| Total | 150 | 170 | 200 |

Source: IJC 1985

Note that although withdrawals from nonlake sources are expected to increase over the forecast period, expected consumption figures do not change. There is no explanation for this trend in either the IDCU (1981) or the IJC (1985) report.

## *Discussion*

The Canadian model differs from the U.S. model most significantly in the use of primary data and statistics to develop the bounds for MLP and the high and low alternative scenarios. The model retains as much disaggregation of data as possible.

The model does not, however, provide any explanation or substantiation for figures used to define losses to municipal systems and consumptive use ratio to withdrawals. A different approach was used later in the report in which a 20% consumptive use coefficient was applied with no additional losses to the system.

## *Options for Further Study*

Apply recommendations made in the municipal water use section for the United States.

A comparison of recent statistics on migration to Ontario with the projected rate of 50,000 persons annually could be useful.

# 5

*Chapter*

# *Rural Domestic Water Use*

The International Joint Commission (IJC) report (1985) defines the rural domestic sector as "private water uses, usually associated with rural populations and ground water sources." This sector accounts for about 7% of total basin consumptive use and is the fifth highest water-using sector in the basin. The U.S. and Canadian models assume that water used by this sector is supplied by sources other than the Great Lakes.

International Great Lakes Diversions and Consumptive Uses Study Board (IDCU) study results (1981) indicate that the Great Lakes region's rural domestic sector is expected to increase its water withdrawal and consumptive use over the forecast period. However, growth in rural domestic water demand is not expected to keep up with other, faster growing economic sectors.

The basic methods used to derive consumptive use estimates for the rural domestic sector consist of applying per capita withdrawal and consumptive use coefficients to the population served by private, non-centralized water systems. A more detailed discussion follows.

## *Rural Domestic Consumptive Water Use — United States*

### *Methods*

1. The U.S. model bases its estimates and projections of rural domestic water use on the methods employed by the U.S. Water Resources Council (WRC 1978) in producing the Second National Water Assessment Study (NAS). IDCU (1981) developed a most likely projection (MLP) with no alternative scenarios for this sector.

Water sources for the rural domestic sector are generally individual ground water wells serving as many as five households; other sources include inland springs, creeks, rivers, lakes and ponds. Because self-supplied systems are not generally metered, few data are available on water use rates. Average per capita water use estimates were derived using data from the U.S. Environmental Protection Agency (EPA), the United States Geological Survey (USGS), and other sources. Withdrawal rates were determined to be 40 gallons per capita daily (gpcd) for those with water pressure and 10 gpcd for those without. IDCU (1981) applied a consumptive use ratio of 60% of withdrawal.

Basically, the model summarized by equation 5.1 multiplies values for projected rural population in the Great Lakes basin by a consumptive use coefficient. Incremental consumptive use estimates are summed over two private water system types. The estimates are also summed over eight assessment sub-areas (ASAs) as delineated by WRC (1978).

$$CUUS(t)_2 = Res_{bj} \cdot (1-q_j)^t \cdot P_j \cdot [1+r(t)_j] \cdot WUS_{2b} \cdot CURUS_2 \cdot WUC \quad (5.1)$$

where:

$CUUS(t)_2$ — total consumptive use (cubic feet per second cfs) at time t = 1975, 1985 and 2000 in the U.S. rural domestic sector (i = 2)

$Res_{bj}$ — the (dimensionless) ratio of residences served by private water systems to total residences in base year 1970 for the b water system, j = 1; where b = 1, private water systems are pressurized; where b = 2, private water systems are not pressurized

$(1-q_j)_t$ — average annual rate of decline in the proportion of total residences served by private water systems from 1960 to 1970 at time t = 1975, 1985 and 2000; where j = 1

$P_j$ — population estimates, where j = 1 (U.S. Department of Agriculture, USDA, 1975)

$[1+r(t)_j]$ — growth multiplier for population at time t = 1975, 1985 and 2000; where $r = [P(t+n)_j - P(t)_j]/P(t)_j$; where j = 1 (WRC 1978; USDA 1975)

$WUS_{2b}$ — withdrawal rate per capita in the U.S. rural domestic sector (i = 2) for the b private water system type; where b = 1, W is estimated at 40 gpcd; where b = 2, W is estimated at 10 gpcd (IDCU 1981)

$CURUS_2$ — consumptive water use ratio (consumptive use rate per capita / withdrawal rate per capita) for the U.S. rural domestic sector (i = 2), assumed to be a constant of 0.60 (IDCU 1981)

WUC — water use conversion factor (cfs/gal/day)

2. *Census of Housing* (IDCU 1981) data were used to calculate an historic rate of decline in the proportion of residences served by private water systems to total residences. Estimates were computed separately for each of the eight ASAs incorporating individual basin characteristics (WRC 1978). This rate of decline was used to establish a multiplier that was applied to USDA (1975) population projections to obtain estimates and forecasts of rural population.

3. Rural population estimates were separated into those served by pressurized vs. nonpressurized self-supplied water systems. Different water withdrawal rates per capita were then applied to these population projections.

## *Assumptions*

- Water supplied to the rural domestic sector was assumed to be from sources other than the Great Lakes.

- The rate of decline in self-supplied systems (in favor of connections to central or municipal systems) is assumed to remain consistent with the rate of decline observed between 1960 and 1970.

## *Results*

**TABLE 4: U.S. Rural Domestic Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 500 | 550 |
| Consumption (cfs) | 300 | 330 |

Source: IJC 1985

## *Discussion*

U.S. methods are strong in that they attempt to track the relevant technological and socioeconomic trends in centralized (public) vs. decentralized (private) residential water systems. Projected rural domestic water use is a function of the regional farm economy and urban vs. suburban demographic trends. Due to the instability in these areas, it is likely that the assumed rate of decline will not be applicable over the forecast period.

There is also a great deal of uncertainty associated with estimating private, unmetered water use, and the analysis was lacking in terms of discussion and substantiation of withdrawal and consumptive use rates.

### *Options for Further Study*

Recent economic trends in the regional farm economy, urbanization and shifts from decentralized to centralized water systems in the Great Lakes basin should be compared to those used to develop IJC (1985) estimates. Revisions in the model should be made if and where appropriate.

Further investigation and substantiation of withdrawal and consumptive use coefficients would clarify the model.

Investigation of the relative proportions of surface vs. ground water supplying the rural domestic sector would clarify demands on the Great Lakes hydrologic budget.

## *Rural Domestic Water Use — Canada*

### *Methods*

1. The model depicted by the equation below was used to generate medium and low rural domestic water use forecasts. The scenarios reflect two population projections based on two levels of fertility and two levels of water demand. In contrast to the Canadian municipal consumptive use model (where different water demand requirements were developed for different geographic areas), the "medium" rural domestic water demand forecast uses a constant daily mean water demand value of 35 gpcd, while the "low" demand uses a value which is two standard deviations below the mean. The ratio of consumptive use to withdrawal is .60. Incremental consumptive use estimates were developed and summed over 42 counties.

$$CUCN(t)_2 = [P(t)_j - P_j \cdot M(t)_j] \cdot WCN_2 \cdot CURCN_2 \cdot WUC \qquad (5.2)$$

where:

$CUCN(t)_2$ — consumptive use (cfs) at time t = 1975, 1980, ..., 2000 in the rural domestic sector (i = 2), Canadian portion of the Great Lakes basin

$P_j$ — estimates and forecasts of total population in base year 1975, where j = 2

$M(t)_j$ — municipal population as a fraction of total population, forecasted at time t = 1975, 1980, ..., 2000; where j = 2

See Chapter 4 for detailed methods.

Note: $P_j - P_j \cdot [M(t)_j]$ = Rural Population$(t)_j$.

$WCN_2$ — water withdrawal rate for the Canadian rural domestic sector (i = 2), assumed to be a constant of 35 gpcd (IDCU 1981)

$CURCN_2$ — consumptive water use ratio (consumptive use rate per capita / withdrawal rate per capita) for the Canadian rural domestic sector (i = 2); assumed to be a dimensionless constant of 0.60 (IDCU 1981)

WUC — water use conversion factor (cfs/gal/day)

2. The Canadian rural domestic sector is defined in the IJC report (1985) as farms plus communities with populations <1,000. Rural domestic population was determined along with derivation of municipal population for the Canadian portion of the basin (rural population = total population - municipal population). The municipal water use model (Chapter 4) used data on municipal and rural populations recorded since 1951 and projected observed trends over the forecast period. A three-period "rolling average" method was used to extrapolate population growth in pertinent counties and to identify demographic trends in urban and rural populations.

## *Assumptions*

- Withdrawals for rural domestic purposes were assumed to be from sources other than the Great Lakes, such as surface tributaries and ground water.

- The ratio of municipal and rural populations was assumed to be consistent with trends observed between 1951 and 1971.

## *Results*

**TABLE 5: Canadian Rural Domestic Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 60 | 90 |
| Consumption (cfs) | 30 | 60 |

Source: IJC 1985

Table 5 indicates water demand will increase about 50% by the year 2000. Note that the ratio of consumptive use to total withdrawal appears to change *and* deviate from the 60% estimate outlined by IDCU (1981). This can presumably be attributed to the rounding of figures to the nearest 10 cfs. Also, there seems to be an error in Table 17 of the report: Figures for the medium and low forecasts are identical.

