SUBURBAN WATER FLOWS

by

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ABSTRACT

Typical suburban housing water cycle practices are polluting the natural water cycle and contributing to the degradation of watersheds. This thesis defines and applies a process that prioritises strategies for transformation of existing suburban housing water cycle into an ecologically sensitive on-site water cycle. An existing typical suburban block located in Brentwood Bay, British Columbia is used as a primary vehicle for this investigation. The process is composed of two distinct sections: assessment and transformation.

The assessment section consists of two principal objectives: assessing existing conditions and prioritising strategies for transformation. The transformation section consists of four objectives prioritised as follows: first, eliminating on-site degradation; second, reducing the water demand; third, treating and using wastewater; and fourth, collecting and using rainwater. This thesis exclusively examines on-site flow management strategies in order to efficiently and appropriately transform the existing conditions. Social, political, and economic strategies are not studied in this thesis.

This research acknowledges the importance of respecting on-site ecological requirements in order to avoid on-site degradation during suburban housing operation. This thesis suggests that it is possible to address the Brentwood Bay suburban housing water cycle on-site with no impact on the host watershed. Furthermore, it is possible to significantly densify the existing site conditions while avoiding degradation of the host watershed.

Given the generic nature of the process, it can be readily applied to other climates, building types, and scales. The process can also be applied to both existing retrofit and new construction. The application of the thesis process facilitates the elimination of on-site degradation, the reduction of municipal loading and the increase of natural on-site water cycle carrying capacity.

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INTRODUCTION

1. INTRODUCTION

1.1. SUMMARY

Typical suburban housing water cycle practices are polluting the natural on-site water cycle and contributing to the overall degradation of water resources. Reducing the negative ecological impacts of buildings on the natural water cycle is an important objective of today's ecological challenges. However, selecting the most appropriate and efficient strategies is a complex task. This thesis defines and applies a process that priorities design decisions in order to transform the current suburban housing water cycle into an ecologically sensitive On-Site Suburban Housing Water Cycle (OSSHWC).

This thesis prioritises on-site flow management strategies in order to efficiently and appropriately transform existing conditions. A typical suburban housing block, located in Brentwood Bay, on Vancouver Island, British Columbia, is used as a primary vehicle for this investigation.

The process consists of two distinct sections: assessment and transformation. The assessment section contains two objectives, assessment of existing conditions and prioritisation of strategies for transformation. The transformation section contains four objectives prioritised according to site-specific conditions. For the Brentwood Bay site, the transformation is prioritised as follows: first, eliminating on-site degradation; second, reducing the on-site demand for water; third, treating and using on-site wastewater; and fourth, collecting and using on-site water supply. The thesis' structure follows the application of this process as it is implemented in the selected site located in Brentwood Bay.

1.2. BACKGROUND

Current research on the planet's ecologically limited ability to produce and to maintain human life-supporting elements such as water, food, material, and energy, as well as its limited capacity to assimilate human generated waste, have raised awareness of ecosystem requirements and limitations. Respecting the ecological limits and needs of the biosphere is crucial to the quality of human existence. In order to avoid degradation of ecosystems, it is necessary to account for the ecological requirements of the biosphere. These ecological requirements are the natural processes necessary to maintain a healthy ecosystem. An example of such requirements is maintaining a certain level of plant absorption of CO_2 to avoid air pollution causing health problems for human and other species.

As an important consumer of resources and as a producer of polluted waste, the built environment is responsible for a large section of resource depletion and environmental degradation (CMHC 1993). For this reason, a building's negative impacts on its host ecosystems need to be reduced or ideally eliminated. This thesis focuses specifically on the adverse affects of the suburban housing fabric. Such negative effects are important to reduce or eliminate since a majority of Canadians (56.7%) live in single family detached housing (Statistic Canada 1997). Single family detached housing is a well-documented contributor to ecological problems such as resource depletion and degradation of life-supporting ecosystems (Friedman et al. 1993).

