Following text prepared by XCG Consultants in January 2008 for Toronto Region Conservation Authority, to document two test applications of the most recent version of QUALHYMO.

This report has been structured to allow it to be incorporated into a stormwater guidelines document being prepared by Aquafor Beech Limited for TRCA. The structure of this report is therefore based on a draft outline for Section 3 of Aquafor's document, as supplied to XCG by Dave Maunder on Dec 19, 2007.

3.8 The Water Balance Model

3.8.1 History of the WBM

In British Columbia, recent initiatives to promote 'green infrastructure' resulted in development of the Water Balance Model (WBM) in 2002. The WBM for British Columbia was created as an extension of “Stormwater Planning: A Guidebook for British Columbia”, a Provincial guidance document finalized in 2002 under the direction of the BC Ministry of Water, Land and Air Protection.

The Water Balance Model (WBM) for British Columbia is an on-line tool that helps users gauge the potential for developing or redeveloping communities while maintaining the original hydrologic condition. The WBM gives users a convenient pre-design planning tool that they can access over the Internet. The model is intended to quantify the effectiveness of various stormwater source control strategies under a range of development conditions.

BC's Water Balance Model project has been funded by an Inter-Governmental Partnership (IGP) comprised of members from federal and provincial agencies and local governments representing the Greater Vancouver, Fraser Valley, Okanagan and Vancouver Island regions. The panel was formed in 2002 as an outcome of a project sponsored by the Greater Vancouver Regional District on the effectiveness of rainwater source control. The IGP's vision is to promote changes in land development practices so that:

- The built environment will preserve and/or restore the natural water balance over time.
- Performance targets will be achieved for runoff volume and flow rate reduction at the source, where rain falls.

The WBM resulted from the desire to create an Internet-based, public-domain scenario modeling tool for rainwater management.

One of the project goals has been to help design engineers ‘think outside the pipe’ when developing sites and neighbourhoods. The objective is that stormwater volume reduction will be seamlessly integrated with land use planning and site development practices.

The hydrology engine for the model was based on a spreadsheet model developed by CH2M HILL Canada Ltd., while Nanaimo-based Lanarc Consultants created the graphical user interface and Internet-accessible platform.

3.8.2 WBM on the Internet

More information on the Water Balance Model for BC can be found at www.waterbalance.ca. The current Web-based implementation of the WBM is accessible through this web site.

3.8.3 The “Next Generation” WBM

In 2007, the BC Inter-Governmental Panel announced that the WBM would be substantially revised and extended. See the following excerpt from www.waterbalance.ca.

Excerpts from www.waterbalance.ca , January 2008

The **Water Balance Model for Canada** is being integrated with **QUALHYMO** in order to provide practitioners with a 'runoff-based tool' for source control evaluation and stream health assessment. The 'runoff-based approach' holds the key to assessing environmental impacts in watercourses and the effectiveness of mitigation techniques….

To sustain the early success of the Water Balance Model, and in response to 'needs and wants' identified through discussions with the **Alberta Low Impact Development Partnership** (ALIDP) and others, the **British Columbia Inter-Governmental Partnership** (IGP) has taken the first steps along a pathway that will materially expand the capabilities of the web-accessible Water Balance Model: This has involved an evaluation of how to most effectively enhance the hydrology engine; and has led to the decision to merge the Water Balance Model with QUALHYMO.

Merging the Water Balance Model with QUALHYMO will dramatically expand the capabilities of the Water Balance Model because it will add:

Rainwater storage routing
Water quality
Stream erosion
Drainage area flow routing
Snowmelt runoff (and ultimately freeze-thaw)

The combination of these two tools will enable assessment of source control performance plus model the overflows from a site once source controls have reached capacity."

One-Stop Shopping for Engineers: "The principal focus of the WBM is on source controls for runoff volume reduction. For drainage engineers, however, a practical modelling tool must also concentrate on the overflows from the site. This is the significance of having the capability to store and route the outflow from a subdivision and/or neighbourhood through a detention pond or down a stream channel", added **Kim Stephens**, Project Coordinator for the Inter-Governmental Partnership.

QUALHYMO is a rainfall-runoff model originally developed in Ottawa by **Dr. Charles Rowney** in the 1980s, with funding from the Ontario Ministry of Environment. The concept of merging the WBM and QUALHYMO emerged as an appropriate next step in the evolution of the WBM because:

- Both are Canadian.
- Both are based on a philosophy of 'keeping it simple'.
- Both are non-proprietary.
- Each has different complementary strengths.
- QUALHYMO contains routines that incorporate many features requested by current WBM users.
- Expanded capability would provide an opportunity to more effectively promote use of the WBM in the rest of the country, and within the engineering community.

QUALHYMO is similar to the WBM in that it offers the potential to have an 'Open Source' calculation engine that has gone through numerous verification and testing processes. The validation of the engine has already been done and the model is a proven piece of software.

In November 2007, the British Columbia Inter-Governmental Partnership (BCIGP) announced the creation of an Inter-Provincial Partnership (IPP) that includes Alberta Low Impact Development Partnership (ALIDP), and the Toronto and Region Conservation Authority (TRCA).

As noted at www.waterbucket.ca, one purpose of the IPP is to promote Canada-wide use of the national **Water Balance Model** as a tool to facilitate 'green' development practices. Integration of the web-based Water Balance Model with the **QUALHYMO** computational engine has included effort invested by an Expert Advisory Panel led by Dr. Charles Rowney to fine-tune the QUALHYMO engine, in part to meet the needs of the Inter-Provincial Partnership.

3.8.4 Evolution of QUALHYMO

The QUALHYMO model was originally developed by Dr. Charles Rowney in the early 1980s. QUALHYMO is based on a continuous simulation methodology that includes rainfall/runoff and snowmelt processes. It can simulate surface hydrology as well as pollutant loads associated with surface runoff, and can route flows and pollutant loads through stream channels and management facilities such as stormwater ponds. Pollutant removal processes that occur along channels or within ponds can be explicitly simulated.

The following excerpts from the user manual for the current version of QUALHYMO summarize important points about QUALHYMO's evolution:

> "QUALHYMO was developed some 25 years ago as a research tool. It was intended to enable the rapid testing of various water quality algorithms related to BMP performance assessment. For that purpose it was decided to create a modular tool in which different sub-systems could be rapidly and easily coded, implemented, and tested on a common basis. The original QUALHYMO tool was developed with that in mind. The selected structure for this has proven to be robust and reliable, and lends itself well to use in assessing watershed-level water quantity and quality problems.
>
> Over the 20 years or so following the initial release of the model, the business activities of the original author tended to conflict with further development of the tool, and no substantive development was attempted by him during that period. Nevertheless, a number of descendant versions or variations of QUALHYMO seem to have emerged over that time. The code to the original model was available to developers and users, and it seems that an undetermined number of alternative versions of QUALHYMO have appeared as a result. No endorsement (or otherwise) of such alternatives will be attempted by the authors, and should not be interpreted from this manual. However it is noted that a casual survey suggests that these versions vary in their approaches to coding and simulation. It is not known to the authors of the present QUALHYMO effort how those multiple versions fared in practice, but discussions with individuals in the field suggested that the multiplicity of versions has led to a multiplicity of issues, not the least of which was a lack of confidence regarding which version of the tool was which.
>
> As the practice of water resources has matured, the need for a tool like QUALHYMO for practical applications has been reinforced. A model targeted at BMP evaluation and designed for rapid simulation of long term quality/quantity behavior has emerged as a requirement in many situations. The decision was made, therefore, to update QUALHYMO into a single current version.....The current version retains no code that is not directly attributable to the identified

authors. This means that the authors can release the model for general use under suitable license conditions. It also means, however, that the model may in some instances produce results that are somewhat different from those other variations of the earlier tool may generate. QA/QC procedures used in developing this tool have been substantial, and we believe that it can be relied on to produce reasonable results when applied by a knowledgeable user, but as noted in the license for the model and documentation, it is up to the user to ensure that the model is effective for the purpose for which they apply it and that the answers they generate are what they require." (QUALHYMO USER DOCUMENTATION, November, 2007)

3.8.5 Structure of QUALHYMO

QUALHYMO is structured as a library of approximately thirty "commands". The modeller invokes these commands as needed to provide run control information, simulate the hydrology of catchment areas, add and route flows through stream reaches or stormwater management facilities, and develop various outputs including statistics on flow rate or pollutant concentrations.