## *Discussion*

The Canadian model is fundamentally strong and conceptually identical to the U.S. model. However, the accuracy of consumptive use projections for the Canadian rural domestic sector will rest on future trends in agriculture and urbanization in the basin. Again, assumed withdrawal and consumptive use rates deserve further investigation and substantiation.

## *Options for Further Study*

See options for further study earlier in this chapter, under the U.S. rural domestic consumption section.

# 6

*Chapter*

# *Manufacturing Water Use*

Manufacturing water use in the International Joint Commission (IJC) report (1985) includes both self–supplied water users and those supplied by central water distribution systems. This sector alone accounted for about half of total consumptive use in the Great Lakes basin in 1975 (IJC 1985).

The manufacture of primary metals (those previously extracted and refined from ores) consumes considerably more water than any other single industry in the Great Lakes basin, and it accounts for nearly 70% of manufacturing consumptive use in the U.S. portion of the basin. The paper and the chemicals industries are the second and third largest water–consuming industries. The chemicals industry accounts for most of Canadian manufacturing consumptive use in the basin.

IJC (1985) based its decision to adopt low consumptive use estimates by the International Great Lakes Diversions and Consumptive Uses Study Board (IDCU 1981) on two factors. First, the low projections of IDCU (1981) were more consistent with USGS estimates. Second, current information indicated that the primary metal industry would continue to produce below historic levels instead of experiencing moderate growth as IDCU (1981) most likely projections (MLPs) assumed.

The complex modeling approaches used by both the United States and Canada share several similarities. Both are based on surveys of manufacturing sector characteristics, and both use the value of manufacturing output as the sole driving variable to forecast water use demand (U.S. Department of Agriculture, USDA, 1975). Also, both studies assume a correlation between output value and industrial water use, and both consider the following industry groups most important for water consumption in the basin: (1) primary metals, (2) paper, (3) chemicals, (4) food and kindred, and (5) petroleum and coal products.

The studies differ in several respects. Canadian MLP assumes constant withdrawal and consumption rates. The U.S. model assumes changes in these parameters based on: (1) growth in the primary metals industry, and (2) industry compliance with Public Law (PL) 95–217, the Water Pollution Control Act of 1972, and its 1977 amendments.

PL 95–217 mandates that industries incorporate best available technology (BAT), which would in theory achieve maximum water recirculation and zero pollutant discharge to the nation's waterbodies by 2000 (Reznek 1976). Further, the U.S. model initially relies on national estimates for manufacturing economic growth and shift–share analysis and later separates the data to reflect regional trends (USDA 1975). Therefore, U.S. projections implicitly reflect nationwide trends. The Canadian model, on the other hand, uses data specific to Ontario, which accounts for 95% of total Canadian manufacturing water withdrawal.

## *Manufacturing Water Use — United States*

The model for estimating water use in the manufacturing sector was developed by modifying forecasts published by the U.S. Water Resources Council (WRC 1978) in the Second National Water Assessment Study (NAS). To prepare the NAS, WRC (1978) used a survey of 10,000 large manufacturing plants, which provided a 3% sample of >312,000 manufacturing plants operating in the United States in 1975. Each of the 10,000 plants withdrew an estimated 10–million gal/year of water (28,000 gal/day), totaling about 99% of all manufacturing water use in the United States. A computerized forecasting model containing a comprehensive industrial data base for each state, region and subregion was used to provide national future projections for manufacturing water requirements. A more detailed discussion follows.

### *Methods*

1. Four alternative water use scenarios were prepared (MLP, 2, 3 and 4) based on modified WRC (1978) forecasts. IJC (1985) selected scenario 2, which gave the lowest consumptive use projections. Scenario 2 is based on projecting gross product values (GPVs) of manufacturing industry groups and multiplying this projected value with a consumptive use coefficient as summarized by the following equation:

$$CUUS(t)_3 = CUR_{cj} \cdot GPV_{cj} \cdot [1+r(t)]_{cj} \qquad (6.1)$$

where:

$CUUS(t)_3$ — total manufacturing consumptive water use (cubic feet per second, cfs) at time t = 1975, 1985 and 2000 in the U.S. portion of the Great Lakes basin; I = 3 (manufacturing sector). Consumptive use is defined by WRC (1978) as the difference between total water withdrawal and effluent discharged

$CUR_{3cj}$ — consumptive water use (cubic feet / GPV in dollars) in 1975 for the U.S manufacturing sector in the cth industry group in the jth assessment sub-area (ASA) where c = industry groups:

- c = 1 (primary metal)
- c = 2 (food and kindred)
- c = 3 (paper and allied products)
- c = 4 (chemical products)
- c = 5 (petroleum and coal)
- c = 6 (others)

and j = 1 (WRC 1978 ASAs)

$GPV_{cj}$ — GPV in dollars in 1975 of the cth industry group in the jth ASA (USDA 1975)

$[1+r(t)]_{cj}$ — growth multiplier of the cth industry group in the jth ASA at time t = 1975, 1985 and 2000, where r represents incremental growth in GPV estimated for 1975, 1985 and 2000. These values were derived for functional economic subareas for the USDA (1975) study using shift–share analysis and a linear growth rate. However, IDCU (1981) considered the decline of the metal industry in the Lake Erie subbasin when using the growth multipliers

2. As stated in the overview, the U.S. model is heavily based on NAS methods, assumptions and results (WRC 1978).

3. Based on USDA (1975), the trends in manufacturing GPV (termed "earnings" in USDA 1975) were projected for the major industry groups represented in the sample from 1975 to 2000 for each ASA.

4. The projected GPV for each ASA was multiplied by a consumptive use coefficient derived by a WRC (1978) survey of industries.

5. With the exclusion of projection 4, each scenario assumes some level of compliance with PL 95–217 and, therefore, the implementation of BAT to maximize water recirculation. To develop the MLP, IDCU (1981) multiplied 1975 consumptive use estimates by a fraction to determine the percentage of water savings attributable to new industry using BAT for maximizing recirculation.

Only projection 4 assumes noncompliance with PL 95–217 and, therefore, water use estimates are not altered to account for water savings from use of BAT.

## *Assumptions*

- As previously mentioned, the reliance of the U.S. model on NAS water use forecasts (WRC 1978) implicitly incorporates those assumptions. Of particular importance to manufacturing sector forecasting are WRC (1978) assumptions of a 4% annual increase in GNP (doubling by 2000), an annual population growth rate <1% and compliance with PL 95–217 mandates.

- Each of the four scenarios developed by IDCU (1981) assumes that water use to sustain the manufacturing sector is directly related to sector GPV.

- Except for projection 4, IDCU (1981) assumes that each major industry group will uniformly adopt the highest recirculation rate recorded for that group in 1975.

- Projection 2 incorporates NAS projections and represents the low water use scenario for the manufacturing sector. This scenario assumes that an eventual phaseout of the primary metals industry will occur.

- Projection 3 differs from projection 2 only in that it assumes a 28% growth rate in earnings rather than an eventual phaseout of the Lake Erie subbasin primary metals industry.

- Projection 4 is founded on the assumption that manufacturers will not comply with the mandates of PL 95–217, which call for the implementation of BAT to attain maximum water recirculation. Noncompliance would result in increased withdrawal rates, causing the ratio of consumption to withdrawal to be lower than in the alternative scenarios.

- The MLP incorporates the water use estimates of projection 3. However, rather than assuming implementation of BAT by *all industries* in the basin, the MLP assumes that only new industrial plants (established after 1975) will recirculate water at high rates using BAT. Water withdrawals for industries established after 1975 are assumed to decrease in direct proportion to increases in consumptive use.

- Under the MLP, plants existing before 1975 would continue to recirculate water at relatively low rates using best practical technologies (BPTs). The relationship between water withdrawals and consumptive use for industry existing in 1975 is assumed to remain constant throughout the forecast period. All firms, whether using a BAT or BPT base, are assumed to be operating at efficient levels for both water use and output under the MLP.

## *Results*

TABLE 6: U.S. Manufacturing Withdrawal and Consumptive Use

| Projections | 1975 | Withdrawal (cfs) 2000 | 1975 | Consumption (cfs) 2000 |
|---|---|---|---|---|
| MLP | 20,450 | 22,800 | 2,280 | 4,040 |
| Projection 2* | 20,450 | 4,360 | 2,280 | 3,180 |
| Projection 3 | 20,450 | 5,740 | 2,280 | 5,120 |
| Projection 4 | 20,450 | 33,000 | 2,280 | 3,530 |

*selected by IJC for use in *Great Lakes Diversions and Consumptive Use* (1985)
Source: IDCU 1981

Table 6 shows a wide range of water use estimates, with projection 2 producing the lowest; projection 3, the highest; expected consumptive use by 2000. After reviewing public input on the IDCU report (1981), IJC deemed projection 2 most likely, as it most closely represented trends indicating a prospective decline, rather than moderate growth, in the basin's primary metals industry. IJC (1985) published a consumptive use estimate of 3,500 cfs by 2000 — revised upward from the 3,180 cfs predicted by IDCU (1981).

