Integrated Watershed Management

Navigating Ontario's Future

Water Budget Overview

Conservation ONTARIO
Natural Champions

ACKNOWLEDGEMENTS

Integral to the development of these reports were a number of individuals from various organizations who provided data, attended meetings, reviewed draft documents and provided input to the project. Significant contributions from Environmental Water Resources Group are acknowledged with regard to the Water Management Framework Report. In addition, full acknowledgement is noted with respect to the work completed by Blackport and Associates for their work on the Water Budget Synthesis Report. The facilitation of workshops and follow up summary reports provided by Kidd Consulting is also acknowledged. The work of Hazel Breton (P.Eng) on the Integrated Watershed Management Reports and overall project management of this initiative is also acknowledged.

Conservation Ontario
Box 11, 120 Bayview Parkway
Newmarket, Ontario L3Y 4W3
(Office) 905-895-0716
(Fax) 905-895-0751
www.conservationontario.ca

2010

TABLE | of Contents

EXECUTIVE SUMMARY

WATER BUDGET OVERVIEW

BIBLIOGRAPHY

DEFINITIONS

INTEGRATED WATERSHED MANAGEMENT
Navigating Ontario's Future

A Water Budget Overview for Ontario

EXECUTIVE SUMMARY

To address current and emerging issues relating to Integrated Watershed Management (IWM), Conservation Ontario in partnership with the Ministry of Natural Resources, and Department of Fisheries and Oceans launched the IWM initiative: **Integrated Watershed Management: Navigating Ontario's Future** in 2008. The objective of the initiative is to update the understanding of IWM in Ontario, assess it against IWM being conducted globally and nationally, identify gaps, and recommend strategic shifts needed to address these gaps.

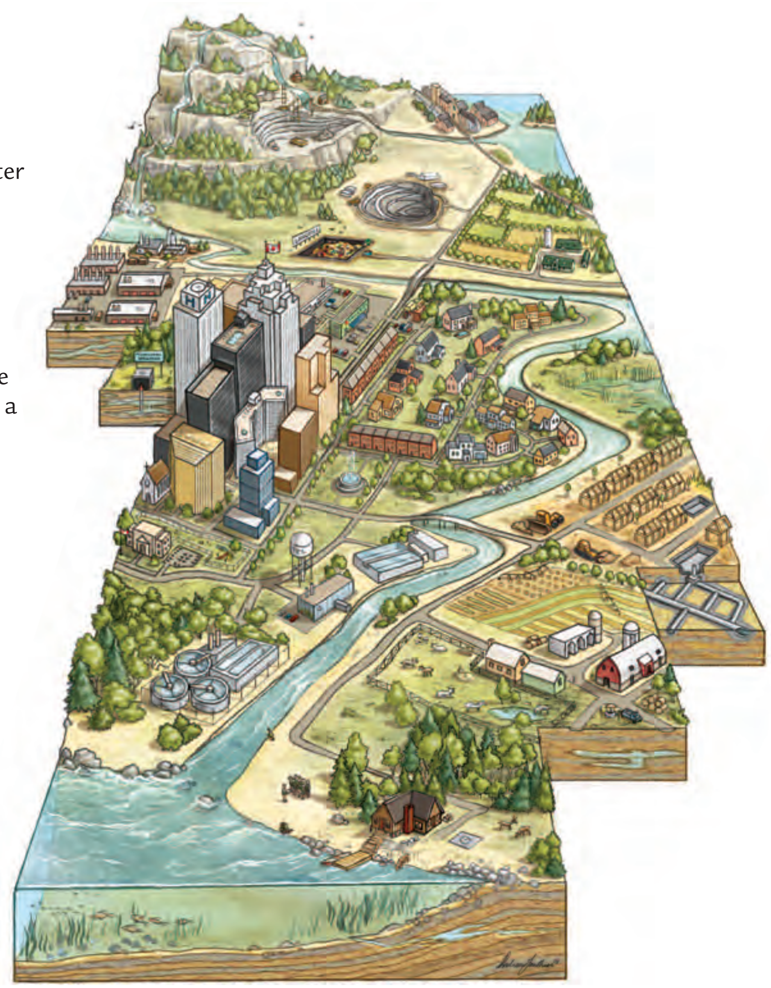
As part of this initiative, a request to explore the development of a Water Management Framework and Water Budget Overview for Ontario was made. These initiatives are discussed in separate reports. Linkages exist between these initiatives as there is a hierarchical relationship with feedback loops between them. This report provides an overview of water budgets, their application elsewhere and their use in Ontario.

In order to properly protect water and related land resources, we need to understand what is going on with Ontario's water – both on the surface and below ground. One tool we use to help us assess and evaluate how best to protect local water quantity and quality is a water budget.

Not unlike a household budget that looks at how much money we make as a whole and then guides us on how much we can spend by looking at expenses today and in the future, a water budget looks at how much water enters a watershed, how it's stored and how much water leaves. It also looks at what we are doing on the land that impacts water quality and quantity and then this information helps us to determine how much water is available for human uses while ensuring there is still enough left for natural processes. This is done on different scales assessing it against our requirements today and what we think we will need for the future.

The Water Budget Overview provides a general understanding of water budgets and the water cycle; it provides a background review of policy and legislation; and it allows for a more detailed analysis of how we use water budgets in Ontario and globally.

The information provided in this overview was obtained from readily available information found online, informal and workshop discussions, plus the results from a survey carried out with Ontario's 36 Conservation Authorities. The intention of the overview is to provide a summary of the technical feedback and provide recommendations for a guidance document (beyond what currently exists for the Drinking Water Source Protection Program), for a governance structure and performance measures.



Conservation Ontario (Andrea Gauthier) 2009.

What is a Water Budget?

A water budget is a basic tool that can be used to evaluate the occurrence and movement of water through the natural environment. Water budgets provide a foundation for evaluating its use in relationship to other important influencing conditions such as other ecological systems and features, as well as social and economic components – how much water is being used by industry, residents, etc.

The water budget process can encompass various levels of assessment which start simple and grow more complex if there are concerns about how much water is available at any level. The higher the 'tier', or level, the more complex the science involved and the narrower the geographic focus.

Water budgets commonly go well beyond how much water is available and where it is. They also include a detailed understanding of the flow dynamics. These flow dynamics include the origin and movement of both groundwater and surface water as well as the interaction between the two systems. This overall interdependent understanding is necessary for sound water management.

Water budget studies consider the volumes of water within the various reservoirs of the hydrologic cycle and the flow paths from recharge to discharge. Water budgets need to consider this information on a variety of spatial and temporal scales.

Hydrological Cycle – Our Water Cycle

We have a finite supply of water and it moves within the hydrologic cycle, or water cycle within a watershed. In order to ensure a sustainable supply of water within the water cycle, we need to pay attention to what is happening on the land and how that impacts our natural environment. Precipitation reaching the land surface is impacted and distributed in numerous ways. Any precipitation that falls within the watershed is influenced by physical characteristics of the land, air pollution, and land uses.

By developing a snapshot of the physical watershed we can determine where water sources are located, how much water is being used, how much is being stored, and where the important recharge areas are located (where surface water and groundwater interact). The way water moves in a watershed relies on the typography of the land, types of soils, etc. Excess water can be stored in a watershed – in low areas or below ground – slowly being released over time during drier periods. However, overuse or contamination of these sources of water significantly impacts the quality and amount of water we have available. The amount of water available in a watershed is not infinite and it is susceptible to stress – there is only so much that is recycled through the water cycle. If we use too much water – faster than it can be replenished naturally – it impacts the amount available today and in the future.

The amount of water available to us is NOT infinite.

Technical Aspects of Water Budget Assessments

The level of detail incorporated into any water budget analysis depends on the study objectives and the data available. In a natural state an unstressed basin experiences negligible long term changes in land surface, soil moisture and groundwater storage. However, this is not always the case. Also, groundwater flows as well as impacts of human activities can result in water moving between watersheds (i.e. inter-basin flow) and may be difficult to adequately quantify.

It is suggested that as an initial approach that water budgets start in a more simplistic state where storage changes and natural inter-basin flows are ignored.
It is also suggested that average saturation state conditions be analysed. This means that input data and calibration targets represent average climate conditions, average groundwater levels and average streamflow conditions.

This provides an initial understanding of the system and allows managers to examine how water is balanced by using these simplifications. Future analysis could build on this initial understanding to determine the nature of inter-basin transfers and storage changes as well as the hydrologic response of the basin to low and high saturation states. If significant, these components would then be incorporated into a refined water budget. In this way the water budget and, indeed, the overall understanding of water movement within the watershed is quantitatively improved over time as more data becomes available and re-assessed.

Water Budget Modeling

A conceptual water budget model is first developed to obtain a basic understanding of the physical flow system. An initial synthesizing of the available data can be used to gain an appreciation of the various fluxes in the watershed. This initial work may indicate where critical data gaps exist.

The use of numerical modeling can provide a more refined understanding of the flow system including both surface and groundwater. Numerical models are tools used to simplify the representation of these processes and enable quantification and evaluation of the hydrologic system at various levels – watershed, subwatershed and site scale. Although these models can provide hard quantitative values, it is important to recognize the uncertainty in numerical modeling and use the models appropriately in making water management decisions.

The most appropriate model for water budget analysis will depend primarily on the dominant flow processes (surface water or groundwater). If changes in the groundwater discharge will significantly affect the flow of a river, then the model used should simulate the complexities of the groundwater system. If flow in the river is most affected by surface runoff and through flow during and following storm events, then the model must be able to simulate the complexities of the surface water processes. In Ontario, most changes in groundwater discharge and storm event processes will affect the flow in the river such that linking surface water and groundwater models, or the use of conjunctive models is most appropriate for water budget analysis.

Water Budget Limitations

There are a number of considerations to be evaluated to ensure effective utilization of the water budget. Generally they are related to whether or not there is understanding of the necessary physical data of sufficient quality to build a conceptual model; as well as calibrate a numerical model that is capable of representing the physical processes at play.

International Water Budget Overview

Although limited information on the use of water budgets from a global perspective was found, some information was gathered on Australia, Great Britain, European Union and the United States. A substantial amount of work would be expected to be carried out in these areas as a result of climate, demand for water and intensity of historical and future development. Further research is needed to gather the technical documents that have been completed.

Ontario Water Budget Overview

Water budgets in various forms and levels of complexity have been carried out in the province dating back to the 1960's in basin studies under the management of the Ontario Water Resource Commission. Although carried out in inconsistent fashion, water budget studies have also and continue to be carried out on various scales for land use and water use developments. As well, watershed and subwatershed studies carried out in the 1990's commonly presented basic water budgets but there was no consistent methodology.