The following table summarizes the primary commands available in the current version of QUALHYMO ("Build 62", January 2008).

A number of these commands are extensions to the original QUALHYMO that have been developed to assist with using the model to examine the effects of specific stormwater source-control measures at the site level or watershed level.

- The PERVIOUS SURFACE and PERVIOUS WITH STORAGE commands are intended to allow for direct representation of measures that promote or are designed to allow for infiltration of urban runoff, including measures such as roof drainage dispersion onto vegetated areas, or infiltration facilities such as surface soakaway areas. Accordingly, these commands allow for the total water input to include lateral inflow from another area or surface, such as might be generated using a GENERATE command or an IMPERVIOUS SURFACE command.

- The complementary IMPERVIOUS SURFACE and IMPERVIOUS WITH STORAGE commands allow for direct representation of specific impervious surfaces such as roadways, parking areas or roof areas. These commands also accept lateral inflows, and this provides capability to explicitly represent various urban drainage connectivity situations in which surface runoff from one surface may drain onto another.

- The PERVIOUS SURFACE and PERVIOUS SURFACE STORAGE simulate a vertical soil matrix profile into which water can infiltrate at the surface, and from which losses occur due to evapotranspiration. As well, any free gravitational water within the soil matrix can percolate downward into a storage reservoir that can be used to conceptually represent the groundwater system. In this way, these commands provide continuous simulation of soil moisture status and surface water budget. Surface infiltration is a function of user-defined infiltration capacities, and percolation capacity is also user-defined based on knowledge of local soil conditions and hydraulic conductivity. Outflow includes direct surface runoff as well as outflow from the subsurface reservoir that is computed as a linear function of storage level.

Application of the PERVIOUS commands requires good information on local soil conditions including soil moisture holding capacity (field capacity as mm of water), surface infiltration capacities (mm/hr) under wet and dry conditions, and vertical percolation capacity (mm/hr). As well, the simulation method applied in these commands is based on the assumption that vertical percolation capacity is maintained at all times, which is a condition that will generally apply only within soil or overburden layers that are above the water table.

QUALHYMO command	Function
START	Run control. Provides information on simulation time span, precip and air temperature data formats, and other simulation control parameters
POLLUTANT SERIES	Simulation of pollutant loadings. Allows user to define build-up/wash-off or rating curve parameters for impervious and pervious areas.
GENERATE	Provides the ability to simulate long-term continuous flow and associated pollutant loadings from a watershed. It is not intended to provide an ability to simulate detailed urban drainage networks as might be done with the EPA SWMM model. Rather, it is intended to enable the representation of catchments at a level of detail suitable for representation of the major factors that govern long-term runoff processes.
REACH	Simulation of stream or river reaches. It routes flows and, optionally, pollutants through the reach, simulating mixing and losses along the way
POND	Simulation of control ponds, reservoirs or small lakes. It routes flows and, optionally, pollutants through the water body, simulating mixing and losses along the way
FILTERED REMOVAL	This command allows users to represent a BMP that operates as a filter medium, such as a sand filter system.
PERVIOUS SURFACE	Simulates hydrologic response (surface runoff, infiltration, evapotranspiration, percolation, soil moisture status) of a vegetated surface and underlying soil profile. Input can include lateral surface inflow time series. Optionally can include pollutant load simulation.
IMPERVIOUS SURFACE	Simulates hydrologic response (surface runoff, evaporation) of an impervious surface. Input can include lateral surface inflow time series. Optionally can include pollutant load simulation.
PERVIOUS WITH STORAGE	Same as PERVIOUS SURFACE, except that a surface storage element is included, defined by a storage depth-area-outflow curve (table of values supplied by user). Water held in surface storage can exfiltrate into the soil.
IMPERVIOUS WITH STORAGE	Same as IMPERVIOUS SURFACE, except that a surface storage element is included, defined by a storage depth-area-outflow curve. Intended to allow simulation of response of such surfaces as parking lots that incorporate surface detention, or flat roofs that include surface storage with controlled discharge.
ADD SERIES	Add any two time series.
SPLIT SERIES	Spit any two time series based on as user-defined flow split curve.
Time series output commands DUMP PRINT, PRINT SPAN, DUMP POND SPAN	These commands allow for printing of internal time series generated by QUALHYMO.
Time series statistical analysis EXCEEDANCE, MAXMIN, CALC POND STATS, CALC SERIES STATS	These commands allow for generation of various parametric and non-parametric statistics for flow or pollutant load time series.
Utility commands: IDENTIFY SERIES PRINT MODEL DETAILS	Read metadata for internal QUALHYMO time series; and have the model issue a set of details that document the major facts of the current model run

3.9 Application of QUALHYMO

Two test applications of the most current version of QUALHYMO have been carried out. Both test applications pertain to hypothetical land development proposals within the Greater Toronto Area.

The purpose of these applications has been as follows:

- To help evaluate whether the QUALHYMO-powered "next generation" Water Balance Model will be suitable for examining the benefits of "low impact development" (LID) approaches to stormwater management at the individual site or property scale.
- To illustrate how the modelling capabilities available in QUALHYMO can be used to model a variety of source control measures and stormwater management facilities that would comprise an LID approach on an individual development site.
- To demonstrate a model-based analysis of the effects and benefits of site-level measures in terms of specific stormwater management targets applicable within the GTA.

The performance targets include those related to flood control, watercourse erosion control and stormwater pollutant load control that are generally applied within southern Ontario, in accordance with the 2003 MOE guidelines. As well, the analysis has considered targets for hydrologic water balance maintenance that are of interest within the jurisdiction of Toronto Region Conservation Authority.

In brief, the two test applications are as follows:

Site Plan example	Industrial/warehousing complex on a site development parcel of 17.8 hectares. Total impervious surface area is approximately 43% of the site area.
Draft Plan of Subdivision example	Residential development on a total property area of approximately 34 hectares, primarily clay/silt till soil, total impervious area is approximately 41% of the property area.

For both cases, a proposed development design has been prepared that includes a number of "LID" measures that include measures to maximize water infiltration, as well as measures such as rainwater harvesting.

3.9.1 *Analysis Procedure*

The purpose of the analysis has been to examine how QUALHYMO can be used to represent the effectiveness of "LID" stormwater measures, with respect to following management targets.

Category	Generalized Control Target
Flood Control	Control peak outflows from the site to pre-development rates, for design storms with return period up to 100 years.
Watercourse Erosion Control	1. In accordance with current MOE guidelines (2003): Capture the runoff volume generated by a 25-mm rain event, and release it to outlet over a minimum of 24 hours; or, 2. Control the frequency and duration of site outflows such that in-stream index of erosion potential (e.g. multi-year erosive impulse) is not increased.
Water Budget Maintenance	At a minimum, maintain the amount of recharge to the groundwater system
Surface Water Quality	Control pollutant loadings in accordance with current MOE guidelines. Achieve "Enhanced" level of protection as defined in 2003 Stormwater Management Planning & Design Manual: i.e. reduce the average annual load of suspended solids by 80%.

To help evaluate QUALHYMO capabilities, and to examine the benefits of LID measures, each test application has included the following model simulations

- Pre-development conditions
- Site development with "conventional" drainage system design
- Site development with proposed LID measures

The "conventional" design approach is considered to generally consist of the following:

- Roadway and parking areas drained by curb-and-catchbasin to conventional storm sewer system
- Roof drainage from commercial/industrial buildings to storm sewer
- Approximately 50% of roof drainage in residential areas drains onto grassed yard areas
- Stormwater impact mitigation by end-of-pipe pond designed with a combination of permanent pool and live storage to provide stormwater treatment and flow control, with pond sizing in accordance with 2003 MOE guidance document.

In this context, the conventional approach does not include measures such as biofilters, infiltration galleries, green roofs or permeable pavements.

The latest version of QUALHYMO (Build 62, December 2007) has been used. Details on how QUALHYMO has been used to represent the various stormwater control measures involved in the two test sites, is provided below.