## *Discussion*

The U.S. model incorporates an extensive data base and is based on sound principles and logic. However, some concern arises over several assumptions embedded in the model. First, it is uncertain whether or to what extent the nation can expect industries to implement technologies allowing maximum water recirculation as required by PL 95–217. To date, there has been little monitoring and enforcement of compliance with PL 95–217, and no significant changes are expected.

The economic variable (GPV) used in the projection of consumptive use presents additional limitations. This index is used in water use estimates as a proxy for output to provide comparison between firms of heterogeneous product mix. However, GPV as a proxy for output is a poor index where the bulk of a firm's output is left unsold or where inventories vary over time.

The assumption of a direct linear relationship between manufacturing GPV and water consumption presents another limitation. For example, where economies of scale exist, one could observe a nonlinear response in water demand as output increases or prices change. Similarly, where system output is reduced, or inefficiencies exist, decreased manufacturing GPV could be accompanied by relative increases in water consumption.

### *Options for Further Study*

Actual trends in industrial development since 1975 should be evaluated and compared with trends as projected by IJC (1985), with particular attention to the primary metals industry. Among the five industries examined, the original (IDCU 1981) projection for the primary metals industry was least valid, and was already lowered in IJC's 1985 report. This projection should receive further scrutiny.

Research should address the status of industry compliance with PL 95–217 and of any general technological advances related to water recirculation and recycling in the manufacturing sector. New information should be included in a model update.

## *Manufacturing Water Use — Canada*

### *Methods*

1. The Canadian model includes the MLP, plus six alternative projections, of which: three are based on high, medium and low economic growth projections; one is based on historic economic trends; three are based on changes in technology that will affect consumption rates; and one is a zero pollutant discharge projection as included in the U.S. model. However, as with the U.S. projection, IJC (1985) selected the scenario with the low economic growth projections. The Canadians first projected consumptive use for all of Ontario from 1975 to 2000. Nevertheless, it is uncertain how consumptive use figures were broken down among individual subbasins. It is assumed this was done by finding the proportion of each subbasin's industries within Ontario, as shown by the following equation:

$$CUCN(t)_3 = GPV_{cj} \cdot [1 + r]_{cj} \cdot FGPV_{cj} \cdot CUR_{3cj} \qquad (6.2)$$

where:

$CUCN(t)_3$ — total manufacturing consumptive water use (cfs) at time t = 1975, 1985 and 2000 in the Canadian portion of the Great Lakes basin

$CUR_{3cj}$ — consumptive use (cubic feet / GPV in dollars) for the cth industry group where c = industry groups:

c = 1 (primary metal)
c = 2 (food and kindred)
c = 3 (paper and allied products)
c = 4 (chemical products)
c = 5 (petroleum and coal)
c = 6 (others in the jth province)

and j = 3 (Ontario). Consumptive use figures were obtained from a survey conducted in 1972 by Environment Canada, while GPV was based on the 1965 Ontario input/output (I–O) model (IDCU 1981).

$GPV_{cj}$ — GPV in dollars of the cth industry group in Ontario, obtained from the 1965 Ontario I–O model (IDCU 1981)

$FGPV_{cj}$ — fraction of total GPV (above) for the cth industry group in the jth province (j = 3, Ontario) in each of the five lake subbasins

$(1 + r)_{cj}$ — constant annual growth rate of the cth industry group in the jth province from 1975, 1985 and 2000

2. Canadian water use estimates for the manufacturing sector are based primarily on the 1965 Ontario I–O model. An I–O model attempts to simulate direct and indirect interactions between different sectors of an economy at a given point in time. The model uses technical coefficients to show the relationship in terms of input and output flows between economic sectors.

The 1965 Ontario I–O model consists of 25 economic sectors and uses manufacturing water use data obtained from a survey conducted by Environment Canada in 1972. According to that survey, total water intake for Ontario manufacturing industries in 1971 was 4,940 cfs, increasing to 5,870 cfs by 1975. Firms in the Great Lakes basin accounted for 95% of the total withdrawal, or about 5,580 cfs.

3. The following steps describe the 1965 Ontario I–O model's development and use:

a) Total water intake by industrial groups for Ontario was collected through a survey of industries conducted in 1972 by Environment Canada.

b) Seven water use parameters were developed but only two were highlighted — total water withdrawal and total consumption. Withdrawal and consumptive use coefficients for the manufacturing sector were developed to represent the unit amount of water / day used to produce a unit worth of output in dollars.

4. To develop variable economic growth scenarios, IDCU (1981) started with real values of shipments data (in 1971 dollars) for Ontario from 1950 to 1975. The 25–year period was split into 5–year increments, and compound annual growth rates for each period were calculated. High, medium, and low growth scenarios were formulated using the highest (5.9% / year), the median (4.4% / year), and the lowest (3.3% / year) 5–year growth rates recorded.

5. For low growth scenario projections, which were finally adopted by IJC (1985), the lowest economic growth rate was multiplied by each industry group's final demand as derived from the 1965 Ontario I–O model.

6. For economic growth–based scenarios, the economic output or "final demand" forecast for each industrial group was multiplied by water use coefficients to give total water intake and consumptive use.

7. Technological change–based projections incorporated actual water use data for the U.S. manufacturing sector for 1954, 1959, 1964, 1968 and 1973. By using intensive, moderate and low water use data, the Canadian model was able to account for potential technological changes, although necessary historic data for Canada were not available.

## *Assumptions*

Projections based on variable economic growth rates assume that technologies remain constant over the forecast period. To develop the "technological change" as well as the "zero pollutant" based projections, it is assumed appropriate to apply U.S. water use data to the Canadian manufacturing sector. Each scenario assumes that the existing distribution of manufacturing sector water use among subbasins and sources is constant over time.

## *Results*

Like the U.S. model, the Canadian model yields a wide range of water use estimates. The MLP projects a consumptive use value of 600 cfs for 2000 — a nearly threefold increase from 1975. Low and high economic growth projections predict consumptive use values ranging from 490 to 910 cfs by 2000.

IJC (1985) selected the low economic growth scenario and used a consumptive use estimate of 500 cfs for 2000 — reasoning for this decision was not discussed.

**TABLE 7: Canadian Manufacturing Withdrawal and Consumptive Use**

| Projections | 1975 | Withdrawal (cfs) 2000 | 1975 | Consumption (cfs) 2000 |
|---|---|---|---|---|
| MLP | 5,570 | 15,200 | 220 | 600 |
| High | -- | 23,420 | -- | 910 |
| Medium | 5,570 | 16,070 | 220 | 620 |
| Low* | -- | 12,120 | -- | 490 |
| Historic | -- | 16,970 | -- | 660 |
| Zero Population | 6,820 | 1,870 | 450 | 1,370 |
| Technological Change | | | | |
| Intensive | -- | -- | 12,050 | 760 |
| Medium | -- | 5,570 | 13,520 | 650 |
| Extensive | -- | -- | 16,090 | 500 |

*scenario adopted by IJC (1985)
Source: IDCU 1981

## *Discussion*

The Canadian model for projecting water use in the manufacturing sector is complex. However, using an I–O model for estimating current and future water demand has several limitations. First, an I–O model assumes that industrial water demand rates or "technical coefficients" are constant and linearly related with industrial output values (in dollars). Actually, industrial water use depends on multiple factors such as the cost of water, per unit operating rate, technological change in the production process, effluent control, and alternative input prices.

In addition, an I–O model assumes a constant ratio between consumptive use and water intake. This assumption cannot accommodate technological change, input substitution, more efficient methods of production or economies of scale. The 1965 Ontario I–O model that was used had not been updated to reflect 20 years of technological innovation in manufacturing.

Despite these limitations, an I–O model is a relatively strong tool by which to estimate industrial water demand. Other methods, such as simple judgement, time extrapolation, the per capita growth method and the single coefficient requirement method, do not account for the indirect interactions that occur among different industrial groups.

## *Options for Further Study*

Both economic and water demand technical coefficients could be updated based on more recent economic trends and in accord with technological changes based on trend line evidence.

The development of a model that determines the functional relationship between water demand and units of output should be considered. An alternative technique, such as the multiple coefficient requirement or the demand method, which estimates coefficients by multiple regression analysis (Davis et al. 1987), could be employed rather than an I–O model. Although such techniques do not account for indirect interactions between sectors, they do accommodate numerous factors (including output values) that affect industrial water demand.

7

Chapter

# Mining Water Use

The International Joint Commission (IJC) report (1985) refers to mining water use as "the water used for the extraction and reduction of metallic and nonmetallic minerals and in the production of coal, petroleum, and natural gas." Of these commodities, only ore is mined in significant quantities in the Great Lakes region.

The IJC report (1985) estimates the mining sector accounts for 5% of total Great Lakes basin consumptive use. By 2000, the mining sector is expected to account for 4% and 1% of U.S. and Canadian consumptive uses, respectively, in the basin.

According to the International Great Lakes Diversions and Consumptive Uses Study Board (IDCU) report (1981), water from the Great Lakes supplies about 80% of U.S. mining water needs in the basin, while Canadian mining water needs are thought to be satisfied primarily by nonlake sources in the Lake Huron subbasin.

The U.S. and Canadian models described below are based primarily on economic growth projections with consumptive use derived per dollar of output produced by the mining sector.

