Ontario Flow Assessment Techniques
Version 1.0
User's Manual

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Version 1.0

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developed and produced by the
Northeast Science and Information Section
of the Ontario Ministry of Natural Resources
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Steve Damaia – GIS Database Specialist
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Using the OFAT Manual

This section can be used as a roadmap for guiding you through the OFAT User’s Manual. It will help you to efficiently use this manual. It also explains any conventions that are followed throughout. Although this manual describes some ArcView functions, it was designed for those who are already familiar with ArcView. It is not intended to take the place of an ArcView GIS manual. Refer to the ArcView User’s Manuals listed in the References for further details on how to use ArcView’s standard features.

The following summarizes the contents of each chapter:

- The Welcome chapter will provide introductory information to answer the “What? Why? Who? How?” questions related to OFAT, including system requirements and where to get help.
- The OFAT installation chapter will instruct the user how to install OFAT software and/or databases properly.
- The Getting Started chapter is designed to help OFAT users get up and running quickly. It describes how to start, run, and exit OFAT.
- Four chapters are then presented which describe, in detail, functions related to the four major steps involved in OFAT operation including:
  - Watershed Delineation
  - Watershed Calculator
  - Hydrologic Modelling
  - Watershed Information Extraction System (WIES)
- The Batch Run chapter describes the module which allows the delineation, parameter calculations, and flow modelling for multiple (or single) watersheds in the same batch run without constant user interventions.
- The OFAT Data Structure chapter describes the application and database directory structures in the user’s hard drive after installation.
- The OFAT Metadata chapter outlines information about the OFAT data to keep track of large databases associated with the application.
- The Frequently Asked Questions (FAQ) chapter can be used to find answers to questions you may have about OFAT software and databases.
- The Troubleshooting chapter is where you can go for help to solve problems encountered when running OFAT.
- The Glossary will provide definitions to key words, abbreviations, and technical terminology used in this manual.

Following the main body of the User’s Manual, the following appendices are also included:

- Appendix A: Corresponding UTM Zones for Major Basins of Ontario – where you can find the UTM zone information for data pertaining to each of major basin of Ontario.
- Appendix B: Watershed Calculator Parameter Descriptions – where you can find symbols, detailed descriptions, and units used for all watershed parameters calculated by the Watershed Calculator.
- Appendix C: Runoff Curve Number (CN) – where you can find detailed information about how the CN databases included in OFAT were created.
• Appendix D: Hydrological Models – where you can find descriptions and limitations of each of the flow models currently in OFAT.
• Appendix E: Flow Charts – where you can find schematic flow charts for all functions found in the OFAT software. Each flow chart breaks down each function into step-by-step procedures. These flow charts will help you understand how each function works and how it links to other relevant functions.

The OFAT Quick Reference Card, accompanied with this manual, includes a simplified flow chart to outline OFAT processes as well as basic information about using OFAT tools and buttons.

**Typographic Conventions**

The following additions to the text are intended to make it easier to follow the manual and learn OFAT:

- **Note:** Contains tips, time savers and general information that may not be apparent.

- **Warning:** Cautions when an irreversible change is about to be performed, and flags critical operations.

Words with the first letter capitalized and in single quotes represent OFAT interface functions accessed from menus, buttons, tools, icons and dialog box options. For example:

```
select the ‘Watershed Delineation’ item from the ‘OFAT’ pull down menu
```

*Italicized* font indicates a reference to a file. For example:

```
name the OFAT project file ofat.apr
```

The word “drive” is used to represent the location of the OFAT software and databases, depending on the context that the word is used in. For example, the “drive” could be the c: drive, the d: drive, the e: drive, etc.
How OFAT Maps Are Referenced

Throughout the text, four different ArcView maps are referenced. It is important that you learn to distinguish which map you are in, as the functions available in each map are different. These four maps are referred to as:

- **Basin Index Map of Ontario**: The map that opens automatically when you start OFAT. It contains an index map of 13 predefined major basins in Ontario. From this map, you can select a major basin of your interest.

- **Tertiary Watershed Index Map**: The map that opens automatically after you select a basin from the ‘Basin Index Map of Ontario’. It contains tertiary watersheds within the selected basin. The title of the map will correspond with the name of the selected basin. From this map, you can select a tertiary watershed in which the watershed outlet of your interest is located.

- **Selected Watershed Area Map**: The map that opens automatically after you select a tertiary watershed from the Tertiary Watershed Index Map. It contains DEM-related databases (such as DEM, flow direction, flow accumulation, and calculated raster drainage network) and base map data layers (such as road, river, and lake) pertaining to the selected tertiary watershed. From this map, you can perform primary OFAT functions associated with the Watershed Delineation, Watershed Calculator, WIES, Flow Prediction Models, and Output Results.

- **Watershed Information Extraction Map**: The map that displays extracted data layers within a watershed boundary while using WIES. From here, the WIES Summary Statistics tool can be accessed.
Welcome to OFAT

What is OFAT?

The Ontario Flow Assessment Techniques (OFAT) Version 1.0, developed by the Northeast Science & Information (NESI) Section of the Ministry of Natural Resources (MNR), is a tool to automatically estimate flow information for watersheds in Ontario (Chang et al., 2002). OFAT is a user-friendly, interactive Geographic Information System (GIS)-based software with accompanying databases used to estimate various flow regimes. These flow regimes include low flows (e.g., $7Q_2$, $7Q_{10}$, $7Q_{20}$, etc.), flood flows (e.g., $Q_2$, $Q_{10}$, $Q_{25}$, $Q_{100}$, etc.), mean annual flows, minimum instream flow requirements, and bankfull flows. OFAT has been created by automating a number of existing regional hydrologic models for Ontario, as well as other empirical relationships pertaining to flow estimation, with the support of GIS to provide various physiographic and climatic inputs. OFAT is a useful tool that effectively and efficiently manages spatial watershed databases and performs hydrologic analyses to support decisions related to water resources planning and management in Ontario.

The framework of OFAT can be found in the end of this chapter. In addition to the hydrological models, it should be noted that there are some other potential modelling components as shown in the framework (e.g., fisheries models). It is hoped that in the future OFAT can be used to support other ecological models that may require flow information.

Why Use OFAT?

“What are the flow regimes for a watershed of interest?” is a question frequently faced by engineers, biologists, river scientists, resource managers, planners, regulatory agencies, hydro, and forestry companies. Baseline flow information is needed to:

- design hydraulic structures such as culverts, bridges, dams, etc.
- protect or enhance fish habitat
- support an ecosystem approach to land/water management

Unfortunately, the question is usually difficult to answer because streamflow data is scarce for the majority of river systems in the world. The high costs to install/maintain hydrometric stations, particularly for those in underdeveloped or remote regions such as the northern part of the province of Ontario, contribute to the scarcity of flow information. In many cases, predictive hydrologic models are required to estimate flow regimes at an ungauged site.

A number of hydrologic models, based upon regional analysis of flow data at gauging stations in Ontario, have been developed to estimate various flow regimes for ungauged watersheds in Ontario. However, if a hydrologic model is used to support decision-making processes related to water resources planning and management, it cannot produce realistic results unless all parameters used in the model can be properly defined. Implementation of hydrologic models often requires dealing with large quantities of spatial data pertaining to a watershed (including climate, landforms, land cover, soil/geoology, etc.) to determine model inputs. Preparation of
model inputs can be laborious, repetitive, costly, and error prone if done manually. To effectively and efficiently manage various spatial watershed databases and perform hydrologic analyses, a system is needed that can estimate flow regimes based on the most updated watershed information. As a result, more comprehensive assessment of risks associated with alternate watershed management decisions can be made.

A GIS provides an efficient way to store, retrieve, analyze, and display a large volume of spatial data. Applications of GIS technology in the area of water resources have been steadily progressive over the past three decades. The use of GIS in hydrologic modelling leads to considerable time and cost savings when preparing modelling inputs such as climatic and physiographic parameters required by models.

The GIS-based OFAT application allows the efficient assessment of various flow regimes (e.g., low flows, flood flows, etc.) for a watershed of interest anywhere in Ontario. The flow information can be used to support diverse planning and management decisions related to watershed resources.

Who Should Use OFAT?

- water resources planners
- water resources managers
- water resources engineers
- riverine/watershed scientists and researchers
- information managers
- aquatic biologists
- instream flow developers
- instream flow regulators
- stakeholders
- field staff

How OFAT Works?

OFAT has been developed in ArcView GIS 3.2a (ESRI, 1996) with the Spatial Analyst Extension 2.0 (ESRI, 1996) loaded, by using the AVENUE programming language. OFAT is made up of two primary components: software and databases.

Software
The ArcView project file, OFAT.apr, contains the software to perform OFAT functions including:
- automatic watershed delineation
- calculation of watershed parameters as well as summary of watershed information, and
- hydrologic modelling.
Flow information (e.g., flood flows, low flows, etc.) can be derived for a watershed anywhere in Ontario by using OFAT, after the watershed has been delineated and watershed parameters calculated. At present, OFAT contains a number of regional hydrological models and empirical relationships to generate flow information. Each model and relationship requires specific climate/physiographic inputs. The following lists five flow model categories currently included in OFAT. Each category contains a number of flow models:

1. Low Flow Prediction Models (LOF)
   - Isoline Method (MOEE, 1995)
   - Graphical Index Method (MOEE, 1995)
   - Statistical Index Method (MOEE, 1995)
   - Regression Method (MOEE, 1995)
2. Flood Prediction Models (HIF)
   - Index Flood Method (Moin & Shaw, 1985)
   - Index Flood Method With Expected Probability Adjustment (Moin & Shaw, 1985)
   - Primary Multiple Regression Method (Moin & Shaw, 1985)
   - Secondary Multiple Regression Method (Moin & Shaw, 1985)
   - Multiple Regression Method (MNR, 2000)
   - Dimensionless Flood Frequency Method (MNR, 2000)
   - Regional Flood Frequency Method (MNR, 2000)
   - Isoline Method (MNR, 2000)
3. Mean Annual Flow Prediction Model (MAF)
   - Isoline Method (Environment Canada, 1986)
4. Minimum Instream Flow Requirement Models (IFR)
   - Montana Method - October to March (Tennant, 1976)
   - Montana Method - April to September (Tennant, 1976)
5. Bankfull Discharge Prediction Model (BFQ)
   - Annable Bankfull Discharge Model (Annable, 1994)
   - Leopold Bankfull Discharge Model (Leopold et al., 1964)
   - Dury Bankfull Discharge Model (Dury, 1973)

Databases

Databases required by and included in OFAT are as follows:
- Digital Elevation Models (DEMs) (created by MNR) based on 1:10,000 and 1:20,000 Ontario Digital Topographic Database (ODTD – formerly Ontario Basic Mapping, OBM) (MNR, 1996). Four different resolutions of DEM cell size have been created by MNR:
  - 10m*10m (southern Ontario only) (MNR, 2002)
  - 20m*20m (northern Ontario only) (MNR, 2002)
  - 100m*100m (all of Ontario) (created by the OFAT project)
  - 1km*1km (all of Ontario) (created by the OFAT project)

All the DEM databases contained in OFAT have been organized in provincial tertiary watersheds (e.g., 4LA, 4LB, etc.) except for 1km*1km DEMs which have been organized in the 13 major basins in Ontario (e.g., the Moose River Basin, the Lake Superior Basin, etc.);
Note: The DEMs of 10m*10m resolution for southern Ontario are not currently included in OFAT Version 1.0. This is because of issues related to the large file size and efficiency in data processing for the 10m*10m DEMs organized in tertiary watersheds. To overcome these issues, a plan is underway to organize the 10m and 20m resolution DEMs into the provincial quaternary watersheds (e.g., 4LA-01, 4LA-02, etc.). Therefore, 10m*10m DEMs for southern Ontario will be included in a future upgraded version of OFAT.

- 1km*1km DEM based on 1:250,000 NTS elevation data (Mackey et al., 1994);
- Databases extracted from Natural Resource Values Information System (NRVIS), including rivers, lakes, wetlands, single-line waterflow, roads, etc. (MNR, 1997);
- DEM-related databases including flow direction, flow accumulation, and raster-based drainage network (created by the OFAT project);
- Databases extracted from the River Information Management System (RIMS) including the major basin boundaries, tertiary watershed boundaries, etc. (Moore and Chang, 1999);
- Ontario Land Cover Data Base with 25m*25m cell resolution (MNR, 1997);
- Soil Landscape of Canada at 1:1,000,000 scale, i.e., CANSIS (Agriculture and Agri-Food Canada, 1996);
- Ontario Land Inventory at 1:1,000,000 scale (MNR, 1997);
- Surficial Geology of Ontario at 1:1,000,000 scale (Perera et al., 1996);
- Quaternary Geology of Ontario at 1:1,000,000 scale (MNDM, 1997);
- Runoff Curve Number (CN) databases with 25m*25m cell resolution, created by the OFAT project using the SCS method (SCS, 1972);
- GIS layers such as mean annual precipitation, which are created from the Canadian Daily Climate Data CD (Environment Canada, 2001);
- Maps that are digitized from the report entitled “Water Quantity Resources of Ontario” (MNR, 1984);
- Databases, maps, equations, tables, charts, and relationships that are digitized from reports entitled “Flood Regionalization for Ontario” (MNR, 2000), “Regionalization of Low Flow Characteristics” (MOEE, 1995), and “Canada/Ontario Flood Damage Reduction Program - Regional Flood Frequency Analysis for Ontario Streams” (Moin and Shaw, 1985); and
- Equations, tables, and relationships that are automated from existing Instream Flow Requirement (IFR) models and Bankfull Flow (BF) models.
Ontario has been divided into 13 major basins (as shown in the following map) to effectively and efficiently manage the OFAT databases.

1. ✔ Moose River Basin
2. ✔ Albany River Basin
3. ✔ Attawapiskat River Basin
4. ✔ Ekwan River Basin
5. ✔ Winisk River Basin
6. ✔ Severn River Basin
7. ✔ Nelson River Basin
8. ✔ Lake Superior Basin
9. ✔ Lake Huron Basin
10. ✔ Lake Erie Basin
11. ✔ Lake Ontario Basin
12. ✔ Ottawa River Basin
13. ✔ Other Basins

What can you do with OFAT?

OFAT can be used to support the following watershed-related business areas:

- **Water management/planning** - Use OFAT in conjunction with other models to assist in deriving water allocation strategies (e.g., determining minimum flow requirements for fish habitat protection, recreation use, or water quality; hydropower peaking/ramping rate impact assessment; relations of flow scenario to water levels, etc.)

- **Fish habitat rehabilitation** - Use products/outputs from OFAT to assist in developing design criteria to protect or enhance fish habitat (e.g., fish spawning habitat enhancements via natural channel design).

- **River/valley segment classification systems** - OFAT would provide the hydrological component of systems presently being developed for classification of aquatic communities within rivers and streams in Ontario.

- **Water crossings design** - Use OFAT as a comparative tool to examine calculation methods used to determine opening size of water crossings such as culverts and bridges to ensure flow efficiency as well as fish passage.

- **Forest hydrology** - Use OFAT to generate hydrologic base for examining changes in local/regional hydrology as a result of forest disturbance.

- **Waterpower** - OFAT can be used to assist in estimating capacity of hydropower for potential hydro sites in Ontario.
• **Environmental assessment** - OFAT can be used to assist in evaluating fish habitat based on stream behaviour and characteristics when conducting environmental assessment for proposed instream development projects.

• **Update/Development of models** – OFAT provides a framework to facilitate the update of existing hydrologic models and the development of new hydrologic models.

**System Requirements**

**Hardware**

- Pentium II processor or higher
- 256 MB RAM or more preferred, 128 MB RAM minimum
- OFAT databases are organized in the context of major basins. It is estimated that the total size of OFAT databases for all the thirteen basins in Ontario is about 50 GB (1GB = 1,000 MB). However, the OFAT installation software provides users with the flexibility to select major basin(s) and DEMs of different cell size for which they would like to install the related databases on their hard drive. It is estimated that about 3 to 8 GB free hard disk space is required for the complete installation of a selected major basin, depending on its size. Disk space of 50 MB is required for OFAT software installation and an additional 400 MB system temporary space is required for running OFAT efficiently and smoothly.
- CD or DVD drive
- 17-inch or larger colour monitor preferred, 15-inch high-resolution colour monitor minimum

**Software**

- ArcView GIS version 3.2a or higher
- ArcView Spatial Analyst Extension 2.0 or higher
- Windows 95, 98, NT 4, 2000, or XP operating system
Where to Go for More Help

There are four different ways from which you can get help about using OFAT software and/or databases:

- You should read the User’s Manual carefully for answers to questions you may have about using OFAT. You can print extra copies of the Manual, if needed. The electronic copy of this User’s Manual is available in Adobe Acrobat Reader format (filename: OFAT User’s Manual.pdf). This file can be found in the \OFAT_APP\Document folder on the OFAT Setup CD or on your hard drive after you have installed OFAT. If you do not have Adobe Acrobat Reader installed on your computer, run the Adobe Acrobat Reader 4.0 installation software (filename: AR40ENG.exe) found in the \OFAT_APP\Other\ folder on the OFAT Setup CD or on your hard drive after you have installed OFAT.
- You can use the OFAT Online Help system when you are running the software. The Windows-standard help system can be accessed by selecting the ‘OFAT Help’ item under the ‘Help’ pull down menu when OFAT is running.
- You can visit the following OFAT Internet and Intranet web sites to get the most updated information about OFAT, including news, upgrades, user discussion forum, etc.:
  
  Internet site:  
  http://www.scienceandinformation.on.ca/nesi/ofat  
  Intranet site:  
  http://mnronline.mnr.gov.on.ca/spectrasites/nesi/nesihomepage.cfm

- You can also reach the OFAT Development Team to get help by contacting:
  
  Dr. Chiadih Chang, OFAT Team Leader  
  Northeast Science & Information  
  Ministry of Natural Resources  
  Highway 101 East, P.O. Bag 3020  
  South Porcupine, Ontario 
  Canada P0N 1H0  
  Tel: (705) 235-1214 (9:00 a.m. – 4:30 p.m. EST, Monday-Friday)  
  Fax: (705) 235-1251  
  E-mail: chiadih.chang@mnr.gov.on.ca
OFAT includes a series of GIS-based flow assessment techniques to estimate various flow regimes. These regimes include flood flows, low flows, mean annual flow, bankfull flow and instream flow requirements for a watershed in Ontario. OFAT involves the automation of regional hydrologic models, using GIS to provide the required input parameters. The parameters are derived from GIS databases such as landform, climate, soil, land cover, and surficial geology. OFAT can be used as a decision support tool in watershed planning and management, providing decision makers with valuable, predicted flow information.
How to Install OFAT

The following steps show how to run the OFAT Setup program to install OFAT software and/or databases:

1. If Windows is not running, start it now.

2. Insert the OFAT Setup CD into your CD-ROM drive. The OFAT Setup program will start automatically and the following welcome dialog box will appear. Go to Step 6 to continue the OFAT installation. Otherwise, if you do not see the following dialog box, proceed to Step 3 to continue.

3. Click the ‘Start’ button on the Windows taskbar. Windows will open the following ‘Start’ menu. Select the ‘Run’ menu item.
4. Windows will open the following ‘Run’ dialog box. Type the drive letter (e.g., d:) of the CD-ROM containing the OFAT Setup CD followed by \setup.exe. To search for the setup.exe file location, click ‘Browse’.

5. Click ‘OK’. Windows will run the OFAT Setup program. The welcome dialog box as shown in Step 2 will appear.

6. Click ‘Next’. The following dialog box will appear. You are asked to specify a source drive (i.e., a CD-ROM drive) from which the OFAT Setup and data CDs will be read. You are also asked to specify a destination drive (i.e., a hard drive) to which you would like to install OFAT software and databases.
7. Click ‘Next’. The following menu will appear and will ask you to select one of the following options for OFAT installation:

- Install both OFAT software and databases
- Install OFAT software only
- Install OFAT databases only

The second and third installation options will only be available for selection if OFAT has previously been installed on the computer. If the second option is selected (i.e., “Install OFAT software only”), by clicking ‘Next’, the Setup program will skip step 8 and go to step 9 directly.

8. Click ‘Next’. The following dialog will appear that asks you to select major basin(s) of Ontario and DEMs of different cell resolutions, for which related databases will be installed on the destination drive of the computer. For example, the Moose River Basin and the Lake Superior Basin as well as available DEMs for the two selected basins are checked in the dialog box below. Note that as soon as a basin is selected, the checkboxes will be selected for DEMs available for that basin. You can select or unselect the checkboxes as you wish except the checkbox of the 1km*1km DEM, which will always remain selected. After you have made your selections, click ‘Next’.
9. The following message will appear showing a summary of required and available disk space. If the destination drive of the computer does not have enough space to install OFAT, the ‘Install’ button will be dimmed out. In this case, you can click ‘Back’ to change your installation settings such as the destination drive, major basin, and DEM selections.

![Disk Space Check]

10. Click ‘Install’. The following ‘Ready to Install OFAT’ message box will appear. At this point, OFAT Setup program has gathered all the necessary information for installation.

![Ready to Install OFAT]

Please note that it may take a while to install OFAT. Please read each subsequent message box carefully before you change a CD. Make sure that you insert a correct CD before clicking OK.
11. Click ‘OK’. The OFAT Setup program will start copying files from the CD-ROM drive to the specified destination hard drive. Once all the files contained in the inserted CD have been copied to the destination drive, the following message box, or similar, will appear and ask you to insert a specific data CD of a selected basin into CD-ROM drive.

Note: Please make sure that you insert the correct data CD of a selected basin into CD-ROM drive in the order of CD #1, #2, #3…

12. Click ‘OK’ after you have inserted the correct data CD of the basin shown in the message box in Step 11 into the CD-ROM drive. Repeat this step until all the data CDs for each of the selected basins have been copied to the destination drive. Please be patient. The copying process will take some time to complete.

13. Once all the data CDs of every selected basin have been successfully copied to the destination drive, the following message box will appear. This message will show you how to start OFAT software.