To protect municipal drinking water sources in the province, the Province of Ontario has mandated the production of locally developed, science-based source water assessment reports and protection plans. This is being done through the *Clean Water Act* (2006). These reports require Conservation Authorities to conduct water budgets. The level of detail of the water budget characterization depends on the associated risk assessment process. As of mid 2009, the Ministry of Natural Resources has reported that all of the Conservation Authorities have carried out Conceptual Water Budgets, the first of four possible levels. A number of higher Tier 2 and Tier 3 Water Budgets have been or are in the process of being completed. These water budgets are being utilized for the management of municipal water supplies.

The technical approach to watershed and subwatershed water budgeting most commonly used in the province is the integration of surface water and ground water models. In order to improve our understanding, methodology and implementation relating to water budgets, the Conservation Authorities and the Ministry of Natural Resources has developed an interim strategy promoting and conducting research initiatives focused on watershed-based management activities. The four themes covered by this research include:

1. Water Quantities and Their Movement Within the Hydrologic Cycle
2. Landscape Characteristics Influencing the Movement of Water
3. Water Quantities and Their Relation to Biological Communities
4. Human Modification of the Hydrologic Cycle

Results from the research projects and assessments will greatly improve the knowledge gaps within Ontario's current water budget process.

Uses of Water Budgets

In addition to protecting sources of drinking water, water budgets can be used for a number of land use and water use developments including: Permit to Take Water applications; landfill site approvals; residential or industrial development; municipal water supplies; aggregate extraction; dam construction; stormwater management; and irrigation.

More specifically, they can be used:

- to set water allocation targets and recharge rates within local watersheds;
- as a decision-making tool to evaluate land and water uses such as restoration and rehabilitation projects identified in management plans;
- evaluate the cumulative effects of land and water uses within watersheds;
- to provide a watershed scale framework for site scale studies (e.g. evaluation of a sewage & water system plan);
- to help make informed decisions about the design of environmental monitoring programs; and
- to assist in setting targets for water conservation.

In order to use the water budgets to their full potential, as the science unfolds and resources are available, we need to address current knowledge gaps, data gaps and issues; and they need to be addressed on an ongoing basis.

Recommendations

1) The technical aspects of the knowledge gaps described above are not just common to Ontario but reflect the world wide state-of-the-science. As such it is recommended that Ontario keep apprised of the ongoing work within the national and international academic and consulting community as it relates to:

a. baseflow quantification;

b. recharge quantification;

c. aquifer mapping; and

d. instream flow needs.

2) Access should be provided to a description of all the technical initiatives, both historical and ongoing, in the province which may aid in carrying out water budgets (i.e. monitoring databases, releasing findings on new methodologies or models, basic research etc.).

3) A hydrological monitoring database framework should be developed that provides practical and timely access to standardized data; and resources to convert and input non-electronic data (i.e. hardcopy hydrographs, borehole logs, groundwater chemistry, baseflow data etc.) into the database.

4) A group or agency should be designated to maintain and provide an additional level of assessment of the knowledge gained from water budgets (i.e., building a cumulative understanding of how much water is moving and where). See Water Management Framework Report under separate cover.

5) Carry out a detailed review of completed and ongoing water budget studies to assess scheduling, human resource and financial needs and deliverables in the context of expected results versus actual results. This will provide direction on future resource needs to complete technically sound studies.

6) Carry out a review, assess the spatial and temporal gaps and provide additional monitoring for:

a. climate data;

b. groundwater level data;

c. streamflow, particularly baseflow, and reach specific discharge;

d. evapotranspiration data;

e. accurate water takings; and

f. aquifer characteristics.

7) Ensure higher level water budgets are carried out in the remaining subwatersheds in the province that were not addressed through the *Clean Water Act*, *Oak Ridges Moraine Act*, and the *Lake Simcoe Act* to provide information to assess cumulative effects, irrigation, flood control etc. See Water Management Framework Report under separate cover.

8) Continue to improve technical methodology to assess water budgets on a local scale (i.e. plans of subdivision to better manage storm water) and incorporate into an ongoing larger scale assessment.

WATER BUDGET OVERVIEW



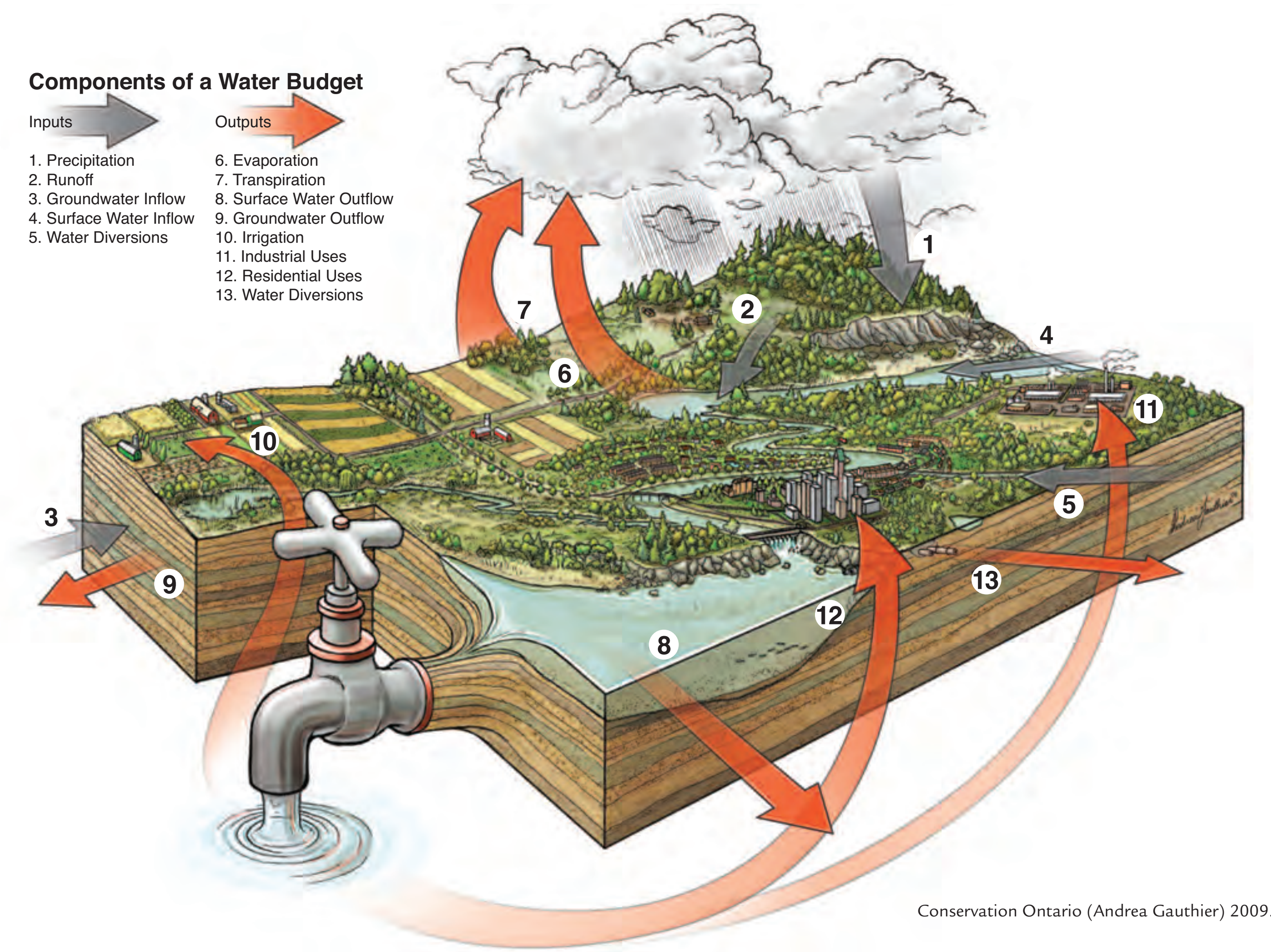
1.0 | Introduction

This work is being done in concert with the Integrated Watershed Management Initiative which is supported by a partnership between Department of Fisheries and Oceans, Conservation Ontario, Ministry of Natural Resources and Ministry of the Environment. There were three separate but linked components that include:

- A report on Integrated Watershed Management in Ontario (Phases I, II, & III);
- A report on a Water Management Framework for Ontario; and
- A report on a Water Budget Overview for Ontario.

A water budget is a basic tool which can be used to evaluate the occurrence and movement of water through the natural environment. The quantification of water budgets and the underlying hydrological processes provide an interdependent foundation for the other ecological, social and economic components within the natural and anthropogenic environments. Some additional necessary tools for the management of watershed processes include those to assess ecological water needs, sediment transport processes, transport of dissolved parameters (nutrient, contaminant, microbiological etc.), surface water hydraulic analysis and groundwater flow. All of these tools and subsequent assessments are interdependent and can feed into each other. This water budget tool can be very simple or very complex depending on the environment we are trying to characterize and the water management objectives for carrying out the water budget.

A water budget is a basic tool which can be used to evaluate the occurrence and movement of water through the natural environment.



Conservation Ontario (Andrea Gauthier) 2009.

This water budget overview is meant to serve a number of purposes:

- provide a general understanding of the technical aspects of water budgets and the basic hydrological processes;
- provide a background review of policy and legislation carried out in the province of Ontario;
- provide a more detailed overview of water budget utilization within Ontario;
- provide a high level overview of water budget utilization within the international community;
- provide a summary of technical feedback from surveys (IWM in Ontario, Appendix 2 & 3) and workshops (A Water Management Framework for Ontario, Appendix 1);
- provide recommendations for a guidance document beyond what currently exists for Ontario's Source Protection initiative for water budgets; and
- provide recommendations for a governance structure and performance measures.

The knowledge base for this overview was obtained for the most part from readily available information online, informal discussions with colleagues, a survey with the Conservation Authorities and discussion and feedback from two formal workshops. The technical discussion in Section 2 The Hydrologic Cycle and Section 3 Technical Aspects of Water Budget Assessments is presented in more detail to frame the potential complexity and limitations in quantifying a water budget. The document "Oak Ridges Moraine Conservation Plan Technical Paper 10 –Water Budgets" was prepared for implementing Section 25 of the Oak Ridges Moraine Conservation Plan (ORMCP) and is a very detailed guidance document for understanding and carrying out water budgets which utilizes an extensive literature review.