## *Mining Water Use — United States*

### *Methods*

1. Withdrawal and consumptive use rates for the mining sector were applied to U.S. Department of Agriculture (USDA 1975) mineral earnings projections in a method developed by the United States Bureau of Mines (USBM) (IDCU 1981) and described by the following equation:

$$CUUS(t)_4 = WUS_{4d}/GPV_{4d} \cdot GPV_{4d} \cdot [1+r(t)]_{dj} \cdot CURUS_{4d} \quad (7.1)$$

where:

$CUUS(t)_4$ — total consumptive use (cubic feet per second, cfs) at time t = 1975, 1985 and 2000 for the U.S. mining sector (i = 4)

$WUS_{4d}$ — withdrawal volume (gallons) for the dth mineral group in base year 1972 where d = 1 (metals), 2 (nonmetals) or 3 (fuels)

$GPV_{4d}$ — gross product value (dollars) for the dth mineral group in base year 1972 (USDA 1975)

$CURUS_{4d}$ — consumptive use coefficient (dimensionless) for the dth mineral group (IDCU 1981)

$[1+r(t)]_{dj}$ — growth multiplier (dimensionless) for dth mineral group earnings at time t = 1975, 1985 and 2000, where j = 1

2. The IDCU report (1981) estimated water use rates for mining activity to range from 52 gallons per production dollar (gppd) for fuel production to 92 gppd for metals production to 163 gppd for nonmetals production. Consumptive use coefficients were estimated to be 40%, 11.8% and 5.6%, respectively.

Mining use projection calculations used rates of incremental change as projected by USDA 1975 for mineral earnings in each mineral group. Mineral industry water withdrawals for 1972 were calculated by multiplying USBM withdrawal averages in gppd by 1972 production totals for each mineral group.

3. No alternative projections were prepared for this sector.

## *Assumptions*

The model assumes a direct, linear relationship between earnings in the mining sector and water use.

## *Results*

**TABLE 8: U.S. Mining Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 1,100 | 1,610 |
| Consumption (cfs) | 240 | 320 |

Source: IJC 1985

### *Discussion*

Although the U.S. model uses a comprehensive data base, the correlation of water use with earnings can be misleading. To the extent that water use can in fact be correlated with earnings, the correlation would be nonlinear due to the influence of economies of scale and physical start-up requirements. In addition, such a model cannot adjust for changes in market prices for commodities directly and indirectly associated with mining.

### *Options for Further Study*

The development of a model correlating water use with actual units of the various goods produced by the mining sector is recommended. Information on economic growth trends in the mining sector since 1975 should be collected and compared with hypothesized trends used in this model.

## *Mining Water Use — Canada*

### *Methods*

1. Like the U.S. model, the Canadian model used economic growth projections for the mining sector and water use per production dollar to derive withdrawal and consumptive use estimates.

2. Mining sector economic growth trends were determined using identical methods as those for the manufacturing sector and include high, medium and low growth projections of 5%, 4.5% and 3% per annum. (Refer to Chapter 6 for equations.)

3. Water withdrawal and consumptive use forecasts were derived for each subbasin and were made proportional to each subbasin's share of mining productivity by taking into account the geographic distribution of different mine types.

### *Assumptions*

- Refer to the first three assumptions in Chapter 6 for manufacturing water use for Canada.

- Mining technology involving water use was assumed constant throughout the forecast period. Therefore, no technological change–based alternative scenarios were developed for this sector.

## *Results*

**TABLE 9: Canadian Mining Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 130 | 370 |
| Consumption (cfs) | 0 | 10 |

Source: IJC 1985

As shown in Table 9, a nearly three-fold increase in water withdrawal in the mining sector is expected by 2000. No discussion of this trend is provided in IDCU (1981) or IJC (1985) reports. Consumptive use is shown to increase from 0 to 10 cfs over the forecast period. Nowhere in the IDCU report (1981) was consumptive use expected to fall below 10 cfs. Therefore, the reason for the 0 cfs figure for 1975 as displayed by IJC (1985) is unclear.

## *Discussion*

Like the U.S. mining sector model, the Canadian model would be weakened attempting to forecast water use by correlating withdrawal and consumption with earnings projections.

## *Options for Further Study*

See options for further study earlier in this chapter, under the U.S. mining water use section.

# 8

*Chapter*

# *Rural Stock Water Use*

The International Joint Commission (IJC) report (1985) defines livestock watering as "animal drinking water, evaporation from stock water ponds, and water used for cleaning." The report estimates this sector accounts for about 4% of total basin consumptive use, ranking seventh in terms of water use. The U.S. model assumes rural stock water use is supplied solely by water sources other than the Great Lakes, such as upland surface tributaries and groundwater. The Canadian analysis provides no source specification. Both approaches attempt to determine an accurate demand for a mix of livestock products, including beef and dairy cattle, pigs, sheep and poultry, as summarized below.

## *Rural Stock Water Use — United States*

### *Methods*

1. To generate a most likely projection (MLP) of consumptive use estimates for the U.S. rural stock sector, a model was developed that basically translates population projections into forecasted demand for livestock-related commodities and multiplies the demand forecasts by a consumptive use coefficient.

The model is summarized by the equation below. Note that total consumptive use comprises consumptive use increments summed for an unspecified number of livestock types over eight assessment sub-areas (ASAs) as delineated by the U.S. Water Resources Council (WRC, 1978).

$$CUUS(t)_5 = P_j \cdot [1+r(t)_j] \cdot LCD_{\bullet} \cdot L_{\bullet j} / LCD_{\bullet} \cdot WUS_{5\bullet} \cdot CURUS_5 \qquad (8.1)$$

where:

$CUUS(t)_5$ — total consumptive water use (cubic feet per second, cfs) at time t = 1975, 1985 and 2000, in the rural stock sector (i = 5), U.S. portion of the Great Lakes basin

$P_j$ — population estimates for j = 1 (WRC 1978; U.S. Department of Agriculture, USDA, 1975)

$1{+}r(t)_j$ — growth multiplier for population at time t = 1975, 1985 and 2000 where $r = [P(t+n)_j - P(t)_j]/P(t)_j$ and j = 1 (WRC 1978, USDA 1975)

$LCD_e$ — livestock–related commodity demand (pounds per capita, ppc) for the eth livestock type and forecast years 1975, 1985 and 2000

$L_{ej}$ — ratio of livestock numbers (for the eth livestock type) to livestock–related commodity demand (units unspecified, assumed to be head of livestock / pound of livestock–related commodity) where j = 1 (WRC 1978)

$WUS_{5e}$ — livestock water requirement (withdrawal by the U.S. livestock sector, i = 5, per livestock unit) for the eth livestock type, includes both drinking water and nondrinking water requirements (International Great Lakes Diversions and Consumptive Uses Study Board, IDCU, 1981)

$CURUS_5$ — consumptive water use ratio (consumptive use rate : withdrawal rate) for the U.S. rural stock sector (i = 5), assumed to be a dimensionless constant of 1.00 (IDCU 1981)

Note: Geographic distribution of forecasted livestock production is apportioned throughout the Great Lakes basin in accordance with forecasted distribution of human population.

## *Assumptions*

- The model assumes that rural stock water comes from sources other than the Great Lakes, such as surface tributaries and groundwater.
- The geographic distribution of livestock production is assumed to coincide with the geographic distribution of human population.
- The proportional demand for livestock–related commodities (commodity mix) is assumed constant over the forecast period.
- The model assumes a linear relationship between livestock production and population growth.
- The model implicitly assumes that no livestock–related commodities are imported or exported from the Great Lakes region.

## *Results*

**TABLE 10: U.S. Rural Stock Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 130 | 130 |
| Consumption (cfs) | 130 | 130 |

Source: IJC 1985

As shown above, no change in rural stock water demand or consumptive use is expected to occur in the U.S. portion of the basin between 1975 and 2000.

## *Discussion*

While U.S. methods follow a logical progression, several aspects warrant critique. First, as with all the U.S. models, population drives the model. Currently, U.S. agricultural production is heavily influenced by federal and state price supports and other incentive programs. Due to this influence, production levels are not good indicators of demand generated by domestic populations. Second, the lack of attention to agricultural import and export markets could be biasing model results. Third, the model does not recognize changing demand for livestock–related commodities.

Further, because livestock production generally occurs outside the urban areas of the Great Lakes basin, it seems unlikely that geographic distribution of livestock production would coincide with the distribution of human population as assumed. Rather, one would expect an inverse correlation.

Again, there is no discussion or substantiation of withdrawal and consumptive use coefficients. To assume that the two are synonymous could be invalid due to the occurrence of runoff generated from stockyards and feedlots. Finally, it is unclear why, given the projected growth in Great Lakes population and a constant livestock commodity demand per capita, there is no change projected for livestock water use over the forecast period.

## *Options for Further Study*

Recent trends in demand for rural stock and related commodities could be compared with those used to develop IJC (1985) projections. Then, revisions could be made where appropriate. Also, the geographic relationship between rural stock production and regional population distribution could be investigated further. Water withdrawal and consumptive use coefficients could be discussed and substantiated.