Note: If you don’t see any OFAT shortcut on the Desktop or in the Start menu as described above, you can also start OFAT by double-clicking the OFAT.APR file which is located under C:\OFAT_APP\APR folder.
14. Click ‘OK’. The ‘Read Me’ dialog box will appear containing the most up-to-date information about OFAT. Please read the entire document carefully.

15. Click ‘Finish’. You have now finished the OFAT installation. An OFAT shortcut will automatically be created on your Desktop. To start OFAT, double-click on the shortcut icon. In addition, an OFAT program folder will be created allowing you to start OFAT through the following steps:

1) Click the ‘Start’ button on the Windows taskbar.

2) Select ‘Programs’ from the ‘Start’ menu.

3) Select ‘OFAT Version 1.0’ from the ‘Programs’ folder.

4) Click ‘OFAT’ option from the ‘OFAT Version 1.0’ folder.

After the installation is finished, you will find two folders created in the specified destination drive: ‘OFAT_APP’ and ‘OFAT_DAT’. The ‘OFAT_APP’ folder contains OFAT software and other supporting files, while the ‘OFAT_DAT’ folder contains databases of the basin(s) you chose to install.
Note: In the process of running the OFAT Setup program, you may click ‘Back’ on the current dialog box to return to the previous dialog box so that you can change Setup settings and/or selections.

Note: While running the OFAT Setup program, you may click ‘Cancel’ in the current dialog box to interrupt the installation. When ‘Cancel’ is clicked the following message box will appear. If you click ‘Resume’, the Setup program will return to the previous dialog box. If you click ‘Exit Setup’, the installation will end immediately. In this case, the Setup process is incomplete. Although some of the OFAT folders/files may have already been copied to the destination drive, you will have to run the Setup program again at a later time to complete installation, enabling OFAT to run properly.

**Cancel OFAT Setup?**

Setup process is incomplete! If you quit the Setup now, OFAT will not be installed!

To run OFAT properly, you may have to run the Setup program at a later time to complete installation.

To continue installing the program, click Resume. To quit the Setup program, click Exit Setup.
Getting Started: The OFAT Way

In this chapter you will find out how to:

- start OFAT
- run an OFAT example
- exit OFAT

The following information is a basic overview of the OFAT process for delineating watersheds, deriving/summarizing watershed information, and calculating various flows. For more detailed information on specific OFAT functions, see the appropriate chapter.

The exercises in this chapter are intended to lead you through the major functions of OFAT. Each exercise builds on the previous one, so it is important to follow them in order. This will ensure that you learn all the basic functions that OFAT provides.

**Note:** The database of the Moose River Basin has been chosen for these exercises. However, if you have not loaded the data for this basin, data for any other OFAT major basin can be used.

Starting OFAT

Double clicking the OFAT icon on your desktop will open ArcView and start the OFAT application.
A welcome window will appear. After a few seconds, it will close and the ‘Basin Index Map of Ontario’ will appear. This map allows you to select a major basin. Basins available for selection are colour coded and named within the table of contents. If the database associated with a basin is not currently installed, the basin will be coloured grey and will not be available for selection.
Quick Start: An Example

Selecting a Basin

With the tool selected on the toolbar, place your cursor on the major basin of interest and click to select.

Delineating or Importing a Watershed?

Once a major basin is selected the following dialog box appears:

Select an option using the radio buttons and press ‘OK’.

If the ‘Delineate a watershed using a DEM?’ option is selected, the tertiary watershed index map will be displayed. This map contains more detailed geographic information that will allow the user to narrow down the area of interest. The name of the selected major basin will be shown in the title of the map.

If the ‘Import an existing watershed?’ option is selected, it will only allow for WIES to run. Using WIES will be reviewed later in this chapter.

For this example, the ‘Delineate a watershed using a DEM?’ option has been selected. This option leads to a map of the selected major basin that has been divided into tertiary watersheds.
Selecting a Tertiary Watershed

The displayed map will allow the selection of a tertiary watershed in order to narrow down the area of interest.

With the tool on the toolbar selected, place the cursor on the tertiary watershed of interest and click to select. You will then be prompted to select a DEM to be used for delineating a watershed.
Note: In general, the larger the watershed you want to delineate, the coarser the resolution of DEM you choose. Finer resolution DEMs generally require longer processing time and larger temporary disk space.

The DEMs currently available will be active and selectable. Select a DEM and click ‘OK’.

**Specifying a Watershed Outlet**

You will be prompted to select a method for identifying the location of the watershed outlet.

The ‘Point and Click the Outlet’ option allows the user to select a watershed outlet using the mouse.

The ‘Enter the Co-ordinates Using the Keyboard’ option allows the user to enter the easting (X) and northing (Y) of the outlet point. These co-ordinates must be in UTM NAD 83 CNT projection.

For this example, select the ‘Point and Click the Outlet’ option and press ‘OK’.
Delineating the Watershed

The ‘Selected Watershed Area’ will appear and the tool will become active. The initial ‘Selected Watershed Area’ shows the whole selected tertiary watershed within the viewing area.

It is recommended that the map be zoomed into the area of interest. This will allow the watershed outlet to be identified with relative ease.

In the ‘Selected Watershed Area’, the blue blocked lines represent the raster-based drainage network that was created using the selected DEM. The network lines should generally correspond to the river lines represented in the vector stream data, which are symbolized using a thin light blue line. It is important that the raster-based drainage lines be used to identify a watershed outlet. When a point is selected, a message box will appear giving the UTM easting (X) and northing (Y) co-ordinates, along with the elevation (Z) for the watershed outlet.
Click ‘Yes’ to continue if the selected outlet is on the point of interest. Clicking ‘No’ will allow the selection of another point.

**Note:** If the watershed outlet you have selected is on the main channel and involves the merging of upstream tertiary watersheds, a warning message will appear asking if you would like to continue. For this example, please select ‘No’. This option will be explained in the following chapter.

The program will then delineate the watershed upstream from the selected outlet and add the watershed boundary to the ‘Selected Watershed Area’ map. The ‘red square’ on the raster-based drainage line represents the outlet (pour point) of the delineated watershed and the green area represents the spatial extent of the delineated watershed.

**Note:** For colour illustrations, please refer to the electronic copy of this manual (filename: OFAT User’s Manual.pdf)
Calculating Watershed Parameters

From this point, the ‘Watershed Calculator’ button will become active, allowing access to the Calculator interface. This function will calculate selected parameters of the delineated watershed.

![OFAT Watershed Calculator](image)

The items from the ‘Parameters to Calculate’ list are required to run flow models currently in OFAT. Any item from the ‘Optional Parameters’ list can be added to the ‘Parameters to Calculate’ list by selecting it from the list on the left, then clicking the ‘Add’ button. This will add the parameter to the ‘Parameters to Calculate’ list. To remove an added optional parameter from the ‘Parameters to Calculate’ list, select it and click the ‘Remove’ button. To run the calculations, click the ‘Calculate’ button. The selected parameters will be calculated and the results will appear in the ‘Watershed Calculator Results’ window (not shown). Click ‘OK’ on the window to close it.
Selecting and Running Models

After the watershed parameters are calculated, the ‘Flow Prediction Models’ button will become active and the ‘Flow Prediction Models’ interface can be accessed. The interface allows the selection of flow models from five available categories.

![Select the desired Flow Prediction Model(s)](image)

Clicking on the desired model category (e.g., Bankfull Discharge Prediction Models) will open the corresponding model selection window (not shown). Within a model selection window, select the models of interest and click ‘OK’. This will add the models to the list on the ‘Flow Prediction Models’ interface above.

If a model needs to be removed from the list, select the model and click the ‘Remove’ button. If all models need to be removed, click ‘Clear All’. Once all desired models have been added to the list, click the ‘Run Models’ button. This will calculate the flow values of the selected models (e.g., 7Q_2, 7Q_20, for LOF: Graphical Index Method), which will be displayed in the ‘View Results’ menu.
Results for the Selected Flow Prediction Models

The ‘View Results’ menu is divided into five available categories for viewing. Clicking on any of the active buttons will display the results for that category (not shown). The ‘View All’ button will display the results for all the selected models in the same window.

\[\textbf{Note: When a button is not active, no models in that category were selected to run.}\]

When modelling results need to be saved, ‘Export All Results’ on the ‘View Results’ menu can be used. This process prompts for a file name and file type, then exports all of the results to the user-specified file.
Watershed Information Extraction System (WIES)

This module can be accessed after a watershed is imported or at any time after a watershed is delineated. To open WIES, click on the button and the following WIES main menu will be displayed:

![Watershed Information Extraction System (WIES): Select data categories.]

The WIES main menu allows the selection of data layers to be clipped to the current delineated watershed. Six data categories are available for selection, each represented by a button on the menu. A layer selection dialog box will appear after a category (e.g., Geology) has been chosen. To select a data layer, check the boxes on the dialog box. Once all selections have been made for the category, click the ‘Return to Main’ button to return to the WIES main menu. The selected data layers will be displayed in the list on the WIES main menu. Data layers can be selected from as many categories as needed, returning to the WIES main menu after each selection. Once all the needed data layers have been selected, click the ‘Apply’ button.
WIES will then extract the selected layers to the watershed and display them in a map called ‘Watershed Information Extraction’.

The ‘WIES Summary Statistics’ button on the toolbar will now become active. This function summarizes the active data layers found in the ‘Watershed Information Extraction’ map. Once the button is clicked, the ‘Select Summary Preference’ dialog box is displayed. Select one or both of the checkboxes and press ‘OK’.
Viewing Summary Table and Chart

When the ‘View Summary Table and Chart’ option is selected, the user is prompted to select a field of an active data layer to summarize. A summary table (not shown) and chart (below) are then produced for each of the active data layers.

Exporting the Summary Table

When the ‘Export Summary Table’ option is selected, the user is prompted to select a field of an active data layer to summarize. The user is also prompted to select the type of export file. Once an export format is chosen, a menu appears prompting for the name and the path of the exported file.
Exiting OFAT

At any time during the OFAT session you may exit the program by clicking on the × in the upper right corner of the ArcView window or the upper right corner of the Project window. You may also exit OFAT through the ‘Exit’ item in the ‘File’ pull down menu. A dialog box will appear verifying if you want to exit the program.
Watershed Delineation

Four major steps are involved in delineating a watershed.

1. Selecting a major basin
2. Selecting a tertiary watershed
3. Selecting a DEM
4. Specifying a watershed outlet

Step one and two are used to narrow down the geographical location within Ontario to an area of the user’s interest. The fourth step involves selecting the location of the watershed outlet using the mouse or by entering the UTM co-ordinates using the keyboard.

Selecting a Major Basin

The first map in OFAT is the ‘Basin Index Map of Ontario’ showing the 13 major basins. Basins available for selection are colour coded and named within the table of contents. If the database associated with a basin is not currently installed, the basin will be coloured grey and will not be available for selection.
You can select a major basin by using the tool on the toolbar. This tool is active when the ‘Basin Index Map of Ontario’ is displayed. Place the cursor over the desired basin and click. Another selection method is available through the ‘Basin’ pull down menu, which displays the basin names available. Find the desired basin and select it.

If a major basin is selected by using the tool, the following message will appear, asking the user to verify their selection.

Clicking ‘No’ will reopen the ‘Basin Index Map of Ontario’ and allow another selection to be made.

**Note:** At any time during an OFAT session if a different major basin is required, click the button or choose the ‘Basin Index Map of Ontario’ item in the ‘Watershed Map’ pull down menu. This will open the ‘Basin Index Map of Ontario’ map.
Click ‘Yes’ to proceed. The tertiary watershed index map appears with the name of the selected major basin. When this map is first displayed, the following menu will appear asking if a watershed is to be delineated or imported.

![Menu for Delineate or Import Watershed](image)

When the ‘Delineate a watershed using a DEM?’ option is selected, the tertiary watershed index map will become active.

When the ‘Import an existing watershed?’ option is selected, please refer to the ‘Importing a Watershed’ section of this chapter.
Selecting a Tertiary Watershed

The tertiary watershed index map shows the selected major basin divided into tertiary watersheds. Selected communities, rivers and lakes are visible on this map to help identify the desired tertiary watershed, which contains the watershed outlet of interest.

At this point, the tool will become active on the toolbar. This tool is necessary to select the tertiary watershed that contains the watershed outlet of interest. Once a tertiary watershed is selected, a message will appear asking the user to verify their selection.
If ‘No’ is selected, the tertiary watershed index map will become active again and another tertiary watershed can be selected.

Note: At any time during the OFAT session if a different tertiary watershed is required, click the button or choose the ‘Tertiary Watershed Index Map’ item in the ‘Watershed Map’ pull down menu. This will open the tertiary watershed index map of the currently selected major basin.

If ‘Yes’ is selected, the next step is to choose a DEM.

Selecting a DEM

DEM selection is a very important step in OFAT. The processing time and accuracy for watershed delineation is dependent on the selected DEM so the user should choose wisely. For example, it would not be wise to select a 1km resolution DEM to delineate a watershed with a drainage area of only 2.0 km².

Warning: Please keep in mind that generally speaking, the finer the resolution of DEM, the longer the processing time. However, finer resolutions are recommended for delineating smaller watersheds due to higher accuracy.

OFAT gives the choice of DEMs at seven different resolutions as illustrated in the menu below. However, some options may be dimmed out because DEM data for that option is unavailable or not installed.

Select the desired DEM and click ‘OK’ to continue. The ‘Cancel’ button will return the user to the tertiary watershed index map from which a different tertiary watershed can be selected.

Note: Currently the ‘User Specified DEM’ option is not available.
Specifying a Watershed Outlet

After the DEM is selected, the ‘Select a Method to Input Watershed Outlet’ menu appears. This allows the user to choose the method for inputting the watershed outlet.

![Select a Method to Input Watershed Outlet](image)

**Point and Click the Outlet**

When the ‘Point and Click the Outlet’ option is selected, the ‘Selected Watershed Area’ map will be displayed. This map contains detailed layers of rivers, roads, lakes and wetlands, etc. The general outline of the selected tertiary watershed is coloured in purple with DEM-related grids extending ten kilometres beyond the outline.

*Note: If you wish to add your own data to this map to help facilitate finding the location of the watershed outlet, please refer to Appendix A for projection information of each major basin.*
At this point, it is recommended that the map be zoomed in to the area of interest. This will ensure that the cursor is clicked over the exact location of the watershed outlet.
The ‘Calculated Drainage’ (the blue raster layer) has been derived using the chosen DEM. Click on this raster-based drainage network to select a watershed outlet. When the watershed outlet is selected, a message will appear showing the UTM co-ordinates and the elevation of the outlet point.

![OFAT Information: Co-ordinates of Watershed Outlet]

To proceed with watershed delineation for the outlet point, click ‘Yes’. To return to the ‘Selected Watershed Area’ map and select a different outlet point, click ‘No’.

If the outlet location you have selected is not located on the blue raster-based drainage network, the following message will appear. To reselect an outlet point, click ‘No’. To continue with watershed delineation using the current selected point, click ‘Yes’. Please be advised that if you continue at this point, most likely the delineated watershed will not correspond with the desired area of your interest.

![OFAT Message: Continue?]

**Enter the Watershed Outlet Co-ordinates Using Keyboard**

The other method to input the watershed outlet for watershed delineation is by selecting the ‘Enter the Co-ordinates Using the Keyboard’ option.
If this option is selected, a menu appears prompting the user to enter the UTM X (easting) and Y (northing) co-ordinates for the outlet point.

* Note: Please refer to Appendix A for projection information of each major basin.

![Image of coordinate entry window]

If the process is cancelled by clicking on ‘Cancel’ button, the ‘Selected Watershed Area’ map will become active with the ‘Point and Click’ tool activated.

![Image of watershed tool message]

Once the co-ordinates are entered, click ‘OK’. The ‘Selected Watershed Area’ map becomes visible with a yellow dot showing the location of the entered co-ordinates. A message appears asking if the location of the dot was the one intended.
Clicking ‘Yes’ will allow the process to continue and the watershed will be delineated with the entered outlet point. Clicking ‘No’ will return to the co-ordinate input menu where the co-ordinates can be re-entered.
The Delineated Watershed

After the watershed has been delineated, the ‘Selected Watershed Area’ map will zoom into the spatial extent of the delineated watershed, which appears in green with a red square. The red square represents the watershed outlet.

*Note:* The original tertiary watershed boundaries were manually traced and digitized based on 1:600,000 provincial paper maps, producing general boundary outlines ( coloured in purple). The boundaries delineated in OFAT are much more accurate since the DEMs were generated based on elevation data of a larger scale (i.e., 1:10,000 for southern and 1:20,000 for northern Ontario). In the future, new tertiary watershed boundaries will be generated using the most up-to-date DEMs so they will match the watershed boundaries delineated by OFAT.

At this stage, the ‘Watershed Calculator’ and/or the ‘Watershed Information Extraction System (WIES)’ can be accessed. Both of these components are explained in detail later in this manual.
Delineating Watersheds Spanning Multiple Tertiary Watersheds

If the outlet point of interest falls on the main channel of a downstream tertiary watershed, the watershed to be delineated will span multiple tertiary watersheds. It includes the tertiary watershed where the outlet is located and the related upstream tertiary watersheds in the current major basin. If this occurs, the DEM-related data will have to be merged in order to delineate the entire watershed. Currently, the merging function can only be applied to the DEMs with 100m resolution.

The 1km resolution DEM is another option to delineate a watershed spanning multiple tertiary watersheds. Since the 1km resolution DEM covers the extent of the entire major basin, the merging function is not required and processing time is substantially reduced.

If the resolution of the selected DEM is 10m or 20m, a message box similar to the one shown below will appear. Click ‘OK’ and the ‘Selected Watershed Area’ map will become active for another point selection.

![OFAT Message: Functionality Not Available]

Note: In order to select another resolution of DEM, the user must return to the tertiary watershed index map using the tool and reselect the tertiary watershed.

When using the merging function with the 100m resolution DEMs, a message box similar to the one below will appear. This message box shows the number of upstream tertiary watersheds that need to be merged.

![OFAT Message: ARE YOU SURE!]

Warning: Merging tertiary watersheds will take time! If it is known that the watershed of interest will be large, the user may consider using a 1km resolution DEM.

Clicking ‘No’ allows the user to select another outlet. If ‘Yes’ is chosen, the DEM-related data of all involved tertiary watersheds is merged and a watershed is delineated for the specified...
watershed outlet. The resulting delineated watershed will be shown in the ‘Selected Watershed Area’ map in green.

\[\text{Note: Not all of the data layers available in the original map are added for the upstream tertiary watersheds when merging DEM-related data. Only the layers needed for delineation and/or for other OFAT components will be added to the map.}\]

Once the DEM-related data have been merged, new watersheds delineated within the same tertiary watershed will use the merged data without a prompt regarding merging.
Saving the Watershed Boundary

After a watershed has been delineated, the ‘Save Watershed’ button becomes available. This function allows the user to save the delineated watershed and/or watershed outlet to an ArcInfo grid and/or shapefile data set.

The export menu uses the check boxes on the left to select which data type to save the delineated watershed in. The filename of each watershed data type can be specified in the corresponding text boxes. If the path to the file is not known, the ‘Browse’ button will open up the file dialog, and the file path can be browsed to and the file name specified. The ‘Use same filename for both’ checkbox allows one filename to be entered for both data types. When this is checked only the top text input line will allow a filename to be entered.

Checking the ‘Save Watershed Outlet’ check box will save the outlet in the selected data types. The outlet file will be saved with the same name as the watershed file, but with an “_OL” added (see example below). Click ‘OK’ to start saving. A message box will display the success of each save process.
Importing a Watershed

The ‘Import an existing watershed?’ option from the menu below allows the user to import an ArcInfo grid or polygon shapefile. Currently imported watersheds can be used for analysis within the ‘Watershed Information Extraction System (WIES)’ component only.

Note: Imported watersheds must be in the same projection as the existing OFAT data. Please refer to Appendix A for projection information for each major basin.

When importing a watershed, a menu will appear asking if the size of the watershed is smaller or larger than one tertiary watershed. If the imported watershed is larger than one tertiary watershed only the 1km or 100m resolution DEMs are available for selection. When using the import option, the DEM will not be used for watershed delineation but it is still needed for some WIES functions.
Importing Watersheds Smaller Than One Tertiary Watershed

When the ‘Smaller than one tertiary watershed?’ option is selected, the program will prompt you to select the tertiary watershed in which the imported watershed falls within.

As with the ‘Delineate a watershed using a DEM?’ option, described previously, the tertiary watershed is selected with the cursor using the tool. After selecting a tertiary watershed, a message box appears asking if the tertiary watershed selection is correct.

If the tertiary watershed selected is not the one of interest, clicking ‘No’ will allow another tertiary watershed to be selected. Clicking ‘Yes’ will continue the process and opens the following menu allowing a DEM to be selected.
After the choice of DEM, a message box will appear with the projection information for the selected tertiary watershed.

![Message Box: Import Information]

Warning: It is important that the imported watershed be in the appropriate projection for WIES to properly perform any information extraction.

At this point the watershed layer selection menu will appear. If the layer to be imported is an ArcInfo grid, set the ‘Data Source Types’ to ‘Grid Data Source’. This setting will only display grid layers in the file selection window. For shapefile layers, set the ‘Data Source Types’ to ‘Feature Data Source’. Select a layer and click ‘OK’.

![Select a Watershed Layer]

When the layer is selected it will be added to the ‘Selected Watershed Area’ map and the WIES component can be run.
Importing Watersheds Larger Than One Tertiary Watershed

When the ‘Larger than one tertiary watershed?’ option is selected, the process is the same as above, however the DEM selection is limited to 100m and 1km resolutions.

After the choice of DEM resolution, the DEM-related data will be merged, if necessary. This process may take time depending on the number of involved upstream tertiary watersheds. A message box will then appear with the projection information that should be used for the imported watershed layer.

! **Warning:** It is important that the imported watershed be in the appropriate projection for WIES to properly perform any information extraction.