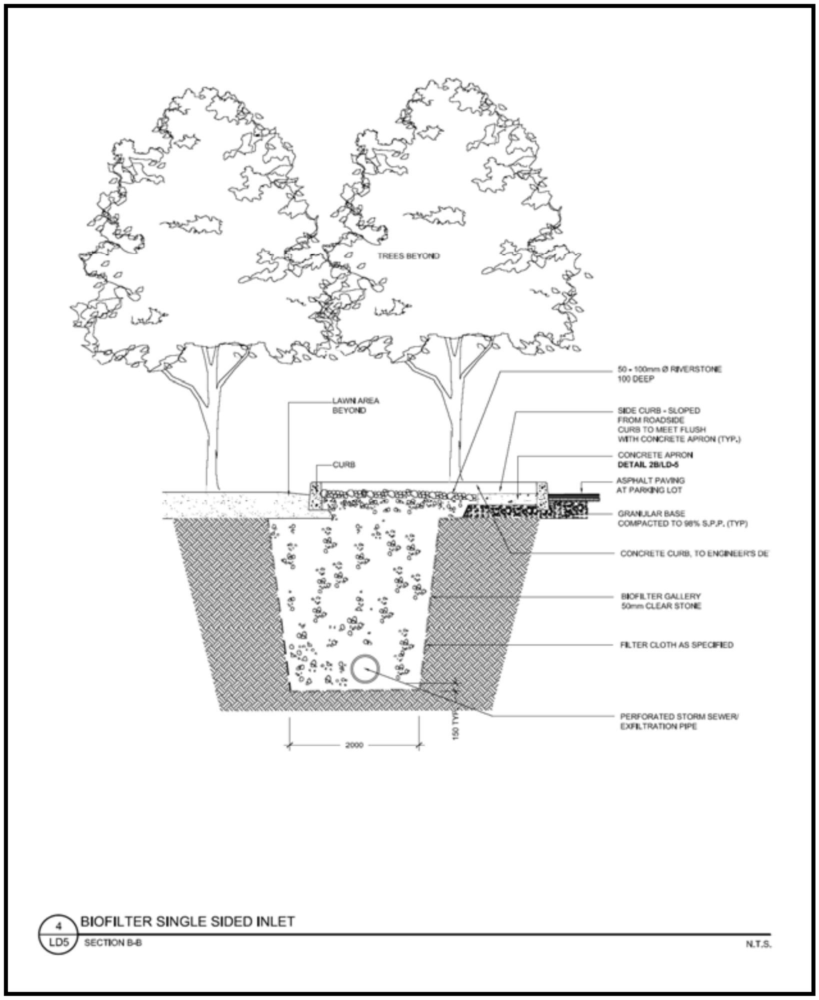
3.9.2 *Test Application #1 - SITE PLAN EXAMPLE*

The Site Plan example is shown in Figure 1. The proposed design includes a number of LID features:

- Roof drainage from main building piped to a subsurface stormwater storage system. This storage is equipped with a pump-out system to allow the water to be used for landscape irrigation.

- Main parking area drainage directed to median biofilters provide filtering through granular material, and provide substantial opportunity to infiltrate the water . See Figure 2 for details.

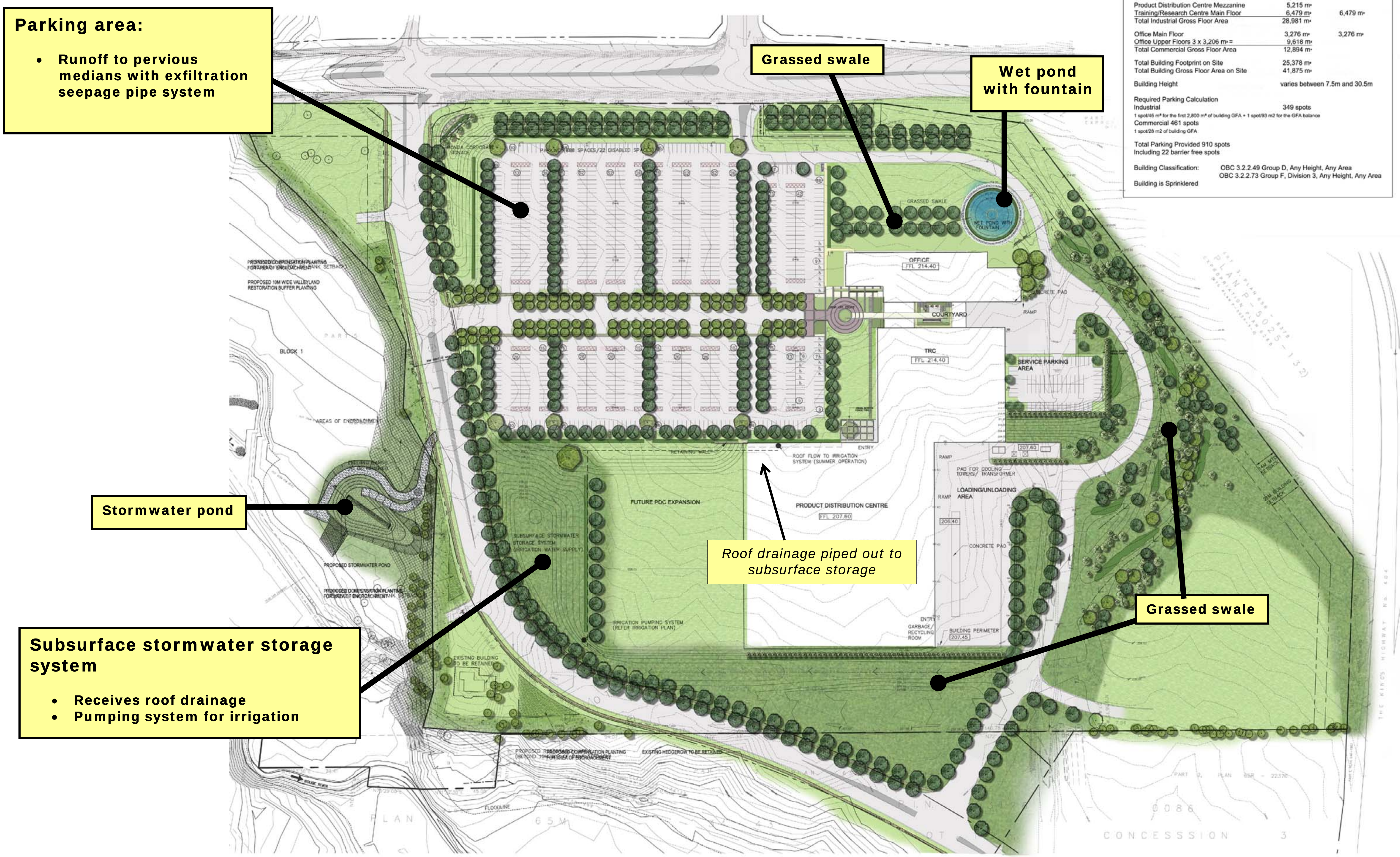
- Perimeter drainage swales to accommodate runoff from the service road, service parking and loading area



Here are site characteristics.

Site element	**Surface area**
Main building roof	1.99 ha
Office roof	0.28 ha
Main parking lot	3.26 ha
Loading area	0.55 ha
Service parking and ramp area	0.35 ha
Service Road	0.46 ha
Main road within property limits	0.81 ha
Landscaped and vegetated areas	10.10 ha
Total impervious area	7.70 ha
Total site area	**17.80 ha**

FIGURE 1: SITE PLAN EXAMPLE



3.9.2.1 Modelling Method

The following table summarizes how the "conventional" and LID approaches have been characterized and modeled.

Site element	**Surface area**	**Conventional SWM approach**	**LID SWM approach**
Main building roof	1.99 ha	Roof drain direct to storm sewer	To subsurface storage system, then used for irrigation (summer operation)
Office roof	0.28 ha	Roof drain direct to storm sewer	Roof drainage onto landscaped area
Main parking lot	3.26 ha	Catchbasins direct to storm sewer to end-of-pipe pond	Surface runoff to median biofilters
Loading area	0.55 ha		Surface runoff to grassed swale
Service parking and ramp area	0.35 ha		Surface runoff to grassed swale
Service Road	0.46 ha		Surface runoff to grassed swale
Main road within property limits	0.81 ha		Catchbasin to storm sewer to storm pond
Landscaped and vegetated areas	10.10 ha	Overland flow to main roadway or to storm pond	Overland flow to main roadway or storm pond

Notes on QUALHYMO modeling method:

1. Each of the roof, parking and roadway elements has been represented as a separate "IMPERVIOUS SURFACE" element in QUALHYMO.

2. Landscaped areas have been represented using a "PERVIOUS SURFACE" element.

3. Rainwater harvesting (roof drainage to irrigation storage) has been modeled as a simple storage tank that receives runoff from the roof surface, and which is drawn down according to a user-supplied daily withdrawal rate that is intended to represent the average irrigation usage. The daily withdrawal rate was varied by month (details below). If the rainwater storage system is full, then any additional flow from the tributary roof area bypasses the storage tank and goes directly to the site outlet (stormwater pond).