## *Rural Stock Water Use — Canada*

### *Methods*

1. The Canadian rural stock sector consumptive use model is fundamentally similar to the U.S. model in that population projections are transformed into projected demand for livestock. The livestock demand forecasts are then multiplied by a consumptive use coefficient to obtain total consumptive water use estimates for the sector. Incremental consumptive use estimates are summed over six livestock types and 42 counties. High and low estimates for this sector were calculated using meat and dairy consumption values 20% higher and lower than those used for the MLP, and using high and low population projections. The model is represented by the equation below.

$$CUCN(t)_5 = [MCF(t)_e \cdot P(t)_j \cdot WMC_e]/AAW_e \cdot WCN_{5e} \cdot CURCN_5 \cdot WUC \qquad (8.2)$$

where:

$CUCN(t)_5$ — total consumptive water use (cfs) at time t = 1975, 1980, ..., 2000 for the Canadian rural stock sector (i = 5)

$MCF(t)_e$ — meat consumption forecast (ppc/year) at time t, developed using separate linear regression equations for the eth livestock type where e = 1, 2, ..., 6 (beef cattle, dairy cattle, pigs, lamb, sheep and poultry). Regional statistics of per capita meat consumption from 1945 to 1977 were used to prepare time series–based estimators for future meat consumption (IDCU 1981).

$P(t)_j$ — annual population estimates and forecasts at time t, for j = 2 (the 42 Canadian counties)

$WMC_e$ — weight (per head) to weight of meat (per head) conversion constant (dimensionless) for the eth livestock type (Note: Though the factor was not mentioned in IDCU 1981, it is implicit in the model.)

$AAW_e$ — average animal weights for the eth livestock type (IDCU 1981)

$WCN_{5e}$ — livestock water requirement for the Canadian rural stock sector (i = 5) for the eth livestock type, in gallons/head/day (IDCU 1981)

$CURCN_5$ — consumptive water use ratio (consumptive use rate per livestock unit : water requirement per livestock unit, withdrawal rate), assumed to be a constant of 1.00 (IDCU 1981)

WUC — water use conversion factor (cfs/gallon•day), implicit in the model

Note: According to the IDCU report (1981), livestock production estimates were disaggregated by the five lake subbasins based on a study of cattle and poultry in the Great Lakes region containing information from 1931.

2. The Canadian model forecasted the numbers of livestock animals by category (beef cattle, dairy cattle, pigs, lamb, sheep, poultry) using per capita meat consumption statistics compiled since 1939 (no citation). A time series from 1945–77 was prepared using linear regression analysis with time as the independent variable.

Logistic curves were developed to fit beef and poultry data and to project maximum values. (Least squares applied to beef consumption resulted in unrealistically high demand projections given 1975 consumption in pounds/year.) An exponential function was developed for dairy cattle to fit a declining demand trend. A constant (mean value) was used for pigs and mutton to represent a trendless distribution of demand over time.

## *Assumptions*

- The model assumes no import or export of meat and dairy products to or from Ontario markets.
- Trends in demand for rural stock and related commodities observed between 1945 and 1977 are assumed to continue throughout the forecast period.

## *Results*

**TABLE 11: Canadian Rural Stock Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 80 | 120 |
| Consumption (cfs) | 80 | 120 |

Source: IJC 1985

Notably, while no change in livestock water use was projected for the U.S. portion of the basin, livestock–related water demand in the Canadian portion of the basin is expected to increase by 50% over the forecast period.

## *Discussion*

The strength of the Canadian model lies in its treatment of commodity demand trends. However, the assumption of no import or export of livestock commodities is questionable. In addition, the IDCU (1981) description of methods does not adequately address withdrawal and consumptive use coefficients.

## *Options for Further Study*

Trends in livestock commodity demand since 1977 could be used to check the validity of regression equations used in this model. Then, revisions could be made where appropriate. Also, further elaboration on withdrawal and consumptive use coefficients could be provided.

9

Chapter

# Irrigation Water Use

The International Joint Commission (IJC) report (1985) refers to irrigation water use as the "watering of all lands except those supplied by the municipal sector." The report estimates irrigation accounts for about 7% of total consumptive water use in the Great Lakes basin, which is relatively small compared to more arid agricultural regions. Irrigation ranks fourth of the seven sectors in terms of consumptive use. The International Great Lakes Diversions and Consumptive Uses Study Board (IDCU 1981) includes irrigated croplands, golf courses and public lands in this sector.

For both the U.S. and Canadian models, the basic method involves multiplying projections of irrigated cropland and golf course (and public land in the United States) acreage by withdrawal and consumptive use coefficients to obtain total estimated consumptive water use in the irrigation sector. For each category, irrigation water is assumed to be supplied by sources other than the Great Lakes themselves.

## *Irrigation Water Use — United States*

IDCU (1981) generated only a most likely projection (MLP) for this sector. The basic model is as follows:

$$CUUS(t)_6 = CUUS(t)_{6,f} \qquad (9.1)$$

where:

$CUUS(t)_{6f}$ — sum of consumptive water use (cubic feet per second, cfs) in the irrigation sector (i = 6) for parameters f = 1, 2 and 3 where f = 1 is irrigated cropland, f = 2 is irrigated golf course and f = 3 is irrigated public land in the U.S. portion of the Great Lakes basin

Models for parameters f = 1, 2 and 3 are depicted separately by the following equations and, where appropriate, with additional explanation.

## *Methods — Irrigated Croplands*

1. The basic model for irrigated cropland consumptive use is summarized in the equation below:

$$CUUS(t)_{6,1} = ICA_j \cdot WUS(t)_{6,1j} \cdot CURUS(t)_{6,1j} \cdot [1+r(t)_j] \qquad (9.2)$$

where:

$CUUS(t)_{6,1}$ — consumptive use in the irrigation sector (i = 6), cropland parameter (f = 1), U.S. portion of the Great Lakes basin, where the U.S. Water Resources Council (WRC, 1978; U.S. Department of Agriculture, USDA, 1975) derived independent variables for an unspecified number of irrigated crop types

$ICA_j$ — irrigated cropland acreage estimate by crop type where j = 1 (United States) (WRC 1978, USDA 1975)

$WUS(t)_{6,1j}$ — crop irrigation requirement (withdrawal rate per irrigated acre) for the U.S. irrigation sector (i = 6), cropland parameter (f = 1) at time t by crop type where j = 1. Crop irrigation requirements were developed by subtracting total crop water requirements from historic rainfall supply with consideration for future improvements in irrigation system conveyance and on–farm efficiency. Estimates assumed trends in irrigation water use would reflect technological improvements such as lining or piping of canals and ditches, and regulation of headgate operations (WRC 1978).

$CURUS(t)_{6,1j}$ — crop consumption requirement (consumptive use rate per acre / withdrawal rate per acre, dimensionless) by crop type for the U.S. irrigation sector (i = 6), cropland parameter (f = 1) at time t where j = 1. Crop consumption requirements were computed using the Blaney Criddle method and ranged from 0.72 to 0.82.

$[1+r(t)_j]$ — growth multiplier for irrigated crop acreage (dimensionless) by crop type at time t = 1975, 1985 and 2000 where j = 1. Incremental fraction of growth, r, can be represented by $[ICA(t+n)_j - ICA(t)_j]/ICA(t)_j$. Distribution of projected national output was used to obtain irrigated cropland acreage estimates based on 1947–70 trends extended over the forecast period through regression analysis. A curvilinear Spillman–type function was employed as a constraint to ensure that these projections would not exceed linear projections to 1990 (WRC 1978, USDA 1975).

## *Methods — Irrigated Golf Courses*

1. The basic model for irrigated golf course consumptive use is summarized in the equation below:

$$CUUS(t)_{6,2} = GCA(t)_j \cdot WUS(t)_{6,2j} \cdot CURUS(t)_{6,2} \cdot PIRR \quad (9.3)$$

where:

$CUUS(t)_{6,2}$ — consumptive use (cfs) in the U.S. irrigation sector (i = 6) for irrigated golf course parameter (f = 2)

$GCA(t)_j$ — projected golf course acreage demand (acres) through 2020 for each of the five subbasins (j = 4) (Great Lakes Basin Commission, GLBC 1975). Demand estimates for golf courses were derived by taking demand in base year 1970 and dividing by supply in 1970. The resulting ratio was used to forecast supply through 2020. (USDA 1975).

$WUS(t)_{6,2j}$ — golf course withdrawal rate per acre at time t for j = 1 (GLBC 1975)

$CURUS_{6,2}$ — consumptive use ratio (dimensionless) for irrigated golf courses, assumed to equal 75% of withdrawal (GLBC 1975)

PIRR — percentage of all golf course acreage that is actually irrigated. IDCU (1981) adjusted golf course acreage projections to reflect USDA (1975) population projections along with the assumption that only 75% of all golf course acreage is actually irrigated (IDCU 1981).

Note: The model appears to have used golf course demand estimates derived by lake subbasin while applying withdrawal rates developed by WRC (1978) assessment sub–area (ASA). It is presumed that an appropriate calibration procedure was used to ensure the correct calculation of water demand for the various geographic units.