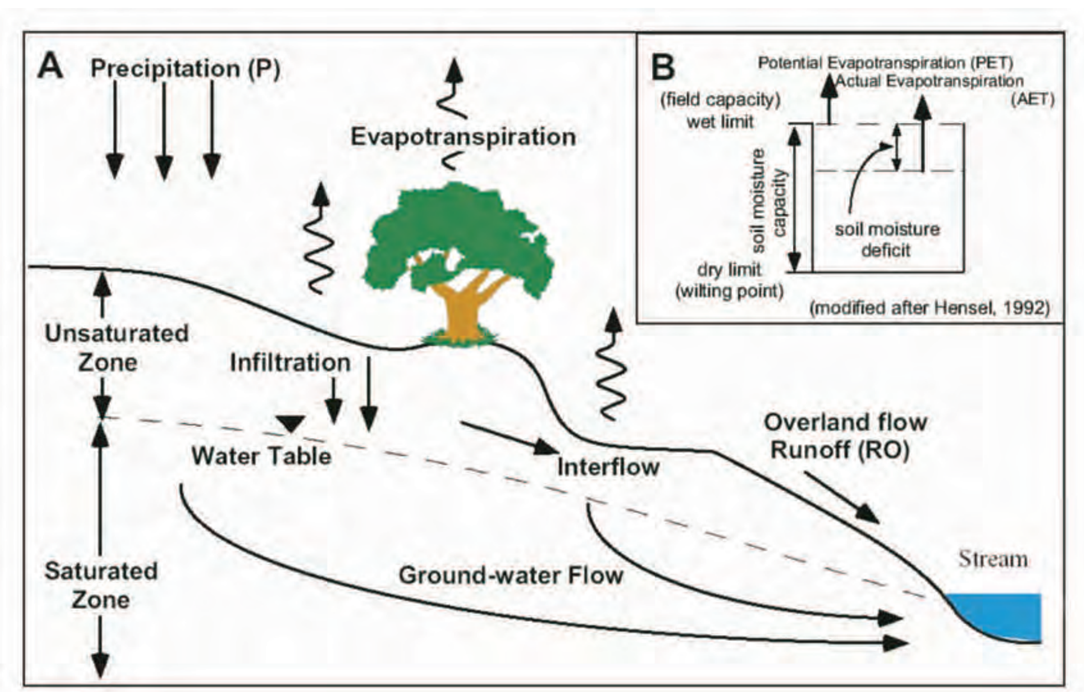
As such, this current overview takes advantage of incorporating various portions of Technical Paper 10 –Water Budgets into Section 2 and Section 3. Section 4 provides a high level overview of water budget practices in Australia, the United States and Great Britain. The amount of detailed information on the utilization of water budgets within the international community and supporting technical documents obtained for this overview was limited. Section 5 provides an overview of water budget practices in Ontario. This section includes input from the survey and the workshops.

2.0 | Hydrologic Cycle

The hydrological processes underlying the water budget are shown in **Figure 1**. Precipitation reaching the land surface is distributed in numerous ways. When the ground surface has a low permeability, precipitation runs off directly towards surface depressions and streams or evaporates back into the atmosphere. When precipitation falls on permeable soils, however, the run-off component can be relatively small (except when soils are frozen or already saturated, i.e. late winter, early spring). Precipitation enters the soil profile where it becomes subjected to free water evaporation, or if vegetation is present, transpiration. The combination of these two processes is termed evapotranspiration. The potential evapotranspiration (PET) is the amount of water that would evaporate and transpire if water was available to the plants and soils in unlimited supply. Since this is not the case in southern Ontario, the term actual evapotranspiration (AET) is used such that AET is less than or equal to PET.

Water that remains after evapotranspiration has the potential to increase the soil moisture content of the soil, and eventually infiltrate to the groundwater reservoir, or move upon the ground surface in the form of runoff. In theory, the soil moisture content cannot exceed its maximum or 'field capacity', also known as the 'wet limit', and any excess will drain from the soil to the groundwater system as infiltration. The lower limit of soil moisture content is known as the 'dry limit' **(Figure 1-B)**. Prior to reaching the groundwater system, water in the unsaturated zone can be directed via field drains or highly permeable layers in the unsaturated zone, horizontally as 'interflow' to nearby streams. Groundwater may be transpired by plants or discharge to springs and surface water bodies where it eventually evaporates into the atmosphere to complete the hydrologic cycle.

Figure 1 **Hydrologic Components** (from Gerber and Howard, 1997)



3.0 | Technical Aspects of Water Budget Assessments

3.1 Basic Components of a Water Budget

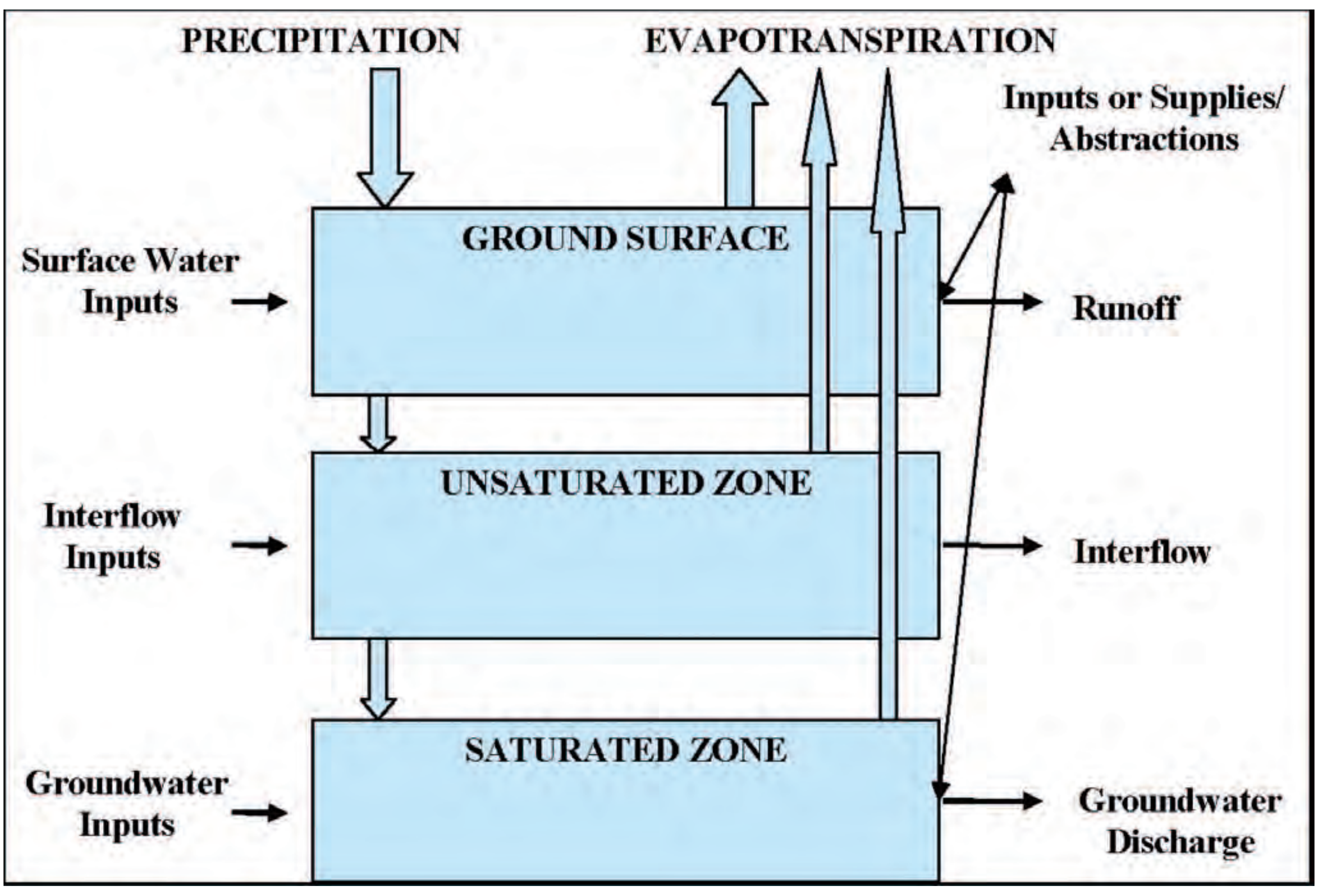
In simple terms a water budget for a given area can be looked at as water inputs, outputs and changes in storage. The inputs into the area of investigation (precipitation, groundwater or surface water inflows, anthropogenic inputs such as waste effluent) must be equal to the outputs (evapotranspiration, water supply removals or abstractions, surface or groundwater outflows) as well as any changes in storage within the area of interest.

In the simplest form this can be expressed as:

Inputs = Outputs + Change in storage P + SWin + GWin + ANTHin = ET + SWout + GWout + ANTHout + ΔS

Where;
P = precipitation,
SWin = surface water flow in,
GWin = groundwater flow in,
ANTHin = anthropogenic or human inputs such as waste discharges,
ET = evaporation and transpiration,
SWout = surface water flow out,
GWout = groundwater flow out
ANTHout = anthropogenic or human removals or abstractions,
ΔS = change in storage (surface water, soil moisture, groundwater).

Figure 2 **Water Budget Components** (ORMCP Technical Paper 10))



More detail is incorporated into the water budget to account for additional physical aspects. Essentially, there are three compartments to consider in the water budget determination as shown in **Figure 2**: the ground surface; the unsaturated zone and the saturated zone.

Precipitation falls onto the ground surface and then can either: i) be evapotranspirated back to the atmosphere; ii) runoff from the surface to surface water bodies (e.g. streams, lakes and wetlands); iii) move downward to the unsaturated zone or iv) be removed for human water supply purposes. In turn, water that moves to the unsaturated zone can either: i) be evapotranspirated back to the atmosphere; ii) move laterally as interflow to discharge to local surface water bodies; or iii) move downward to the saturated zone. Similarly, water that moves to the saturated zone can: i) be evapotranspirated back to the atmosphere (e.g. via plants whose roots extend to near the water table); ii) move in the groundwater system and eventually discharge into a surface water body; or iii) be removed for human water supply purposes.

Figure 2 illustrates that evapotranspiration can occur from any of the three compartments. This figure also shows anthropogenic inputs and/or abstractions. These are both related to human intervention in the water cycle. Inputs would occur in an instance where water external to a watershed (e.g. a water supply from Lake Ontario or Lake Simcoe) was being brought into, and disposed of, within the watershed, thereby increasing the water volume in the watershed. Supplies or abstractions would occur where water was being withdrawn from either a surface water body or the groundwater system and was being removed from the watershed (e.g. a water supply within the watershed, but with treated wastewater disposed directly to Lake Ontario or Lake Simcoe).