Suburban housing's extensive use of energy and resources are directly and indirectly degrading many components of the ecosphere such as ambient air, water resources as well as biological productivity. For example, detached homes consume anywhere from 15 to 67 percent more energy than other common ground oriented housings forms (CMHC 1991). Of all these adverse effects, reducing the damage to water resources is necessary since the water cycle plays a significant role in the health of life-supporting ecosystems as well as in human health (Roley 1992). This thesis focuses exclusively on suburban housing's relationship with the natural water cycle.

According to a United Nations report, addressing water quality and quantity issues tops a list of pressing problems facing humanity for the 21st century (UNEP 1999). This report highlights the need for prevention of freshwater scarcity and pollution as the most important issue followed by climate change issues. Clearly, this report suggests that the demand for suburban housing with low negative impacts on the quality and quantity of freshwater will increase in the near future.

Suburban housing fabric has both direct and indirect negative impacts on the natural water cycle. Direct effects are defined as those related to the disruption of natural on-site water cycle flows. These flows are: runoff, evaporation, and infiltration. Indirect effects of suburban housing are defined as those which have a broad scope and include, for example, the effects of the production of building materials on the natural water cycle as well as the effects of water supply infrastructure related to suburban sprawl of single detached housing. Given the broad scope of the adverse indirect impacts, this thesis solely addresses direct negative impacts to the natural on-site water cycle flows. The direct negative impacts are those which reduce quantity and quality of natural flows necessary to maintain healthy watersheds and aquifers.

For most suburban housing in British Columbia, the natural on-site water cycle flows and the human made suburban on-site water cycle flows are totally disconnected. In a typical suburban housing fabric, there are few design strategies in place to permit infiltration of rainwater. On the contrary, rainwater is channeled and disposed of in surrounding water bodies where it causes serious ecological problems such as species depletion and site contamination. Natural on-site flows are typically not considered in current suburban development.

Moreover, typical suburban housing water cycle practices are causing direct degradation to the on-site natural water cycle. In addition, the municipal/regional piped water systems of water supply and wastewater treatment serving typical suburban housing produce a significant amount of degradation to natural water resources (Environment Canada 1992). The degradation associated with the use of typical municipal/regional services (referred in the thesis as municipal loading) is analysed in detail in chapter 6.

This thesis studies existing suburban housing water cycle and proposes the prioritisation of strategies for its transformation into an ecologically sensitive on-site suburban housing water cycle (OSSHWC). This research isolates water cycle issues in order to analyse them in detail, although it is understood that, in application, water cycle issues can not be disassociated from the contextual issues influencing them. Their isolation in this research permits an in depth and focused look at the relationship between suburban housing and the natural water cycle. A discussion regarding the influence and importance of contextual issues concludes this research.

1.3. OBJECTIVE AND SCOPE

The objective of this thesis is to define a process that prioritises strategies for transformation of existing suburban water cycle conditions into an ecologically sensitive OSSHWC. In applying the process to a typical site, the thesis verifies that application of the process efficiently eliminates on-site degradation and reduces the use of municipal services, and that it effectively increases the natural on-site water cycle carrying capacity. In addition, the thesis verifies that the increase in natural on-site water cycle carrying capacity permits a possible densification of the existing suburban housing fabric.

By applying the process to a suburban block, the thesis studies the suburban housing water cycle issues beyond the single detached family house. This thesis analyses the negative effects of single family houses and its attendant conditions on host watersheds rather than focussing on the house as a unit isolated from its surrounding watershed.

This thesis acknowledges that social, political, and economic strategies would influence the transformation of existing conditions. However, the thesis limits its research to flow management design strategies applicable at the block, lot, and/or unit scale. A discussion of the importance acknowledging the role of social, political and economic strategies is included in the thesis.

1.4. SUBURBAN HOUSING BLOCK

It was decided early in this research to select a suburban housing block as an appropriate scale for the investigation. This scale was chosen since studying water degradation beyond the single family residence is an objective of this thesis. The selected site is composed of eleven private lots and half of the road right of way (see figure 8). The thesis proposes that the municipal right of way is an important component to consider when addressing water degradation since it includes almost two thirds of the impervious surfaces of the selected site (see chapter 3 assessing the built environment). Acknowledging the significant influence of municipal infrastructure on direct negative impacts of suburban housing on watersheds suggests that larger municipal and regional scales have great potential to address overall suburban housing water cycle. However, this thesis focuses on the block scale to remain at a level that directly influences housing design.