At this point the layer selection menu will appear. If the layer to be imported is an ArcInfo grid, set the ‘Data Source Types’ to ‘Grid Data Source’. This setting will only display grid layers in the file selection window. For shapefile layers, set the ‘Data Source Types’ to ‘Feature Data Source’. Select a layer and click ‘OK’.

When the layer is selected it will be added to the ‘Selected Watershed Area’ map and the WIES component can be run.
Delineating a New Watershed

After a watershed has been delineated or imported, if a new watershed is needed within the same tertiary watershed, click the ‘Delineate New Watershed’ button. This option can also be accessed through the ‘OFAT’ pull down menu by clicking on the ‘Watershed Delineation’ item.

The following menu appears allowing the user to select a method of creating a new watershed.

! **Warning**: New delineated watersheds will replace previous delineated watersheds. OFAT will not automatically save the boundary of the delineated watershed. Please follow the procedures outlined in this manual to save any results generated by OFAT, if they are needed for future use.

Once a method has been selected, follow the steps previously described in this manual to create a new watershed.
Watershed Calculator

Accessing the Watershed Calculator

The Watershed Calculator component allows the user to calculate a variety of hydrologic parameters for the delineated watershed currently in the ‘Selected Watershed Area’ map. After a watershed has been delineated, you can run the ‘Watershed Calculator’.

There are two ways to access the ‘Watershed Calculator’ interface:

- Click the button on the toolbar.
- Open the ‘OFAT’ pull down menu, and then select the ‘Watershed Calculator’ menu item.

Note: The ‘Watershed Calculator’ button and menu item will only become available once a watershed has been delineated by OFAT. Currently, this feature is not available for watersheds that have been imported into OFAT.

Watershed Calculator Parameters

The Watershed Calculator interface, as shown on the following page, consists of two list boxes for watershed parameters:

- ‘Parameters to Calculate’ – these include the watershed parameters required to calculate the flow models currently in OFAT. Required parameters cannot be removed from the list and will be calculated every time the Watershed Calculator is run.
- ‘Optional Parameters’ – these include watershed parameters that are not required to run the flow models currently in OFAT but provide the user with additional information about the watershed.

A description of each parameter, along with their units and symbols used in OFAT, can be found in Appendix B.
At any time, the ‘Cancel’ button can be used to close the Watershed Calculator interface and the user will be returned to the ‘Selected Watershed Area’ map.

Selecting the Parameters

The parameters listed in the ‘Parameters to Calculate’ list box will be automatically calculated when the user clicks the ‘Calculate’ button. To add optional parameters, choose the parameter(s) from the ‘Optional Parameters’ list box. Once a selection is made, the ‘Add’ button will become active. Clicking the ‘Add’ button will remove the selected parameters from the ‘Optional Parameters’ list box and move them to the ‘Parameters to Calculate’ list box. All of the parameters in the ‘Optional Parameters’ list box can be added to the ‘Parameters to Calculate’ list box by clicking on the ‘Add All’ button.
Removing the Parameters

To remove optional parameters from the ‘Parameters to Calculate’ list box, choose the parameters to remove. Once a selection is made, the ‘Remove’ button will become active. Clicking ‘Remove’ will clear the selected parameters from the ‘Parameters to Calculate’ list box and return them to the ‘Optional Parameters’ list box. All of the optional parameters can be cleared by clicking ‘Remove All’.
Running the Watershed Calculator

To run the calculation for the watershed parameters chosen in the ‘Parameters to Calculate’ list box, click ‘Calculate’. While the parameters are being calculated, two new data layers (i.e., ‘End of Longest Channel’ and ‘1km Res. Watershed’) are created and added to the ‘Selected Watershed Area’ map. These two layers are needed when calculating some of the parameters and running some of flow models. Do not remove them from the map.

⚠️ **Note:** Some parameters may take longer to calculate if finer resolution DEMs are selected. Please exercise patience when calculating parameters using the 10m and 20m resolution DEMs.

⚠️ **Note:** The ‘Selected Watershed Area’ map will refresh multiple times while calculating parameters. Please wait until the ‘Watershed Calculator Results’ window appears before continuing.
Watershed Calculator Results

When the selected parameters have been calculated, the results will be displayed in the ‘Watershed Calculator Results’ window.

To save the results of calculation, click the ‘Export Results’ button which will be described later in the manual.

**Warning**: Running the ‘Watershed Calculator’ again for another delineated watershed will replace the calculation results of previous watershed.

At this point, the user can run flow models by clicking ‘Run Models’. This will close the ‘Watershed Calculator Results’ window and open the ‘Flow Prediction Models’ interface that will be described later in the manual.

When finished viewing the results, close the window by clicking ‘OK’ or by clicking the **X** in the top right hand corner of the window. This will return the user to the ‘Selected Watershed Area’ map.
To open the ‘Watershed Calculator Results’ window at anytime after the Watershed Calculator has been run, click the button in the toolbar or select the ‘Watershed Calculator Results’ item under the ‘OFAT’ pull down menu.

The button and menu option will only become active after the ‘Watershed Calculator’ has been run. If another watershed is delineated, these options will become inactive and all the calculated parameter results for the previous watershed will be replaced.

**Exporting Watershed Calculator Results**

From the ‘Watershed Calculator Results’ window, the calculation results of watershed parameters can be exported to a table. Clicking the ‘Export Results’ button will open a window that prompts the user to select the type of file to be created in the export process.
After the choice of file format is made, click ‘OK’. The following ‘Export Table’ window will appear where the file name and path can be entered. A default name will appear in the ‘File Name:’ text box, but this can be changed. Once the file name and path are specified, click ‘OK’ to start exporting.

At any time, the user can click ‘Cancel’ button to stop the export process. This will return the user to the ‘Watershed Calculator Results’ window.
Using OFAT for Flow Prediction: Hydrologic Modelling

This chapter will introduce the flow models included in OFAT, and describe the procedures used to generate and report various flow modelling results.

OFAT contains a number of regional hydrologic models and empirical relationships that generate flow information. After a watershed is delineated and the required watershed parameters/information are calculated/extracted, various flow regimes can be generated for the watershed.

Introduction of Flow Models in OFAT

OFAT currently contains five flow model categories, as listed below. Each category contains a number of models. Please see Appendix D for a brief description of each of the models currently in OFAT. The limitations of each model, if mentioned in the original literature, are also included in the Appendix. For details about each individual model, please refer to its original literature listed in the References section.

1. Low Flow Prediction Models (LOF)
   This type of model generates low flow such as \( mQ_n \) representing \( m \)-day low flow in a \( n \)-year return period. For example, \( 7Q_{20} \) represents the 7-day low flow in a 20-year return period.
   - Isoline Method (MOEE, 1995)
   - Graphical Index Method (MOEE, 1995)
   - Statistical Index Method (MOEE, 1995)
   - Regression Method (MOEE, 1995)

2. Flood Prediction Models (HIF)
   This type of model generates flood flows such as \( Q_n \) representing flood in a \( n \)-year return period. For example, \( Q_{10} \) represents the flood in a ten-year return period.
   - Index Flood Method (Moin & Shaw, 1985)
   - Index Flood Method With Expected Probability Adjustment (Moin & Shaw, 1985)
   - Primary Multiple Regression Method (Moin & Shaw, 1985)
   - Secondary Multiple Regression Method (Moin & Shaw, 1985)
   - Multiple Regression Method (MNR, 2000)
   - Dimensionless Flood Frequency Method (MNR, 2000)
   - Regional Flood Frequency Method (MNR, 2000)
   - Isoline Method (MNR, 2000)

3. Mean Annual Flow Prediction Model (MAF)
   This type of model generates the mean annual flow for the watershed.
   - Isoline Method (Environment Canada, 1986)
4. Minimum Instream Flow Requirement Models (IFR)
   This type of model relates mean annual flow to the flow ranges rated by the degree to
   which aquatic resources are protected. Flow ratings include flushing to maximum,
   optimal, outstanding, excellent, good, fair or degrading, poor or minimum, and severe
   degradation.
   - Montana Method - April to September (Tennant, 1976)
   - Montana Method - October to March (Tennant, 1976)

5. Bankfull Discharge Prediction Model (BFQ)
   Generally, this type of model relates the bankfull discharge to floods occurring in a 1- to
   2-year return period.
   - Annable Bankfull Discharge Model (Annable, 1994)
   - Leopold Bankfull Discharge Model (Leopold et al., 1964)
   - Dury Bankfull Discharge Model (Dury, 1973)

The user can select several models from different model categories, and then execute them in the
same run. This allows the user to compare the results from a variety of models (e.g., Isoline
Method versus Regression Method of Low Flow Prediction Model). After the selected flow
models are executed, OFAT reports the results of flow information for the delineated watershed.

- **Note:** Most models included in OFAT are regional hydrologic models. To estimate flows for
  a watershed, OFAT uses an appropriate map (e.g., low flow regions map, flood
  regions map) to determine automatically which region or sub-region the watershed is
  located. Then, appropriate sets of equations/relationships are used to calculate
desired flow information.

- **Warning:** Each flow model in OFAT has its own limitations. This means that the models
  included in OFAT should only be used for a watershed within the ranges of the
  parameters (e.g., drainage area) that were originally used for developing the
  models. Use of the equations/relationships is not encouraged outside of their
  parameter ranges. For example, using the Regression Method (MOEE, 1995) in
  the low flow category for a small watershed would likely generate incorrect
  “negative” low flow values. It is strongly suggested that the original model
  document be referred to, or consult with a water professional, before using
  generated flow values for any decision making purpose.
Accessing the Model Interface

Flow models in OFAT calculate flow values for the current delineated watershed shown in the ‘Selected Watershed Area’ map.

The model interface can be accessed at any time after the ‘Watershed Calculator’ has been run. There are three ways available to access this interface:

- Click the ‘Run Models’ button on the ‘Watershed Calculator Results’ window.
- Click the button in the toolbar.
- Select ‘Flow Prediction Models’ item found in the ‘OFAT’ pull down menu.

⚠️ **Note:** OFAT does not currently have the functionality to run the flow prediction models for imported watersheds.

⚠️ **Note:** The button and ‘Flow Prediction Models’ pull down menu item are only active if a watershed has been delineated and watershed parameters have been calculated. If another watershed is delineated, Flow Prediction Models will be unavailable until the ‘Watershed Calculator’ is run for the newly delineated watershed.
The Flow Prediction Models Interface

The ‘Flow Prediction Models’ interface consists of five model category buttons and a list box for model selections.

Note: The ‘Waterpower Potential Estimation Models (WPP)’ category is not available at present.

By clicking on any of the categories, a selection menu will be displayed containing the available models for the selected category.

At any time, the ‘Cancel’ button can be used to close the ‘Flow Prediction Models’ interface and return the user to the ‘Selected Watershed Area’ map.
Selecting Models

To select a flow model under the selected category, click on the model you wish to run. For multiple selections, press and hold down the SHIFT key and select the desired models. When complete, click ‘OK’ to return to the main ‘Flow Prediction Models’ interface. The models that were selected will be added and displayed in the list box on the interface. Clicking ‘Cancel’ will return to the ‘Flow Prediction Models’ interface, but will not add any of the selected models to the list box.

Selecting Low Flows for the Isoline Method (MOEE, 1995)

Since the Isoline Method (MOEE, 1995) has more flow scenarios to select from than any other model in OFAT, choosing this method opens a separate flow selection interface. This interface allows the selection of different low flows to be estimated by this particular method.
The Isoline Method (MOEE, 1995) has 67 low flows to choose from. Select the appropriate low flows from the ‘Available Flows (Q)’ list on the left. When a flow has been selected, the ‘Add’ button will become active. Click ‘Add’ to add the flows to the ‘Selected Flows (Q)’ list on the right.

To make multiple selections from the ‘Available Flows (Q)’ list, hold down the SHIFT key and select the flows. Using the ‘Add All’ button will add every item in the ‘Available Flows (Q)’ list to the ‘Selected Flows (Q)’ list.
To remove items from the ‘Selected Flows (Q)’ list, highlight the flows you want to remove and click the ‘Remove’ button.

**Note:** The ‘Remove’ button only becomes active after an item is selected in the ‘Selected Flows (Q)’ list. As with the ‘Available Flows (Q)’ list, multiple selections can be made by holding down the SHIFT key and selecting the flows. To clear all entries in the ‘Selected Flows (Q)’ list, click ‘Remove All’.

When all the desired flows in the ‘Available Flows (Q)’ list have been added to the ‘Selected Flows (Q)’ list, click ‘OK’. This will return to the main ‘Flow Prediction Models’ interface.

The Isoline Method (MOEE, 1995) is added to the list box on the main ‘Flow Prediction Models’ interface. If you would like to make changes to the flows selected for this method, you can access the above interface directly through the ‘Flow Prediction Models’ interface by clicking the following button.

If there are no selections made for the Isoline Method (MOEE, 1995), clicking ‘OK’ will remove this method from the list box on the ‘Flow Prediction Models’ interface and the button, shown above, will be dimmed out.
Removing Models

In the ‘Flow Prediction Models’ interface, models can be deleted from the list box by selecting the model and clicking ‘Remove’.

*Note: In the list box on the ‘Flow Prediction Models’ interface, multiple selection is not available. Models may only be removed from the list box one at a time.*

To remove all the models from the list box at once, click ‘Clear All’.

Running Models

To run the selected models, click ‘Run Models’ on the ‘Flow Prediction Models’ interface. When the models have finished processing, the ‘View Results’ menu will open.
Viewing the Flow Model Results

The ‘View Results’ menu is divided into the five model categories similar to the ‘Flow Prediction Models’ interface. When a flow model from a specific category has been executed, the corresponding button will be active.

To view the model results, click on the category button in the ‘View Results’ menu. This will open the ‘Model Results’ window.

The ‘View All Results’ button on the ‘View Results’ menu will allow you to see all the modelling results in the same window.
The ‘Model Results’ window shows the title of the model category in the header of the window (e.g., High Flow Model Results). The window displays four columns of information about the models:

- **Category**: the three letter short form used to identify different model categories (e.g., HIF)
- **Model Description**: a descriptive name for each model
- **Flow**: the flow being calculated (e.g., Q₅, 7Q₃₀)
- **Result**: the flow result calculated by the model in cubic meters per second (cms)

Clicking ‘OK’ will close the window and return the user to the ‘View Results’ menu.

To close the ‘View Results’ menu, click ‘Close’. However, if at any time after a model has been executed, and before another watershed is imported or delineated, the ‘View Results’ menu can be accessed using one of two methods:

- Clicking the ‘Flow Prediction Model Results’ button
- Opening the ‘OFAT’ pull down menu and clicking the ‘Flow Prediction Model Results’ item
Exporting Flow Model Results

OFAT allows you to export the flow modelling results into a table by clicking the ‘Export All Results’ button on the ‘View Results’ menu. The ‘Export Table’ menu appears prompting the user to select the file type to be created in the export process.

After the choice of file type is made, click ‘OK’. The ‘Export Table’ window (shown below) will appear where the file name and path can be entered. A default name will appear in the ‘File Name:’ text box, but this can be changed. Once the file name and path are specified, click ‘OK’ to start the export process.

Model Warnings

Each flow model within OFAT was originally developed to work within a range of watershed parameters (e.g., drainage area). If the parameters for a delineated watershed are outside the limitations of a selected model, a ‘Model Warning Messages’ window will appear after the
models have been run. The information within these warning messages includes the model where a specific parameter(s) may not meet the criteria of the parameter ranges, and the watershed parameter(s) that is outside these ranges. Please read these warnings carefully. Extra information pertaining to the limits of each model can be found within the original model documents listed in the References.

The ‘Model Warning Messages’ window will also be shown when one model uses another model to find flow information. In these cases, the warning will include the models used. The following figure contains an example warning message for the Dury Model (Dury, 1973) in which $Q_{1.58}$ is used to estimate the bankfull discharge and is calculated using the Index Flood Method (Moin and Shaw, 1985).

After the warnings window has been closed by clicking ‘OK’, it can be accessed at any time from the ‘View Results’ menu by clicking on the ‘View Warnings’ button.

⚠️ Note: Please read the model warnings carefully. Professional judgement is needed when using flow values derived with parameters outside the specified model limitations.
Watershed Information Extraction System (WIES)

The Watershed Information Extraction System (WIES) is a component within OFAT that extracts and summarizes information from user-selected data layers for the delineated watershed. At this time, this is the only component in OFAT that can be used with an imported watershed.

Using WIES

WIES becomes available when the ‘Selected Watershed Area’ map is open and a watershed has been delineated or imported.

There are two ways to access the WIES component:

- Clicking the ‘WIES’ button on the toolbar; or
- Selecting the ‘Watershed Information Extraction System (WIES)’ item from the ‘OFAT’ pull down menu.

WIES Menus and Selections

When WIES is opened, the following WIES main menu appears. The data layers have been grouped into six categories, each represented by a button on the menu. The ‘OFAT Data Structure’ chapter in this manual explains the data in more detail.
The following lists the data layers and data type within each category:

<table>
<thead>
<tr>
<th>Category</th>
<th>Data Layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>Surficial Geology – coverage, Surficial Geology (Terrain Adjusted) – coverage, Quaternary Geology – coverage</td>
</tr>
<tr>
<td>Land Cover</td>
<td>Land Cover (28 Classes) – ArcInfo grid</td>
</tr>
<tr>
<td>Soil</td>
<td>Soil Landscapes of Canada – coverage, Ontario Land Inventory – coverage</td>
</tr>
<tr>
<td>Runoff Curve Number (CN)</td>
<td>CN₁ (Dry AMC) – calculation based on CN₁ grid, CN₂ (Average AMC) – ArcInfo grid, CN₃ (Wet AMC) – calculation based on CN₂ grid</td>
</tr>
<tr>
<td>DEM-Related</td>
<td>Digital Elevation Model (DEM) – ArcInfo grid, Slope – ArcInfo grid, Aspect – ArcInfo grid</td>
</tr>
<tr>
<td>User-Defined</td>
<td>User-Defined Layer 1 to 4 – ArcInfo grid or shapefile</td>
</tr>
</tbody>
</table>

*Note: See Appendix C for detailed information on the CN database.*
When a category button is pressed, a sub-menu appears. Select the data layer(s) of interest by checking the appropriate checkbox(es). The following figure is an example of the Geology category and the associated data layers.

The 'User-Defined' sub-menu (seen below) is slightly different from the other sub-menus. The user has the choice of using data not supplied by OFAT. Click on a text box and specify where the data is located. The user can define up to four data layers. Presently, these data layers must be shapefiles or ArcInfo grids.

! **Warning:** User-defined data must be in the appropriate projection. Please refer to Appendix A for projection information for each major basin.

When the ‘Return to Main’ button on a sub-menu is pressed, the user is returned to the WIES main menu, their selection(s) appearing in the list box.

If the user needs to change their selections, they can clear the entire list box on the WIES main menu by clicking on the ‘Clear All Selections’ button. Another option is to return to each individual sub-menu and make changes there. To clear all the selections of each sub-menu, click ‘Clear Selections’ or uncheck the selection.
Running WIES

When finished making selections, click ‘Apply’ on the WIES main menu to extract the selected data layers to the spatial extent of the delineated watershed. The ‘Watershed Information Extraction’ map will appear, displaying all the extracted data layers.

At any time before the ‘Apply’ button is clicked, ‘Exit’ can be pressed to close the WIES main menu and return to the ‘Selected Watershed Area’ map.
Data Summarizing Using WIES

At this stage, the results of the clipped data layers can be summarized in tables and charts. To access this function, click on the ‘WIES Summary Statistics’ button or select the ‘WIES Summary Statistics’ item in the ‘OFAT’ pull down menu while the ‘Watershed Information Extraction’ map is open.

Only active themes will be summarized. To make a theme active, click on the theme’s name in the Table of Contents (left side of the map). The theme will be highlighted to show that it is active. To make more than one theme active, hold down the SHIFT key while clicking on the themes to be made active.
The user now has two options for summarizing from the ‘Select Summary Preference’ menu:

These options can be selected by clicking in the appropriate checkbox(es). After selection, click ‘OK’.

The user is required to select a field they wish to summarize for each active theme. A menu, similar to the following figure, appears with a list of fields from each of these themes. Select a field and click ‘OK’ for each active theme.
‘Export Summary Table’ gives the user a choice of file types for the table to be exported in. Make a selection and click ‘OK’.

The user will also be prompted to select a path to store the file.

**Tables for Polygon Shapefiles**

The derived summary table for a polygon theme is similar to that seen on the next page. The six fields included are as follows:

- Shape
- The selected field for summarizing (e.g., Unit_name)
- Count (number of polygons)
- Sum_Area (area in square meters)
- Sum_SqKm (area in square kilometres)
- Percentage (percentage of area)
Tables for Grids

Summary tables for ArcInfo grids are slightly different than tables for shapefiles. ‘Value’ is always the field that is summarized for grids, so no field selection is needed. The fields included are as follows:

- Value (e.g., 1)
- Count (number of cells)
- Sum_Area (area in square metres)
- Sum_SqKm (area in square kilometres)
- Percentage (percentage of area)
- Name (associated with corresponding Value, if available (e.g., water))

<table>
<thead>
<tr>
<th>Polygon</th>
<th>Unit_name</th>
<th>Count</th>
<th>Sum_Area</th>
<th>Sum_SqKm</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polygon</td>
<td>Bedrock</td>
<td>23</td>
<td>1578750125.2439</td>
<td>15787502</td>
<td>58.28</td>
</tr>
<tr>
<td>Polygon</td>
<td>Fluvial deposits</td>
<td>1</td>
<td>14175064.6953</td>
<td>141751</td>
<td>0.52</td>
</tr>
<tr>
<td>Polygon</td>
<td>Glaciolfluvial ice-contact deposits</td>
<td>23</td>
<td>205972592.232</td>
<td>205972592</td>
<td>7.50</td>
</tr>
<tr>
<td>Polygon</td>
<td>Glaciolfluvial outwash deposits</td>
<td>21</td>
<td>199082061.0151</td>
<td>199082061</td>
<td>7.35</td>
</tr>
<tr>
<td>Polygon</td>
<td>Glaciolacustrine deposits</td>
<td>9</td>
<td>375319537.2228</td>
<td>375319537</td>
<td>13.96</td>
</tr>
<tr>
<td>Polygon</td>
<td>Lake</td>
<td>1</td>
<td>18151176.9063</td>
<td>18151176</td>
<td>0.57</td>
</tr>
<tr>
<td>Polygon</td>
<td>Organic deposits</td>
<td>15</td>
<td>79302852.8222</td>
<td>79302852</td>
<td>2.93</td>
</tr>
<tr>
<td>Polygon</td>
<td>Till</td>
<td>28</td>
<td>23820817.1339</td>
<td>23820817</td>
<td>8.79</td>
</tr>
</tbody>
</table>
Charts

The chart in the viewing option displays summary information for the selected field. The user can select whether they want the chart displayed with summary information in percentage or area.