It is important to note that these human interventions are often difficult to account for in a water budget owing to the fact that a certain portion of the withdrawn water is likely re--circulated back within the same watershed (e.g. through lawn watering or through leakage from municipal infrastructure, etc.). **Figure 2** also shows inputs into the three compartments (i.e. surface water inputs, interflow inputs, groundwater inputs). Water budgets are generally carried out on a watershed or subwatershed scale and the surface water inputs and interflow inputs tend to be negligible.

Water budgets are generally carried out on a watershed or subwatershed level.

Mathematically, the water budget can be expressed as follows:

$$P = RO + AET + I + D + A \pm \Delta l \pm \Delta s \pm \Delta g \qquad [1]$$

Where;
P = precipitation
RO = surface runoff
AET = actual evapotranspiration
I = interflow
D = groundwater discharge
A = anthropogenic inputs (septic systems) and/or supplies/abstractions
Δl = change in land surface storage
Δs = change in soil moisture storage
Δg = change in groundwater storage

Following from equation 1:
Stream Flow Discharge (SFD) = I + D + RO [2]
Infiltration (Inf) = P - AET - RO – Δs -Δl [3]
Aquifer Recharge (R) = P - AET - RO – Δs -Δl – I [4]

Over long periods of time in an unstressed, natural state basin (no groundwater pumping or other anthropogenic influences), the natural inputs will balance the natural outputs so the change in storage will be zero. Soil moisture storage may vary considerably on a daily basis but the net change (Δs) over an annual cycle will be negligible compared to other water budget components. Similarly, groundwater storage and land surface storage may fluctuate on a monthly or annual basis, but Δg and Δl will approach zero (steady state) over an extended period of time provided other water budget components remain essentially constant. If Δs, Δl and Δg equal zero, then substitution of equation [4] into equation [1] reveals that

Aquifer Recharge (R) = D + A [5]

Substitution of equation [2] into [1] gives us

Stream Flow Discharge (SFD) = P - AET - A [6]

If groundwater pumping is small, (i.e. A ~ 0), then annual recharge can be equated to groundwater discharge,

R=D [7]

and streamflow discharge will be the difference between precipitation and actual evapotranspiration.

The preceding quantification assumes the groundwater divides would have to correspond to a large degree to the surface water divides in a 3-dimensional sense and this depends on the size of study area and the nature of the groundwater flow system. It is important to understand the relationship between the groundwater and surface water divides. Where these divides are not coincidental, groundwater inputs within the surface watershed may not be reflected in the groundwater discharge within the surface watershed.

The above discussion presents a rather detailed description of the quantification of the physical processes. The objectives of the water budget assessment will determine to what level of detail these parameters are analyzed including the level of detail relating to:

- the temporal and spatial scale of assessment;
- the extent of the conceptual understanding of the flow system;
- the type and amount of data to be collected and
- the choice of a analysis technique for detailed quantification.

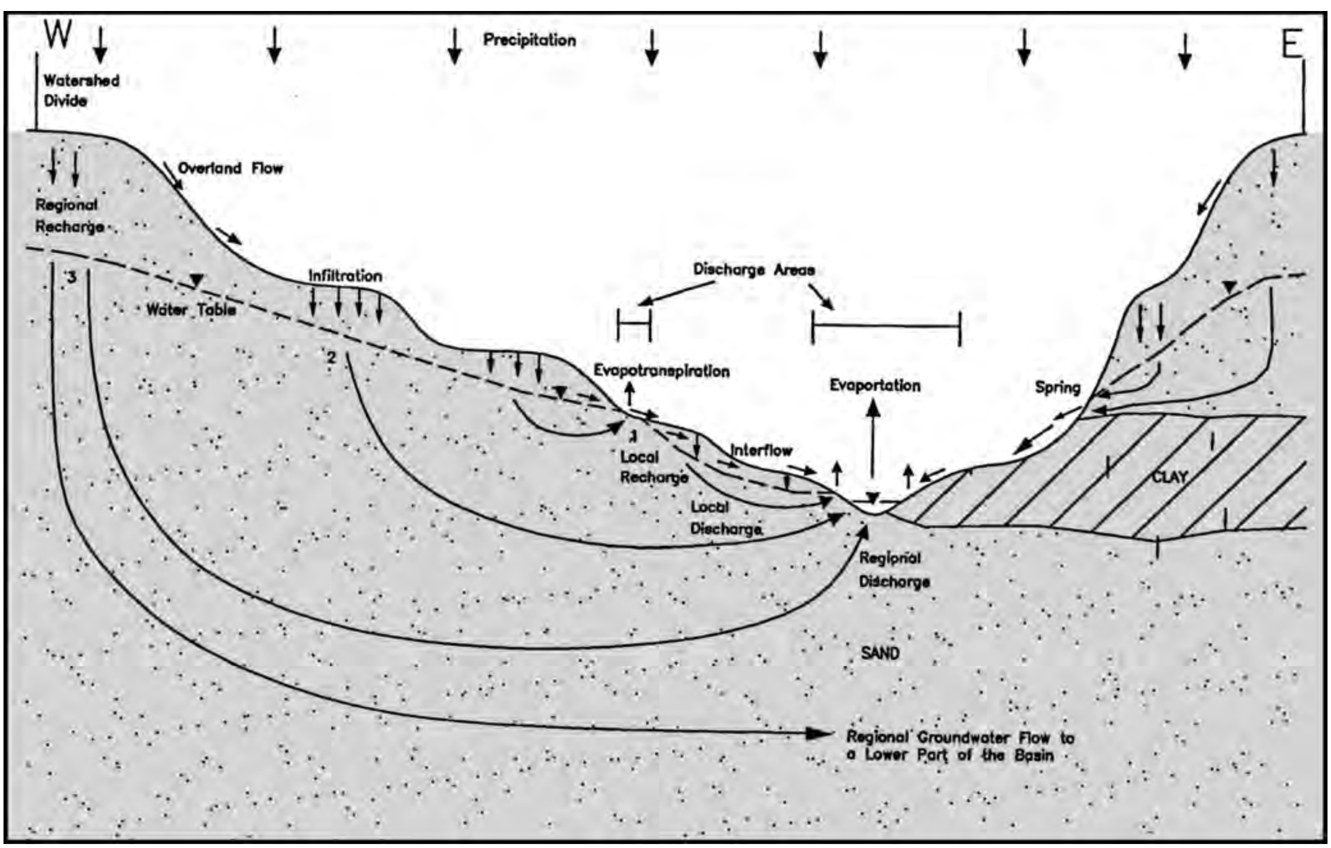
It is important to note that the utilization of water budgets more commonly goes well beyond how much water is available and where but includes a detailed understanding of the flow dynamics. These flow dynamics include the origin and movement of both groundwater and surface water and the interaction between the two systems. This overall interdependent understanding is necessary for sound water management.

Assessment Scale, Flow System Conceptualization and Data Collection

The volumes of water within the various reservoirs of the hydrologic cycle associated with watershed and subwatersheds vary both spatially and temporally. In addition, the flow paths from recharge to discharge occur on various scales both spatially and temporally. Water budget studies must consider this variability and how it relates to the intended objectives of the study. For instance, climate may vary appreciably across a physiographic area due to topography, terrestrial cover or urbanization.

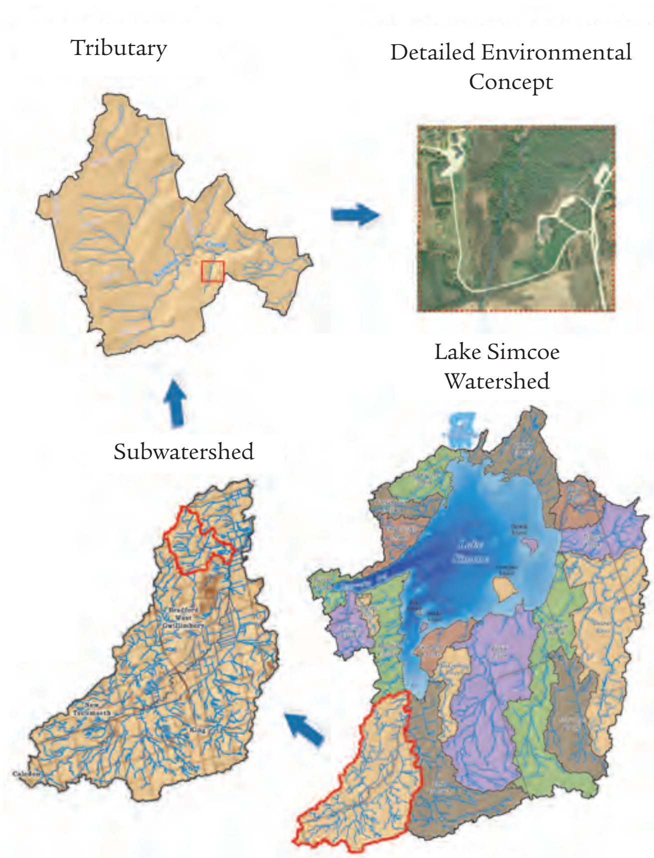
Ecosystem processes also operate on a variety of spatial and temporal scales. Scale dependency in ecosystems may be continuous, every change in scale bringing with it changes in patterns and processes, or there may be "domains" characterized by relatively sharp transition from dominance by one set of factors to dominance by another set (Wiens, 1989). Relationships between physical and biological attributes may be evident at broad scales but overwhelmed by biological interactions at finer scales. Human observation of ecological processes may also be made at a variety of scales. For logistical reasons, expanding the extent of the area of observation usually requires decreasing the resolution. This leads to an increased ability to detect broad-scale patterns and processes and a reduced ability to detect fine-scale details. If we study a system at an inappropriate scale, we may not detect the actual system dynamics but only artifacts of scale. For these reasons the scale of dynamic assessment for water budgets will invariably take into account these interdependent ecological considerations. **Figure 3** shows an example of the different scales for a groundwater flow system and **Figure 4** shows various surface water spatial scales.

Figure 3 **Spatial Scales for a Groundwater Flow System**



Although constrained by the scale of observation; the analysis, interpretation and subsequent management may also be done at a variety of scales. For example, groundwater systems may be interpreted at regional, watershed, and site scales. Analysts need to be cautious about translating observed relationships between domains of scale and be aware of the potential for spatial and temporal lags. These lags are more pronounced with groundwater flow systems. The temporal dynamics are readily observed in event, seasonal and long term climate variations which again must feed back into the assessment within the various components. It is always noted that groundwater divides do not necessarily correspond with surface water divides which must be accounted for in all aspects of the water budget assessment. We must also note that groundwater flow systems are three dimensional in nature not just within one particular subsurface hydrostratigraphic unit but between many such units. Given the nature of the topography and hydrogeological units in Ontario the deeper hydrostratigraphic units may not be as significant.