The selected suburban block is located in Brentwood Bay, British Columbia. The Brentwood Bay neighbourhood is a suburban community of Victoria, the second largest urban agglomeration of the province. This research opted for a site connected to a significant urban center since suburban fabric constitutes a significant portion of urban regions. Moreover, the densification of existing suburban fabric is more likely to occur in proximity of urban centers. The Victoria region is selected over the greater urban Vancouver region due to its significantly dryer climate. This research analyses the transformation to an OSSHWC in a dry urban center in order to test the process in a feasible yet challenging suburban situation.

It was also decided that the thesis should address a complete transformation of the existing conditions towards an OSSHWC. Achieving an on-site water cycle disconnected from municipal services forces the analysis of the complete cycle: from water supply to wastewater treatment. The thesis does not imply that the transformation to an OSSHWC at the block scale is a universal solution to overall watershed degradation. However, making a complete transformation exposes and assesses water cycle flow consequences as well as gauges potential for OSSHWC to address overall watershed degradation throughout typical suburban housing fabric.

1.5. DEFINING ON-SITE SUBURBAN HOUSING WATER CYCLE

Achieving the transformation from existing conditions to an OSSHWC requires the merging of the natural on-site water cycle flows with existing suburban housing conditions. This merger looks at the existing suburban housing water cycle's ability to incorporate the natural on-site water cycle into its functioning, facilitating a symbiotic relationship between the human made suburban housing water cycle and the natural water cycle.

The natural water cycle has two sources of on-site water supply: groundwater and precipitation. It is also composed of natural on-site water cycle flows, these flows are: runoff, infiltration and evaporation.

Existing suburban housing water cycle conditions are composed of a series of flows and architectural components. Municipal services of water supply, wastewater treatment and runoff collected by storm sewers are the in and out flows in a typical suburban fabric. Existing architecture and infrastructure components such as roofs, roads, and driveways direct existing flows.

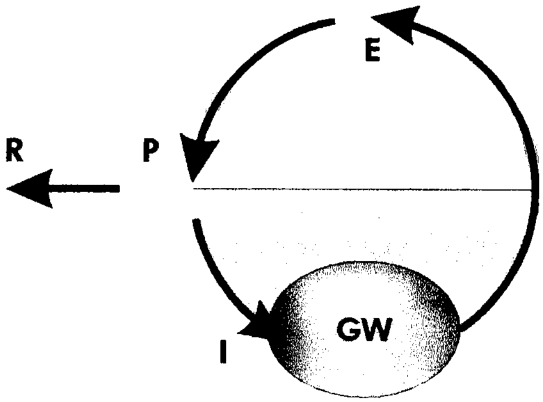
Since the OSSHWC is achieved through the merging of natural and existing conditions, it is composed of a series of flows and architectural components. Similar to the natural water cycle, the OSSHWC is composed of two sources of on-site water supply: groundwater and precipitation. It is also composed of three on-site flows: runoff, infiltration, and evaporation. Moreover, it consists of four architectural components: collection area, storage, wastewater treatment system, and overflow of treated wastewater. Figure 1 illustrates the merging of the two water cycles necessary to achieve the OSSHWC.

The components of the OSSHWC operate within a cycle. As in the natural water cycle, connections exist between each component of the cycle. A significant change in one of the components will modify the water flows within the OSSHWC. The inter-connectedness of the components suggests that it is necessary to analyse the consequences on the entire OSSHWC when modifying one component within it. Therefore, analysing these inter-connections facilitates the prioritisation of process steps during the transformation of existing conditions.