## *Methods — Irrigated Public Lands*

1. In the IDCU report (1981) water required for use on public lands included water used in national parks and forests and on lands administered by the U.S. Bureau of Land Management (BLM) for timberland and watershed irrigation, human and domestic/wild animal use, fire protection, and recreational and mining activities. It comprised about 6% of total consumptive use in the U.S. irrigation sector (IDCU 1981). The basic model is summarized in the equation below.

$$CUUS(t)_{6,3} = P_j \cdot [1+r(t)_j] \cdot [1+q(t)_j] \cdot WUS_{6,3j} \cdot CURUS_{6,3} \cdot a \quad (9.4)$$

where:

$CUUS(t)_{6,3}$ — consumptive use (cfs) for the U.S. irrigation sector (i = 6) public lands parameter (f = 3)

$P_j$ — population projections for an unspecified base year where j = 1 (WRC 1978, USDA 1975)

$1+r(t)_j$ — population growth multiplier where r equals a linear annual growth rate developed for t = 1975, 1985 and 2000, and j = 1 (WRC 1978, USDA 1975)

$1+q(t)_j$ — projected growth in irrigated public lands capacity (dimensionless) for 1975, 1985 and 2000 where j = 1 (WRC 1978; USDA 1975)

$WUS_{6,3j}$ — irrigation withdrawal requirement per capita (i = 6) in national parks and forests (f = 3)

$CURUS_{6,3}$ — ratio of consumptive use to withdrawal

a — adjustment coefficient based on expected administrative and resources management plans for public lands

*Assumptions* (for all three U.S. irrigation water use parameters)

- Water is supplied by nonlake sources.
- Withdrawal estimates will reflect ongoing improvements in on–farm conveyance and irrigation technologies. This assumption was adopted based on a nationwide increase in the lining and piping of irrigation canals, the use of computerized irrigation systems, and so on.
- Distribution of national agricultural output would reflect trends observed from 1947 to 1970.
- Golf course construction will continue at a constant linear rate throughout the forecast period.
- Recreation and livestock activity will increase at a constant linear rate throughout the forecast period.
- Groundwater use will continue to increase.
- Energy production on forest lands will remain constant over time.

## *Results*

**TABLE 12: U.S. Irrigation Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 350 | 600 |
| Consumption (cfs) | 180 | 500 |

Source: IJC 1985

In its 1981 report to IJC, IDCU asserted that although irrigated cropland acreage was expected to stabilize over time, a nearly three-fold increase in irrigation consumptive use was predicted by 2000. However, as a percentage of total Great Lakes basin consumptive use, this sector was expected to decline slightly.

## *Discussion*

The U.S. model was developed using an extensive data base to evaluate trends in irrigated agriculture, irrigation technology, and the ratio between irrigation requirements (or withdrawal) and crop consumption. However, several aspects of the model warrant additional insight.

There is some question as to the appropriateness of applying the Blaney–Criddle method to estimate crop consumption in the Great Lakes region. Because the method was developed to evaluate evapotranspiration in arid western states where nearly all agriculture is irrigated, it could be unsuitable for humid regions such as the Great Lakes basin. Also, it remains unclear as to why the withdrawal and consumptive use estimates for 1975 indicate a consumptive use ratio of 51%, which is significantly lower than the 72% to 85% range applied in the analysis. (This consumptive use factor can get as high as 95%.)

In addition, assuming widespread implementation of improved irrigation technology could be misleading. While these trends are now occurring in areas of water scarcity, the expense of replacing or installing new high efficiency irrigation systems could seem unwarranted in agricultural regions where conserving water is not a high priority.

As mentioned, to forecast golf course water demand, IDCU (1981) assumed that golf course construction would continue through 2020. Considering that GLBC (1974) had assumed no golf course construction after 1980, the question of some maximum golf course capacity arises.

### *Options for Further Study*

Recent statistical information on irrigated acreage, commodity markets and the application of new irrigation technologies in the Great Lakes region should be used to evaluate IJC (1985) projections. Revisions to the model should be made if appropriate.

## *Irrigation Water Use — Canada*

The basic model is as follows:

$$CUCN(t)_6 = CUCN(t)_{6,f} \tag{9.5}$$

where:

$CUCN(t)_6$ — sum of consumptive water use (cfs) in the irrigation sector (i = 6) for parameters f = 1 and 2 where f = 1 is irrigated cropland and f = 2 is irrigated golf course. In contrast to the U.S. model, the Canadian model did not consider irrigated public land, and therefore there is no f = 3 parameter.

Models for parameters 1 and 2 are depicted separately by the following equations and, where appropriate, with additional explanation.

### *Methods — Irrigated Cropland*

1. Using the Canadian model, IDCU (1981) generated MLP plus high and low water use forecasts for the irrigation sector. MLP uses medium population growth projections to develop irrigated acreage projections. High and low forecasts were prepared by using estimates of irrigated acreage 20% higher and lower than those used in developing MLP. The equation representing MLP is shown below.

$$CUCN(t)_{6,1} = ICA_j \cdot (1+r_j)_t \cdot (1+q_j)_t \cdot WCN_{6,1} \cdot CURCN_{6,1} \tag{9.6}$$

where:

$CUCN(t)_{6,1}$ — consumptive use (cfs) at time t = 1975, 1980, ..., 2000 for the irrigation sector (i = 6), cropland parameter (f = 1) in the Canadian portion of the Great Lakes basin

$ICA_j$ — irrigated cropland acreage estimate for the base year 1970 for the entire Great Lakes basin as the sum of acreage in 42 counties

| | | |
|---|---|---|
| $(1+r_j)_t$ | — | growth multiplier used to extrapolate an irrigated cropland acreage estimate for 1970 to 1975 (dimensionless) where r = an average annual compound growth rate based on trends in irrigated agriculture observed between 1960 and 1970 for Ontario (j = 3) and t = 5 |
| $(1+q_j)_t$ | — | population growth multiplier (dimensionless) developed for each lake subbasin (j = 4) where t equals 0, 10 and 25 (IDCU 1981) |
| $WCN_{6,1}$ | — | crop irrigation requirement (water withdrawal rate per acre), assumed a constant average of 5.87 inches of water/acre/year |
| $CURCN_{6,1}$ | — | consumptive water use ratio (consumptive water use rate per acre / crop irrigation requirement per acre, dimensionless), estimated to be a constant ratio of .50 |

The above equation shows that irrigated cropland acreage forecasts were apportioned throughout the Great Lakes basin coincident with forecasts of regional population distribution. In addition, growth in demand for irrigated crops is based on population growth projections in the region.

## *Methods — Irrigated Golf Courses*

1. Data on golf course irrigation were obtained from government and private sources. The geographic distribution of golf courses is allocated among the five lake subbasins based on information from the same sources.

2. No discussion of withdrawal requirements for golf courses is provided in the discussion of this model. However, the ratio of consumptive use to withdrawal rates selected by IDCU (1981) was 1.0.

## *Assumptions* (for both Canadian irrigation water use parameters)

- Growth in demand for irrigated crops is linearly related to population growth. That no export of irrigated crops will occur is implicitly assumed.
- All water is obtained from sources other than the Great Lakes.
- All irrigated acreage reported in counties either wholly or partially within the Great Lakes basin was included as in the basin for the purposes of estimating consumptive use.

- Irrigated acreage will be apportioned throughout the five individual subbasins in proportion to forecasted geographic population distribution.
- Potential reduced demand for certain irrigated crops (tobacco) will be offset by increased demand for substitute irrigated crops (vegetables) resulting in consistent water demand rates.
- Although not stated specifically, it appears that analysis assumes irrigation of 100% of estimated golf course acreage.

## *Results*

**TABLE 13: Canadian Irrigation Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 130 | 190 |
| Consumption (cfs) | 100 | 130 |

Source: IJCs 1985

## *Discussion*

First, the application of an average irrigation requirement (5.87 inches/irrigated acre) to all irrigated cropland acreage warrants substantiation. Second, the inclusion of irrigated acreage that is outside basin boundaries could reduce the accuracy of independent variable estimates. Third, apportioning irrigated acreage in direct proportion to projected geographic distribution of human population could bias regional estimates. Because most farmland is outside urban areas, it would be more appropriate to assume an inverse relationship between these two variables.

In addition, it is unclear whether and in what proportions irrigation water is supplied by Great Lake or non–Great Lake sources. IDCU (1981) does not address changing trends in irrigated agriculture or irrigation technologies within the basin. Nor does IDCU (1981) identify irrigation requirement used to calculate water demand for irrigating golf courses. No explanation or citation exists pertaining to consumption : withdrawal ratios used.

## *Options for Further Study*

A regional land use study should be conducted to determine the proportion of irrigated acreage actually within Great Lakes basin boundaries. Acreage estimates should be revised as appropriate.

The potential impacts on water use of recent trends in irrigated agriculture, markets for irrigated crops produced in Ontario, commodity composition, and changing import/export relationships, should be evaluated and compared with those used to develop IJC (1985) projections. Revisions should be made as appropriate.

Clarification and substantiation of the 5.87 inches/acre annual irrigation requirement should be provided.

The assumed correlation between geographic distribution of irrigated agricultural production and regional population should be investigated.

Although golf course irrigation comprises only a minute percentage of water use in the basin, irrigation requirements and consumptive use rates should be clarified.