Figure 4 **Surface Water Spatial Scales**



Lake Simcoe Region Conservation Authority (GIS Department), 2010

The level of detail incorporated into any water budget analysis depends on the study objectives and the data available. It was previously presented that in a natural state, unstressed basin long-term changes in land surface, soil moisture and groundwater storage are often negligible; however, this is not always the case. Also, groundwater flows and anthropogenic movement of water between watersheds (ie inter-basin flow) may be difficult to adequately quantify. It is suggested that as an initial approach that water budgets start in a more simplistic state where storage changes and natural inter-basin flows are ignored. It is also suggested that average saturation state conditions be analysed. This means that input data and calibration targets represent average climate conditions, average groundwater levels and average streamflow conditions. This provides an initial understanding of the system and allows managers to examine how water is balanced by using these simplifications. Future analyses could then build on this initial understanding to determine the nature of inter-basin transfers and storage changes and hydrologic response of the basin to low and high saturation states. If significant, these components would then be incorporated into a refined water budget. In this way the water budget, and indeed the overall understanding of water movement within the watershed is quantitatively improved over time as more data becomes available and re-assessed.

3.2 Water Budget Model Utilization

A conceptual model (i.e. a general physical model) is first developed to obtain a basic understanding of the physical flow system. This step involves the development of an initial overview understanding of the various water quantity components (fluxes) in the study area (precipitation, recharge, runoff, evapotranspiration, groundwater flow etc.) including a preliminary synthesis and assessment of the available data to gain an appreciation of how much water is available in the study area and its relative partitioning between the ground and surface water systems. This step also involves the development of an understanding of the geologic system and consideration of surficial features (e.g. wetlands, large paved areas, etc.) that would have to be built into the modeling framework for both subsurface and surface water models.
The conceptual understanding developed at this stage will aid in the selection of the calculation procedure or numerical model chosen for further analysis.

An initial synthesizing of the available data can be used to gain an appreciation of the various fluxes in the study watershed. For instance, using average annual precipitation and calculated evapotranspiration from a local climate station, coupled with annual surface discharge rates at a long-term streamflow gauging station, one can quickly determine whether or not the discharge at the gauge station appears reasonable with respect to the climate data on an annual basis. If it appears too low or too high, then there are likely subsurface geological conditions that are acting to direct water into or out of the area of consideration. These geological considerations will have to be built into the modeling process of the water budget exercise.

This initial conceptualization may also indicate where critical data gaps exist. The collection of additional data may be initiated and depending on timing may be available a quick refinement of the flow dynamics, for calibration of the numerical model in the next step or for long term water budget assessment. The ability to have suitable and ongoing monitoring data cannot be overstated.

While an estimation of the various components of the hydrologic cycle can be useful, surface and groundwater models allow us to understand, estimate and analyse the various states of dynamic equilibrium that will be attained in response to various stresses imposed upon the flow system. These numerical models are built by incorporating or inputting the field observations which correspond to the physical conceptual model into a computer program. The level of complexity of these programs varies greatly. Although the actual computer programs (ie. FEFLOW, HSP-F) are commonly referred to as numerical models, it is the incorporation the physical data into the program which constitutes the model.

Through numerical modeling a greater understanding of the three-dimensional flow system including both the surface and subsurface flow can be characterized.
Surface characteristics include streams, lakes and wetlands and the nature of the storage and conveyance of water that these features provide. Subsurface characteristics include the architecture (thickness and extent) of aquifer and aquitard units and their hydraulic parameters which dictate how ground water will move through the geological framework. Numerical models are developed and used to account for, at a more refined level of detail, the fluxes through the various reservoirs that comprise the hydrologic cycle. Such processes include, but are not limited to:

- Precipitation in the form of both rain and snow, and snow melt processes and events;
- The evaporation of water from surface water bodies (and the subsurface) back to the atmosphere;
- The transpiration of water by vegetation back to the atmosphere;
- The use and diversion of water in support of various human endeavours;
- The movement of water across the ground surface as runoff and streamflow; and
- The movement of water through the subsurface within both the saturated and unsaturated zones.

It is important to note that although water budgets tend to focus on the quantity of water, water quality data is commonly utilized to conceptualize and quantify flow directions in groundwater and fluxes in both surface water and groundwater.

In a given watershed or study area there are a multitude of components and processes that comprise the hydrologic system. It is impossible to measure and characterize every single component/process.
As mentioned above, in a water budget analysis the volume of water entering the system will equal the volume of water leaving the system (assuming the change in storage is negligible); otherwise the analysis has neglected the contribution of at least one component/process.
Numerical models are tools used to simplify the representation of these processes and enable quantification and evaluation of the hydrologic system at the watershed, sub-watershed or site scale.
Although models provide hard quantitative values, it is important to recognize the uncertainty in numerical modeling and to use the models appropriately in making water management decisions.

3.3 Types of Models

A numerical model is a type of mathematical model used to approximate a field situation by solving governing equations that represent the physical processes of the hydrologic system. Analytical models provide a direct solution of the governing equations for simple homogeneous systems, whereas numerical models simulate more complex systems where the various parameters can vary spatially and temporally and the governing equations are solved approximately.

A lumped parameter model is a type of numerical model that solves the equations describing a system at a large scale by assuming that average values for physical parameters can be used to describe or predict the behaviour of a system. In a lumped parameter model the spatial position is not considered important to answer a question such as the total runoff in a watershed. These types of models are applied to large scale problems.

A physically based model is a type of numerical model that solves equations where spatial position is an important consideration. Physically based model equations are derived from fundamental physical principles and/or extensive observations to describe the causes and effects of the system processes and their combined effects on the system behaviour. In these models, the actual rather than average (lumped) physical parameter value is important. Physically based models simulate small-scale to large-scale problems by incorporating spatial variability and interdependence of processes (Cumming Cockburn Limited, 2001; MAGS, 2003).

Physically based numerical models take advantage of readily available datasets that exist within Geographical Information Systems (GIS) and describe the spatial variability of the physical properties or parameters (e.g. soil type). These models are considered universally applicable models in that they can be used to make predictions at the small scale and can be summed to make predictions at the large scale (upscaling). In reality, due to the complex, multi-scaled and heterogeneous nature of the coupled atmospheric-surface-hydrologic system, there are many factors that affect the physical basis, and hence the universal applicability of physically based numerical models. It is necessary to be fully aware of inherent limitations of a particular model in order to confidently apply the model-derived understanding of the system and the predictions to water management decisions.

The three basic types of numerical models that are built and used for water budget analysis are:

1. Groundwater models;
2. Surface water models;
3. Conjunctive or integrated continuum models.

Commonly an integrated approach is used where output from both a surface water model and a groundwater flow model is iteratively compared. Traditionally, assumptions are made about all processes in a model. The processes of greatest interest are those that are explicitly represented in the model equations. The processes considered least important are treated as lumped processes and are specified as inputs or outputs to the model. They may be spatially variable but are not explicitly derived by equations in the particular model. In a groundwater flow model the recharge is input directly and is derived from field values or output from a surface water model.

A particular model domain (area) is chosen where the processes outside of the model domain are well characterized such that they can be specified as input or output values. Similarly, where data on these external processes are not available and of secondary importance, they may be specified from estimates based on other studies or knowledge of physical processes.

Table 1 lists examples of each of the three main types of models, the processes simulated and the processes that aren't simulated but treated as inputs or output quantities to the model. A discussion of most appropriate application of each type of model follows.

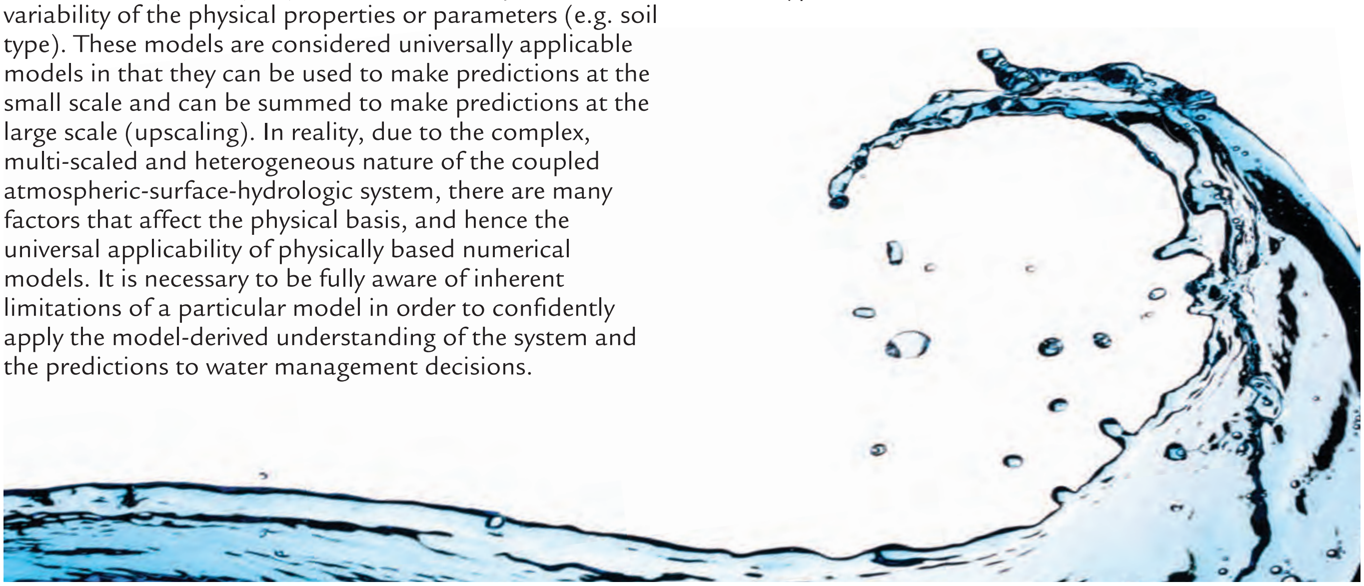


Table 1 **Commonly Applied Models** (Revised from ORMCP Technical Paper)

Model	Type of Model	Lumped Parameter vs. Physically Distributed Based Model	Process Simulated	Scale
GAWSER	Surface Water	Lumped/Physical/ Distributed	Climate: Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Watershed/ Subwatershed
HSP-F	Surface Water	Lumped	Climate: Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Watershed/ Subwatershed/Site
SWMM	Surface Water	Lumped General Water Budget	Climate: Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Subwatershed/Site
SWAT	Surface Water	Lumped/Physical	Climate: Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Watershed/ Subwatershed/Site
QUALHYMO	Surface Water	Lumped	Climate: Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Subwatershed/Site
AGNPS	Surface Water	Physical/Distributed	Climate: Budget Approach Surface: Detailed Equations Unsaturated: None Saturated: None	Watershed/ Subwatershed
SHE	Surface Water	Physical/Distributed	Climate: Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Watershed/ Subwatershed
HELP	Surface Water	2-D Physical	Climate: Simple Budget Approach Surface: Detailed Equations Unsaturated: Budget Approach Saturated: None	Site