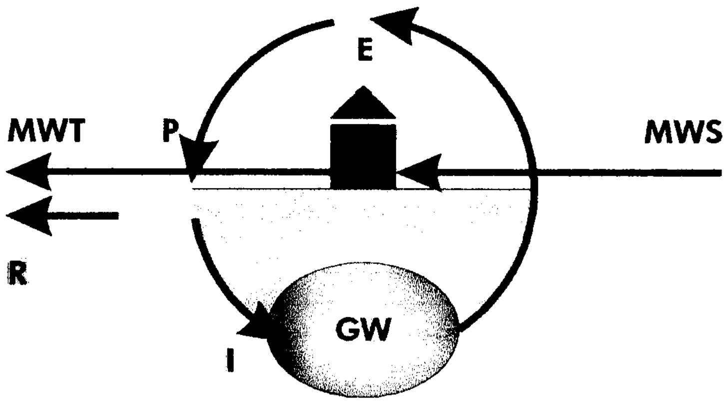
The goal of the merger is to re-establish the concept of natural water cycle within suburban water conditions. The existing conditions ignore that suburban housing inhabitants living on a particular site influence the ecological processes of their host natural water cycle. Acknowledging the impact of the suburban fabric on host water cycle is the first step towards an ecologically benign OSSHWC. It has been demonstrated that holistic natural water cycle and watershed management is necessary to address overall water resources degradation (Berka, McCallum and Wernick 1995; WCSWG 1998).

FIGURE 1: THE THREE WATER CYCLES

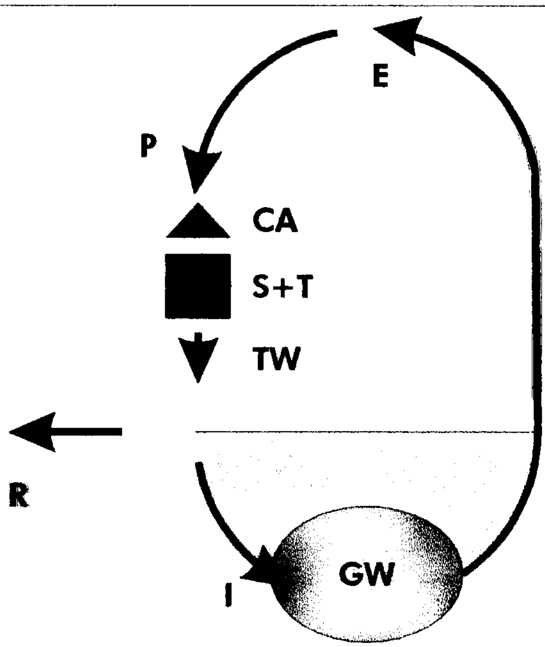
NATURAL ON-SITE WATER CYCLE



CURRENT ON-SITE WATER CYCLE



OSSHWC



Legend

Precipitation = P
Evaporation = E
Infiltration = I
Runoff = R
Groundwater = GW
Municipal Wastewater Treatment = MWT
Municipal Water Supply = MWS
Treated Wastewater = TW
Storage and Treatment = S+T
Collection Area = CA

The watershed, a measurable unit in the natural water cycle, is the area that drains into a river or creek. Because of water's dynamic nature, each site included in the drainage area of the watershed affects an area much larger than its physical boundaries; it affects an entire watershed and/or aquifer.

An aquifer is a natural reservoir of groundwater located below the earth's surface. Reduction of infiltration occurring on-site may lead to the degradation of an aquifer. In coastal regions for example, a lack of infiltration can lead to salt water intrusion in the groundwater reservoir, contaminating the entire aquifer. Contaminated aquifers can lead to significant water supply problems if a community is solely dependant on groundwater as a source of water supply (Environment Canada 1992).

1.6. DEFINING THE THESIS PROCESS

Early in this research, two factors emerged as significant in triggering recognition of the need for a process definition that prioritises issues related to the transformation of typical suburban fabric into an OSSHWC. First, water cycle degradation caused by suburban housing varies according to site-specific conditions. Second, the transformation must acknowledge that the order in which strategies are applied profoundly affects the outcome. These factors define the need to assess the selected site and prioritise the strategies for transformation. The process ensures that the most pressing problems are addressed first and that the transformation is successfully and efficiently achieved.