4. Grassed swales have been represented as a "PERVIOUS WITH STORAGE" element that consists of a pervious surface which has a surface storage volume. The storage volume is characterized using a table of depth-area-outflow values. The depth-area-outflow for the grassed swale was developed by presuming that the grassed swale is an approximate trapezoidal channel with 0.9 m bottom width and 6:1 h:v sideslopes and bed slope of 0.5%. Pollutant removal by first-order die off and sediment settling takes place within the surface storage using the same approach as in QUALHYMO's POND command.

5. Parking area biofilters were modeled as a “PERVIOUS SURFACE” element with surface area and water holding capacity set appropriately to represent the proposed design.

6. End-of-pipe stormwater pond has been modeled using the POND command. Settling of suspended solids was modeled using representative settling velocities reported by Driscoll et al. (1986).

7. Suspended solids loadings from impervious surfaces and landscaped area have been simulated using mean surface runoff concentrations for respective surfaces as reported in Heaney et al. (1999). The values applied in QUALHYMO (via POLLUTANT SERIES commands) are below.

Surface type	Mean concentration of SS in surface runoff
Streets and parking areas	800 mg/L
Industrial/commercial roofs	10 mg/L
Vegetated and landscaped areas	100 mg/L

3.9.2.2 Modelling Results

The model has been used to simulate site response for the following events and periods:

Flood control performance	100-year event for durations of 1 hour, 6 hours and 12 hours, using AES event distribution, rainfall volumes based on IDF stats for Toronto Pearson. Simulation time step of 5 and 10 minutes.
Erosion control target	25-mm event, 6-hour duration, simulation time step 5 minutes.
Pollutant loadings analysis and water budget analysis	Year 1991, based on applying hourly precip and air temperature from Pearson Airport

<u>Flood Control</u>

The following table summarizes the results in terms of control volumes needed for peak-flow attenuation during the 100-year rainfall. The results show that the LID approach will provide roughly 40% reduction in the required end-of-pipe live storage needed to control the 100-year peak outflow to predevelopment rate.

Estimated storage volume (m^3) needed to control peak site outflow to pre-development rates, For 100-year storm event		
Storm event	Conventional design	LID design
100-year 1-hour	3,000	3,000
100-year 6-hour	4,600	2,800
100-year 12-hour	5,300	3,400

The lack of benefit during the 1-hour 100-year storm is due to the intensity of this event (53 mm in 1 hour) which overwhelms infiltration capacities.

Erosion Control

Performance has been examined with respect to the target that for erosion control, the runoff from the first 25 mm of rain should be held and released over a period of not shorter than 24 hours. This target has been widely applied in Ontario in situations where there has been no watershed-scale analysis to determine a more site-specific control target to address downstream watercourse erosion.

Simulation of a 25-mm event of 6-hour duration has been used to estimate the surface runoff volume from the site for this event

- For the conventional design, the surface runoff volume is 1,690 m^3.
- For the LID design, the volume is 1,000 m^3.

This result means that substantially less detention storage is needed at the site outlet (end of pipe) to meet erosion control requirements.

Surface Water Quality Protection:

QUALHYMO has been used to simulate suspended solids (SS) loadings generated by impervious and pervious surfaces, and has been used to explicitly model settling removal in the end-of-pipe wet pond (conventional case) and along the grassed swale system (LID case).

For the LID scenario, the biofilter system that receives parking lot runoff is assumed to provide effective filtration (i.e. all water that passes through the granular filtration matrix and then infiltrates into the native soil is subject to effective filtration that removes virtually all suspended solids; and therefore the resulting subsurface flow --- groundwater system discharge --- will have very low SS of 1 mg/L). It has been assumed that any bypass flow (*i.e.* runoff directed to the infiltration facilities but which cannot be accommodated by those facilities because the granular matrix is saturated) will receive no treatment.

The table below summarizes the simulated loadings for the period April 1, 1991 to November 30, 1991. The full year of 1991 was not simulated due to absence of hourly precipitation data for December, January, February and March.

Note that the QUALHYMO model has a fully functional snowmelt routine and can simulate snowpack accumulation and melting based on the supplied air temperature time series.

Simulated site outflow volumes and SS loads For April 1 to November 30, 1991		
Scenario	Flow volume (m^3)	SS load (kg)
Conventional system design: Total inflow to end-of-pipe treatment pond	41,547	17,930
Conventional system design: Total outflow from end-of-pipe pond	41,483	2,690
LID design: Total site outflow	33,176	3,570

In the above table, the load generated by the conventional system design as input loading to the end-of-pipe pond, is effectively the SS load without any stormwater treatment in place and therefore represents the 0% reduction loadings. The MOE guideline for an "Enhanced" level of protection (per the 2003 MOE guidance document) requires 80% reduction in this load.

According to the model, the conventional design's wet pond achieves 85% removal, somewhat more than required.

The LID approach achieves 80% reduction, and therefore does away with any requirement for a wet pond for treatment. This could represent a cost savings, as it eliminates the need for approximately 2,800 m^3 of treatment volume (estimate based on Table 3.2 of MOE guidance document, for site with 45% imperviousness, wet pond design requiring a total of 160 m^3/ha).

Water Budget Maintenance

The following table provides water budget component volumes for the site area based on simulation of the 8-month period (April 1 to November 30, 1991).

Water budget summary, April 1 to November 30, 1991			
	Pre-Development	**Conventional design**	**LID design**
Precipitation (Pearson, Apr 01 – Nov 30, 1991)	94,732 m^3 (532.2 mm)		
Surface runoff	4,249 m^3 (23.8 mm)	33,171 m^3 (186.4 mm)	16,177 m^3 (90.9 mm)
Evapotranspiration	79,151 m^3 (444.7 mm)	46,804 m^3 (262.9 mm)	56,411 m^3 (316.9 mm)
Percolation to groundwater	18,095 m^3 (101.7 mm)	9,014 m^3 (50.6 mm)	18,874 m^3 (106.0mm)
Note: (Precipitation – Surface runoff – ET – Percolation) does not balance to zero in the above, because of net changes in soilwater storage between April 1 and Nov. 30, 1991.			

These results show that the “conventional” design approach will result is approximately 50% resduction in the April-November recharge to groundwater. This is due to the fact that as modeled, all runoff from impervious surfaces is drained away to site outlet without any opportunity to infiltrate. In contrast, the LID approach provides substantial opportunties to infiltrate surface runoff that is directed to soakaway areas and infiltration trenches. The results show that these measures will maintain the recharge at pre-development level.

3.9.3 Test Application #2 - DRAFT PLAN EXAMPLE

The Draft Plan example is a proposed residential subdivision with the following characteristics:

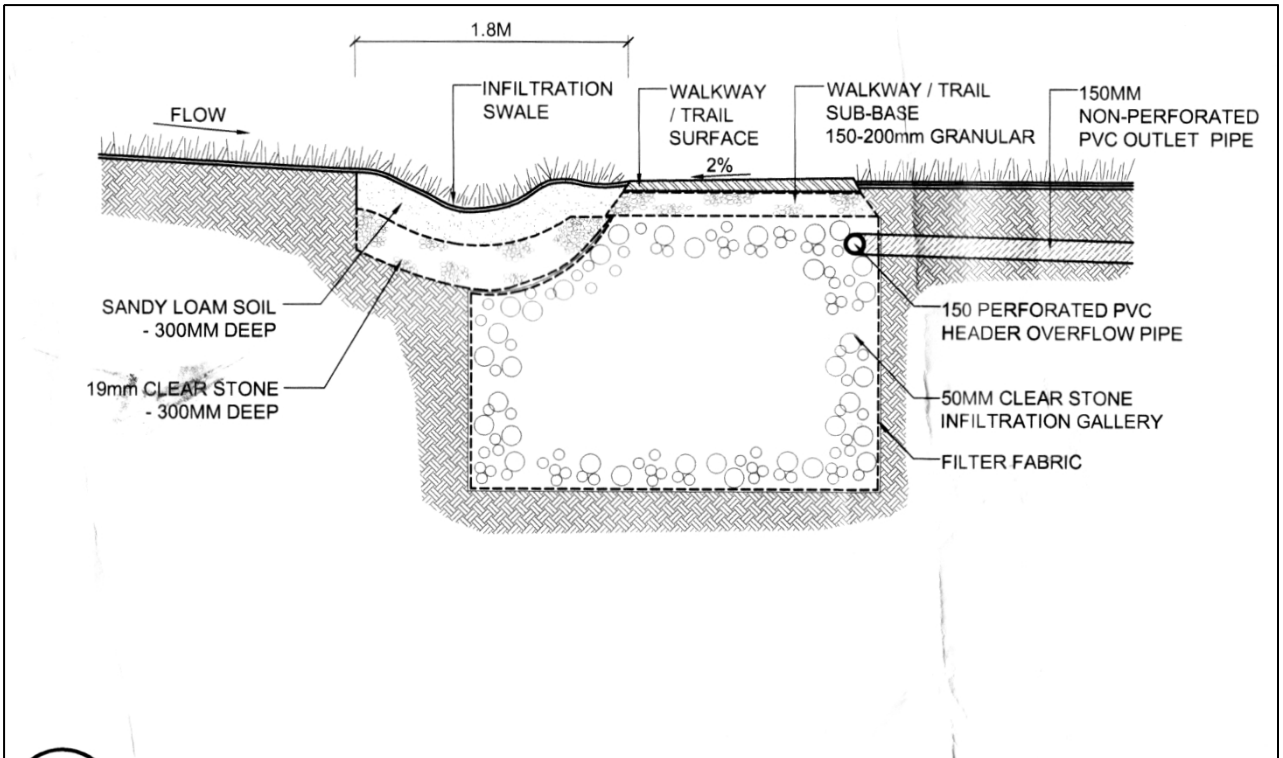
Total land area	33.2 ha
Impervious area: Roofs	5.45 ha
Impervious area: Roadways and parking including driveways	8.16 ha
Total impervious area	13.61 ha = 41.0% of total land area
Surficial soils	Described as predominantly “till/silt/clay”
Topography	Ground slope varies from approximately 2% to 5%.
Pre-development land use	Abandoned farm fields with some wooded area.

The proposed design includes a number of LID design features that are intended to provide substantial opportunity for surface runoff to be infiltrated. The LID features include:

- Subsurface infiltration galleries beneath park areas
- Infiltration trenches along rear lot lines
- Infiltration galleries beneath walkways through the residential area
- Soakaway areas within grassed boulevards along residential streets

In general, the design of the infiltration galleries and trenches consists of coarse granular material (50 mm clear stone) in a geotextile filter fabric surround. See the example detail shown below. The designs also incorporate an overflow pipe such that once the granular matrix is filled with water, excess inflow can be carried away to the storm sewer system by the overflow pipe. Water held within the granular matrix can infiltrate downward into the surrounding soil profile.

The use of a combination of park areas, walkway corridors and rear-lot lines for infiltration means that it is fairly distributed across the development site. In total, the proposed infiltration facilities comprise a total plan area of approximately 0.6 ha. The total storage capacity within the granular matrix materials is 2,100 m^3, which corresponds to an equivalent depth of 6.3 mm over the total development area of 33.2 ha.



INFILTRATION TRENCH AT WALKWAY / TRAIL
SECTION

3.9.3.1 Modelling Method

The modeling procedure was as follows:

1. Roof area (5.45 ha) was a separate “IMPERVIOUS SURFACE” element. The total runoff from roof area was split in two: 50% goes directly to the storm sewer system (“connected” roof drainage”), and 50% is discharged out onto grassed yard areas (“disconnected”).

2. It was assumed that the grassed yard area over which the disconnected drainage is infiltrated is the same in area as the disconnected roof area; *i.e.* runoff from 2.73 ha of roof area was diverted onto a PERVIOUS SURFACE with an area of 2.73 ha. This is effectively assuming that the disconnected roof drainage is discharged onto grassed yard area in a reasonably distributed way using devices such as splash pads.

3. The roadway and parking areas (8.16 ha) were represented as a separate IMPERVIOUS SURFACE in QUALHYMO. Runoff goes to storm sewer.

4. The remaining landscaped area (*i.e.* not receiving roof drainage, area = 10.88 ha) has been represented using a “PERVIOUS SURFACE” element. Runoff goes to storm sewer.

5. End-of-pipe stormwater pond modeled using the POND command. Settling of suspended solids was modeled using representative settling velocities reported by Driscoll et al. (1986).

6. Suspended solids loadings from impervious surfaces and landscaped area have been simulated using mean surface runoff concentrations for respective surfaces as reported in Heaney et al. (1999). The values applied in QualHymo (via POLLUTANT SERIES commands) are below.

Surface type	Mean concentration of SS in surface runoff
Residential streets and driveways	400 mg/L
Residential roofs	22 mg/L
Vegetated and landscaped areas	100 mg/L

7. For the LID scenario, the proposed infiltration features (infiltration galleries, trenches and soakways) were represented in aggregate as a PERVIOUS SURFACE element with a surface area of 0.6 ha and a soilwater storage capacity of 350 mm (to provide granular matrix water storage capacity of 2,100 m^3). The percolation rate was set to 1 mm/hr. This is rate at which water can exfiltrate from the infiltration gallery's granular matrix down into the surrounding native soil layers. A value of 1.0 mm/hour was selected as a long-term sustainable rate for the native soil described as "till/silt/clay", based on ranges of hydraulic conductivity values provided in Freeze and Cherry (1979).

3.9.3.2 Modelling Results

<u>Flood Control</u>

The results show that the LID approach will reduce the required end-of-pipe live storage needed to control the 100-year peak outflow to predevelopment rate, as listed below.

Estimated storage volume (m^3) needed to control peak site outflow to pre-development rates, For 100-year storm event		
Storm event	Conventional design	LID design
100-year 1-hour	7,600	5,600
100-year 6-hour	9,400	6,400
100-year 12-hour	9,600	6,800

The LID scenario provides an approximate 30% reduction in the estimated control volume requirements. This would translate into a smaller end-of-pipe control pond.

<u>Erosion Control</u>

Again, performance has been examined with respect to the target that for erosion control, the runoff from the first 25 mm of rain should be held and released over a period of not shorter than 24 hours. Results are based on simulating a 25-mm event of 6-hour duration.

- For the conventional design, the surface runoff volume is 5,400 m^3
- For the LID design, the volume is 3,800 m^3.

The LID approach has reduced the detention storage volume needed at the site outlet (end of pipe) by approximately 30%.

Surface Water Quality Protection:

QualHymo has been used to simulate suspended solids (SS) loadings generated by impervious and pervious surfaces, and has been used to explicitly model settling removal in the end-of-pipe wet pond (conventional case). The end-of-pipe pond for the "conventional" design scenario is as follows

- Treatment volume per 2003 MOE guidelines for "wet pond" = 155 m^3/ha X 33.2 ha = 5,146 m^3 (say 5,200 m^3)
- Treatment volume comprised of permanent pool of 3,800 m^3 and live storage (so called "extended detention") of 1,400 m^3.
- Additional live storage of 4,000 m^3 provided to give total live storage of 5,400 m^3 as needed to detain runoff from 25-mm 6-hour event (for erosion control).

In the LID scenario, for the infiltration galleries and trenches it has been assumed that all water that passes through the granular filtration matrix and then infiltrates into the native soil is subject to filtration that removes virtually all suspended solids; and therefore the resulting subsurface flow (groundwater system discharge) will have very low SS (1 mg/L). It has been assumed that any bypass flow (*i.e.* runoff directed to the infiltration facilities but which cannot be accommodated by those facilities because the granular matrix is saturated) will receive no treatment.

The table below summarizes the simulated loadings for the period April 1 to Nov. 30, 1991.

Test Application #2: DRAFT PLAN example
Simulated site outflow volumes and SS loads
For April 1 to November 30, 1991

Scenario	Flow volume (m^3)	SS load (kg)
Conventional system design: Total inflow to end-of-pipe treatment pond	66,270	15,950 kg (avg. conc. 241 mg/L)
Conventional system design: Total outflow from end-of-pipe pond	64,300	3,160 kg (80.2% removal)
LID design without end-of-pipe treatment: Total site outflow	78,700	8,260 kg (48.2% removal)

In the above table, the load generated by the conventional system design as input loading to the end-of-pipe pond, is effectively the SS load without any stormwater treatment in place and therefore represents the 0% reduction loadings. The MOE guideline for an "Enhanced" level of protection (per the 2003 MOE guidance document) requires 80% reduction in this load.