# 10

*Chapter*

# *Thermal Power Water Use*

Thermal power generation is currently the third leading sector of consumptive use in the Great Lakes basin, constituting 10% of the total. It is expected to become the second leading sector by 2000, when it could account for 26% of all use, according to the International Joint Commission (IJC 1985). Withdrawals for thermal power plant cooling represent the greatest single use of water in the basin, accounting by volume for more than half of all withdrawals.

IJC (1985) considered only withdrawal and consumption of condenser (cooling) water. Other use is negligible and not included in this section. Condenser water estimates are based on projections of gross generating capacity for all thermal plants per subregion. This capacity is allocated among fuel types (coal or nuclear) and condenser designs. Each combination of fuel type and condenser design has a particular water requirement per unit of energy production.

## *Thermal Power — United States*

### Methods

1. The IJC model for estimating consumptive use is represented by the equation below.

$$CUUS(t)_7 = CUR_g \cdot CON_g \cdot CMIX(t)_g \cdot FMIX(t)_{gj} \cdot CAP(t)_j \qquad (10.1)$$

where:

$CUUS(t)_7$ — consumptive water use in the U.S. portion of the Great Lakes basin at time t = 1975, 1985 and 2000 where i = 7 thermal power

$CUR_g$ — consumptive use / unit production in cubic feet per second (cfs)--years / gigawatt hour (GWH) (fixed at .0075)

$CON_g$ — conversion from installed capacity in MW to annual production in GWH (load factor times hours/year divided by 1,000) where, when g = 1 and 2, $CON_g$ = 6.72, and when g = 3 and 4, $CON_g$ = 4.15

$CMIX(t)_g$ — percentage of U.S. plant capacity employing cooling systems where, when g = 1 and 3, cooling system = once through, and when g = 2 and 4, cooling system = closed

$FMIX(t)_{gj}$ — percent of capacity produced in subbasin j = 4 (lake basins) where, when g = 1 and 2, plant type = nuclear, and when g = 3 and 4, plant type = coal

$CAP(t)_j$ — installed thermal power plant capacity (MW) in subbasin j

2. Total power plant capacity within each subbasin was determined using data from the Great Lake Basin Commission (GLBC 1975) and power pool reports (IDCU 1981).

3. Installed capacities in each subbasin and the mix of fuel types (either nuclear or coal) and cooling systems (either once through or closed cycle) were projected.

4. Water use rates for consumption and withdrawal are expressed as a rate of water use per unit of energy generated in a year. These rates were estimated using information from GLBC (1975) and the U.S. Water Resources Council (WRC, 1978) Assessment Sub-Areas (ASAs). They represent averages among plants with each type of fuel and cooling system, and are given in Table 14.

**TABLE 14: Water Use Per Unit of Energy Production***

| Fuel Cooling System | Withdrawal | Consumptive Use |
|---|---|---|
| Fossil Once through | 0.198 | 0.0021 |
| Nuclear Once through | 0.297 | 0.0032 |
| Fossil Closed cycle | 0.008 | 0.0054 |
| Nuclear Closed cycle | 0.011 | 0.0073 |

* In cfs-years / GWH
Source: IDCU 1981

5. Total power generation in each subbasin was determined by multiplying total fossil fuel plant capacity by 4.15 and total nuclear power plant capacity by 6.72. These numbers were not justified by the International Great Lakes Diversions and Consumptive Uses Study Board (IDCU 1981) but are recalculated here. (See discussion section.)

6. For each fuel-cooling system combination, consumptive use is the product of total power generation times the corresponding consumptive use rate from Table 14.

7. The proportion of water obtained from lake and nonlake sources was estimated from Federal Energy Regulatory Commission projections (IDCU 1981) of future plant sightings, according to the expected location of demand centers and the availability of water supplies.

## *Assumptions*

- IDCU (1981) assumed that installed capacity would annually increase 4.7% from 1980 through 2000. IJC (1985) revised the annual rate of increase to 2.5% for this period.

- IDCU (1981) projected the percentage of nuclear–derived power would increase from 20% in 1975 to 34% in 1980 and 39% in 2000. These are basinwide averages; each basin was assigned a nuclear–derived proportion ranging from 0 (Superior) to 63% (Ontario) in 2000. IJC 1985 revised the projected contribution of nuclear power in 2000 to a basinwide average of 28%.

- Once–through cooling was used in 89% of plants, compared with 11% that used closed–cycle cooling. IDCU 1981 assumed that in 2000, closed cycle would be predominant with a 59% share.

## *Results*

Results of the IDCU (1981) report clearly overstate withdrawals and consumptive use. This is due to two dramatic changes in the electric power industry around 1980 when the report was being prepared. First, the industry abandoned construction plans for nuclear power plants because it was impossible to control costs. Second, during the 1970s, Americans proved they could and would reduce their energy demand if prices were high enough. IDCU (1981) data relating to energy use trends were obtained during a period of strong growth in electricity demand and at a time when utilities favorably viewed nuclear facilities. However, the projected installed capacity for nuclear plants for 2000 cannot be realized because of curtailed construction. Furthermore, the facilities cannot be designed, built and licensed in fewer than 10 years.

IJC (1985) withdrawal and consumptive use estimates were recomputed using reduced demand and nuclear contribution. According to the report, the U.S. share of total Great Lakes consumptive use is as follows:

**TABLE 15: U.S. Thermal Power Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 33,470 | 48,170 |
| Consumption (cfs) | 420 | 2,260 |

Source: IJC 1985

## Discussion

There are several problems with the U.S. model. First, the calculations should be set up so the results are in units of water flow rather than annual water volume. Withdrawal and consumptive use coefficients are reported as cfs/GWH. Such units are inappropriate because cfs is a flow rate, while GWH is a volume of energy. What was meant in the report is cfs/GWH/year, which is identical to cfs–years/GWH, as used in Table 14.

The unit conversion problem here is rather confusing, as exhibited by the errors in describing the methods in IDCU (1981). On page 93 of Appendix F, the report states: "... fossil fuel plant capacities in megawatts for each lake basin were multiplied by 4.15 and nuclear plant capacities were multiplied by 6.72 to obtain GWH generation." No explanation of these constants is put forth. If, however, a power plant operated at full capacity throughout a year, the conversion factor would be:

$$\frac{8{,}766 \text{ hours}}{} \times \frac{1 \text{ GWH}}{1000 \text{ MW}} = 8.766 \text{ GWH/yr per 1 year MW of capacity}$$

The multipliers used in IDCU 1981 yield total power production in GWH/year not GWH as was stated. The units are inappropriate because three time measures are present: seconds, hours and years. It would have been clearer to apply load factors to plant capacities and obtain average rates of power generation, which lead directly to water use rates. The number of hours/year need not be employed. Therefore, the factors 4.15 and 6.72 represent load in terms of the number of hours plants operate per year. Loads work out to 0.473 and 0.767 for coal–fired and nuclear plants, respectively.

IDCU (1981) does not explain how current installed capacities were determined, nor the basis for the growth rate used. On page F–94, the growth rate in power demand is reported to range from 1% to 9% with a basinwide average of 4%. The report estimates a 4.7% growth rate for 1980 to 2000. The latter is based on planned construction, which would seem to indicate this figure is an estimate of growth rate for installed capacity, not demand. Only installed capacity is of interest to estimate consumptive use because some power demand could be satisfied using facilities outside the Great Lakes basin. In fact, this is likely, according to IDCU (1981).

## *Options for Further Study*

It seems as though the number of large thermal power plants in the basin ($\geq$100 MW) is limited enough to enable a complete inventory of the facilities. A useful database would consist of installed capacity, fuel type, condenser design, water source (lake or inland) and subbasin. Such a database would provide reliable estimates of the mix of fuels and cooling systems. The inventory could also be extended to include plants under construction or contemplation. Construction plans can provide information about future installed capacity up to 15 years in advance. Perhaps these data can be obtained from government documents, thus avoiding the task of making inquiries to the utilities. Appendix 10 of GLBC (1975) contains a complete inventory of plants >10 kW.

Consumptive use is a fraction of total withdrawal. In IDCU (1981), the fraction was 1.07% in the case of once–through systems and 67% for closed–cycle systems. The latter covers a wide range of condenser designs that are from 30% to 100% consumptive. Perhaps it would be appropriate to consider more condenser categories.

The prevailing methods to estimate consumptive use rely on three parameters: installed capacity, load factor and water requirement per unit production. The installed capacity estimates could be improved by inventorying existing facilities and applying reasonable growth rates. Load factors vary from year to year, but most utilities try to maintain a fixed amount of excess capacity in the long run. Water requirement per unit production can be determined thermodynamically as a function of operating conditions and condenser design. For a given condenser type, the withdrawal also depends on cooling water temperature, cooling water temperature rise, and the amount of heat the plant requires to generate a given amount of energy. The latter ratio is the inverse of thermal efficiency. Thermal efficiency is primarily a function of fuel type because nuclear plants are approximately 20% less efficient. A suggested framework for computing consumptive use is based on the following relationship:

$$CUUS(t)_7 = C_{gj} \cdot LF_{gj} \cdot W_g \cdot CUR_g$$

where:

$CUUS(t)_7$ — average consumptive use (cfs) for i = 7, the thermal power sector

$C_{gj}$ — installed capacity (MW) for power plant type g in lake basin j

$LF_{gj}$ — annual load factor for power plant type g in lake basin j

$W_g$ — withdrawal requirement (cfs/MW) for power plant type g

$CUR_g$ — consumptive use ratio for power plant type g

Table 16 shows values of withdrawal and consumptive use ratios used in IDCU 1981.