1.6.1. PROCESS DESCRIPTION

The thesis process is composed of two sections: assessment and transformation. Initial assessment permits the ranking of issues that inform the transformation of existing water cycle conditions to an ecologically sensitive OSSHWC. The second section of the process addresses the transformations necessary to efficiently achieve an OSSHWC. The process consists of eleven steps, seven in the assessment section, and four in the transformation section. After a complete transformation, the option of densifying the existing conditions is evaluated.

The thesis suggests that addressing the direct negative impacts of suburban housing begins with an assessment of existing conditions. The first section, assessment, looks at the conditions of the selected site. The steps are to: identify ecological requirements; assess OSSHWC flows; assess the built environment; assess on-site degradation; assess municipal loading; and finally, assess natural on-site water cycle's carrying capacity. The last step of the assessment section is the prioritisation for transformation.

The second section, transformation, is composed of four prioritised steps. For the Brentwood Bay site, the prioritised steps are to: eliminate on-site degradation; reduce water demand; treat and use wastewater; and collect and use rainwater. These steps are ranked to efficiently complete the transformation of existing conditions.

This process is iterative; the constant use of feedback loops is necessary to avoid using incompatible strategies while achieving a well prioritised and efficient transformation. The process facilitates the appropriate implementation of strategies by analysing the flow consequences of each of the transformation steps. Figure 2 illustrates the thesis process.

1.6.2. PROCESS ASSESSMENT

In order to study the consequences of a partial application of the process, the thesis independently assesses the performance of each step in the transformation towards an OSSHWC. This is important since the transformation can occur all at once or over a undetermined retrofit period. The incremental process represents degrees of commitment regarding elimination of overall watershed degradation. The thesis characterizes ecological commitment to reducing watershed degradation in shades of green: pale green represents low commitment, whereas dark green, at the other end of the scale, represents high commitment to reducing watershed degradation. This characterization parallels current debates and terminology concerning the need for major modifications to the status quo (dark green) or simple readjustments of current practices (light green).

FIGURE 2: THE THESIS PROCESS AS APPLIED TO THE BRENTWOOD BAY SITE

Process

Assessment

- Identifying ecological requirements
- Assessing the built environment
- Assessing OSSHWC flows
- Assessing on-site degradation
- Assessing municipal loading
- Assessing carrying capacity
- Prioritising strategies for transformation

Transformation

- Eliminating on-site degradation
- Reducing on-site water demand
- Treating and using on-site wastewater
- Collecting and using on-site water supply

The thesis process analyses the OSSHWC water flows using a flow diagram representing monthly flows of water in the OSSHWC. It also illustrates the inter-connections between each element of the OSSHWC and the natural on-site water cycle flows quantities influencing the host watershed and aquifer. Each flow diagram is analysed in detail throughout the application of the process. The following chapters apply the process to a typical suburban block located in Brentwood Bay, British Columbia.

PROCESS

SECTION 1: ASSESSMENT

This thesis proposes that the transformation process from typical suburban water cycle conditions into an ecologically benign OSSHWC must begin with an assessment of the existing site. Assessing existing conditions is important since the natural water cycle degradation, exacerbated by suburban housing, is site-specific. Site conditions vary significantly depending on the characteristics of the selected site thus the assessment permits prioritisation of water cycle design strategies required to efficiently achieve an OSSHWC.

The assessment section is composed of seven steps. The six first steps assess existing site conditions and the last step of the assessment prioritises strategies for the transformation process. Each step is described and analysed in separate chapters. The assessment steps are: identifying the ecological requirements; assessing the built environment; assessing the OSSHWC flows; assessing on-site degradation; assessing municipal loading; and assessing natural on-site water cycle carrying capacity. The last step of the assessment prioritises strategies for transformation.

2. IDENTIFYING ECOLOGICAL REQUIREMENTS

2.1. BACKGROUND

The ecological requirements are the flow quantities that need to be maintained in order to minimize watershed degradation. This thesis acknowledges the importance of preserving or restoring the health of a watershed when retrofitting or building suburban housing. It is essential to identify and to respect the ecological requirements of a site in order to reduce watershed degradation and, in some cases, to minimize shortage of water available for human use (Roley 1992).