Click ‘OK’ to proceed once the selection has been made. A chart similar to the following figure will appear.
Each theme is processed individually. The chart and table will both be displayed for one theme before the summary field for the next theme is chosen. To view all charts and tables at once, resize and rearrange the windows.

To summarize other themes that have already been extracted, go back to the ‘Watershed Information Extraction’ map, select different themes on the map and start the process over again. To return to the ‘Watershed Information Extraction’ map at any time while in the chart or table window, click on the button on the toolbar.

If new extracted layers are desired, return to the ‘Selected Watershed Area’ map by first clicking on the button and then clicking on the ‘WIES’ button to access the WIES main menu. Every time the ‘WIES’ button is clicked the previous selections are erased and the user is free to make new selections.

! **Warning:** Running WIES for new data layer selections will replace the results of previous selections. To save the results, use the export summary table function.
Batch Run

The Batch Run component allows single or multiple watersheds to be delineated without constant user interaction. Along with watershed delineation, any number of flow models and watershed parameters can be calculated in one batch run. Results are stored in an output table file.

! **Warning:** Running OFAT with fine resolution DEMs will create large temporary files that can quickly use up computer resources. Make sure there is sufficient space on the hard drive containing the system’s temporary directory (e.g., c:\temp) before running a batch containing several watershed delineations based on fine resolution DEMs.

Accessing the Batch Run

There are two ways to access the batch run:

- Click the ‘Batch Run’ button on the toolbar
- Select the ‘Batch Run’ item from the ‘OFAT’ pull down menu
A blank copy of the ‘Batch Run’ interface will open. All of the inputs for the batch run can be interactively completed from this interface.
Using the Batch Run

A batch run contains a list of watersheds to be delineated and analyzed. There are several sections on the ‘Batch Run’ interface that must be entered before a watershed can be included in a batch run:

- Basin
- Tertiary Watershed
- DEM
- Pour Point Co-ordinates (UTM)
- Save Watershed boundary (optional)
- Parameters
- Models (optional)
- Results Output File

Basin Selection

The ‘Basin’ combo box contains a list of all the major basins currently installed. To choose a basin, click on the arrow to the right of the combo box to open the selection list (as shown below). Scroll through the list and click on the desired basin.

The basin does not have to be selected if the desired tertiary watershed is known. Choosing a tertiary watershed before a major basin is selected will automatically select the proper basin. If a basin is selected first, only the tertiary watersheds within the basin will appear in the tertiary watershed list.

Tertiary Watershed Selection

The tertiary watershed is selected in the same way as the major basin is selected. The tertiary watersheds appearing in the selection list will vary depending on the major basin that is selected. If a basin has not been selected, a complete list of available tertiary watersheds will appear for selection. A selection at this stage will automatically choose the appropriate major basin. After a basin has been selected, only the tertiary watersheds within the basin will be available within the selection list.
DEM Selection

The DEM selection combo box will become active only after a selection has been made from both the tertiary watershed and basin combo boxes. When active, the DEM selection list will contain the available DEMs for the selected tertiary watershed.

Pour Point Co-ordinate Input

If known, the X and Y co-ordinates can be entered in the corresponding text lines. If the exact UTM co-ordinates of a watershed pour point are not known, the ‘Interactive Co-ordinate Selection’ button can be used. The interactive button will become active after a basin, tertiary watershed and DEM have been selected.

Clicking the ‘Interactive Co-ordinate Selection’ button will open the ‘Selected Watershed Area’ map and make the tool on the toolbar active (if the tool does not become active, click it). Click the pour point of interest using this tool. The ‘Batch Run’ interface will reopen and populate the X and Y co-ordinate lines with the co-ordinates from where the tool was clicked.

Note: It is recommended that when using the ‘Interactive Co-ordinate Selection’, the user zooms into the area of interest within the map before the pour point is selected. The ‘Interactive Co-ordinate Selection’ does not give a warning if a selection is made off the drainage network as when using the regular method.

Saving the Watershed Boundary

The ‘Save Watershed’ checkbox allows the watershed boundary to be saved for each individual watershed. This function is optional.

To save a watershed boundary, make sure the ‘Save Watershed’ check box has been checked. This will allow access to both the ‘File Name’ and the ‘Data Type’ options. The ‘File Name’ text box allows the file name and path of the watershed boundary to be specified. If the path to the new file is not known, clicking ‘Browse’ will open the file dialog. It is recommended to change the default name. The ‘Data Type’ combo box contains three choices; ‘Shape’ which...
will save a shapefile, ‘GRID’ that will save an ArcInfo grid, or ‘Both’ that will save a shapefile and a grid with the specified name.

**Parameter and Model Selection**

Parameters and models can be selected in the batch run. Clicking on the ‘Select Parameters’ or ‘Select Models’ buttons will access the appropriate selection menus (not shown). See the ‘Watershed Calculator’ chapter in this manual for information on selecting parameters and the ‘Using OFAT for Flow Prediction: Hydrologic Modelling’ chapter for information on selecting models.

After parameter and model selections have been made, click ‘Add to Batch’ in the appropriate selection menu to return to the ‘Batch Run’ interface. The selections made will appear in the appropriate list boxes. The selected parameters and models will be overwritten with subsequent selections or can be cleared totally using the corresponding clear button. In order to run any flow models, the parameters must be selected.

**Results Output File Selection**

The batch run creates a table that contains all of the results for each watershed in the batch. Three options for file type are available:

- dBase
- comma delimited text
- INFO
The default file type for the output table is dBase (.dbf). To change the file type, use the ‘File Type’ combo box. To change the default file path, either type the new path into the ‘Results Output File’ text line, or click on the ‘Browse’ button to access the file dialog. The file dialog allows the user to browse through the drives and folders to find the correct location and select a file to overwrite or type in a new file name.

![File Name dialog](image)

**Adding to Batch**

When all the required information is entered, the ‘Add To Batch’ button will become active. This button will move the entered information from the top of the interface to the Batch List at the bottom of the ‘Batch Run’ interface (shown below). When the batch run is executed, the watersheds in the list will be delineated and analyzed.

![Batch Run interface](image)

**Editing the Batch**

To edit a record in the Batch List, select the record by clicking on it. The information pertaining to that record will appear in the appropriate location on the ‘Batch Run’ interface. Edit
information that needs to be changed and click the ‘Add to Batch’ button to update the selected record.

If a selected record needs to be removed, clicking the ‘Delete Row’ button will clear the selected row. If the whole Batch List is incorrect, click ‘Clear Batch’. When this button is pressed, a message box will appear asking if the Batch List is to be cleared. Pressing the default ‘No’ will return to the ‘Batch Run’ interface. Pressing ‘Yes’ will clear the Batch List.

! **Warning:** If the Batch List has not been saved, there is no way to recover it once the list has been cleared or after the batch has been run.

**Saving Batch Files**

To save a Batch List, click ‘Save Batch to File’ in the ‘Batch Run’ interface. This will open the ‘Export Table’ dialog (shown below) where the name and path of the batch file is specified.

The exported table will be saved as a .dbf (dBase) file that can be reloaded into OFAT using the ‘Load File’ button on the ‘Batch Run’ interface.
Loading a Batch File

The ‘Load File’ button on the ‘Batch Run’ interface allows loading of a previously saved batch file, or a user-generated table with batch information. Clicking the button will open the ‘Select Batch File’ menu. This menu allows the user to browse to a file to import into the Batch List. If the selected file cannot be imported into OFAT, a warning message will appear and the loading operation will stop. A file must be in a dBase, delimited text or INFO format to be imported into the OFAT batch process.

![Select Batch File dialog](image)

If the selected file has been created using OFAT, it will automatically load into the Batch List. If the file has not been created with OFAT (e.g., created in MS Access), it still can be loaded using the ‘Field Select’ dialog that appears. The user is asked to identify the following fields within the imported table:

- X Co-ordinate
- Y Co-ordinate
- Name of the Major Basin
- Name of the Tertiary Basin
- DEM
- Decision to Save the Watershed
- File Name of the Watershed
- Data type of the Saved Watershed
- Name of the Results Output File
- Type of Results Output
- List of Parameters
- List of Models

Select the field that corresponds to the item shown in the ‘Field Select’ dialog message. If the item shown in the message is not available from the imported file, click ‘OK’ with the blank field selected or click ‘Cancel’, to take you to the next message. When each corresponding field has been identified, the file will be added to the Batch List. If a loaded file does not contain all
required information (e.g., DEM, co-ordinates), the records (watersheds) must be edited or they will not be delineated and analyzed.

Running the Batch

When the batch has been set up, click the ‘Run Batch’ button. Each record in the Batch List will be executed and saved in the specified file. Any record in the Batch List that can not be executed will be skipped. When all records have been completed, the following message box will appear:

When the batch run is completed, OFAT will return to the ‘Selected Watershed Area’ map.

! **Warning:** *If the Batch List has not been saved, there is no way to recover it once the list has been cleared or after the batch has been run.*
Batch Run Results

The batch run results will be added to OFAT as a table and saved to the specified file. To view the results table, click on ‘Tables’ in the ArcView project window and double click on the appropriate table.

The title of the table is the I.D. of the selected tertiary watershed combined with the selected DEM used in the batch run process (see figure above). The saved results file may also be accessed by using another program (e.g., MS Access).
OFAT Data Structure

Description of OFAT Application Folder Structure (OFAT_APP)

The OFAT software and supporting files are kept within the ‘OFAT_APP’ folder on the drive OFAT was installed. Several sub-folders used to organize components of the application are also contained in this folder. This folder can also be found on the OFAT Setup CD.

The following describes the file structure for ‘OFAT_APP’ as illustrated in the diagram above:

1. Av
   - Contains the Apr folder
   - May be used in future expansion of OFAT

2. Apr
   - Contains Ofat.apr project file (Ofat.apr is the OFAT software that contains all scripts and customizations within ArcView)
   - Contains Ofatdata.txt text file (used to define the ‘OFATDATA’ system variable that points to the ‘OFAT_DAT’ folder)

3. Backup
   - May be used in future expansion of OFAT

4. Document
5. Graphic
   - Contains all graphics used in the application

6. Help
   - Contains the Online Help file OFAT.hlp

7. Model
   - Models.txt is a text file which the application uses to display available flow models
   - Wshedtopology.txt is a text file which lists the topology of tertiary watersheds (i.e., upstream-downstream relationship)

8. Other
   - Stores other supporting files including the Adobe Acrobat Reader 4.0 installation software (filename: AR4ENG.exe)

9. Sound
   - Contains sound files used in the application

10. Vb
    - May be used in future expansion of OFAT

Description of OFAT Database Folder Structure (OFAT_DAT)

The OFAT database and supporting files are kept within the ‘OFAT_DAT’ folder on the drive OFAT was installed. To accommodate the large number and size of data files required for OFAT, the database was divided into a series of folders. The primary folder structure begins with the major basin names of Ontario (e.g., ‘Moose_River_Basin’), plus two folders titled ‘Other_Basins’ and ‘Whole_Ontario’. The number of major basin folders depends on the data that has been installed by the user. The data in the ‘Whole_Ontario’ folder is installed automatically during the initial set up in order to run OFAT properly. ‘Other_Basins’ contains several individual tertiary watersheds that flow directly into James Bay and Hudson Bay. This basin is treated in the same manner as the rest of the major basins.

◆ **Note:** Information on data formatting can be found throughout this chapter and in the ‘Metadata’ section of the OFAT Online Help.

◆ **Note:** Future versions of OFAT will enhance data importing capabilities. Currently, only the WIES component can be used with imported watershed data. Other components of OFAT require specific data formatting and folder structure.
OFAT DATABASE FOLDER STRUCTURE
The following describes data structure for ‘OFAT_DAT’ folder as illustrated in the preceding diagram. Data pertaining to the Moose River Basin is used as an example:

A1 ‘MOOSE_RIVER_BASIN’
- This is an example of a major basin folder showing its sub-folders.
- All the OFAT data pertaining to a major basin is stored in each of these folders named by corresponding major basin names.

A2 ‘WHOLE_ONTARIO’
- The contents of the ‘Whole_Ontario’ folder includes the ‘Legend’ and ‘MajBasin’ sub-folders.
- The ‘Legend’ sub-folder contains legend files that are used for legend text and graphics.
- The ‘MajBasin’ folder contains the ‘MajBasin’ coverage that allows the user to select a major basin.

B1 ‘Community’
- The ‘Community’ sub-folder contains a coverage of communities within a particular major basin.
- The ‘Community’ coverage is used for visual representation in the tertiary watershed index map.

B2 ‘Lake’
- The ‘Lake’ sub-folder contains a coverage of lakes and wetlands within a particular major basin.
- The ‘Lake’ coverage is used for visual representation in the tertiary watershed index map.

B3 ‘River’
- The ‘River’ sub-folder contains a coverage of the rivers within a particular major basin.
- The ‘River’ coverage is used for the visual representation in the tertiary watershed index map.

B4 ‘Road’
- The ‘Road’ sub-folder contains a coverage of the roads within a particular major basin.
- The ‘Road’ coverage is used for the visual representation in the tertiary watershed index map.

B5 ‘Tertiary_watershed’
- The ‘Tertiary_watershed’ sub-folder contains all the sub-folders of the tertiary watersheds within a particular major basin (e.g., sub-folder ‘w4la’ is for tertiary watershed 4LA) and the ‘Whole’ folder.
- All available data for a particular tertiary watershed is stored in each corresponding sub-folder.
- The ‘Whole’ sub-folder contains coverages of tertiary watersheds within a major basin.
B6 ‘Whole_watershed’
- The ‘Whole_watershed’ sub-folder contains several sub-folders that store 1km resolution grids pertaining to flow models, climate, and DEMs.
- All the data under this sub-folder covers the full spatial extent of a major basin.
- ‘Wb_mjr’ is the coverage for the boundary of the major basin.

B7 ‘Wies’
- The ‘Wies’ sub-folder contains all coverage and grid data needed in WIES. This data covers the full spatial extent of a major basin.
- ‘CN2’ is a 25m resolution grid used for extracting runoff curve numbers under average AMC (CNII). CNII is used to calculate CNI and CNIII. Refer to Appendix C for more details about runoff curve numbers.
- ‘Landcover28’ is a 25m resolution grid used for extracting land cover classifications.
- ‘Ontli’ coverage is used for extracting Ontario Land Inventory (OLI) data.
- ‘Quat_geology’ coverage is used for extracting quaternary geology data.
- ‘SLC’ coverage is used for extracting soil landscape data.
- ‘Surf_geol_ta’ coverage is used for extracting terrain adjusted surficial geology data.
- ‘Surf_geology’ coverage is used for extracting surficial geology data.

C1 ‘w4la’
4LA is an example of a tertiary watershed sub-folder containing selected NRVIS base layers, the watershed boundary, and all NRVIS-based 20m and 100m resolution grid data for a particular tertiary watershed.
- ‘Lakes’ coverage is used for visual representation in the ‘Selected Watershed Area’ map.
- ‘Rivers’ coverage is used for visual representation in the ‘Selected Watershed Area’ map.
- ‘Roads’ coverage is used for visual representation in the ‘Selected Watershed Area’ map.
- ‘w4la’ is a coverage used for displaying the boundary of tertiary watershed in the ‘Selected Watershed Area’ map.
- ‘w4la_cut10’ is a coverage of a tertiary watershed boundary with a 10km buffer that is used to clip DEM-related data.
- ‘w4la_dem100’ is a NRVIS-based 100m resolution DEM, generated by the OFAT project, used for watershed delineation and analysis.
- ‘w4la_dem20’ is a NRVIS-based 20m resolution DEM used for watershed delineation and analysis (MNR, 2002).
- ‘w4la_drain100’ is a NRVIS-based 100m resolution drainage line grid, generated by the OFAT project, used for watershed delineation and analysis.
- ‘w4la_drain20’ is a NRVIS-based 20m resolution drainage line grid, generated by the OFAT project, used for watershed delineation and analysis.
- ‘w4la_facc100’ is a NRVIS-based 100m resolution flow accumulation grid, generated by the OFAT project, used for watershed delineation and analysis.
- ‘w4la_facc20’ is a NRVIS-based 20m resolution flow accumulation grid, generated by the OFAT project, used for watershed delineation and analysis.
- ‘w4la_fdir100’ is a NRVIS-based 100m resolution flow direction grid, generated by the OFAT project, used for watershed delineation and analysis.
- ‘w4la_fdir20’ is a NRVIS-based 20m resolution flow direction grid, generated by the OFAT project, used for watershed delineation and analysis.
C2 ‘Whole’
- ‘Whole’ is a sub-folder of tertiary watersheds containing the polygon coverage of tertiary watersheds within the major basin.
- ‘wb3_geo’ coverage is used to visually identify a tertiary watershed projected in Geographic (latitude-longitude).
- ‘wb3_utm’ coverage is used to visually identify a tertiary watershed projected in UTM.

C3 ‘hif_isoline’
- ‘hif_isoline’ is a sub-folder containing all grid data generated from hydrometric station data pertaining to high flow models for a major basin.
- ‘q100y’ is a 1km resolution grid representing unit-high flow in a 100-year return period and is used by the Isoline Model (MNR, 2000).
- ‘q10y’ is a 1km resolution grid representing unit-high flow in a 10-year return period and is used by the Isoline Model (MNR, 2000).
- ‘q20y’ is a 1km resolution grid representing unit-high flow in a 20-year return period and is used by the Isoline Model (MNR, 2000).
- ‘q2y’ is a 1km resolution grid representing unit-high flow in a 2-year return period and is used by the Isoline Model (MNR, 2000).
- ‘q50y’ is a 1km resolution grid representing unit-high flow in a 50-year return period and is used by the Isoline Model (MNR, 2000).
- ‘q5y’ is a 1km resolution grid representing unit-high flow in a 5-year return period and is used by the Isoline Model (MNR, 2000).

C4 ‘lof_isoline’
- ‘Lof_isoline’ is a sub-folder containing all grid data generated from hydrometric station data pertaining to low flow models for a major basin.
- ‘15d_1-005y’ is a 1km resolution grid representing 15-day average unit-low flow in a 1.005-year return period and is used by the Isoline Model (MOEE, 1995).
- ‘15d_100y’ is a 1km resolution grid representing 15-day average unit-low flow in a 100-year return period and is used by the Isoline Model (MOEE, 1995).
- ‘mo_7q20-jan’ is a 1km resolution grid representing 7-day average unit-low flow in a 20-year return period for the month of January and is used by the Isoline Model (MOEE, 1995).

Note: There are many variations of the above, however, there are too many to list.

C5 ‘Other’
- ‘Other’ is a sub-folder containing additional grid data and selected NTS 1:250,000 base layers.
- ‘bfi’ is a 1km resolution grid used by the Watershed Calculator for extracting the base flow index.
- ‘dem1k’ is a NRVIS-based 1km resolution DEM, generated by the OFAT project, used for watershed delineation and analysis.
- ‘demn11’ is a NTS-based (1:250,000) 1km resolution DEM, used for watershed delineation and analysis.
• ‘drain1k’ is a NRVIS-based 1km resolution drainage line grid, generated by the OFAT project, used for watershed delineation and analysis.
• ‘drainn11’ is a NTS-based (1:250,000) 1km resolution drainage line grid, used for watershed delineation and analysis.
• ‘eva’ is a 1km resolution grid used by the Watershed Calculator for extracting average mean annual lake evaporation values.
• ‘facc1k’ is a NRVIS-based 1km resolution flow accumulation grid, generated by the OFAT project, used for watershed delineation and analysis.
• ‘faccn11’ is a NTS-based (1:250,000) 1km resolution flow accumulation grid, used for watershed delineation and analysis.
• ‘fdir1k’ is a NRVIS-based 1km resolution flow direction grid, generated by the OFAT project, used for watershed delineation and analysis.
• ‘fdirn11’ is a NTS-based (1:250,000) 1km resolution flow direction grid, used for watershed delineation and analysis.
• ‘map’ is a 1km resolution grid used by the Watershed Calculator for extracting mean annual precipitation values.
• ‘mar’ is a 1km resolution grid used by the Watershed Calculator for extracting mean annual runoff values.
• ‘mas’ is a 1km resolution grid used by the Watershed Calculator for extracting mean annual snowfall values.
• ‘mnr00_h5rg’ is a 1km resolution grid representing five high flow regions and is used by high flow models (MNR, 2000).
• ‘moe95_l6rg’ is a 1km resolution grid representing six low flow regions and is used by low flow models (MOEE, 1995).
• ‘moin85_h12rg’ is a 1km resolution grid representing 12 high flow regions and is used by high flow models (Moin and Shaw, 1985).
• ‘moin85_h3rg’ is a 1km resolution grid representing three high flow regions and is used by high flow models (Moin and Shaw, 1985).
• ‘nts1_lake’ is a lake coverage used for visual representation in the ‘Selected Watershed Area’ map when the 1km resolution DEM is used.
• ‘nts1_river’ is a coverage used for visual representation in the ‘Selected Watershed Area’ map when the 1km resolution DEM is used.
• ‘nts1_road’ is a coverage used for visual representation in the ‘Selected Watershed Area’ map when the 1km resolution DEM is used.
OFAT Metadata

Online Help for Metadata

In order to keep track of the large database associated with the OFAT application, a ‘Metadata’ section has been developed as part of the OFAT Online Help. Before using this section of the Online Help, take a moment to understand how it is constructed and what information it can provide. Metadata stores information about data layers such as projections, scale/resolutions, source, and how it was created or where it was acquired.