According to the model, the conventional design's wet pond achieves 80.2% removal.

The LID approach without any end-of-pipe treatment achieves 48% reduction. This reflects the fact that of the total runoff volume diverted towards the infiltration facilities, the model has predicted that approximately 50% will be infiltrated, and that the remaining 50% is in excess of the infiltration facility capacity.

The LID scenario as modeled was therefore modified to include an end-of-pipe wet pond to provide that additional TSS removal to meet target load reduction of 80%. A sequence of model runs was used to estimate what size of end-of-pipe pond would be needed. Result was as follows:

Wet pond characteristic	Conventional design scenario	LID scenario
Permanent pool volume	3,800 m^3	1,400 m^3
Live storage volume	5,400 m^3	3,800 m^3
Total volume for treatment and erosion contro1	9,200 m^3	5,200 m^3

The result is an approximate 44% reduction in the estimated design volume for the end-of-pipe control pond, which could represent a significant cost and space savings.

Water Budget Maintenance

The following table provides water budget component volumes for the site area based on simulation of the 8-month period (April 1 to November 30, 1991).

Test Application #2, Draft Plan example: Water budget summary, April 1 to November 30, 1991			
	Pre-Development	**Conventional design**	**LID design**
Precipitation (Pearson, Apr 1 – Nov 30, 1991)	176,690 m^3 (532.2 mm)		
Surface runoff	22,900 m^3 (69.0 mm)	66,300 m^3 (199.6 mm)	34.200 m^3 (103.1 mm)
Evapotranspiration	151,100 m^3 (455.2 mm)	105,800 m^3 (318.6 mm)	106,000 m^3 (319.3 mm)
Percolation to groundwater	24,100 m^3 (72.7 mm)	16,300 m^3 (49.1 mm)	46,400 m^3 (139.9 mm)
Note: (Precipitation – Surface runoff - ET - Percolation) does not balance to zero in the above, because of net changes in soilwater storage between April 1 and Nov. 30, 1991.			

These results show that the proposed infiltration measures will provide groundwater recharge that potentially exceeds the pre-development amount. Also there is an estimated 48% reduction in surface runoff volume.

The overall conclusion with respect to this Draft Plan example is that the proposed infiltration measures are adequate to meet the primary target of maintaining local groundwater recharge over the development area. There is also a substantial benefit in terms of surface runoff volume reduction and pollutant load reduction.

However, these latter benefits are not enough to meet targets related to surface water quality protection or flood flow control. In part, this is due to the restricted infiltration capacity (hydraulic conductivity) of the native soils.

The upshot is that an “end-of-pipe” control pond or similar facility will still be needed. However, the required design volumes for this pond will be substantially less (roughly 30% to 40% reduction) than in the “conventional” scenario.

3.9.4 Further Details on Modelling Method with QUALHYMO

Both of the above test applications of QUALHYMO have shown that at the site level, infiltration techniques can maintain local recharge to the groundwater system, and that the resulting reductions in surface runoff volume and pollutant loadings can substantially reduce the size of end-of-pipe mitigation measures such as treatment ponds.

For both test applications, recently developed extensions to the QUALHYMO command set have been employed to represent site-level measures that promote infiltration and provide physical filtration to help with pollutant load reduction.

The extensions which have been employed are the following commands:

Command	Comments on use in test applications
IMPERVIOUS SURFACE	Used to separately simulate different types of hard surfaces, including roadways, parking lots and roofs. These types of surface were simulated separately so that different mean pollutant concentrations can be applied to each surface type. This is accomplished by preceding each use of IMPERVIOUS SURFACE with appropriate POLLUTANT SERIES command to apply the mean SS concentrations tabulated above.
PERVIOUS SURFACE	Used to simulate vegetated areas including landscaped areas. This command has been used to represent vegetated yard areas that receive roof drainage in residential areas. This command has been coded so that any existing (previously generated) flow time series can be supplied by the user as a lateral input to the surface (e.g. to roof runoff draining onto a grassed area).
PERVIOUS WITH STORAGE	Use to simulate grassed swales and soakaway infiltration facilities. This command has been coded so that any existing (previously generated) flow time series can be supplied by the user as a lateral input to the surface.

These commands complement the QUALHYMO GENERATE command by providing alternate means of simulating surface runoff processes within smaller-scale situations. The GENERATE command is intended more for simulating the hydrologic response of larger watershed areas. Accordingly, GENERATE makes use of estimates of effective imperviousness over larger areas, and uses a modified SCS Curve Number approach that uses Antecedent Precipitation Index (API) to provide continuous simulation of surface runoff production at the watershed scale.

Separate representation of impervious and pervious surfaces, and allowing for surface runoff from one to be diverted onto the other, provides a more explicit means of modelling urban processes, especially when dealing within smaller-scale areas such as individual development areas or properties. This was the impetus for extending QUALHYMO's command set.

Further notes on these commands are as follows:

1. In the case of the IMPERVIOUS SURFACE command, the command has been coded such that the surface runoff and pollutant loadings can be split into as many a three fractions. This allows, for example, one fraction to be diverted onto a pervious vegetated surface (e.g. roof drainage onto grassed area) while another fraction goes directly to storm outlet.

2. Both the PERVIOUS SURFACE and PERVIOUS WITH STORAGE provide continuous simulation of soil moisture status within and vertical water movement through a porous soil profile. The user must supply the following input parameters

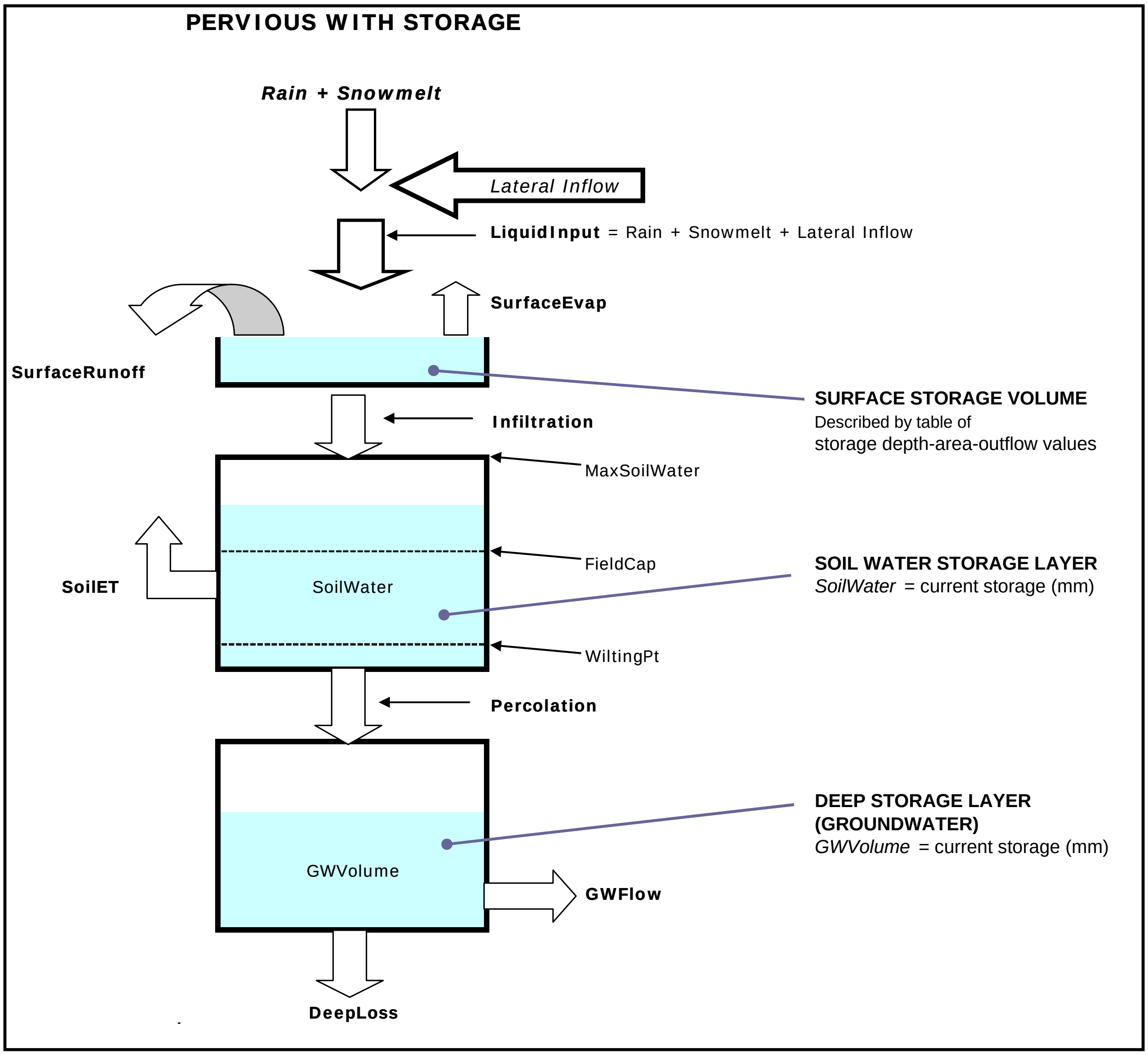
    - Surface area in hectares
    - Maximum and minimum surface infiltration rates. The actual surface infiltration capacity at any point in time varies between these two rates depending on soil moisture status.
    - The soil moisture holding capacity, field capacity and wilting point. These are input as mm of water depth. The holding capacity is a function of the depth of the soil profile and the available porosity. Field capacity represents that amount of water that can be held against gravity drainage (*i.e.* held within the soil matrix by capillary tension). Wilting point is the amount of water held in the matrix at the point at which vegetation root systems can no longer extract moisture. Holding capacity, field capacity and wilting point will vary with soil texture. As well, when expressed as mm of water, the values will depend on the depth of the soil profile being modelled. Since all ET losses are accounted for within this layer, the depth should be at least equal to the full depth over which the vegetation's root system can extract water.
    - Percolation rate. This is the rate at which free water (*i.e*. amount of water in excess of field capacity) can move gravitationally downward through the profile and into the underlying layers, which are represented in the model as a conceptual groundwater storage reservoir. In other words, percolation is groundwater recharge. The percolation rate should be based on the limiting saturated hydraulic conductivity of the soil layers through which the water must percolate to reach the water table. The model assumes that this percolation capacity is always available.