Model	Type of Model	Lumped Parameter vs. Physically Distributed Based Model	Process Simulated	Scale
WATER BUDGET	Surface Water	Physcial	Climate: Detailed Equations Surface: Detailed Equations Unsaturated: Budget Approach Saturated: Budget Approach	Watershed/ Subwatershed/Site
MODFLOW	Groundwater	3-D Physical Finite Difference	Climate: None Surface: Surface Water Bodies Only Unsaturated: Net Recharge Only Saturated: Detailed Equations	Watershed/ Subwatershed/Site
FEFLOW	Groundwater	3-D Physical Finite Element	Climate: None Surface: Surface Water Bodies Only Unsaturated: Net Recharge Only Saturated: Detailed Equations	Watershed/ Subwatershed/Site
MIKE SHE	Conjunctive	3-D Physical Finite Element	Climate: Detailed Equations Surface: Detailed Equations Unsaturated: Detailed Equations Saturated: Detailed Equations	Watershed/ Subwatershed/Site
MODFLOW-HMS	Conjunctive	3-D Physical Finite Difference	Climate: Detailed Equations Surface: Detailed Equations Unsaturated: Detailed Equations Saturated: Detailed Equations	Watershed/ Subwatershed/Site
InHM	Conjunctive	3-D Physical Finite Element	Climate: Detailed Equations Surface: Detailed Equations Unsaturated: Detailed Equations Saturated: Detailed Equations	Watershed/ Subwatershed/Site
HydroGeo-Sphere	Conjunctive	3-D Physical Finite Element	Climate: Detailed Equations Surface: Detailed Equations Unsaturated: Detailed Equations Saturated: Detailed Equations	Watershed/ Subwatershed/Site

Groundwater Water Models

Groundwater models are most appropriately applied where the goal of the water budget analysis is to answer questions relating to groundwater levels, recharge discharge pathways and groundwater-surface water interactions. Changes in groundwater budgets due to changes in climate, land use, groundwater takings, and groundwater and surface water body interactions are directly evaluated with groundwater models.

Groundwater models can be used to evaluate changes over hours or days to seasons or years (ie transient conditions). However, groundwater monitoring data are typically only available representing the average or long-term (ie.steady-state) condition. More detailed monitoring data may be available for shorter time periods such as a storm event for small areas (subwatershed), which allows model calibration to a transient event. However, net recharge still must be defined by other means. Typically groundwater models are used to evaluate changes in the steady-state water budget.

These models solve the equations describing the hydrologic processes in the saturated zone and at the interface between surface water bodies and the saturated zone. Groundwater models are usually calibrated to observed static water levels in wells and the observed discharge in rivers. Spatial variability of geological features (hydraulic conductivity / porosity) and the hydraulic gradients determine how groundwater will flow and define areas of potential groundwater recharge and discharge. Groundwater models solve equations that simulate the three-dimensional complexity of the subsurface. Homogenous two-dimensional models for groundwater flow also exist but fail to simulate local and regional flow systems and are generally not appropriate for detailed water budget analysis.

Surface Water Models

Surface water models are most appropriately applied where the goal of the budget analysis is to answer questions relating to runoff and peak flows over short time periods (hours/days), as well as net infiltration over long time periods (years). Changes in water budgets due to changes in climate, land use, surface water takings, wetland modifications, storm water management and flow diversions are directly evaluated with surface water models. In addition, these models are often used to predict floodlines, flow duration and frequency of lows to assess erosion and to predict water quality based on assessed flows.

These models solve the equations describing the hydrologic processes at the surface and in the unsaturated zone and are usually calibrated and validated using storm event data. Generally these types of models involve the most rigorous simulation of climate processes. Surface water models, such as GAWSER, work in a continuous simulation mode allowing incorporation of multiple storm events and low flow conditions over periods ranging from hours to years.

Groundwater recharge and groundwater discharge to rivers are secondary fitting-parameters in these models. Surface water models are appropriate tools for water budget analysis where changes in surface and unsaturated zone processes are the focus of the budget analysis. These models do not include detailed calculations for saturated groundwater flow but do estimate net infiltration.

Integrated Model Approach

Surface water and groundwater systems are dynamically linked due to climatic and geologic conditions. An integrated surface water-groundwater modeling approach attempts to use the strengths of two or more models to reduce the uncertainty in parameters that are simplified in a particular model.

Essentially, an integrated model provides output to the second model without being directly affected by feedback. The quantity of data required for these simulations is less than is required for a conjunctive model, since a single time scale or spatial scale can be simulated that is common between the two models. In a conjunctive model, the entire dataset needs to exist at the same time and spatial scales. However, the integrated approach still has to address differences in spatial scale/model domain, and time scale since the models are not created for the same purpose and should be developed in parallel for effective integration.

Surface and groundwater systems are dynamically linked due to climatic and geologic conditions.

Conjunctive Models

Conjunctive models solve the governing equations for both surface water and groundwater simultaneously but generally simplify the representation of climate processes. These models recognize that surface water and groundwater processes are components of one larger system. Using only a surface water or only a groundwater model can lead to over-simplification of processes and may limit the model's ability to making accurate predictions at a particular spatial or temporal scale.

Typically conjunctive models are physically based models, incorporating small-scale spatial variability, and continuous simulation of climate (not explicitly). This approach to modeling provides detailed analyses of small-scale features, but also enables spatial and temporal upscaling. The model is also not limited to the boundaries of the surface water divides (catchments), but will be constrained by the boundaries of the regional groundwater flow. However, the complexity of the processes simulated with conjunctive models requires a large amount of data that is not typically available. In addition, users of these types of models usually require highly specialized knowledge of both surface water and groundwater systems and the numerical methods used to simulate the systems to ensure that model assumptions are valid for a particular analysis.

Model Selection

The most appropriate model for water budget analysis will depend primarily on the dominant flow processes (surface water or groundwater). If changes in groundwater discharge will significantly affect the flow in a river, then the model used should simulate the complexities of the groundwater system. If flow in the river is most affected by surface runoff and through flow during and following storm events (intermittent streams), then the model must be able to simulate the complexities of the surface water processes. In most watersheds in Ontario changes in groundwater discharge and storm event processes will affect the flow in the river such that linking of surface water – groundwater models, or the use of conjunctive models is most appropriate for water budget analysis.

Effective application of a numerical model for water budget analysis requires:

- definition of specific objectives of the analysis at the start;
- identifying the characteristics of the hydrologic system through development of a conceptual model (review existing reports: size, spatial variations, land use variability, topography, geologic structure, etc.);
- determination of the "Scale of the Problem" or the level of detail that needs to be included (e.g. subwatershed versus site scale or forested versus open areas) depends on processes;
- determination of the appropriate time scale;
- collection or compilation of sufficient data to evaluate each process;
- suitability for linkage to GIS;
- ease of calibration and validation;
- recognition and minimization of the uncertainty in the analysis; and
- re-evaluation of the applicability of the analysis prior to addressing new objectives.

Secondary considerations include:

- available resources (e.g. for model application, training and maintenance, etc.); and
- model availability, preferably from an organization that provides regular updates and technical assistance.

Water Budget Assessment Limitations

A brief discussion of the limitations of carrying out water budgets, within the context of both the quantity of water and the dynamic flow characterization, can aid in decisions relating to implementation of the water budget in water management including the limitations in the use or implementation of the water budget results. This relates directly to the confidence in the accuracy of the water budget.

Most of these limitations have been touched on or inferred in previous discussion but are generally related to the following:

- Is there a sufficient understanding of the necessary spatial and temporal level of physical data to build a conceptual model and calibrate a numerical model;
- Do sufficient spatial and temporal databases exist or can they be developed;
- Is there a sufficient accuracy in the methodology to determine the various input parameters (i.e. ET, field recharge, hydraulic conductivities);
- The accuracy in the representation of the physical process within the conceptual and numerical models;
- The available resources to collect the data;
- The available resources to run the appropriate model.


Photo Credit: Jackie O'Neill

4.0 | International Water Budget Overview

As was previously mentioned, gathering information on the use of water budgets, related guidance documents or technical case studies was rather limited for the international venue. Information that was available was focused on Australia, Great Britain, the more general European Union (EU) and the United States. A substantial amount of work would be expected to be carried out in these areas as a result of climate, demand for water and intensity of historical and future development. The information gathered was basic overviews and detailed technical documents (i.e. ORMCP Technical Paper 10) or actual integrated water budgets (i.e. Integrated Water Budget of the Grand River Basin) were not found. There is no doubt these documents exist but were not found during the limited internet searches carried out for this overview. This is more likely a reflection on the amount of additional time and resources necessary to “mine” this information through internet sources.

The following examples provide brief descriptions of water budget exercises carried out in the United States, Australia and Great Britain and may include spatial scale, physical hydrological units, field data, objectives and results.

United States Geological Survey

Beaverdam Creek Basin (Maryland)

- 20 mi^2
- 25 wells, 12 rainfall gauges, one complete weather station, continuous stream flow
- Soil moisture depth profiles at 3 locations
- Groundwater recharge based on water table fluctuation method
- Baseflow from hydrograph separation

Soil Water Budget (Wisconsin)

- Assess the effects of agricultural practices on drainage beneath the root zone at 3 field sites (natural prairie, corn-no tillage, corn-tillage)
- Rain and snow gauges
- Soil moisture content at 3 location at each site
- Tension lysimiters at each site
- Drainage below the root zone was found to be greatest at the corn-tillage site attributed to increased disturbance of the land surface

Colorado River Basin

- 637,000 km^2 , major water budget units include reservoirs, aquifers, agricultural fields and headwater watersheds
- Main issue is to manage the resources while accounting for errors in the water budget estimates
- Reservoir water budgets focus on water release rates which depend on storage, rate and timing of inflow and subsequent needs for power generation, flood control, irrigation, legal and environmental requirements
- The models include usual parameters but incorporate probabilities into the discharge values
- Groundwater budget models must be continually updated because of inherent uncertainties in aquifer characterization and future patterns for groundwater development

Australia

- Major national effort to carry out water budgets and characterize water resources (Australian National Water Initiative)
- Scope of water budgets commonly incorporate:
  - detailed water use
  - water conservation
  - models for water allocation

The national project consists of a "strategic framework that encompass short, medium and long term objectives that involve an integrated approach for understanding the current and future demands of the total water cycle balance. The second aspect of the strategy involves predictive software modeling that will provide a clear understanding of surface and groundwater flows integrating all forms of land use across the study area catchments. This methodology will address environmental flows, surface water, groundwater, waste water and water supply distribution and adopt the principles of Ecologically Sustainable Development and Water Sensitive Urban Design with an emphasis on the sustainability of the ecosystem health."