**TABLE 16: Water Use Coefficients — Thermal Power***

| Nation | Fuel | System | Withdrawal (cfs/MW) | Consumptive Use (percentage) |
|---|---|---|---|---|
| U.S.A. | Nuclear | Once through | 2,600 | 1.07 |
| U.S.A. | Coal | Once through | 1,700 | 1.07 |
| U.S.A. | Nuclear | Closed cycle | 0.095 | 67.0 |
| U.S.A. | Coal | Closed cycle | 0.070 | 67.0 |
| Canada | Nuclear | Once through | 2.000 | 0.75 |
| Canada | Coal | Once through | 1.200 | 0.75 |

* Employed either directly or indirectly by IDCU 1981

## *Thermal Power — Canada*

### *Methods*

1. The model for estimating consumptive use is represented by the equation below.

$$CUCN(t)_7 = CUR_g \cdot WR_g \cdot LF_g \cdot FMIX(t)_g \cdot [1.2 \cdot Demand(t)] \qquad (10.2)$$

where:

$CUCN(t)_7$ — total manufacturing consumptive water use at time t = 1975, 1985 and 2000 in the Canadian portion of the Great Lakes basin, where i = 7 is thermal power

$CUR_g$ — consumptive use ratio which is fixed at $CUR_g$ = .0075 where g = power plant type: 1 = nuclear once through, 2 = nuclear closed, 3 = coal once through, 4 = coal closed and 5 = hydroelectric

$WR_g$ — water requirement (or withdrawal) for power plant type g in cfs/MW: when g = 1 and 2, $WR_g$ = 2.0 cfs/MW; when g = 3 and 4, $WR_g$ = 1.2 cfs/MW; and when g = 5, WRg = 0.0 cfs/MW

$LF_g$ — load factor of plants using fuel g: when g = 1 and 2, $LF_g$ = 0.70; when g = 3 and 4, $LF_g$ = adjustable (per note below); and when g = 5, $LF_g$ = 0.75

FMIX(t)g — percentage of projected capacity for power plant type g

DEMAND(t) — projected total demand for power (MW) from Ontario Hydro plants in year t. Since 25% overcapacity is assumed, 1.25•DEMAND represents projected system capacity.

Note: In a given year t, $LF_g$ is adjusted to assure demand is met; this is expressed as:

$$DEMAND(t) = LF_g \cdot FMIX(t)_g \cdot [1.25 \cdot DEMAND(t)]$$

which is equivalent to: $0.8 = LF_g \cdot FMIX(t)_g$. The equation is solved for $LF_g$.

2. Consumptive use was estimated for the entire basin and was subsequently disaggregated into individual subbasin use rates.

3. Demand for energy was projected through 2000. Speculation was used to identify a likely power network to meet the needs.

4. Forecasts of peak energy demand were obtained from Ontario Hydro (IDCU 1981), the only electric utility operating in the Canadian portion of the Great Lakes basin. For each five–year period between 1975 and 2005, installed generating capacity was assumed to exceed the peak demand by 25%.

5. With installed capacity known, the number of plants and the mix of plant types (hydro, fossil and nuclear) were specified through examination of current trends and informed speculation.

6. Load factors of 0.70 for nuclear plants and 0.75 for hydro plants were used. Load factors for fossil plants varied year–to–year to meet the remaining demand. The product of capacity times load factor is the average power output for the year.

7. Withdrawal and consumptive use rates were computed by multiplying average power by a water use coefficient. These were 2.0 cfs/MW for nuclear plants and 1.2 cfs/MW for fossil fuel plants. Consumption was taken as 0.75% of withdrawal.

*Assumptions*

- All thermal plants in Ontario will employ once–through cooling, hence the single relationship between consumptive use and withdrawal.
- Nonconventional sources (other than hydroelectric, fossil or nuclear) will provide <10% of total energy production.

## *Results*

**TABLE 17: Canadian Thermal Power Withdrawal and Consumptive Use**

| | 1975 | 2000 |
|---|---|---|
| Withdrawal (cfs) | 6,600 | 41,270 |
| Consumption (cfs) | 60 | 310 |

Source: IJC 1985

Reported values reflect the assumption that consumptive use is 0.75% of withdrawal for every facility in Ontario.

## *Discussion*

The Canadian approach to estimating water use from plant capacity is straightforward and incorporates the recommendations outlined above for the U.S. power industry.

Canadian–installed capacity for the current year was determined using a comprehensive inventory of all plants in the region. This was possible because Ontario Hydro is the only producer operating thermal plants in the region. (The utility's name dates from early in the century when it operated hydroelectric facilities exclusively.) Because of its monopolist status, it has less design variability, and characteristics such as load factors are easier to estimate.

Ontario Hydro has only once–through cooling systems, which provided the average water use rates shown in Table 16. Note that U.S. withdrawal rates are 33% greater than those reported for Canada, and the fraction consumed is 43% greater in the U.S. procedure. As a result, U.S. methods generate consumptive use estimates that are almost twice as big as what would be obtained using the Canadian numbers. Because U.S. and Canadian reports were prepared independently, this potential discrepancy is not noted.

The assumption that all plants will employ once–through cooling is in opposition to the U.S. projection that nearly 60% of production will occur at plants using closed–cycle cooling. Neither report gives any basis for these projections. It is likely that the U.S. forecast is based on federal policies that aspire to eliminate industrial thermal and chemical discharges to surface waters. The Canadian projections seem to reflect the fact that most plants are located at lakeshore sites and once–through cooling is used in all cases. The significance of environmental impacts is uncertain because the Great Lakes have tremendous assimilative capacities for heat.

## *Options for Further Study*

The Canadian methods are strong, but the projected increases in generating capacity seem unrealistically large. The installed capacity in Ontario would have to increase from its 1975 level of 11,000 MW to 45,000 MW by 2000. The Ontario Hydro system has traditionally expanded faster than its own demand so that it could sell power to users outside its service district, including on the U.S. side of the Great Lakes basin. Perhaps a general review of trends in energy generation capacity in both Canada and the United States is necessary now that these systems are connected.

# *Conclusions and Future Directions*

- ***Considering only consumptive use quantity as a fraction of net Great Lakes basin water supply, constraints do not appear imminent.***

Earlier estimates of Great Lakes water consumption appeared substantial. Many consumptive use models were not clearly delineated; underlying assumptions and attributes were obscure and difficult to quantify. By collecting and synthesizing the available information on past models, we have attempted to illuminate the models on which current consumptive use estimates are based. These we have presented in a consistent notation, allowing ready comparison among them. Even under varied parameter refinements, estimated consumptive use is a small fraction of basin supply.

- ***Water quality implications have generally not been acknowledged.***

In the past, water consumption was estimated for each of the use sectors, by country, over all the Great Lakes. This aggregation obscures differences between on-lake users, who take water directly from one of the Great Lakes, and off-lake users, who draw on other surface water or groundwater supplies in the Great Lakes basin. For off-lake users, both quantity and quality constraints could soon be important issues. These constraints would be compounded by drought and/or economic development.

# References

David, M.H., S. Rosenthal, E.D. Loucks, E.F. Joeres, and K. Potter. 1988. *Diversion of Great Lakes Water, Part 2: Economic Impacts.* University of Wisconsin–Madison Institute for Environmental Studies Report 131, University of Wisconsin Sea Grant Institute Report 247. Madison, WI.

Davis, Y.W., D.M. Rodrigo, and E.M. Opitz. 1987. *IWR-MAIN Water Use Forecasting System, Version, 5.0: User's Manual and System Description.* Carbondale, IL.

Great Lakes Basin Commission (GLBC). 1974. *Great Lakes Basin Framework Study, Appendix 15: Irrigation.* Ann Arbor, MI.

————. 1975. *Great Lakes Basin Framework Study, Appendix 10: Power.* Ann Arbor, MI.

International Great Lakes Diversions and Consumptive Uses Study Board (IDCU). 1981. *Great Lakes Diversions and Consumptive Uses, Annex F: Consumptive Water Use.* N.p.

International Joint Commission (IJC). 1985. *Great Lakes Diversions and Consumptive Uses.* N.p.

Loucks, E., E.F. Joeres, M.H. David, K. Potter, and S. Rosenthal. 1987. *Diversion of Great Lakes Water, Part 1: Hydrologic Impacts.* University of Wisconsin–Madison Institute for Environmental Studies Report 130, University of Wisconsin Sea Grant Institute Report 246. Madison, WI.

Reznek, S.R. 1976. The National Commission on Water Quality Study of the Impacts of Public Law 92-500 on Industry. *Industrial Water Engineering.* 13(1):12–13.

U.S. Department of Agriculture (USDA) Economic Research Service, Natural Resources Economics Division. 1975. *1972 Obers Projections: Regional Economic Activity in the U.S.* Washington, DC.

U.S. Water Resources Council (WRC). 1978. *The Nation's Water Resources 1975–2000, Volume 2: Water Quantity, Quality, and Related Land Considerations.* N.p.