3. In all of these commands, the total liquid input to the surface will be comprised of rain plus snowmelt, plus any lateral inflow as specified by the modeler. The lateral inflow could, for example, be the surface runoff outflow from an IMPERVIOUS SURFACE.

4. In the PERVIOUS commands, actual evapotranspiration is computed based on potential ET rates supplied as input to the model. When soil moisture is at or above field capacity, actual ET will be equal to potential ET. Once soil moisture drops below field capacity, actual ET will be lower than the potential rate; the actual ET rate approaches zero as soil moisture approaches wilting point.

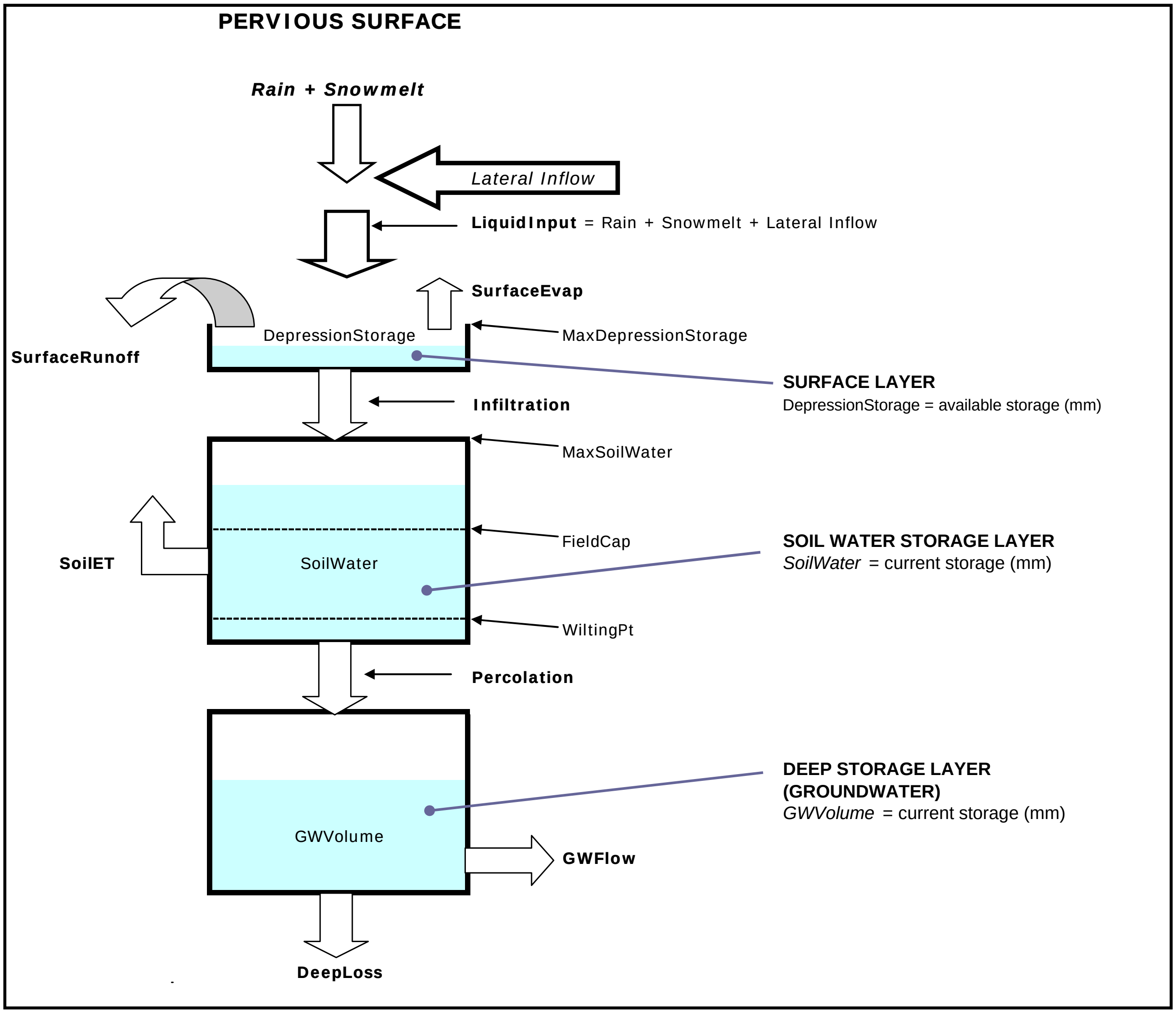
5. In the case of the PERVIOUS SURFACE command, when the total liquid input to the surface exceeds surface infiltration capacity, then surface runoff is generated. The rate of runoff (flowrate) is based on surface roughness (Manning n value), slope and characteristic length supplied by the user.

6. In the case of PERVIOUS WITH STORAGE, the user does not supply surface slope, length and roughness. Instead, a surface storage element is defined using a table of depth-area-outflow values that the user must compute and supply to the model. When total liquid input exceeds surface infiltration capacity, water will be stored within the surface storage element. The model continuously tracks the water depth, inundated area and volume within the surface storage element; and surface evaporation and exfiltration of stored water into the soil profile occur over only the inundated area.



7. Total outflow from the conceptual groundwater storage layer is computed as a simple linear function of storage level. The modeler can specify that a percentage of this outflow be considered as "deep losses" which do not contribute to the subsurface outflow rate.

Please refer to the schematic diagrams that help to further explain how the PERVIOUS SURFACE and PERVIOUS WITH STORAGE commands function.



The PERVIOUS commands do not provide any simulation of pollutant removal by filtration or other processes associated with vertical water movement downward through the soil matrix. However, the effect of this filtration process can be represented by using the POLLUTANT SERIES command to assign appropriate average pollutant concentration values to the subsurface (groundwater) outflow.

Note that in the case of the PERVIOUS WITH STORAGE command, pollutant removal (solids settling and first-order decay) is simulated within the volume held in the surface storage element, in the same manner as used in the POND and REACH commands. That is, the surface storage volume is represented as a number of completely-mixed tank reactors, with solids settling and first-order decay occurring based on rate parameters supplied with the START command.

The PERVIOUS commands provide a conceptual representation of infiltration into, movement through and ET losses from a porous medium. These commands can therefore be used to simulate hydrologic response of vegetated areas on native soils.

As well, through appropriate values for input parameters, the PERVIOUS SURFACE and PERVIOUS WITH STORAGE commands can be used to represent various site-level BMPs such as infiltration trenches, vegetated swales, soakaway areas, subsurface infiltration galleries or bioretention facilities. Refer to the following table.