Great Britain

- Coordinated effort to look at the majority of the watersheds
- Focus on flood management, domestic use and ecological protection
- Extensive water use database and management
- Water budgeting for abstraction, allocation

The European Union (EU) has a major ongoing water initiative through the EU Water Framework Directive including but not limited to detailed river basin management which assess water quality and quantity and the interrelationship with the ecosystem. Additional water quantity programs focus on flood control, drought and long term climate change. These programs are also assessed within the social/economic framework.

In discussions with Dr. Edward Sudicky (University of Waterloo) who is a key collaborator with academic and government venues in the EU, he presented that in support of the water initiative and other independent projects fully coupled groundwater and surface water flow and contaminant transport models are commonly utilized. These models are used to quantify the location and movement of water (water budget) as well as dissolved contaminants within the groundwater and surface water. The scales of these models can vary from smaller subwatersheds to huge river basins and multi-aquifer systems.

Examples of the utilities of the models include:

- Water supply management
- Contaminant loadings and water quality management (i.e. contaminant source control)
- Ecosystem impacts and target setting
- Climate change assessment

5.0 | Ontario Water Budget Overview

5.1 Historical Water Budget Characterization

Water budgets in various forms and levels of complexity have been carried out in the province dating back to the 1960's in basin studies under the management of the Ontario Water Resource Commission. Although carried out in inconsistent fashion, water budget studies have also and continue to be conducted on various scales for land use and water use developments.

Watershed and subwatershed studies carried out the 1990's commonly presented basic water budgets but there was no consistent methodology. The need for guidance documents in the Province was recognized in the 1990's when the Watershed Management Committee consisting of staff from the Ministry of Natural Resources (MNR), the Ministry of the Environment (MOE), the Ministry of Municipal Affairs and Housing (MMAH) and the Ministry of Agriculture, Food and Rural Affairs (OMAFRA) prepared a technical document, *Water Budget Analysis on a Watershed Basis* to standardize an approach by practitioners to undertake water budget analyses. (Cumming Cockburn Limited, 2001).

Credit Valley Conservation (CVC) and the Grand River Conservation Authority (GRCA) were the first to carry out detailed pilot water budget studies in partnership with the Province and have prepared draft water budget modules stating the procedures that were taken by staff and consultants at these agencies in developing water budgets for their respective watersheds.

Through the Oak Ridges Moraine Conservation Plan a detailed water budget guidance document was prepared ("Technical Paper 10 – Water Budgets") which was used in the technical background in this document.

To protect drinking water in the province the *Clean Water Act* has mandated the production of locally developed, science based source water assessment reports and protection plans. Part of the preparation of these reports includes carrying out water budgets. The level of detail of the water budget characterization depends on the associated risk assessment process. Technical direction as to carrying out water budgets as they relate to Source Protection is documented in "Water Budget and Water Quantity Risk Assessment – Guidance Module 7". The legal requirements for water budgets under the *Clean Water Act* are set out in regulations and the Director's Technical Rules: Assessment Report. The Ministry of Natural Resources has been working with the Ministry of the Environment, who is the lead for the *Clean Water Act*. The MNR has reported that all the Conservation Authorities have carried out Conceptual Water Budgets. A number of higher level Tier 2 and Tier 3 Water Budgets have been or are in the process of being completed and include:

- Lake Erie Source Water Protection Authority; GRCA: Regional Municipality of Waterloo; City of Guelph
- Credit Valley, Toronto Region and Central Lake Ontario (CTC) Source Water Protection Authority; CVC: Regional Municipality of Halton, Town of Orangeville and Mono and Amaranth Townships; TRCA: Regional municipality of Durham
- South Georgina Bay Lake Simcoe Source Water Protection Authority: Regional Municipality of York

It is also noted that that an MNR pilot project utilizing a conjunctive model approach (GSFLOW and MIKESHE) is being carried out in the CVC and GRCA watersheds.

5.2 Legislation and Policy Incorporating Water Budget Assessments

As discussed, the *Clean Water Act* is a major driving force for the watershed and subwatershed scale water budgets that are currently being carried out in the province.

The Water Budget and Water Quantity Risk Assessment Guidance Module provide the basic direction to carry out the technical water budget characterization. These water budgets, once incorporated into a provincially approved assessment report will be used to set policies to manage water uses within local areas to protect sources of municipal drinking water.

The Oak Ridges Moraine Conservation Plan specifies that detailed water budgets be carried out to support land use plans.

The Provincial Policy Statement presents that ": "natural heritage features and areas will be protected from incompatible development" (2.3.1), and "the quality and quantity of ground water and surface water and the function of sensitive ground water recharge/ discharge areas, aquifers and headwaters will be protected or enhanced" (2.4.1). Water budgets are encouraged to meet these requirements.

To a limited extent and without formal water budget guidance, the following provincial guidelines and manuals inherently promote the use water budgets to meet their technical objectives:

- Stormwater Management Planning and Design Module
- Hydrogeological Technical Information Requirements for Land Development Applications
- Guidelines for the Preparation of a Rural Servicing Report for Development to be Serviced by On-Site Sewage Systems
- Permit to Take Water Manual

Official Plans across Ontario mention water conservation, environmental protection and other things related to the protection and enhancement of ground and surface water quantity. Water budgets are a basic tool to fulfill the objectives and are commonly used in support of water supply and land use management.

5.3 Current Technical Approach to Water Budget Assessment

The technical approach to watershed and subwatershed water budgeting most commonly used in the province is the integration of surface water and groundwater models. Conjunctive models, although considered more physically applicable, have not been used to any extent due to data requirements, and resources available to run them. The future use of conjunctive models may be promoted where the objectives of the modeling warrant more physical detail, the data is available and the financial and human resources are in place.

As previously discussed there are various levels of complexity of water budgeting and it is expected that site-specific water budgeting will continue to provide an assessment for the impact on local water resources and local water management. These local water budgets should be captured in larger scale water budgets on an ongoing basis. In essence, this takes the form of a cumulative assessment which utilizes an increased amount of site specific data input into a larger scale model.

In support of providing state-of-the-art science to improve upon our understanding, methodology and implementation relating to water budgets, the Ministry of Natural Resources has an interim science strategy focused on promoting the state of knowledge for watershed based management activities. The research initiatives are directed by the following four themes:

Theme 1-Water Quantities and their Movement within the Hydrologic Cycle

The first theme is focused on the physical characterization of the hydrologic environment and will assist in guiding science and applied research related to the *movement of water* throughout the hydrologic cycle. Understanding where water is located (e.g. what physical domain), how it moves between these locations, and the trends in movement over time, are key issues to be addressed under this theme. With this knowledge we can begin to reduce the uncertainty in estimating the quantities of water flowing through a watershed and begin to understand the processes and pathways that water follows.

Theme 2-Landscape Characteristics Influencing the Movement of Water

The second theme is focused on the physical characterization of the hydrologic environment and will assist in guiding science and applied research related to the *landscape features* that control the movement of water. A conceptual understanding of the geologic environment is critical to the flow of water in the sub-surface. Additionally, knowledge of soils, land form, land cover and land use are imperative to understanding the flow of water over the surface of the earth. Through an understanding of these characteristics we also reduce the uncertainty in estimating the quantities of water flowing through a watershed and begin to understand the processes and pathways that water follows.

Theme 3-Water Quantities and their Relation to Biological Communities

Theme 3 is focused on the understanding of biological/human inter-dependencies with water and watershed processes. Science and applied research under this theme aims to further refine our knowledge of how *biological communities* are dependent on water (e.g. species/habitat) and how water is dependent on biological communities to maintain the natural hydrologic cycle (e.g. wetlands/forests). Investigations of these types of inter-dependencies are guided by and encouraged under this theme.

Theme 4-Human Modification of the Hydrologic Cycle

Theme 4 is also focused on the understanding of biological/human inter-dependencies with water and watershed processes. Science and applied research under this theme aims to further refine our knowledge of how *human activities* modify the hydrologic cycle and how restoration of disturbed ecosystems can be accomplished. Understanding these processes will assist the province in developing and delivering effective watershed management policies and programs.

5.4 Potential Utilization of Water Budgets

The uses of groundwater budgets were initially presented in the description of the historical types of characterization. The historical and ongoing use of water budgets for various land use and water use developments includes:

- Permit to Take Water applications;
- landfill site approval (leachate generation, purge well impacts);
- residential/industrial development;
- municipal water supplies;
- aggregate extraction;
- dam construction;
- stormwater management;
- irrigation.

These groundwater budgets are generally incorporated in Terms of Reference developed by various stakeholders (i.e. Conservation Authorities, Municipalities, Federal and Provincial agencies) involved in the development process.

The Oak Ridges Moraine Conservation Plan presented the following potential uses for water budgets:

- to set quantitative hydrological targets (e.g. water allocation, recharge rates, etc.) within the context of watershed plans
- as a decision-making tool to evaluate, relative to established targets, the implications of existing and proposed land and water uses within watersheds, including, for example, restoration and rehabilitation projects identified in management plans;
- to evaluate the cumulative effects of land and water uses within watersheds;
- to provide a watershed-scale framework within which site-scale studies, such as a hydrological evaluation or a sewage and water system plan;
- to help make informed decisions regarding the design of environmental monitoring programs; and
- to assist in setting targets for water conservation.

In addition water budgets can be can provide support for:

- Low water response
- Flood management
- The assessment of contaminant movement and attenuation in both groundwater and surface water.
- Managing stream erosion
- Setting wastewater treatment effluent criteria
- Public education
- The evaluation of planning documents including Master Servicing Plans
- The evaluation of climate change

5.5 Knowledge Gaps, Data Gaps and Issues

In order to progress in the utilization of water budgets for water resource management extensive, ongoing consideration and follow-up action must occur to deal with the current knowledge gaps, data gaps and issues.

Knowledge Gaps

- The quantification of baseflow both on a reach and basin scale has many different methodologies but the science of groundwater/surface water interaction and the quantification needs ongoing support;
- The quantification of recharge from a local scale to a basin scale also has many different methodologies that are continuously being refined and needs support;
- A consistent methodology for mapping aquifers is needed;
- Keeping apprised of all the technical initiatives in the province which may aid in carrying out water budgets (ie updating monitoring databases, releasing findings on new methodologies or models etc.); and
- Instream flow needs methodology.