*Note:* To access the Online Help, please refer to the ‘Where to Go for More Help’ section of this manual.
Each booklet of metadata help is organized in the same sequence as the sub-folders found under the ‘OFAT_DAT’ folder. A topic provides specific information for a data layer (see the following figure). Key words have been highlighted and can be clicked to provide a more detailed description.

Each topic includes the following:

- **Layer Specifications** – provides information on projection, datum, spheroid, units, resolution, and zone
- **How Was the Data Created** – provides information on source data (e.g., scale) and data preparation
- **A Sample Graphic** – provides a visual representation of the layer; not all data layers will be visible while using OFAT
Frequently Asked Questions (FAQ)

This chapter will help users find answers to questions they may have about OFAT software and databases.

1. Can I share OFAT data with others or use OFAT data for other purposes?
   A The OFAT software and all related databases are copyright protected. Please refer to the ‘Trademarks and Copyright’ section in the beginning of this user’s manual.

2. Can I run OFAT with the ArcView 8.x or ArcGIS 8.x working environment?
   A No, OFAT cannot be run with ArcView 8.x or ArcGIS 8.x working environment. OFAT was designed to run with ArcView 3.2a.

3. What should I do if I want to install a database for a basin that has never been loaded, or update databases for basins that have been previously loaded, after OFAT is installed?
   A Re-install OFAT using the OFAT CDs. When prompted to select an installation option, choose the ‘Install OFAT databases only’ option and proceed to select the desired basins and databases to install or update.

4. Why are some of the options on OFAT interfaces (e.g., DEM selection menu) dimmed out?
   A When a database is not available, the corresponding options are dimmed out on the interfaces. In order to have the options become available for selection, appropriate databases must be installed by using the OFAT CDs. Also, certain options in dialogs are dimmed out and used as placeholders. They will be available for a future version of OFAT.

5. Why are the buttons on the OFAT toolbar dimmed out?
   A The buttons and tools on the OFAT toolbar are dimmed out when the necessary tasks preceding the button/tool functions have not been performed yet. Make sure all the preceding steps have been completed to make the button/tool become available.

6. How many watersheds can I perform OFAT functions on at once?
   A By following the standard OFAT process, functions of OFAT major components (including Watershed Delineation, Watershed Calculator, Flow Prediction Models, and WIES) can be performed on only one watershed, at a time. However, the Batch Run can be used to perform OFAT functions on multiple watersheds. The selected watersheds can be selected from different tertiary watersheds and different major basins. Please note that the more watersheds to be delineated and analyzed, the longer the processing time it will take.

7. Can I use my own dataset (e.g., DEM) in OFAT?
   A Currently, WIES is the only component in OFAT that allows the users to use their own data. Users can not use their own dataset with other components in OFAT yet.
8. How do I use OFAT outputs to support other water resource-related applications?
   A OFAT can export the results of delineated watershed boundary, WIES summary statistics, watershed parameters, and flow modeling in different formats. These exported results (e.g., shapefile, delimited text file, .dbf file) can then be imported into other water resource-related applications for other purposes.

9. How can I save the project? Can I save and start where I left off during a process if I run out of time?
   A The OFAT project file (i.e., OFAT.apr) can not be saved. However, results generated by OFAT (e.g., delineated watershed, calculated watershed parameters, summarized watershed information, flow information, batch run) can be exported into various formats. Also, when using the Batch Run, a batch file can be saved and then loaded back into OFAT.

10. When I click on a major basin to select it, why do I get a message stating “The basin is not available”?
    A The major basin that you are clicking on should be coloured grey. This means the database for that basin has not been installed. To add the databases for that basin, please install using the OFAT CDs.

11. What resolution of DEM should I use to delineate/analyze the watershed of my interest?
    A The choice of DEM depends on your application and the accuracy you would like to achieve. Generally, a DEM of finer resolution would provide you with results at higher accuracy but will take longer to delineate/analyze the watershed.

12. Why does OFAT take so long to delineate a watershed?
    A Please check if your computer hardware meets the minimum system requirements of OFAT. Also, please note that the finer the DEM cell resolution you choose, the longer time OFAT takes to delineate a watershed. For example, if you are working with a DEM of 20m or finer resolution, please be patient.

13. Why does the tertiary watershed boundary not match the boundary delineated by using the selected DEM?
    A The original tertiary watershed boundaries were manually traced and digitized based on 1:600,000 provincial paper maps, producing general boundary outlines. The boundaries delineated in OFAT are much more accurate since the DEMs were generated based on elevation data of a larger scale (i.e., 1:10,000 for southern and 1:20,000 for northern Ontario). In the future, new tertiary watershed boundaries will be generated using the most up-to-date DEMs so they will match the watershed boundaries delineated by OFAT.
14. What should I do if the watershed of my interest is larger than a whole tertiary watershed?
   A If the watershed to be delineated is larger than one whole tertiary watershed, a DEM with a cell resolution of 100m or greater must be used. Make sure the specified pour point is on the main channel of the most downstream tertiary watershed. Algorithms have been built into OFAT to automatically merge related upstream tertiary watersheds. Please note that merging tertiary watersheds will take time.

15. Can I import an existing watershed boundary delineated from other methods?
   A Yes, an existing watershed boundary in ArcView shapefile or ArcInfo grid format can be imported into OFAT. However, at this time, the imported watershed can only be used with the WIES component. The imported watershed boundary can not be used with the Watershed Calculator and Flow Prediction Models components, which only use watersheds directly delineated by OFAT.

16. What if I only need a watershed boundary but no watershed parameters or flow information?
   A OFAT will delineate a watershed based on the user-specified pour point. The delineated watershed can be exported as a shapefile or ArcInfo grid. The exported watershed boundary can then be used for different purposes (e.g., importing into other water resource-related applications). It is not necessary to run the Watershed Calculator or Flow Prediction Models components if the watershed parameters or flow information are not needed.

17. What is the difference between optional and required parameters in the Watershed Calculator?
   A The required parameters are needed to run the flow models currently included in OFAT. The optional parameters are not currently needed for the flow models in OFAT but can provide extra information about a watershed. The user is given the choice of calculating the optional parameters because the calculations for some parameters are very time consuming such as maximum flow distance (MFD).

18. How do I know which model works best for a specific geographic area?
   A Each regional hydrological model in OFAT has its own limitations. It is highly recommended that users refer to the original model document, or if necessary a water professional, before using generated flow values for any decision making purpose.

19. How many flow prediction models can I run at once?
   A You can run as many flow models as you want at the same time. Not only can any number of models be selected for each model category (e.g., low flow) but also models from multiple categories can be selected and run consecutively.
20. **Why does OFAT show negative values for some low flow models?**
   - A Negative values do not reflect an incorrect algorithm in OFAT but simply a misuse of the model for the delineated watershed. For example, using the low flow models, such as the Regression Method (MOEE, 1995), for a very small watershed may result in negative values. The low flow models chosen by the user may not be suitable for the delineated watershed (i.e., the calculated watershed parameters, such as drainage area, are outside the limits originally used to develop the models). Please consult a water professional and refer to the original model documents for more information about the use of different flow models.

21. **Where can I find a model that will give me Q\textsubscript{25} (i.e., flood flow in a 25-year return period)?**
   - A Currently, the only model in OFAT that can calculate Q\textsubscript{25} is the Index Flood, Regional Flood Frequency Curve Method (MNR, 2000).

22. **Can OFAT produce hydrographs (the graph showing time versus discharge)?**
   - A Although OFAT can generate flow information for a watershed such as floods (Q\textsubscript{25}, Q\textsubscript{100}, etc.), low flows (7Q\textsubscript{2}, 7Q\textsubscript{20}), etc., it cannot derive a hydrograph for the watershed.

23. **Can I use WIES in a batch run for multiple watersheds?**
   - A The current batch run in OFAT cannot be used with WIES to summarize spatial databases for multiple watersheds. That means that the WIES component can only be used for a single watershed at a time. There are plans to include this feature in a future version of OFAT.

24. **Can I execute a batch run for watersheds in different tertiary watersheds of different major basins?**
   - A Yes, a batch run can perform OFAT functions for watersheds in different tertiary watersheds of different major basins. Also, different resolution DEMs can be used for delineating watersheds selected in the batch run.

25. **What should I do when I get an error message upon exiting OFAT?**
   - A When exiting, OFAT will delete temporary files that have been created during OFAT sessions. If this procedure can not be completed properly, an error message will occur. In this case, to exit OFAT, click ‘OK’ in the error message. OFAT requires large temporary hard disk space to run the software efficiently and smoothly. Although OFAT has been designed to automatically delete unnecessary temporary files on-the-fly, sometimes the temporary files created by OFAT cannot be deleted. Therefore, it is strongly suggested that users delete the temporary files remaining in their system temporary folder on (e.g., c:\temp folder) before/after running OFAT.
26. What is the future of OFAT?

A The following lists the plans for future developments of OFAT:

- Automate more flow models or estimation techniques (e.g., models to generate natural flow duration curves and daily flow time-series at ungauged or regulated sites, to support water-crossing design such as culverts and bridges, and to simulate rainfall-runoff events).
- Create an interface to access and analyze historical daily flow and water level data from Environment Canada’s HYDAT database.
- Improve the efficiency and effectiveness of database management (e.g., organizing DEM-related databases in quaternary watersheds instead of current tertiary watersheds).
- Add new software features to enhance current OFAT capabilities (e.g., adding batch run functions for the WIES component, adding user-specified DEM functions so that user can use their own data, adding a vector-based algorithm to delineate watershed boundary in addition to the current raster-based algorithm).
- Build an interface to link OFAT with the Ontario River/Stream Ecological Classification Techniques (ORSECT). ORSECT is a GIS-based tool to automatically segment/classify a river/stream network in Ontario, based on its various landscape characteristics (e.g., slope, sinuosity, surficial geology, etc). OFAT and ORSECT will be able to share databases and functionalities as well as modelling results generated from each tool.
- Adopt new GIS technology, including migration of OFAT software from the current ArcView AVENUE programming language into ArcGIS 8.x VB/VBA.
- Develop web-based solutions for OFAT to increase accessibility to the most up-to-date flow information and spatial databases in Ontario.
- Continue to update spatial databases and perform quality control analysis on data.

Please visit the OFAT Internet site (http://www.scienceandinformation.on.ca/nesi/ofat) or Intranet site (http://mnronline.mnr.gov.on.ca/spectrasites/nesi/neshomepage.cfm) to get the most updated information about OFAT, including news, upgrades, user discussion forum, etc.
Troubleshooting

This chapter will help the user solve technical problems encountered when running OFAT.

1. **OFAT installation did not successfully complete.**
   - A Please re-install the OFAT software and/or databases using the OFAT CDs.

2. **I do not see the OFAT shortcut on the desktop after installation.**
   - A Browse to OFAT_APP\Av\Apr\ folder using Windows Explorer. Drag and drop the `OFAT.apr` file onto the desktop using the right mouse button to create the OFAT shortcut. Once created, you can double-click the shortcut to start OFAT.

3. **ArcView can not find Spatial Analyst when OFAT starts.**
   - A Make sure Spatial Analyst has been properly installed on your computer. If Spatial Analyst is on your computer but ArcView still can not find it, browse to the `spatial.avx` file when prompted.

4. **A message, stating that OFATDATA environment variable and OFATDATA.txt file does not exist, appears when OFAT starts.**
   - A Please re-install the OFAT software using the OFAT Setup CD.

5. **OFAT won’t open or run properly.**
   - A Make sure that your computer hardware and software meet the minimum system requirements of OFAT. To run OFAT, you need ArcView 3.2a (with the patch) with Spatial Analyst 2.0. Also, make sure that OFAT software and/or databases have been properly installed. If the problem persists, you may need to re-install the OFAT software or/databases using the OFAT CDs.

6. **The Watershed Calculator runs but the results are not shown.**
   - A Check to see how many other ArcView extensions you have loaded. To check loaded extensions, select the ‘Extensions’ menu item from the ‘File’ pull down menu. The only necessary extension for OFAT is Spatial Analyst. Turn off all other extensions, particularly the Digitizer and Modelbuilder extensions.

7. **When running the Flow Prediction Models, some error messages occur.**
   - A Make sure the model folder (i.e., OFAT_APP\Model\) is present. If not, re-install the OFAT software using the Setup CD. If the problem persists, some data files used by the models may be missing or corrupted. In this case, re-install the OFAT databases using the OFAT CDs.
8. When setting up a batch run, an error message appears: “ERROR. Script ‘OFAT.dlgBatchlbClick’ is already in the process of being executed.”
   A This occurs because OFAT has not had time to catch up with the user’s selections. Click ‘OK’ on the error message and wait for OFAT to finish its current process. Proceed as normal.

9. I’m having problems with the Batch Run.
   A If problems persist when executing the Batch Run, it is recommended that OFAT be exited and re-started.

10. The imported database does not geographically match the OFAT data.
    A Make sure the imported data for a selected major basin is in the appropriate projection. Please see Appendix A for the projection used for each major basin.
Glossary

AMC – antecedent moisture condition (see Appendix C for more details)

ASCII file – a file containing only American Standard Code for Information Interchange (ASCII) characters (i.e., no pictures or formatting codes) for representing alphanumeric information, allowing different makes and models of computers to communicate with one another

Bankfull flow – flow corresponds to bankfull stage at which water just begins to enter onto the floodplain

Base flow – portion of flow in a stream derived from soil moisture or ground water

Basin Index Map of Ontario – an interactive map that displays the 13 major basins of Ontario; helps narrow down the watershed outlet of interest

Batch Run – a component included in OFAT that allows the delineation, parameter calculations, and flow modelling for multiple (or single) watersheds in the same batch run without constant user interventions

Calculated drainage – see raster-based drainage network

Cell resolution – the amount of earth surface covered by a single grid cell in a raster-based data structure, specified in units of metres, kilometres, or simple relative units

Centroid – refers to a watershed centroid in OFAT whose co-ordinates can be determined by using the following ‘centre of gravity’ or ‘centre of mass’ formula:

\[
\begin{align*}
    c_x &= \frac{1}{6A} \sum_{i=0}^{N-1} (x_i + x_{i+1})(x_i y_{i+1} - x_{i+1} y_i) \\
    c_y &= \frac{1}{6A} \sum_{i=0}^{N-1} (y_i + y_{i+1})(x_i y_{i+1} - x_{i+1} y_i)
\end{align*}
\]

where \(c_x\) and \(c_y\) are the x and y co-ordinates of watershed centroid, respectively; and \(x_i\) and \(y_i\) are the x and y co-ordinates of the \(i^{th}\) vertex of the polygon representing watershed boundary, respectively

cms – cubic meters per second

CN – see Runoff Curve Number

Coverage – coverage refers to an ArcInfo coverage, a database that stores geographic and tabular data in a set of files stored within a common directory

Database – a collection of data stored and arranged for ease and speed of expansion, update, search, and retrieval
**dBase file** – a database file saved in dBase format (e.g., *.dbf) that can be manipulated by most commonly used database management systems

**Delimited text file** – an ASCII text file that contains string or/and numeric values separated by a delimiter (e.g., a comma, space, etc.)

**Delineated watershed** – refers to a watershed whose boundary is delineated using the ‘Watershed Delineation’ component of OFAT

**DEM** – see Digital Elevation Model

**Digital Elevation Model (DEM)** – a matrix consisting of a data file representing a topographic surface arranged as a set of regularly spaced (x, y) co-ordinate locations where each cell contains an elevation value

**Discharge** – a volume of flow per unit of time passing a point of interest, expressed in cubic meters per second (cms or m³/s) in the metric system

**Flood** – a flow event that causes a river, lake, or other water bodies to rise above normal non-damaging limits

**Flow** – see discharge

**Flow accumulation grid** – a grid that is derived from the flow direction grid; a cell value of flow accumulation grid representing the number of “upstream” cells whose flow path passes through the cell (i.e., high accumulation values indicating points in the stream, whereas low values indicating areas of overland flow)

**Flow direction grid** – a grid that is derived from the DEM; a cell value of flow direction grid indicating the direction of the steepest descent from the cell (i.e., identifying which neighbouring cell has the lowest elevation)

**Flood frequency curve** – a curve that shows the relationship between flood magnitudes and corresponding return periods in years

**Frequency** – the number of observations of a random variable

**Geographic Information System (GIS)** – a system which is the collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, retrieve, manipulate, analyze, and display all forms of geographically referenced information

**GIS** – see Geographic Information System

**Grid** – a group of square cells (each cell having an attached value) arranged in rows and columns in the raster-based GIS data structure
Hydrologic model – see regional hydrologic models

IFR – see instream flow requirements

Index flood – the flood magnitude, generally the mean annual flood, used in the index flood method

Index flood method – a simple regionalization technique that assumes the probability distribution of floods at different sites in hydrologically homogeneous region are the same except for a scale or index flood parameter (generally the mean annual flood) which reflects the size, meteorological, and physiographic characteristics of each watershed

INFO file – a database file that contains the attribute information of an ArcInfo coverage

Instream flow requirements – flows in a regulated stream channel that are required to enhance, or at least maintain, aquatic resources at various designated levels such as optimal, outstanding, excellent, good, fair or degrading, etc.

Layer – an integrated, logical, areal distributed set of thematic spatial data, usually organized by subject matter

Low flow – the dry-season stream flow that, in the absence of rain and/or snowmelt, is sustained by discharge from groundwater

Major Basin – refer to any of 13 major basins of Ontario (e.g., the Moose River Basin, the Lake Superior Basin, etc.)

Mean annual flow – the average value of annual flows for a watershed

Metadata – information about data (e.g., source of data, scales, etc.)

NAD83 CNT – a reference system (datum) for North America derived in 1983 with a Canadian National Transformation

NRVIS – the Natural Resource and Values Information System of the Ontario Ministry of Natural Resources

NTS – National Topographic Series

OBM – Ontario Base Map

Outlet – see watershed outlet

Pour point – see watershed outlet
**Projection** – a mathematical model that transforms the locations of features on the earth’s surface from three-dimensional spherical to two-dimensional planar co-ordinates, allowing flat maps to depict three-dimensional features; some map projections preserve the integrity of shape, others preserve accuracy of area, distance, or direction

**Q** – symbol for discharge/flow

**Raster** – a cellular GIS data structure that is compose of uniformly spaced rows and columns; groups of cells represent features on the earth’s surface, and the value assigned to each cell represents the value of the feature

**Raster-based drainage network** – the drainage network derived from a flow accumulation grid

**Regional hydrologic models** – refer to the mathematical models included in OFAT that have been developed for different hydrologically homogeneous regions in Ontario, based on streamflow information from provincial hydrometric gauging stations; the models can be used to determine the magnitude and frequency of floods or low flows for ungauged watersheds located within a hydrologically homogeneous region

**Resolution** – see cell resolution

**Return period** – the time interval for which an event of a given quantity will occur once on the average

**RIMS** – the River Information Management System, developed by the Ontario Ministry of Natural Resources, which is an interactive, GIS-based application to manage multimedia information (including text, figures, tables, maps, photos/images, video and sound clips) pertaining to rivers/watersheds

**Runoff Curve Number** – an index of runoff potential, ranging from 0 to 100, which can be determined based on land cover/use type, hydrologic soil group (or soil drainage), and antecedent moisture condition; see Appendix C for details

**Selected Watershed Area Map** – an interactive map that displays the selected tertiary watershed (contains layers such as the DEM); can be zoomed into for selection of a watershed outlet of interest

**Shapefile** – the native ArcView spatial data format

**Tertiary watershed** – a watershed used for organizing DEM-related databases of OFAT (e.g., 4LA, 4LB, etc.)

**Tertiary Watershed Index Map** – an interactive map that displays the tertiary watersheds of the selected major basin; helps narrow down watershed outlet of interest
**Text file** – see ASCII file

**Unit-flood** – the ratio of a flood flow to drainage area in cubic meters per second per square kilometre (i.e., cms/km$^2$)

**Unit-high flow** – see unit-flood

**Unit-low flow** – the ratio of a low flow to drainage area in cubic meters per second per square kilometre (i.e., cms/km$^2$)

**Universal Transverse Mercator (UTM)** – a widely used planar co-ordinate system based on a specialized application of the Transverse Mercator projection. The extent of the co-ordinate system is broken into 60, 6-degree zones. Within each zone, co-ordinates are usually expressed as meters north or south of the equator and east from a reference axis.