Type of BMP	QUALHYMO command	Notes on input parameters
Soakaway area: Designed as area for temporary surface ponding on native soils	PERVIOUS WITH STORAGE	• Storage depth-area-outflow table based on actual surface grading and estimate of ponding depth before spill outflow occurs. • Surface infiltration capacity and percolation capacity based on estimated saturated hydraulic conductivity of soil layers.
Infiltration trench or infiltration gallery: Designed using coarse granular filtration media surrounded by geotextile; allows for water to exfiltrate into surrounding native soils. May include an overflow pipe to collect water in excess of exfiltration capacity	PERVIOUS SURFACE	• Lateral inflow time series is the facility inflow • Surface area equal actual trench surface area • Surface infiltration rates set to represent high capacity for water to enter top of granular matrix. • Soil moisture holding capacity based on depth, width and effective porosity of granular matrix. • Field capacity minimal and wilting point zero (minimal water held in matrix by capillary potential). • ET factor set to zero, as no vegetative root system within granular matrix. • Percolation rate set to value representative of saturated hydraulic conductivity of surrounding native soil.
Bioretention facility: Designed to provide some surface storage ponding capacity, either on native soils or on granular fill material intended to promote infiltration	PERVIOUS WITH STORAGE	• Similar to soakaway area (above) • Storage depth-area-outflow table based on actual surface grading and estimate of ponding depth before spill outflow occurs. • Surface infiltration capacity based on estimated conductivity of surface soil layer or granular material • Percolation rate based on estimated conductivity of underlying soil layers
Grassed swales: Linear vegetated swales allow for infiltration of water into native soils	PERVIOUS WITH STORAGE	• Storage depth-area-outflow table based on average or typical swale cross-section, hydraulic roughness and bed slope to develop flow-vs-depth rating curve, which can then be used to estimate depth-area-outflow from length of swale. • Surface infiltration capacity and percolation capacity based on estimated saturated hydraulic conductivity of soil layers.

The IMPERVIOUS and PERVIOUS commands can accept lateral inflow time series as part of the total liquid water input to the surface. And, as noted above, surface outflows from IMPERVIOUS SURFACEs can be divided into three fractions. This allows for a good deal of flexibility in representing drainage connectivities that may be of significance at the urban site level.

A schematic of how this can be accomplished is shown below. This example is a model of a residential development site that includes an infiltration facility that receives all surface runoff from the site area. In this example,

- Separate IMPERVIOUS SURFACEs represent roofs versus roadways and parking areas. The roof runoff is split into two equal fractions, one of which is used as lateral input to a PERVIOUS SURFACE that represents grassed yard areas that receive the roof runoff.

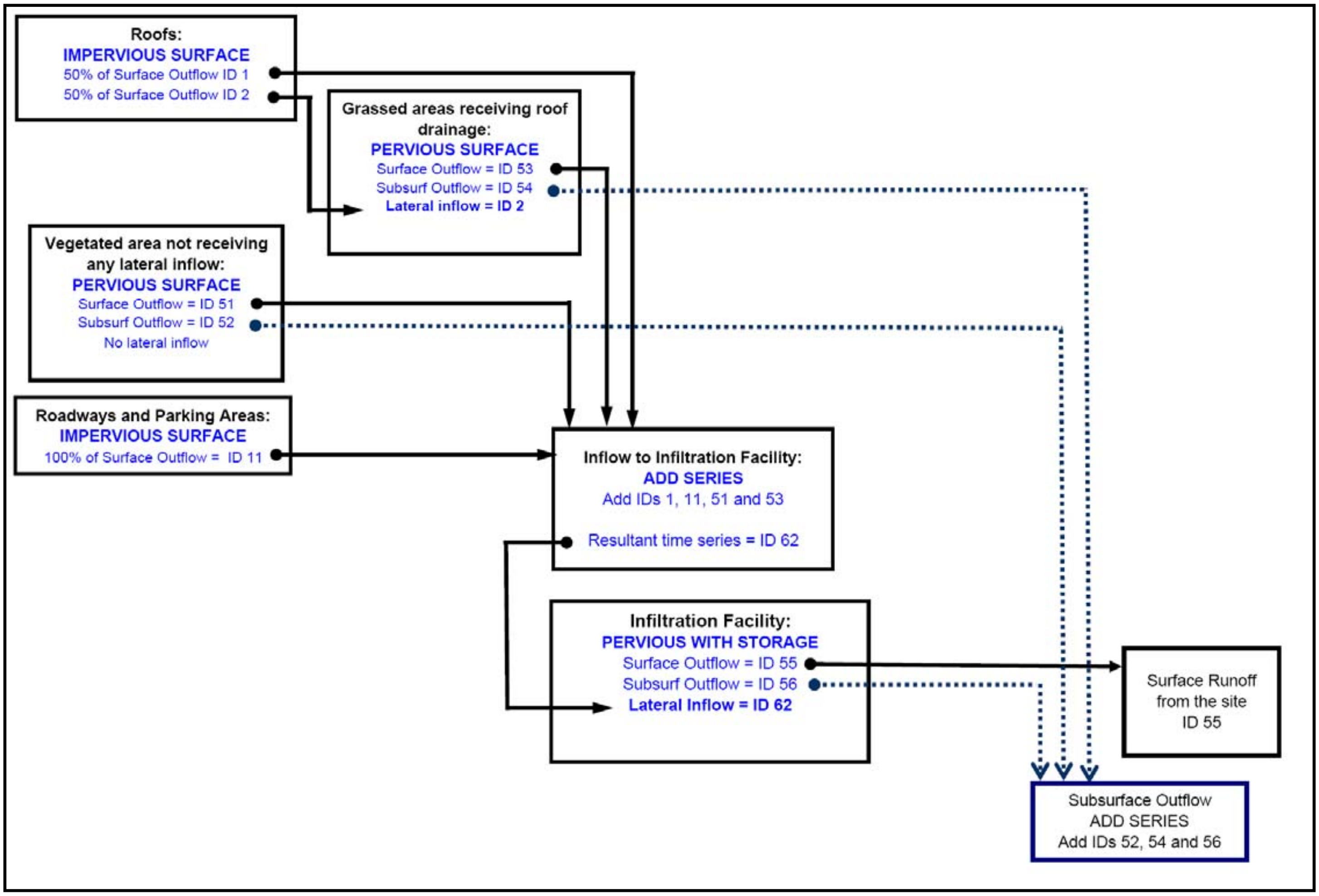
- A separate PERVIOUS SURFACE represents other vegetated area.

- The ADD SERIES command is then used to add up the surface runoff from the various surfaces to generate a single time series representing the total surface runoff from the area.

- This time series is then used as lateral input to a PERVIOUS WITH STORAGE that represents the infiltration facility itself. In this case, the infiltration facility is within a park area and consists of a surface ponding area over top of a granular fill matrix that allows for exfiltration into the surrounding native soils. The outflow from the surface storage element represents the net surface runoff from the site.

- The ADD SERIES command is used to add up the subsurface outflow components from each of the PERVIOUS SURFACE elements, to get the total subsurface outflow from the site.

Note that QUALHYMO generates a standard text output file that provides a water balance summary for each individual PERVIOUS or IMPERVIOUS element. These summaries include total volumes for liquid water input, surface evaporation, infiltration, ET from the soil layer and percolation to the conceptual groundwater layer, along with mass balance checks (i.e. continuity error checks). The modeler can then take the volumes from these summaries to compute the overall water balance for the site.


Roofs:
IMPERVIOUS SURFACE
50% of Surface Outflow ID 1
50% of Surface Outflow ID 2
Grassed areas receiving roof drainage:
PERVIOUS SURFACE
Surface Outflow = ID 53
Subsurf Outflow = ID 54
Lateral inflow = ID 2
Vegetated area not receiving any lateral inflow:
PERVIOUS SURFACE
Surface Outflow = ID 51
Subsurf Outflow = ID 52
No lateral inflow
Roadways and Parking Areas:
IMPERVIOUS SURFACE
100% of Surface Outflow = ID 11
Inflow to Infiltration Facility:
ADD SERIES
Add IDs 1, 11, 51 and 53
Resultant time series = ID 62
Infiltration Facility:
PERVIOUS WITH STORAGE
Surface Outflow = ID 55
Subsurf Outflow = ID 56
Lateral Inflow = ID 62
Surface Runoff from the site ID 55
Subsurface Outflow
ADD SERIES
Add IDs 52, 54 and 56

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