Data Gaps

There was a long list of data gaps at various temporal and spatial scales including:

- Climate data;
- Groundwater level data;
- Stream flow data particularly low flow data and reach specific groundwater discharge including locations of seeps and springs;
- Evapotranspiration data;
- Accurate surface water and groundwater takings for both permitted and non-permitted sources. (Note: the province is endeavoring to obtain more accurate consumptive use on the permitted takings);
- Aquifer characteristics; and
- Uncertainty on the reliability of data.

Issues

- Maintain ongoing databases and revisit water budget assessments at appropriate times (i.e. more data, more land use change, more refined methodology);
- Ensure higher level water budgets are carried out in the remaining subwatersheds in the province that were not addressed through the *Clean Water Act*, *Oak Ridges Moraine Act*, and the *Lake Simcoe Act* to provide information to assess cumulative effects, irrigation, flood control etc;
- Maintain an effective level of collaboration and communication amongst partners and stakeholders;
- Appropriate levels of financial and manpower resources must be provided including ongoing training for data collection and modeling;
- An appropriate amount of time is necessary to carry out the water budgets given limitations on data retrieval, manpower resources etc;
- Conservation Authority staff and other interested parties within the watersheds need to be involved in the development of the water budgets so they can play a more direct role;
- The limitations of water budgets should be considered when using water budgets to make decisions. This reflects that water budgets are a “tool”;
- There should be a group or agency that is responsible for maintaining the knowledge gained from water budgets (i.e., building a cumulative understanding of the how much water is moving and where);
- As more knowledge on climate change impacts is obtained, this information should be integrated into water budgets to facilitate their use for future planning; and
- There is a need for additional monitoring and continued improvement of science to understand the impacts of climate change and build climate change into watershed management decisions.

6.0 | Recommendations

1) The technical aspects of the knowledge gaps described above are not just common to Ontario but reflect the world wide state-of-the-science. As such it is recommended that Ontario keep apprised of the ongoing work within the national and international academic and consulting community as it relates to:

a. baseflow quantification;

b. recharge quantification;

c. aquifer mapping; and

d. instream flow needs.

2) Access should be provided to a description of all the technical initiatives, both historical and ongoing, in the province which may aid in carrying out water budgets (i.e. monitoring databases, releasing findings on new methodologies or models, basic research etc.).

3) A hydrological monitoring database framework should be developed that provides a practical and timely access to standardized data; and resources to convert and input non-electronic data (i.e. hardcopy hydrographs, borehole logs, groundwater chemistry, baseflow data etc.) into the database.

4) A group or agency should be designated to maintain and provide an additional level of assessment of the knowledge gained from water budgets (i.e., building a cumulative understanding of how much water is moving and where). See **A Water Management Framework for Ontario** report under separate cover.

5) Carry out a detailed review of completed and ongoing water budget studies to assess scheduling, human resource and financial needs and deliverables in the context of expected results versus actual results. This will provide direction on future resource needs to complete technically sound studies.

6) Carry out a review, assess the spatial and temporal gaps and provide additional monitoring for:

a. climate data;

b. groundwater level data;

c. streamflow particularly baseflow and reach specific discharge;

d. evapotranspiration data;

e. accurate water takings; and

f. aquifer characteristics.

7) Ensure higher level water budgets are carried out in the remaining subwatersheds in the province that were not addressed through the *Clean Water Act*, *Oak Ridges Moraine Act*, and the *Lake Simcoe Act* to provide information to assess cumulative effects, irrigation, flood control etc. See A Water Management Framework for Ontario report under separate cover.

8) Continue to improve technical methodology to assess water budgets on a local scale (i.e. plans of subdivision to better manage storm water) and incorporate into an ongoing larger scale assessment.

BIBLIOGRAPHY

AquaResource Inc., 2008. Integrated Water Budget Report – Grand River Watershed.

Gerber, R.E. and K.W.F Howard. 2002. Hydrogeology of the Oak Ridges Moraine aquifer system: implications for protection and management from the Duffins Creek watershed. Canadian Journal of Earth Sciences, 39: 1333-1348.

Cumming Cockburn Limited. 2001. Water Budget Analysis on a Watershed Basis. Prepared for the Watershed Management Committee. May 2001.

MAGS. 2003. www.usask.ca/geography/MAGS/

Ontario Minstry of the Environment Guidelines. http://www.ene.gov.on.ca/en/publications/index.php

Ontario Ministry of the Environment. 1989. Guidelines for the Preparation of a Rural Servicing Report for Development to be Serviced by On-Site Sewage Systems.

Ontario Ministry of the Environment. 1995. Hydrogeological Technical Information Requirements for Land Development Applications.

Ontario Ministry of the Environment. 2003. Stormwater Management Planning and Design Manual. Publication #4329e.

Ontario Ministry of the Environment. 2005. Water Budgets, Technical Paper #10, Oak Ridges Moraine Conservation Plan. DRAFT

Ontario Ministry of the Environment 2005. Permit To Take Water (PTTW) Manual.

Wiens, J.A. 1989. Spatial scaling in ecology. Functional Ecology, 3, 385-397.

DEFINITIONS

Aquatic Ecosystem: An aquatic ecosystem refers to a community of organisms (bugs, plants, wildlife, surroundings) that live in water and are dependent on each other for survival.

Aquifer: An underground layer of permeable rock, sediment (usually sand or gravel), or soil where groundwater is stored. Aquifers are connected to other aquifers and surface water bodies and can occur at various depths.

Biodiversity: Refers to the uniqueness and variability of all life with particular emphasis on genes, species, landscapes or ecosystems.

Ecosystem: A dynamic complex of organisms and their associated non-living environment, interacting as an ecological unit composed of primary producers, consumers and decomposers.

Elasticity: Refers to the ability of an ecosystem to accommodate change while maintaining its structure and function.

Ecological resilience refers to the capacity of natural ecosystems, social resilience to the capacity of human communities to cope with change.

The term **ENVIRONMENT** as used in this document refers to the natural components of aquatic ecosystems, the flora and fauna, and the natural ecological processes that take place between individual plants and animals, their surroundings, and between each other. The maintenance of species biodiversity, community structure and functioning and natural ecological processes are important elements (and indicators) of the maintenance of overall environmental integrity.

Ecological Values are defined as the natural ecological processes occurring within water dependent ecosystems and the biodiversity of these systems.

Environmental Water Requirements are descriptions of the water regimes needed to sustain the ecological values of aquatic ecosystems at a low level of risk. These descriptions are developed through the application of scientific methods and techniques or through the application of local knowledge based on many years of observation.

Environmental Water Provisions are that part of environmental water requirements that can be met.

Environmental Water Provisions may refer to:

- unregulated flows in rivers and water in wetlands and aquifers;
- specific volumetric allocations and/or releases from storages;
- water levels maintained in wetlands; and
- water in transit for other users, the pattern of flow of which may be defined to meet an environmental need.

Complexity: A feature of systems that comprise diverse components among which there are many interactions, the resulting implications of which are often unpredictable.

Cumulative Impact: The incremental impact of an action on the environment when the impacts are combined with those from other past, existing and future actions.

Driver: Any natural or anthropogenic factor that causes change within a system, whether through direct or indirect means, regardless of whether it is internal or external to the system.

Erosion: The wearing away, by water, of the banks or bed of a stream or of the materials used in any works.

Green Infrastructure: An interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations.

Impact: Any aspect of an action that may cause an effect; for example, land clearing during construction is an impact, while a possible effect is loss and fragmentation of wildlife habitat.

Impact Model: A formal description of a cause-effect relationship that allows the assessing of various components of that relationship through the use of an Impact Statement, a Pathways Diagram, and the validation of linkages and pathways.

Indicator: Anything that is used to measure the condition of something of interest. Indicators are often used as variables in the modeling of changes in complex environmental systems.

Infrastructure: An underlying base or foundation especially for an organization or system. The basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons.

Integrated Management: An approach to management through which multiple actors collaborate and share risk in defining, analyzing, and resolving social ecological challenges for the common good. This approach moves beyond conventional single-species management to consider the implications of, species interactions, habitat and ecosystem linkages, and cumulative effects.

Mitigation: In the context of climate change, a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Examples include: using fossil fuels more efficiently for industrial processes or electricity generation, switching from oil to natural gas as a heating fuel, improving the insulation of buildings, and expanding forests and other "sinks" to remove greater amounts of carbon dioxide from the atmosphere.

Precautionary Principle: See the report, Integrated Watershed Management in Ontario (Phases I-III), Appendix 4.

Resilience: Refers to the capacity of an ecological or social system to accommodate change, stress and variability without altering its structure and function.

Riparian Zone: The riparian zone is the area between the land and a surface water body. Plants alongside the banks of the water body are called riparian vegetation and are important for the health of the stream and to stop bank erosion.

Robust Management: Management that is designed to ensure an acceptable level of performance despite conditions of elevated scientific uncertainty and limited control over exploitation.

Social Capital: The social norms, networks of reciprocity and exchange, and relationships of trust that enable people to act collectively.

Social Learning: The collaborative or mutual development and sharing of knowledge by multiple stakeholders through learning-by-doing.

Stakeholders: Individuals or groups (including government and non-government institutions, communities, research institutions, development agencies, etc.) with an interest or claim.

Surface Water: Surface water is the water that runs over or sits on the land. This includes lakes, rivers, streams, creeks and ponds. It is usually fresh water and it is not stored in the ground.

Threshold: The critical boundary (e.g. spatial or temporal) where the attraction of a system to a new equilibrium or configuration supersedes the system's attractions to its current state.

Watershed: The region or area of land that drains into a river, river system, or other body of water. Watersheds are divided by mountains or hill ridges.

Water Dependent Ecosystems: Those parts of the environment, the species composition and natural ecological processes of which are determined by the permanent or temporary presence of flowing or standing water. The instream areas of rivers, riparian vegetation, springs, wetlands, floodplains and estuaries are all water dependent ecosystems.

Water Flow Requirement: Water flow requirement refers to the amount of water that nature (fish, wildlife, streams) needs in a water body so that it can function properly. Water flow requirement needs relate to adequate water flow, water quality, riparian margins and water temperature.

Wetland: Wetlands refer to a body of land saturated by water and include swamps, marshes and bogs. Wetlands are the interface between land and aquatic ecosystems and usually support diverse forms of life and provide significant benefits to the environment.

Conservation
ONTARIO
Natural Champions

www.conservationontario.ca