**UTM** – see Universal Transverse Mercator

**View** – refer to an interactive map created in ArcView GIS, which contains a collection of data layers that share a common co-ordinate system and usually a common spatial extent as well

**Watershed** – a region or area bounded peripherally by a topographic divide that ultimately drains to a particular watercourse or water body

**Watershed Calculator** – a component included in OFAT, that can be used to calculate various hydrologic parameters for the delineated watershed

**Watershed Delineation** – a component included in OFAT, that automatically derives watershed boundary for a watershed outlet, based on DEM-related databases

**Watershed Information Extraction Map** – a map in OFAT that displays selected layers clipped to the boundary of the delineated watershed in the WIES component

**Watershed Information Extraction System** – a component included in OFAT that extracts selected data layers to the boundary of the delineated watershed, and generates charts and summary statistics for the layers within the watershed

**Watershed outlet** – the pour point of a watershed; all water from that watershed flows into that point

**Watershed parameters** – physiographic and climatic parameters pertaining to the delineated watershed, which can be calculated by the Watershed Calculator and are required for running flow models included in OFAT; see Appendix B for detailed description of each parameter

**WIES** – see Watershed Information Extraction System
References


Appendix A: Corresponding UTM Zones for Major Basins of Ontario
The OFAT spatial database, pertaining to each of the major basins of Ontario, is in the UTM projection (NAD83 CNT) with an assigned UTM zone. In reality, some parts of the basin may extend into more than one zone. However, since data layers can only contain one projection, the basin has been assigned to the zone in which most of its area falls within. Please refer to the following table and map for information about the UTM zones assigned to the 13 major basins:

<table>
<thead>
<tr>
<th>Name of Major Basin</th>
<th>UTM Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albany River Basin</td>
<td>16</td>
</tr>
<tr>
<td>Attawapiskat River Basin</td>
<td>16</td>
</tr>
<tr>
<td>Ekwan River Basin</td>
<td>16</td>
</tr>
<tr>
<td>Lake Erie Basin</td>
<td>17</td>
</tr>
<tr>
<td>Lake Huron Basin</td>
<td>17</td>
</tr>
<tr>
<td>Lake Ontario Basin</td>
<td>17</td>
</tr>
<tr>
<td>Lake Superior Basin</td>
<td>16</td>
</tr>
<tr>
<td>Moose River Basin</td>
<td>17</td>
</tr>
<tr>
<td>Nelson River Basin</td>
<td>15</td>
</tr>
<tr>
<td>Other Basins</td>
<td>16</td>
</tr>
<tr>
<td>Ottawa River Basin</td>
<td>18</td>
</tr>
<tr>
<td>Severn River Basin</td>
<td>15</td>
</tr>
<tr>
<td>Winisk River Basin</td>
<td>16</td>
</tr>
</tbody>
</table>
Figure: Major Basins of Ontario and Corresponding UTM Zones.
Appendix B: Watershed Calculator Parameter Descriptions
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACLS</td>
<td>Percentage of Water and Wetland Cover in a Watershed</td>
<td>The percentage of area covered by lakes and wetlands within the delineated watershed.</td>
<td>dimensionless (represented in %)</td>
</tr>
<tr>
<td>BFI</td>
<td>Base Flow Index</td>
<td>The ratio of base flow to total flow volume.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>BR</td>
<td>Basin Relief</td>
<td>The total change in elevation for the watershed.</td>
<td>m</td>
</tr>
<tr>
<td>CN₁</td>
<td>U.S. Soil Conservation Service (SCS) Runoff Curve Number (CN) under Antecedent Moisture Condition (AMC) I</td>
<td>The average CN value within the watershed under dry antecedent moisture condition based on 5-day antecedent precipitation. See Appendix C for a more detailed description.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>CN₂</td>
<td>U.S. SCS Runoff Curve Number under AMC II</td>
<td>The average CN value within the watershed under average antecedent moisture condition based on 5-day antecedent precipitation. See Appendix C for a more detailed description.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>CN₃</td>
<td>U.S. SCS Runoff Curve Number AMC III</td>
<td>The average CN value within the watershed under wet antecedent moisture condition based on 5-day antecedent precipitation. See Appendix C for a more detailed description.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>DA</td>
<td>Drainage Area</td>
<td>The area of the delineated watershed.</td>
<td>km²</td>
</tr>
<tr>
<td>EVA</td>
<td>Mean Annual Lake Evaporation</td>
<td>The average amount of annual evaporation from lakes within the delineated watershed.</td>
<td>mm</td>
</tr>
<tr>
<td>Lca</td>
<td>Main Channel Length from Watershed Outlet to Watershed Centroid</td>
<td>The length of the main channel (longest calculated drainage line), from the watershed outlet to the point on the main channel that is closest to the watershed centroid.</td>
<td>km</td>
</tr>
<tr>
<td>LNTH</td>
<td>Length of Main Channel</td>
<td>The length of the longest calculated drainage line within the derived watershed.</td>
<td>km</td>
</tr>
<tr>
<td>Symbol</td>
<td>Parameter</td>
<td>Description</td>
<td>Units</td>
</tr>
<tr>
<td>--------</td>
<td>-----------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>MAP</td>
<td>Mean Annual Precipitation</td>
<td>The average amount of annual precipitation within the delineated watershed.</td>
<td>mm</td>
</tr>
<tr>
<td>MAR</td>
<td>Mean Annual Runoff</td>
<td>The average amount of annual runoff within the delineated watershed.</td>
<td>mm</td>
</tr>
<tr>
<td>MAS</td>
<td>Mean Annual Snowfall</td>
<td>The average amount of annual snowfall within the delineated watershed.</td>
<td>cm</td>
</tr>
<tr>
<td>MaxE</td>
<td>Maximum Watershed Elevation</td>
<td>The maximum elevation value of the DEM within the delineated watershed.</td>
<td>m</td>
</tr>
<tr>
<td>ME</td>
<td>Mean Elevation</td>
<td>The average elevation value of the DEM within the delineated watershed.</td>
<td>m</td>
</tr>
<tr>
<td>MFD</td>
<td>Maximum Flow Distance</td>
<td>The longest path of water from the watershed outlet to the watershed divide.</td>
<td>km</td>
</tr>
<tr>
<td>MinE</td>
<td>Minimum Watershed Elevation</td>
<td>The minimum elevation of the DEM within the delineated watershed.</td>
<td>m</td>
</tr>
<tr>
<td>MSW</td>
<td>Mean Slope of Watershed</td>
<td>The average slope of the watershed in percentage (%) calculated using the slope grid.</td>
<td>dimensionless (represented in %)</td>
</tr>
<tr>
<td>P</td>
<td>Perimeter</td>
<td>The total length along the watershed boundary.</td>
<td>km</td>
</tr>
<tr>
<td>SF</td>
<td>Shape Factor</td>
<td>The square of the length of the main channel divided by the drainage area.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>SLP</td>
<td>Slope of Main Channel</td>
<td>The slope of the longest channel within the delineated watershed.</td>
<td>dimensionless (represented in m/km)</td>
</tr>
</tbody>
</table>
Appendix C: Runoff Curve Number (CN)
The Soil Conservation Service (SCS) of the U.S. Department of Agriculture developed the runoff Curve Number (CN) method to compute the precipitation loss from storm rainfall. The details about the CN method can be found in the “National Engineering Handbook, Section 4, Hydrology” (SCS, 1972). The CN, ranging from 0 to 100, is an index of runoff potential and is inversely proportional to the precipitation loss within a watershed (infiltration into the ground and interception by land cover). The greater the CN value, the higher the runoff potential and the lower the precipitation loss.

The major factors that determine CN are the land cover/use type, hydrologic soil group (or soil drainage), and antecedent moisture condition (AMC). The Watershed Calculator and Watershed Information Extraction System (WIES) of OFAT can automatically calculate and summarize the average CN values of different AMCs for a delineated watershed. Although the calculated CN values are not used for any regional flow models currently included in OFAT, they are important hydrologic information for estimation of runoff potential, which can be used by other hydrologic models.

The land cover database used in OFAT, based on the Ontario Land Cover Data Base of 25m resolution grid (MNR, 1997), contains 28 classes as follows:

<table>
<thead>
<tr>
<th>Land Cover ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water</td>
</tr>
<tr>
<td>2</td>
<td>Coastal Mudflats</td>
</tr>
<tr>
<td>3</td>
<td>Intertidal Marsh</td>
</tr>
<tr>
<td>4</td>
<td>Supertidal Marsh</td>
</tr>
<tr>
<td>5</td>
<td>Freshwater Coastal Marsh / Inland Marsh</td>
</tr>
<tr>
<td>6</td>
<td>Deciduous Swamp</td>
</tr>
<tr>
<td>7</td>
<td>Conifer Swamp</td>
</tr>
<tr>
<td>8</td>
<td>Open Fen</td>
</tr>
<tr>
<td>9</td>
<td>Treed Fen</td>
</tr>
<tr>
<td>10</td>
<td>Open Bog</td>
</tr>
<tr>
<td>11</td>
<td>Treed Bog</td>
</tr>
<tr>
<td>12</td>
<td>Tundra Heath</td>
</tr>
<tr>
<td>13</td>
<td>Dense Deciduous Forest</td>
</tr>
<tr>
<td>14</td>
<td>Dense Coniferous Forest</td>
</tr>
<tr>
<td>15</td>
<td>Coniferous Plantation</td>
</tr>
<tr>
<td>16</td>
<td>Mixed Forest – mainly Deciduous</td>
</tr>
<tr>
<td>17</td>
<td>Mixed Forest – mainly Coniferous</td>
</tr>
<tr>
<td>18</td>
<td>Sparse Coniferous Forest</td>
</tr>
<tr>
<td>19</td>
<td>Sparse Deciduous Forest</td>
</tr>
<tr>
<td>20</td>
<td>Recent Cutovers</td>
</tr>
<tr>
<td>21</td>
<td>Recent Burns</td>
</tr>
<tr>
<td>22</td>
<td>Old Cuts and Burns</td>
</tr>
<tr>
<td>23</td>
<td>Mine Tailings, Quarries, and Bedrock Outcrop</td>
</tr>
<tr>
<td>24</td>
<td>Settlement and Developed Land</td>
</tr>
<tr>
<td>25</td>
<td>Pasture and Abandoned Fields</td>
</tr>
<tr>
<td>26</td>
<td>Cropland</td>
</tr>
<tr>
<td>27</td>
<td>Alvar</td>
</tr>
<tr>
<td>28</td>
<td>Unclassified (Cloud &amp; Shadow)</td>
</tr>
</tbody>
</table>
The soil drainage database used in OFAT is based on the Soil Landscape of Canada (SLC) Version 2.2 at a scale of 1:1,000,000 (Agriculture and Agri-Food Canada, 1996). It should be noted that the Canadian classification system for soil drainage is different from the one defined by the SCS (1972). The Canadian system has six soil drainage classes defined as follows:

1. Rapidly drained
2. Well drained
3. Moderately drained
4. Imperfectly drained
5. Poorly drained
6. Very poorly drained

However, the SCS has classified U.S. soils into four hydrologic soil groups (A, B, C, and D), according to their infiltration rate. The Group A soils have higher water transmission rates and low runoff potential while the Group D soils have a very low water transmission rates and high runoff potential. To correlate the Canadian classification system with the U.S. SCS system, an empirical relationship derived by Pomeroy (1987) has been used by OFAT. The relationship between the U.S. and Canadian soil drainage classification systems is as follows:

<table>
<thead>
<tr>
<th>Canadian Classification</th>
<th>U.S. SCS Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapidly</td>
<td>A</td>
</tr>
<tr>
<td>Well</td>
<td>B</td>
</tr>
<tr>
<td>Moderately Well</td>
<td>C</td>
</tr>
<tr>
<td>Imperfect</td>
<td>C</td>
</tr>
<tr>
<td>Poorly</td>
<td>C</td>
</tr>
<tr>
<td>Very Poorly</td>
<td>D</td>
</tr>
</tbody>
</table>

The CN method uses an antecedent rainfall index (i.e., 5-day antecedent precipitation) to estimate AMC. AMC I, AMC II, and AMC III represent dry, average, and wet antecedent moisture conditions, respectively. AMC I has the lowest runoff potential while AMC III has the highest. The SCS (1972) has developed a series of tables for CN values to represent average antecedent runoff conditions (AMC II) for various combinations of land cover/use and hydrologic soil groups. Hawkins et al. (1985) derived the equations to directly compute CN values for AMC I and AMC III from CN values of AMC II as follows:

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281*CN_{II}}$$

and

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573*CN_{II}}$$

$CN_I$, $CN_{II}$, and $CN_{III}$ are runoff curve numbers for AMC I, AMC II, and AMC III, respectively.
The following CN\textsubscript{II} reference table lists the CN values of average antecedent moisture condition for possible combinations of land cover and soil drainage classification encountered in Ontario. The CN\textsubscript{II} values assigned in the table are cited directly, if applicable, or extrapolated from CN\textsubscript{I} tables suggested by SCS (1972), the U.S. Bureau of Reclamation (1976), and Chang (1992).

<table>
<thead>
<tr>
<th>Land Cover ID (28 classes)</th>
<th>Description</th>
<th>U.S. SCS Soil Drainage Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>Water</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Coastal Mudflats</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>Intertidal Marsh</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>Supertidal Marsh</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>Freshwater Coastal Marsh / Inland Marsh</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>Deciduous Swamp</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>Conifer Swamp</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>Open Fen</td>
<td>55</td>
</tr>
<tr>
<td>9</td>
<td>Treed Fen</td>
<td>45</td>
</tr>
<tr>
<td>10</td>
<td>Open Bog</td>
<td>55</td>
</tr>
<tr>
<td>11</td>
<td>Treed Bog</td>
<td>45</td>
</tr>
<tr>
<td>12</td>
<td>Tundra Heath</td>
<td>45</td>
</tr>
<tr>
<td>13</td>
<td>Dense Deciduous Forest</td>
<td>36</td>
</tr>
<tr>
<td>14</td>
<td>Dense Coniferous Forest</td>
<td>26</td>
</tr>
<tr>
<td>15</td>
<td>Coniferous Plantation</td>
<td>26</td>
</tr>
<tr>
<td>16</td>
<td>Mixed Forest – mainly Deciduous</td>
<td>36</td>
</tr>
<tr>
<td>17</td>
<td>Mixed Forest – mainly Coniferous</td>
<td>26</td>
</tr>
<tr>
<td>18</td>
<td>Sparse Coniferous Forest</td>
<td>46</td>
</tr>
<tr>
<td>19</td>
<td>Sparse Deciduous Forest</td>
<td>46</td>
</tr>
<tr>
<td>20</td>
<td>Recent Cutovers</td>
<td>56</td>
</tr>
<tr>
<td>21</td>
<td>Recent Burns</td>
<td>56</td>
</tr>
<tr>
<td>22</td>
<td>Old Cuts and Burns</td>
<td>46</td>
</tr>
<tr>
<td>23</td>
<td>Mine Tailings, Quarries, and Bedrock Outcrop</td>
<td>100</td>
</tr>
<tr>
<td>24</td>
<td>Settlement and Developed Land</td>
<td>60</td>
</tr>
<tr>
<td>25</td>
<td>Pasture and Abandoned Fields</td>
<td>54</td>
</tr>
<tr>
<td>26</td>
<td>Cropland</td>
<td>54</td>
</tr>
<tr>
<td>27</td>
<td>Alvar</td>
<td>54</td>
</tr>
<tr>
<td>28</td>
<td>Unclassified (Cloud &amp; Shadow)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The provincial CN database, based on the above CN\textsubscript{II} cross-reference table, has been generated by the OFAT project by overlaying the provincial land cover and soil drainage GIS databases. A CN\textsubscript{II} value is assigned to each 25m*25m grid cell, depending on the combination of land cover class and soil drainage class for each cell. The resulting CN\textsubscript{II} database can then be used to calculate CN values for dry and wet antecedent moisture conditions (i.e., CN\textsubscript{I} and CN\textsubscript{III}, respectively) by using the equations proposed by Hawkins \textit{et al.} (1985) as mentioned earlier.
Appendix D: Hydrological Models
Model Categories

1. Low Flow Prediction Models (LOF)
2. Flood Prediction Models (HIF)
3. Mean Annual Flow Prediction Models (MAF)
4. Minimum Instream Flow Requirements Models (IFR)
5. Bankfull Discharge Prediction Models (BFQ)

1. Low Flow Prediction Models (LOF)

Four low flow prediction models for Ontario were developed by the MOEE (1995). Ontario was divided into six regions with low-flow equations developed for each region:

![Six Low Flow Regions](image)

Figure: Six Low Flow Regions in Ontario (MOEE, 1995).

Isoline Method (MOEE, 1995)

1-, 3-, 7-, 15-, and 30-day average low flows of 1.005-, 1.01-, 1.111-, 1.25-, 2-, 5-, 10-, 20-, 50-, 100-, and 200-year return period (i.e., $1Q_{1.005}$, $1Q_{1.111}$, $1Q_{1.25}$, … $30Q_{200}$) derived at provincial hydrometric gauging stations were divided by the station’s drainage area to obtain unit-low flows in cms/km$^2$ (i.e., $1q_{1.005}$, $1q_{1.111}$, $1q_{1.25}$, … $30q_{200}$). The 1km*1km resolution grids were created by interpolating the unit-low flow point data at the hydrometric stations. Using OFAT, the low
flows at an ungauged watershed can be estimated by multiplying the drainage area with the average unit-low flow values within the watershed boundary.

**Graphical Index Method (MOEE, 1995)**

**Northern, Central and Southeastern Regions**

The index low flow, $7Q_2$, is strongly correlated to and can be estimated by drainage area (DA). The following table lists the equations used to estimate $7Q_2$ for the three regions in northern Ontario, the Central and Southeastern regions:

<table>
<thead>
<tr>
<th>Region</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$7Q_2 = 8.681 + 0.00208 \times DA$</td>
</tr>
<tr>
<td>2</td>
<td>$7Q_2 = -2.494 + 0.00325 \times DA$</td>
</tr>
<tr>
<td>3</td>
<td>$7Q_2 = -1.341 + 0.00353 \times DA$</td>
</tr>
<tr>
<td>Central Region</td>
<td>$7Q_2 = 0.383 + 0.00161 \times DA$</td>
</tr>
<tr>
<td>Southeastern Region</td>
<td>$7Q_2 = -1.60 + 0.00251 \times DA$</td>
</tr>
<tr>
<td>Combined Central and Southeastern Regions</td>
<td>$7Q_2 = 0.118 + 0.00205 \times DA$</td>
</tr>
</tbody>
</table>

After $7Q_2$ is estimated for a watershed, 3-, 7-, 15-, and 30-day low flows of 2-, 5-, 10-, 20-, 50-, and 100-year return period can then be estimated using a series of graphs included in the original report (MOEE, 1995).

**Southwestern and West Central Regions**

The index low flow, $7Q_2$, is strongly correlated to drainage area (DA). $7Q_2$ can be estimated by using the $7Q_2$ - DA relationship included in the original report (MOEE, 1995). After $7Q_2$ is estimated for a watershed, 3-, 7-, and 30-day low flows of 2-, 5-, 10-, 20-, 50-, and 100-year return period can then be estimated using a series of graphs included in the original report (MOEE, 1995).
Statistical Index Method (MOEE, 1995)

Northeastern and Northwestern Regions

To use this method for predicting low flows for ungauged watersheds, OFAT first uses the regression method to estimate the index low flow $7Q_2$. Next the regional parameters of Weibull III distribution for the sub-region (i.e., Regions 1, 2, or 3) in which the site is located are identified from the following table:

<table>
<thead>
<tr>
<th>Region</th>
<th>Duration (days)</th>
<th>a</th>
<th>e</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.952</td>
<td>0.341</td>
<td>1.136</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.150</td>
<td>0.349</td>
<td>1.121</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1.272</td>
<td>0.403</td>
<td>1.105</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>2.031</td>
<td>0.407</td>
<td>1.117</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1.095</td>
<td>0.424</td>
<td>1.116</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.362</td>
<td>0.090</td>
<td>1.281</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.484</td>
<td>0.089</td>
<td>1.255</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1.772</td>
<td>0.050</td>
<td>1.190</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1.694</td>
<td>0.078</td>
<td>1.223</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1.842</td>
<td>0.104</td>
<td>1.197</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1.400</td>
<td>0.194</td>
<td>1.241</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.610</td>
<td>0.190</td>
<td>1.207</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1.580</td>
<td>0.221</td>
<td>1.203</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1.605</td>
<td>0.239</td>
<td>1.195</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1.503</td>
<td>0.259</td>
<td>1.205</td>
</tr>
</tbody>
</table>

The following equation is used to estimate the regional quantile with return period $y$:

$$q_y = e + (u-e) \times \left\{ -\ln\left[1 - \frac{1}{y}\right]\right\}^{1/a}$$

The low flows for various durations of $y$-year return periods can then be estimated by:

$$Q_y = 7Q_2 \times q_y$$

Central, Southeastern, Southwestern and West Central Regions

The Statistical Index Method is not available in these regions.
Regression Method (MOEE, 1995)

Northeastern and Northwestern Regions

The following parameters are used in the final regression:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Area (km$^2$)</td>
<td>DA</td>
</tr>
<tr>
<td>Length of main channel (km)</td>
<td>LNTH</td>
</tr>
<tr>
<td>Mean Annual Runoff (mm)</td>
<td>MAR</td>
</tr>
</tbody>
</table>

The general form of multiple regression equation to estimate $7Q_2$ and $7Q_{20}$ is:

$$Y = a_0 + a_1(DA) + a_2(DA)^{1/2} + a_3(DA)^2 + a_4(LNTH) + a_5(LNTH)^{1/2} + a_6(MAR) + a_7(MAR)^2$$

The following table lists multiple regression equations for $7Q_2$:

<table>
<thead>
<tr>
<th>Region</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-35.766</td>
<td>0.8628</td>
<td></td>
<td></td>
<td></td>
<td>-4.130</td>
<td></td>
<td>0.000353</td>
</tr>
<tr>
<td>2</td>
<td>21.65</td>
<td>0.00337</td>
<td></td>
<td></td>
<td></td>
<td>-4.791</td>
<td>1.0888</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7.506</td>
<td>1.581*10^{-7}</td>
<td></td>
<td></td>
<td></td>
<td>0.5491</td>
<td></td>
<td>-0.0156</td>
</tr>
<tr>
<td>1,2 and 3</td>
<td>-3.15</td>
<td>0.00323</td>
<td></td>
<td>-0.01898</td>
<td></td>
<td></td>
<td></td>
<td>0.00756</td>
</tr>
</tbody>
</table>

The following table lists multiple regression equations for $7Q_{20}$:

<table>
<thead>
<tr>
<th>Region</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-25.718</td>
<td>0.5587</td>
<td></td>
<td></td>
<td></td>
<td>-2.89</td>
<td></td>
<td>0.000272</td>
</tr>
<tr>
<td>2</td>
<td>8.124</td>
<td>0.00125</td>
<td></td>
<td></td>
<td></td>
<td>-0.796</td>
<td>-0.0104</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.4185</td>
<td>9.777*10^{8}</td>
<td></td>
<td></td>
<td></td>
<td>0.3403</td>
<td></td>
<td>-0.0055</td>
</tr>
<tr>
<td>1,2 and 3</td>
<td>-2.45</td>
<td>0.0016</td>
<td></td>
<td>-0.0021</td>
<td></td>
<td></td>
<td></td>
<td>0.0047</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.718</td>
<td>0.5587</td>
<td></td>
<td></td>
<td></td>
<td>-2.89</td>
<td></td>
<td>0.000272</td>
</tr>
<tr>
<td>2</td>
<td>8.124</td>
<td>0.00125</td>
<td></td>
<td></td>
<td></td>
<td>-0.796</td>
<td>-0.0104</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.4185</td>
<td>9.777*10^{8}</td>
<td></td>
<td></td>
<td></td>
<td>0.3403</td>
<td></td>
<td>-0.0055</td>
</tr>
<tr>
<td>1,2 and 3</td>
<td>-2.45</td>
<td>0.0016</td>
<td></td>
<td>-0.0021</td>
<td></td>
<td></td>
<td></td>
<td>0.0047</td>
</tr>
</tbody>
</table>

Central and Southeastern Regions

The following parameters are used in the final regression for both regions:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Area (km$^2$)</td>
<td>DA</td>
</tr>
<tr>
<td>Base Flow Index (dimensionless)</td>
<td>BFI</td>
</tr>
</tbody>
</table>
The general form of multiple regression equation to estimate various low flows for the Central Region is:

\[ Y = a_0 + a_1(DA) + a_2(BFI) \]

The following table lists multiple regression equations in the Central Region:

<table>
<thead>
<tr>
<th>Flow (cms)</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7Q_{20}</td>
<td>-0.2134</td>
<td>0.00066184</td>
<td>0.7022</td>
</tr>
<tr>
<td>7Q_{2}</td>
<td>-0.7216</td>
<td>0.0018060</td>
<td>1.7386</td>
</tr>
<tr>
<td>3Q_{2}</td>
<td>-0.5398</td>
<td>0.0016260</td>
<td>1.2856</td>
</tr>
<tr>
<td>3Q_{20}</td>
<td>-0.1841</td>
<td>0.00058893</td>
<td>0.6295</td>
</tr>
<tr>
<td>3Q_{50}</td>
<td>-0.1331</td>
<td>0.00045199</td>
<td>0.5160</td>
</tr>
<tr>
<td>30Q_{2}</td>
<td>-0.7119</td>
<td>0.0022380</td>
<td>1.6806</td>
</tr>
<tr>
<td>30Q_{20}</td>
<td>-0.3275</td>
<td>0.00097749</td>
<td>0.9305</td>
</tr>
<tr>
<td>30Q_{50}</td>
<td>-0.2839</td>
<td>0.00087086</td>
<td>0.8045</td>
</tr>
</tbody>
</table>

The general form of multiple regression equation to estimate various low flows for the Southeastern Region is:

\[ Y = a_0 + a_1(DA)^3 + a_2(BFI) \]

The following table lists multiple regression equations in the Southeastern Region:

<table>
<thead>
<tr>
<th>Flow (cms)</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7Q_{20}</td>
<td>-0.5084</td>
<td>7.6323E-11</td>
<td>1.1460</td>
</tr>
<tr>
<td>7Q_{2}</td>
<td>-0.9018</td>
<td>1.3049E-10</td>
<td>2.2728</td>
</tr>
<tr>
<td>3Q_{2}</td>
<td>-1.0351</td>
<td>1.2409E-10</td>
<td>2.3828</td>
</tr>
<tr>
<td>3Q_{20}</td>
<td>-0.6133</td>
<td>7.0980E-11</td>
<td>1.2527</td>
</tr>
<tr>
<td>3Q_{50}</td>
<td>-0.6226</td>
<td>6.5153E-11</td>
<td>1.2372</td>
</tr>
<tr>
<td>30Q_{2}</td>
<td>-1.0195</td>
<td>1.4637E-10</td>
<td>2.6144</td>
</tr>
<tr>
<td>30Q_{20}</td>
<td>-0.5196</td>
<td>8.5495E-11</td>
<td>1.3062</td>
</tr>
<tr>
<td>30Q_{50}</td>
<td>-0.4643</td>
<td>7.9836E-11</td>
<td>1.1773</td>
</tr>
</tbody>
</table>

**Southwestern and West Central Regions**

The following parameters are used in the final regression for these regions:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Area (km²)</td>
<td>DA</td>
</tr>
<tr>
<td>Base Flow Index (dimensionless)</td>
<td>BFI</td>
</tr>
<tr>
<td>Length of main channel (km)</td>
<td>LNTH</td>
</tr>
<tr>
<td>Mean Annual Runoff (mm)</td>
<td>MAR</td>
</tr>
<tr>
<td>Mean Annual Snow (cm)</td>
<td>MAS</td>
</tr>
</tbody>
</table>
The general form of multiple regression equation to estimate various low flows for these regions is:

\[ Y = a_0 + a_1 (DA)^3 + a_2 (BFI)^2 + a_3 (LNTH)^2 + a_4 \log(MAR) + a_5 \log(MAS) \]

The following table lists multiple regression equations for the regions:

<table>
<thead>
<tr>
<th>Flow (cms)</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(a_4)</th>
<th>(a_5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7Q₂</td>
<td>-0.190</td>
<td>1.24E-10</td>
<td>1.67</td>
<td>8.35E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7Q₂₀</td>
<td>-0.166</td>
<td>9.03E-11</td>
<td>1.10</td>
<td>4.67E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7Q₅₀</td>
<td>-0.160</td>
<td>8.54E-11</td>
<td>1.02</td>
<td>3.92E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3Q₂</td>
<td>-0.183</td>
<td>1.21E-10</td>
<td>1.55</td>
<td>7.81E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3Q₂₀</td>
<td>-0.158</td>
<td>8.57E-11</td>
<td>0.99</td>
<td>4.30E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3Q₅₀</td>
<td>-0.150</td>
<td>7.92E-11</td>
<td>0.91</td>
<td>3.64E-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30Q₂</td>
<td>-0.233</td>
<td>1.29E-10</td>
<td>2.12</td>
<td>1.12E-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30Q₂₀</td>
<td>-0.227</td>
<td>9.38E-11</td>
<td>1.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30Q₅₀</td>
<td>-0.078</td>
<td>1.25E-10</td>
<td>1.44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Limitations for Low Flow Prediction Model (MOEE, 1995)**

Each low flow region uses a different range of hydrologic parameters to develop models, limiting their use. The following tables show the parameter ranges used in developing the models:

<table>
<thead>
<tr>
<th>Region 1</th>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAP</td>
<td>500</td>
<td>830</td>
</tr>
<tr>
<td></td>
<td>MAS</td>
<td>190</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>MAR</td>
<td>108</td>
<td>456</td>
</tr>
<tr>
<td></td>
<td>EVA</td>
<td>340</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>DA</td>
<td>401</td>
<td>94300</td>
</tr>
<tr>
<td></td>
<td>BFI</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>LNTH</td>
<td>25</td>
<td>476.3</td>
</tr>
<tr>
<td></td>
<td>ACLS</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Region 2</td>
<td>Variable</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>MAP</td>
<td>695</td>
<td>790</td>
<td></td>
</tr>
<tr>
<td>MAS</td>
<td>190</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>MAR</td>
<td>154</td>
<td>406</td>
<td></td>
</tr>
<tr>
<td>EVA</td>
<td>490</td>
<td>515</td>
<td></td>
</tr>
<tr>
<td>DA</td>
<td>744</td>
<td>50200</td>
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</tr>
<tr>
<td>BFI</td>
<td>0.68</td>
<td>0.99</td>
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<td>LNTH</td>
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</tr>
<tr>
<td>ACLS</td>
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<table>
<thead>
<tr>
<th>Region 3</th>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>MAP</td>
<td>720</td>
<td>999</td>
<td></td>
</tr>
<tr>
<td>MAS</td>
<td>230</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>MAR</td>
<td>193</td>
<td>799</td>
<td></td>
</tr>
<tr>
<td>EVA</td>
<td>400</td>
<td>525</td>
<td></td>
</tr>
<tr>
<td>DA</td>
<td>8.64</td>
<td>47900</td>
<td></td>
</tr>
<tr>
<td>BFI</td>
<td>0.23</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>LNTH</td>
<td>3</td>
<td>465</td>
<td></td>
</tr>
<tr>
<td>ACLS</td>
<td>0</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region 4 (Central)</th>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP</td>
<td>780</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>MAS</td>
<td>120</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>MAR</td>
<td>189</td>
<td>527</td>
<td></td>
</tr>
<tr>
<td>SLP</td>
<td>0.02</td>
<td>9.434</td>
<td></td>
</tr>
<tr>
<td>EVA</td>
<td>665</td>
<td>830</td>
<td></td>
</tr>
<tr>
<td>DA</td>
<td>24.3</td>
<td>1520</td>
<td></td>
</tr>
<tr>
<td>BFI</td>
<td>0.17</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>LNTH</td>
<td>9</td>
<td>94.3</td>
<td></td>
</tr>
<tr>
<td>ACLS</td>
<td>0</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region 5 (Southeastern)</th>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP</td>
<td>800</td>
<td>920</td>
<td></td>
</tr>
<tr>
<td>MAS</td>
<td>170</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>MAR</td>
<td>260</td>
<td>540</td>
<td></td>
</tr>
<tr>
<td>SLP</td>
<td>0.14</td>
<td>12.19</td>
<td></td>
</tr>
<tr>
<td>EVA</td>
<td>635</td>
<td>790</td>
<td></td>
</tr>
<tr>
<td>DA</td>
<td>7</td>
<td>4120</td>
<td></td>
</tr>
<tr>
<td>BFI</td>
<td>0.3</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>LNTH</td>
<td>5</td>
<td>112.4</td>
<td></td>
</tr>
<tr>
<td>ACLS</td>
<td>0</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
2. Flood Prediction Models (HIF)

Index Flood Method (Moin & Shaw, 1985)

In this method, the Ontario has been divided into twelve homogeneous flood regions as shown in the following figure:

![Twelve Flood Frequency Regions](image)

Figure: Twelve Flood Regions of Index Flood Method (Moin & Shaw, 1985).

For each flood region, the general form index flood \( Q_2 \) can be expressed as follows:

\[
Q_2 = C \times A^n
\]

where\( Q_2 \) = flood in a 2-year return period in cms

\( A \) = Drainage area in \( \text{km}^2 \)

\( C \) = Constant

\( n \) = Exponent
The values of C and n for each of 12 flood regions are listed in the following table:

<table>
<thead>
<tr>
<th>Region</th>
<th>Constant C (A &lt; 60 km²)</th>
<th>Exponent n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(a)</td>
<td>0.22</td>
<td>1.000</td>
</tr>
<tr>
<td>1(b)</td>
<td>0.73</td>
<td>0.707</td>
</tr>
<tr>
<td>2</td>
<td>0.51</td>
<td>0.896</td>
</tr>
<tr>
<td>3</td>
<td>0.20</td>
<td>0.957</td>
</tr>
<tr>
<td>4</td>
<td>0.71</td>
<td>0.842</td>
</tr>
<tr>
<td>5</td>
<td>0.45</td>
<td>0.775</td>
</tr>
<tr>
<td>6</td>
<td>0.41</td>
<td>0.806</td>
</tr>
<tr>
<td>7</td>
<td>1.13</td>
<td>0.696</td>
</tr>
<tr>
<td>8</td>
<td>0.72</td>
<td>0.785</td>
</tr>
<tr>
<td>9</td>
<td>0.40</td>
<td>0.81</td>
</tr>
<tr>
<td>10</td>
<td>0.28</td>
<td>0.849</td>
</tr>
<tr>
<td>11</td>
<td>0.38</td>
<td>0.706</td>
</tr>
<tr>
<td>12</td>
<td>0.59</td>
<td>0.765</td>
</tr>
</tbody>
</table>

For each region, ratios of floods in different return periods (e.g., $Q_{10}$, $Q_{20}$, $Q_{50}$, and $Q_{100}$) to index flood $Q_2$ are represented by a regional frequency curve that can be found in the original report (Moin & Shaw, 1985). That means that floods in different return periods can be estimated from the corresponding regional frequency curve after index flood $Q_2$ is estimated.

The following table contains the range of drainage area (in km²) used by each region to develop this method.

<table>
<thead>
<tr>
<th>Region</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.11</td>
<td>9270</td>
</tr>
<tr>
<td>2</td>
<td>76.1</td>
<td>3816</td>
</tr>
<tr>
<td>3</td>
<td>86.0</td>
<td>3960</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>5910</td>
</tr>
<tr>
<td>5</td>
<td>14.2</td>
<td>4300</td>
</tr>
<tr>
<td>6</td>
<td>5.2</td>
<td>697</td>
</tr>
<tr>
<td>7</td>
<td>63.5</td>
<td>293</td>
</tr>
<tr>
<td>8</td>
<td>4.9</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>24.3</td>
<td>1520</td>
</tr>
<tr>
<td>10</td>
<td>18.6</td>
<td>11900</td>
</tr>
<tr>
<td>11</td>
<td>0.7</td>
<td>24200</td>
</tr>
<tr>
<td>12</td>
<td>4250</td>
<td>94300</td>
</tr>
</tbody>
</table>

**Index Flood Method With Expected Probability Adjustment (Moin & Shaw, 1985)**

Mathematically, the expected probability concept has a sound basis when applied in a regional sense. It is presumed that the frequency curves will have similar slopes in a hydrologic homogeneous region. Ontario has adopted the policy whereby all frequency distributions will be adjusted for the expected probability computation (Moin and Shaw, 1985). In this method,
expected probability adjustments were made to all twelve regional index flood frequency curves. Details about this method can be found in the original report (Moin & Shaw, 1985).

For each region, ratios of floods in different return periods (e.g., Q_{10}, Q_{20}, Q_{50}, and Q_{100}) to index flood Q_2 is represented by a regional frequency curve with expected probability adjustment that can be found in the original report (Moin & Shaw, 1985). That means that floods in different return periods can be estimated from the corresponding regional frequency curve after index flood Q_2 is estimated.

**Primary Multiple Regression Method (Moin & Shaw, 1985)**

In this method, Ontario has been divided into three flood regions as shown in the following figure:

![Three Flood Frequency Regions](image)

Figure: Three Flood Regions of Primary Multiple Regression Method (Moin & Shaw, 1985).

Although a number of physiographic and climatic parameters were considered, only the following parameters proved significant in the final regression:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Area (km^2)</td>
<td>DA</td>
</tr>
<tr>
<td>Mean Channel Slope (m/km)</td>
<td>SLP</td>
</tr>
<tr>
<td>Index of Area Controlled by Water and Wetland (%)</td>
<td>ACLS</td>
</tr>
<tr>
<td>Shape Factor (dimensionless) (= LNTH^2/DA, where LNTH = length of main channel (km) and DA = drainage area (km^2))</td>
<td>SF</td>
</tr>
<tr>
<td>Base Flow Index (dimensionless)</td>
<td>BFI</td>
</tr>
<tr>
<td>Mean Annual Runoff (mm)</td>
<td>MAR</td>
</tr>
<tr>
<td>Mean Annual Precipitation (mm)</td>
<td>MAP</td>
</tr>
</tbody>
</table>
The general form of primary multiple regression equation is:

$$\log(Q_T) = a_0 + a_1 \log(DA) + a_2 (BFI)^{1/2} + a_3 (SLP)^{1/3} + a_4 (ACLS)^{1/2} + a_5 (SLP) + a_6 \log(MAR) + a_7 (MAR) + a_8 \log(ACLS+1) + a_9 (MAP) + a_{10} (SF)$$

The following table lists primary multiple regression equations of $Q_2$, $Q_5$, $Q_{10}$, $Q_{20}$, $Q_{50}$, and $Q_{100}$ for flood region A:

<table>
<thead>
<tr>
<th>Flood (cms)</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
<th>$a_8$</th>
<th>$a_9$</th>
<th>$a_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_2$</td>
<td>-4.8779</td>
<td>0.8368</td>
<td>0.1796</td>
<td>-0.0381</td>
<td>1.7082</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_5$</td>
<td>-1.1385</td>
<td>0.8303</td>
<td>0.2261</td>
<td>-0.0357</td>
<td>0.0020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{10}$</td>
<td>-1.0170</td>
<td>0.8225</td>
<td>0.2521</td>
<td>-0.0338</td>
<td>0.0018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{20}$</td>
<td>-0.9146</td>
<td>0.8154</td>
<td>0.2775</td>
<td>-0.0319</td>
<td>0.0017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{50}$</td>
<td>-0.8641</td>
<td>0.8256</td>
<td>0.3270</td>
<td>-0.0243</td>
<td>0.0014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{100}$</td>
<td>-0.7961</td>
<td>0.8208</td>
<td>0.3486</td>
<td>-0.0225</td>
<td>0.0013</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following table lists primary multiple regression equations of $Q_2$, $Q_5$, $Q_{10}$, $Q_{20}$, $Q_{50}$, and $Q_{100}$ for flood region B:

<table>
<thead>
<tr>
<th>Flood (cms)</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
<th>$a_8$</th>
<th>$a_9$</th>
<th>$a_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_2$</td>
<td>0.4371</td>
<td>0.8669</td>
<td>-1.2282</td>
<td>-0.0089</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>$Q_5$</td>
<td>0.5732</td>
<td>0.8385</td>
<td>-1.1327</td>
<td>-0.0101</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$Q_{10}$</td>
<td>0.7043</td>
<td>0.8110</td>
<td>-1.1273</td>
<td>-0.0105</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{20}$</td>
<td>0.5895</td>
<td>0.8509</td>
<td>-1.2714</td>
<td>0.1593</td>
<td>-0.0432</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{50}$</td>
<td>0.6412</td>
<td>0.8410</td>
<td>-1.2773</td>
<td>0.1978</td>
<td>-0.0530</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$Q_{100}$</td>
<td>0.6808</td>
<td>0.8337</td>
<td>-1.2924</td>
<td>0.2264</td>
<td>-0.0521</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following table lists primary multiple regression equations of $Q_2$, $Q_5$, $Q_{10}$, $Q_{20}$, $Q_{50}$, and $Q_{100}$ for flood region C:

<table>
<thead>
<tr>
<th>Flood (cms)</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
<th>$a_8$</th>
<th>$a_9$</th>
<th>$a_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_2$</td>
<td>-2.3410</td>
<td>0.9976</td>
<td>-1.6600</td>
<td>0.3436</td>
<td>0.9347</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_5$</td>
<td>-2.0193</td>
<td>0.9699</td>
<td>-1.5162</td>
<td>0.3591</td>
<td>0.8538</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{10}$</td>
<td>-1.8562</td>
<td>0.9514</td>
<td>-1.4305</td>
<td>0.3597</td>
<td>0.8178</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{20}$</td>
<td>-1.7345</td>
<td>0.9362</td>
<td>-1.3582</td>
<td>0.3597</td>
<td>0.7925</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{50}$</td>
<td>-1.3014</td>
<td>0.9045</td>
<td>-1.2890</td>
<td>0.0573</td>
<td>0.7859</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{100}$</td>
<td>-1.2500</td>
<td>0.8933</td>
<td>-1.2419</td>
<td>0.0575</td>
<td>0.7840</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Secondary Multiple Regression Method (Moin & Shaw, 1985)

Similar to the primary multiple regression equation, the general form of secondary multiple regression equation is:

\[
\log(Q_T) = a_0 + a_1 \log(DA) + a_2 (BFI)^{1/2} + a_3 (SLP)^{1/3} + a_4 (ACLS)^{1/2} + a_5 (SLP) + a_6 \log(MAR)
+ a_7 (MAR) + a_8 \log(ACLS+1) + a_9 (MAP) + a_{10} (SF)
\]

The following table lists secondary multiple regression equations of \(Q_2\), \(Q_5\), \(Q_{10}\), \(Q_{20}\), \(Q_{50}\), and \(Q_{100}\) for flood region A:

<table>
<thead>
<tr>
<th>Flood (cms)</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(a_4)</th>
<th>(a_5)</th>
<th>(a_6)</th>
<th>(a_7)</th>
<th>(a_8)</th>
<th>(a_9)</th>
<th>(a_{10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q_2)</td>
<td>0.5473</td>
<td>0.9418</td>
<td>-2.3038</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_5)</td>
<td>0.4916</td>
<td>0.8952</td>
<td>-1.7518</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0012</td>
<td>-0.1007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{10})</td>
<td>0.6927</td>
<td>0.8859</td>
<td>-1.8087</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0010</td>
<td>-0.0907</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{20})</td>
<td>0.8670</td>
<td>0.8767</td>
<td>-1.8563</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.5 E-4</td>
<td>-0.0819</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{50})</td>
<td>1.0335</td>
<td>0.9005</td>
<td>-2.3169</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.2 E-4</td>
<td></td>
</tr>
<tr>
<td>(Q_{100})</td>
<td>1.0929</td>
<td>0.8889</td>
<td>-2.2764</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.1 E-4</td>
<td></td>
</tr>
</tbody>
</table>

The following table lists secondary multiple regression equations of \(Q_2\), \(Q_5\), \(Q_{10}\), \(Q_{20}\), \(Q_{50}\), and \(Q_{100}\) for flood region B:

<table>
<thead>
<tr>
<th>Flood (cms)</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(a_4)</th>
<th>(a_5)</th>
<th>(a_6)</th>
<th>(a_7)</th>
<th>(a_8)</th>
<th>(a_9)</th>
<th>(a_{10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q_2)</td>
<td>0.2143</td>
<td>0.7464</td>
<td>-0.2172</td>
<td>-0.0194</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.0077</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_5)</td>
<td>0.2746</td>
<td>0.7443</td>
<td>-0.1961</td>
<td>-0.0198</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{10})</td>
<td>0.3795</td>
<td>0.7217</td>
<td>-0.1799</td>
<td>-0.0202</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{20})</td>
<td>0.2311</td>
<td>0.7461</td>
<td></td>
<td>-0.0197</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.0081</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{50})</td>
<td>0.3659</td>
<td>0.6989</td>
<td></td>
<td>-0.0275</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{100})</td>
<td>0.4471</td>
<td>0.6839</td>
<td></td>
<td>-0.0276</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following table lists secondary multiple regression equations of \(Q_2\), \(Q_5\), \(Q_{10}\), \(Q_{20}\), \(Q_{50}\), and \(Q_{100}\) for flood region C:

<table>
<thead>
<tr>
<th>Flood (cms)</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(a_4)</th>
<th>(a_5)</th>
<th>(a_6)</th>
<th>(a_7)</th>
<th>(a_8)</th>
<th>(a_9)</th>
<th>(a_{10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q_2)</td>
<td>-1.7155</td>
<td>0.8734</td>
<td></td>
<td>-0.0167</td>
<td></td>
<td></td>
<td>0.5580</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_5)</td>
<td>-1.7967</td>
<td>0.9031</td>
<td>0.1721</td>
<td>-0.0180</td>
<td></td>
<td></td>
<td>0.5424</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{10})</td>
<td>-1.6547</td>
<td>0.8897</td>
<td>0.1841</td>
<td>-0.0177</td>
<td></td>
<td></td>
<td>0.5261</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{20})</td>
<td>-1.5499</td>
<td>0.8876</td>
<td>0.1937</td>
<td>-0.0174</td>
<td></td>
<td></td>
<td>0.5173</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{50})</td>
<td>-1.1793</td>
<td>0.8759</td>
<td></td>
<td>0.0337</td>
<td>0.4698</td>
<td>-0.0800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Q_{100})</td>
<td>-1.1375</td>
<td>0.8676</td>
<td></td>
<td>0.0349</td>
<td>0.4804</td>
<td>-0.0811</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Limitations for Flood Prediction Models (Moin and Shaw, 1985)

The following tables contain ranges of hydrologic parameters used to develop the equations for each flood region:

### All Ontario

<table>
<thead>
<tr>
<th>Variable</th>
<th>Q2 – Q20</th>
<th>Q50 – Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>BFI</td>
<td>0.15</td>
<td>1.00</td>
</tr>
<tr>
<td>SLP</td>
<td>0.02</td>
<td>9.42</td>
</tr>
<tr>
<td>ACLS</td>
<td>0.00</td>
<td>122.00</td>
</tr>
<tr>
<td>MAR</td>
<td>137.00</td>
<td>626.00</td>
</tr>
<tr>
<td>MAP</td>
<td>500.0</td>
<td>1000.0</td>
</tr>
</tbody>
</table>

### Region A

<table>
<thead>
<tr>
<th>Variable</th>
<th>Q2 – Q20</th>
<th>Q50 – Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>BFI</td>
<td>0.36</td>
<td>1.00</td>
</tr>
<tr>
<td>SLP</td>
<td>0.02</td>
<td>4.14</td>
</tr>
<tr>
<td>ACLS</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>MAR</td>
<td>193.00</td>
<td>598.00</td>
</tr>
<tr>
<td>MAP</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Region B

<table>
<thead>
<tr>
<th>Variable</th>
<th>Q2 – Q20</th>
<th>Q50 – Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>BFI</td>
<td>0.26</td>
<td>0.82</td>
</tr>
<tr>
<td>SLP</td>
<td>0.14</td>
<td>5.77</td>
</tr>
<tr>
<td>ACLS</td>
<td>0.00</td>
<td>97.00</td>
</tr>
<tr>
<td>SHP</td>
<td>1.41</td>
<td>42.14</td>
</tr>
</tbody>
</table>

### Region C

<table>
<thead>
<tr>
<th>Variable</th>
<th>Q2 – Q20</th>
<th>Q50 – Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>BFI</td>
<td>0.15</td>
<td>0.81</td>
</tr>
<tr>
<td>SLP</td>
<td>0.21</td>
<td>9.42</td>
</tr>
<tr>
<td>ACLS</td>
<td>0.00</td>
<td>122.00</td>
</tr>
<tr>
<td>MAR</td>
<td>137.00</td>
<td>527.00</td>
</tr>
</tbody>
</table>
Multiple Regression Method (MNR, 2000)

In this method, Ontario has been divided into five flood regions, as shown in the following figure:

![Five Flood Regions in Ontario (MNR, 2000).](image)

The flood generating characteristics of each of five homogeneous flood regions in Ontario were used to develop regression equations to predict flood peaks $Q_{20}$ and $Q_{100}$ for ungauged watersheds. The climatic and physiographic variables selected for development of the regression equations are listed as follows:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Area (km$^2$)</td>
<td>DA</td>
</tr>
<tr>
<td>Mean Annual Precipitation (mm)</td>
<td>MAP</td>
</tr>
<tr>
<td>Mean Annual Snowfall (cm)</td>
<td>MAS</td>
</tr>
<tr>
<td>Mean Annual Runoff (mm)</td>
<td>MAR</td>
</tr>
<tr>
<td>Base Flow Index (dimensionless)</td>
<td>BFI</td>
</tr>
<tr>
<td>Index of Area Controlled by Water and Wetland (%)</td>
<td>ACLS</td>
</tr>
<tr>
<td>Mean Channel Slope (m/km)</td>
<td>SLP</td>
</tr>
<tr>
<td>Main Channel Length (km)</td>
<td>LNTH</td>
</tr>
<tr>
<td>Mean Annual Evaporation (mm)</td>
<td>EVA</td>
</tr>
</tbody>
</table>
The following table lists main variables used in regression equation (in Nature Logarithm Ln - form) to estimate \( Q_{20} \) and \( Q_{100} \) for each flood region:

<table>
<thead>
<tr>
<th>Region</th>
<th>Important Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>DA, MAR, BFI, SLP, MAS</td>
</tr>
<tr>
<td>Region 2</td>
<td>DA, BFI, EVA</td>
</tr>
<tr>
<td>Region 3</td>
<td>DA, BFI, LNTH</td>
</tr>
<tr>
<td>Region 4</td>
<td>DA, MAR</td>
</tr>
<tr>
<td>Region 5</td>
<td>DA, BFI, MAS, MAR</td>
</tr>
</tbody>
</table>

The following table lists regression equations for \( Q_{20} \) for different flood regions:

<table>
<thead>
<tr>
<th>Region</th>
<th>( a_0 )</th>
<th>( a_1 )</th>
<th>( a_2 )</th>
<th>( a_3 )</th>
<th>( a_4 )</th>
<th>( a_5 )</th>
<th>( a_6 )</th>
<th>( a_7 )</th>
<th>( a_8 )</th>
<th>( a_9 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>-6.50311</td>
<td>1.04071</td>
<td>-0.44965</td>
<td>1.12477</td>
<td>-1.18165</td>
<td>0.35189</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 2</td>
<td>6.63186</td>
<td>0.92763</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.35820</td>
<td>-1.32909</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 3</td>
<td>-1.46476</td>
<td>0.70779</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.02959</td>
<td>0.25610</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 4</td>
<td>-8.11137</td>
<td>0.85064</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.17958</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 5</td>
<td>-15.6738</td>
<td>0.92284</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.54533</td>
<td>0.84134</td>
<td>-1.87067</td>
<td></td>
</tr>
</tbody>
</table>

where \( Q_{20} = a_0 + a_1 \ln(DA) + a_2 \ln(MAP) + a_3 \ln(MAS) + a_4 \ln(MAR) + a_5 \ln(BFI) + a_6 \ln(LNTH) + a_7 \ln(ACLS) + a_8 \ln(SLP) + a_9 \ln(EVA) \)

The following table lists regression equations for \( Q_{100} \) for different flood regions:

<table>
<thead>
<tr>
<th>Region</th>
<th>( a_0 )</th>
<th>( A_1 )</th>
<th>( a_2 )</th>
<th>( a_3 )</th>
<th>( a_4 )</th>
<th>( a_5 )</th>
<th>( a_6 )</th>
<th>( a_7 )</th>
<th>( a_8 )</th>
<th>( a_9 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>-5.98417</td>
<td>1.053201</td>
<td>-0.528969</td>
<td>1.133408</td>
<td>-1.18942</td>
<td>0.38408</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 2</td>
<td>6.82101</td>
<td>0.921807</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.39894</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 3</td>
<td>-1.32542</td>
<td>0.698088</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.12021</td>
<td>0.27759</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 4</td>
<td>-9.07059</td>
<td>0.879464</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.339485</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 5</td>
<td>-15.5088</td>
<td>1.056567</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.455453</td>
<td>0.972502</td>
<td>-2.06328</td>
<td>-0.2707</td>
</tr>
</tbody>
</table>

where \( Q_{100} = a_0 + a_1 \ln(DA) + a_2 \ln(MAP) + a_3 \ln(MAS) + a_4 \ln(MAR) + a_5 \ln(BFI) + a_6 \ln(LNTH) + a_7 \ln(ACLS) + a_8 \ln(SLP) + a_9 \ln(EVA) \)
Dimensionless Flood Frequency Method (MNR, 2000)

In this method, the index flood frequency curves (i.e., $Q_T/Q_2$ frequency curve) for each of the five flood regions (MNR, 2000) were derived and summarized in the following table:

<table>
<thead>
<tr>
<th>Region</th>
<th>$Q_5/Q_2$</th>
<th>$Q_{10}/Q_2$</th>
<th>$Q_{20}/Q_2$</th>
<th>$Q_{50}/Q_2$</th>
<th>$Q_{100}/Q_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>1.464128</td>
<td>1.757267</td>
<td>2.034288</td>
<td>2.392525</td>
<td>2.663892</td>
</tr>
<tr>
<td>Region 2</td>
<td>1.302343</td>
<td>1.48103</td>
<td>1.641315</td>
<td>1.838523</td>
<td>1.98150</td>
</tr>
<tr>
<td>Region 3</td>
<td>1.379202</td>
<td>1.611009</td>
<td>1.819888</td>
<td>2.084759</td>
<td>2.282126</td>
</tr>
<tr>
<td>Region 4</td>
<td>1.339553</td>
<td>1.55357</td>
<td>1.755341</td>
<td>2.015529</td>
<td>2.212111</td>
</tr>
<tr>
<td>Region 5</td>
<td>1.519678</td>
<td>1.85933</td>
<td>2.186755</td>
<td>2.616432</td>
<td>2.946388</td>
</tr>
</tbody>
</table>

Therefore, $Q_5$, $Q_{10}$, $Q_{20}$, $Q_{50}$, and $Q_{100}$ can be estimated by using the above table after the $Q_2$ value is estimated. $Q_2$ for each flood region can be estimated by using the equations in the following table:

<table>
<thead>
<tr>
<th>Region</th>
<th>Regional Correlation Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>$\ln(Q_2) = 0.76492 \times \ln(DA) - 0.27829$</td>
</tr>
<tr>
<td>Region 2</td>
<td>$\ln(Q_2) = 0.84944 \times \ln(DA) - 1.36550$</td>
</tr>
<tr>
<td>Region 3</td>
<td>$\ln(Q_2) = 0.73647 \times \ln(DA) - 0.69874$</td>
</tr>
<tr>
<td>Region 4</td>
<td>$\ln(Q_2) = 0.706116 \times \ln(DA) - 0.47834$</td>
</tr>
<tr>
<td>Region 5</td>
<td>$\ln(Q_2) = 0.85252 \times \ln(DA) - 2.23819$</td>
</tr>
</tbody>
</table>

Regional Flood Frequency Method (MNR, 2000)

The general principle of this method is similar to the Dimensionless Flood Frequency Method (MNR, 2000), with the main difference being that the parameters of the regional index frequency curves are calculated by empirical equations.

The frequency curves for five flood regions in Ontario (MNR, 2000) are listed in the following table:

<table>
<thead>
<tr>
<th>Region</th>
<th>Regional Flood Frequency Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>$q_t = -0.19620 + \exp(0.17195 + 0.37267 \times t)$</td>
</tr>
<tr>
<td>Region 2</td>
<td>$q_t = -0.14974 + \exp(0.13954 + 0.26534 \times t)$</td>
</tr>
<tr>
<td>Region 3</td>
<td>$q_t = -0.20479 + \exp(0.18631 + 0.31158 \times t)$</td>
</tr>
<tr>
<td>Region 4</td>
<td>$q_t = -0.14184 + \exp(0.15297 + 0.37182 \times t)$</td>
</tr>
<tr>
<td>Region 5</td>
<td>$q_t = -0.09669 + \exp(0.10169 + 0.49145 \times t)$</td>
</tr>
</tbody>
</table>

In the above table, $t$ is the frequency factor corresponding to the return period $T$ and $q_t = Q_T/Q_2$ where $Q_T$ is the flood of $T$-year return period and $Q_2$ can be estimated from the same regional $Q_2$ equations used in the Dimensionless Flood Frequency Method (MNR, 2000). Currently, OFAT uses the Regional Flood Frequency Method to calculate $Q_5$, $Q_{10}$, $Q_{20}$, $Q_{25}$, $Q_{50}$, and $Q_{100}$. However, this method can be used to estimate a flood of any return period.
Isoline Method (MNR, 2000)

Floods (i.e., Q₅, Q₁₀, Q₂₀, Q₅₀, and Q₁₀₀) derived at provincial hydrometric gauging stations were divided by drainage area to obtain unit-floods in cms/km² (i.e., q₅, q₁₀, q₂₀, q₅₀, and q₁₀₀). Grids with a resolution of 1km * 1km for q₅, q₁₀, q₂₀, q₅₀, and q₁₀₀ were created by interpolating unit-floods point data at the hydrometric stations. Using OFAT, the flood flows at an ungauged watershed can be estimated by multiplying the drainage area with the average unit-flood values within the watershed boundary.

Limitations for Flood Prediction Models (MNR, 2000)

The following table lists each region and ranges of watershed parameters used in developing the flood prediction models.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
<th>Region 1</th>
<th>Region 2</th>
<th>Region 3</th>
<th>Region 4</th>
<th>Region 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>94300</td>
<td>2.51</td>
<td>3700</td>
<td>0.1</td>
<td>9090</td>
</tr>
<tr>
<td>MAP</td>
<td>500</td>
<td>1000</td>
<td>780</td>
<td>1000</td>
<td>790</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>350</td>
<td>90</td>
<td>300</td>
<td>110</td>
<td>350</td>
</tr>
<tr>
<td>MAR</td>
<td>137</td>
<td>826</td>
<td>137</td>
<td>480</td>
<td>255</td>
<td>540</td>
</tr>
<tr>
<td>EVA</td>
<td>340</td>
<td>820</td>
<td>550</td>
<td>820</td>
<td>510</td>
<td>780</td>
</tr>
<tr>
<td>BFI</td>
<td>0.1</td>
<td>0.99</td>
<td>0.1</td>
<td>0.82</td>
<td>0.27</td>
<td>0.88</td>
</tr>
<tr>
<td>MCL</td>
<td>3.0</td>
<td>465</td>
<td>5.5</td>
<td>100.9</td>
<td>5.0</td>
<td>190.5</td>
</tr>
<tr>
<td>ACLS</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>SLP</td>
<td>0.34</td>
<td>9.4</td>
<td>0.34</td>
<td>9.4</td>
<td>0.04</td>
<td>7.1</td>
</tr>
</tbody>
</table>

3. Mean Annual Flow Prediction Models (MAF)

Currently, OFAT contains the Isoline Method (Environment Canada, 1986) to estimate mean annual flow (cms). The original provincial isoline map for mean annual runoff (mm) was first digitized and then a continuous surface (a map) with 1km * 1km cell resolution was created from the isolines. The mean annual runoff (mm) for the watershed is calculated by averaging all the cell values within the watershed boundary, which can be converted into mean annual flow (cms).
4. Minimum Instream Flow Requirement Models (IFR)

The Tennant Method or Montana Method (Tennant, 1976) provides a quick and easy methodology for determining flows to protect the aquatic resources in both warm water and cold water streams. It is based on the ratio of the various flow ratings to the mean annual flow for the periods of October to March and April to September, as shown in the following table. In OFAT, the mean annual flow is estimated by using the Isoline Method (Environment Canada, 1986).

Table: Flow ratings as percent of Mean Annual Flow.

<table>
<thead>
<tr>
<th>Flow Rating</th>
<th>October to March</th>
<th>April to September</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flushing to Maximum</td>
<td>200 percent</td>
<td>200 percent</td>
</tr>
<tr>
<td>Optimal Range</td>
<td>60-100 percent</td>
<td>60-100 percent</td>
</tr>
<tr>
<td>Outstanding</td>
<td>40 percent</td>
<td>60 percent</td>
</tr>
<tr>
<td>Excellent</td>
<td>30 percent</td>
<td>50 percent</td>
</tr>
<tr>
<td>Good</td>
<td>20 percent</td>
<td>40 percent</td>
</tr>
<tr>
<td>Fair or Degrading</td>
<td>10 percent</td>
<td>30 percent</td>
</tr>
<tr>
<td>Poor or Minimum</td>
<td>10 percent</td>
<td>10 percent</td>
</tr>
<tr>
<td>Severe Degradation</td>
<td>&lt; 10 percent</td>
<td>&lt; 10 percent</td>
</tr>
</tbody>
</table>

5. Bankfull Discharge Prediction Models (BFQ)

Most commonly, bankfull discharge corresponds to floods occurring in 1 to 2-year return period. In OFAT, the Index Flood Method (Moin & Shaw, 1985) has been used to estimate n-year return period flood corresponding to bankfull discharge used in the following models.

**Annable Bankfull Discharge Model (Annable, 1994)**

Annable (1994) estimated that the bankfull discharge corresponds to 1.6-year return period based on his study on rivers in southwestern Ontario.

**Leopold Bankfull Discharge Model (Leopold et al., 1964)**

Leopold *et al.* (1964) estimated that the bankfull discharge corresponds to 1.5-year return period.

**Dury Bankfull Discharge Model (Dury, 1973)**

Dury (1973) estimated that the bankfull discharge corresponds to 1.58-year return period.
Appendix E: Flow Charts
Flow Chart Legend

* Multiple Selections Allowed

Optional Feature Selection

Data

User Decision

User Input or Selection

Maps and Menus

Process

Connector

Flow Chart Number
OFAT.apr
Start

Batch Run
FC 3

OFAT User’s Manual

FC 1 Opening Sequences

OFAT User’s Manual

FC 1 Opening Sequences

OFAT User’s Manual

FC 1 Opening Sequences

OFAT User’s Manual

Batch Run
FC 3

Select a major basin

Tertiary Watershed Index Map

Delineate or import watershed?

Delineate

Select a tertiary watershed

Select a DEM

Select smaller or larger than one tertiary watershed?

Select a tertiary watershed

Select a DEM

Select a tertiary watershed

Select a DEM

Enter UTM x,y from keyboard

Enter file name and type

Selected Watershed Map

Click mouse on screen

Delineating watershed

Selected Watershed Map (with delineated watershed)

Save watershed and/or pour point

Watershed Information Extraction System (WIES) (WIES)

FC 4
**FC 2 Watershed Calculator and Hydrologic Models**

START

Select Watershed Calculator function

Watershed Calculator Menu

Select Optional Parameters

Click on 'Calculate' button

Watershed Calculator processing

Click on 'OK' button

Watershed Calculator Results

Click on 'Run Models' button

Enter output file name and type

Select Flow Prediction Models function

Return to Selected Watershed Map (with del. ws.)

Select flow models

Model processing

View Model Results

Click 'Close' button

Return to Selected Watershed Map (with del. ws.)

Select model category to view results

Return to Selected Watershed Map (with del. ws.)

Low Flow Prediction Models

Flood Prediction Models

Mean Annual Flow Prediction Models

Minimum Instream Flow Requirement Models

Bankfull Discharge Prediction Models
**FC 3 Batch Run**

START

Batch Run menu

Click on 'Load Batch File' button

Select Batch file type and name

Batch file loaded

Input Pour Point?

Select DEM

Select Tertiary Watershed

Enter Co-ordinates from keyboard

Click 'Interactive Co-ordinate Selection' button

Select Major Basin

Select Models to be run

Select Parameters to be calculated

Save Watershed option

Enter output file name and select data type

Click on 'Interactive Co-ordinate Selection' button

Click on 'Add to Batch' button

Enter results output file name and select file type

Click on 'Run Batch' button

Batch Run processing

Batch Run Complete message

Click on 'Delete Row' button

Enter Output file name

Cancel

Return to Selected Watershed Map (with del. ws.)

Click on 'Clear Batch' button

Add another watershed

Click on 'Load Batch File' button

Select Batch file type and name

Batch file loaded

Enter output file name and select data type

Save Watershed option

Click on 'Interactive Co-ordinate Selection' button

Select Dem, Major Basin, and Tertiary Watershed.

Enter co-ordinates from keyboard or select interactive co-ordinate selection.

Select Major Basin and add models to be run.

Save Watershed option.

Enter output file name and select data type.

Click on 'Run Batch' button for processing.

Click on 'Delete Row' button to remove selected watershed.

Click on 'Clear Batch' button to clear all batch files.
FC 4 Watershed Information Extraction System (WIES)

- Surfacial Geology
- Surficial Geology (Terrain-Adjusted)
- Quaternary Geology
- Runoff Curve Number CN_I (dry AMC)
- Runoff Curve Number CN_II (avg. AMC)
- Runoff Curve Number CN_III (wet AMC)
  for diff. antecedent moisture conditions
- Land Cover (28 Classes)
- Soil Landscapes of Canada
- Ontario Land Inventory
- Digital Elevation Model (DEM)
- Slope
- Aspect
- User-Defined Layer 1
- User-Defined Layer 2
- User-Defined Layer 3
- User-Defined Layer 4

START

WIES Main Menu

Select data category and data layers

Geology Menu

Runoff Curve Number Menu

Land Cover Menu

Soil Menu

DEM-Related Menu

User-Defined Menu

WIES processing

Click 'Apply' button

Click 'Exit' button

Return to Selected Watershed Map (with del. ws.)

Click on 'WIES Summary Statistics' button

and/or

Select themes in the legend to be summarized

Watershed Information Extraction Map

Click on 'Return to Selected Watershed Map' button

View summary table and chart

Export a summary table

Select a field to summarize

Select file type to export to

Enter export file name for table

Table displayed

Select area or percentage for chart

Chart displayed

Select data category and data layers

FC 1
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