2.2. GENERAL DEFINITION

To define the ecological requirements of a given site, the thesis identifies the quantities of natural on-site water cycle flows necessary to reduce degradation of the host watershed. Identifying the ecological requirements permits the estimation of the quantity of on-site water supply available for human use. The available rainwater for human use also influences the natural on-site carrying capacity.

2.2.1. NATURAL-ON-SITE WATER CYCLE FLOWS

Natural on-site water cycle flows quantities are influenced by site-specific conditions such as microclimate, soil conditions, and topography. The natural on-site water cycle flows have previously been defined as runoff, evaporation and infiltration. Identifying the ecological requirements requires the assessment of the quantity of the natural on-site flows.

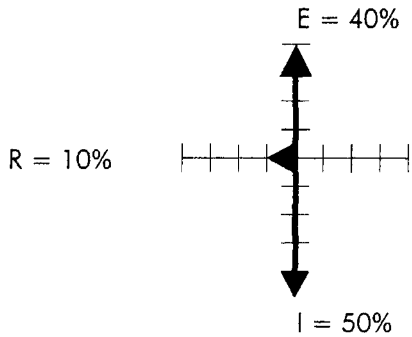
2.2.1.1. QUANTITY OF NATURAL ON-SITE WATER CYCLE FLOWS

To maintain a healthy on-site water cycle, the pre-development (natural) quantity of these on-site water cycle flows needs to be identified. Figure 3 illustrates the impacts of urbanisation on the pre-development on-site flows of a typical site. This figure is used in many studies related to the disruption of on-site flows, such as in the study by Arnold and Gibbons (Arnold and Gibbons 1996) as well as the report by Wilson (Wilson 1994). This figure illustrates how current development patterns significantly disturb natural water cycle flows. It estimates the quantities of on-site flows associated with a given amount of impervious surfaces within a study area. The flows in figure 3 are expressed in percentage of annual precipitation. Re-establishing the quantities of on-site flows as close as possible to their pre-development state should be the goal in order to minimize degradation. The pre-development state is defined as the natural state of the site prior to human intervention on the site. In this case, the natural flow conditions are assumed to be those of a typical site. Typical pre-development flow conditions are: 10% runoff; 50% infiltration; and 40% evaporation. These conditions define the ecological requirements of a typical site in order to protect the host watershed.

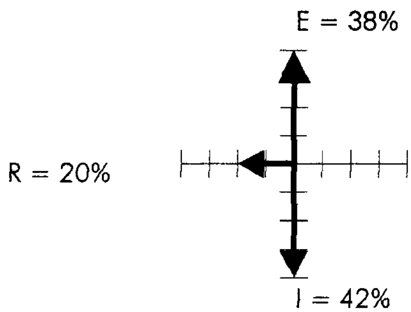
The most significant modification to the pre-development flows caused by urbanisation is the increase in runoff. This increase in runoff lowers the percentage of precipitation available for evaporation and infiltration. This thesis proposes that the more precipitation removed from the natural water cycle, the greater the impact. According to Arnold and Gibbons, disruptions to typical natural on-site water cycle flows can be classified into three categories: minor disruptions with no impact on the health of the watershed; disruptions that impact the health of the watershed; and finally, disruptions that degrade the watershed (Arnold and Gibbons 1996).

Arnold and Gibbons' three categories represent degrees of negative impacts to the watershed. A protected watershed means that negative impacts are assimilated by the watershed without lowering habitat quality, species diversity, and abundance.

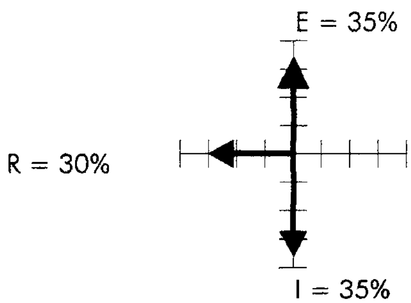
FIGURE 3: ON-SITE FLOWS AND URBANISATION



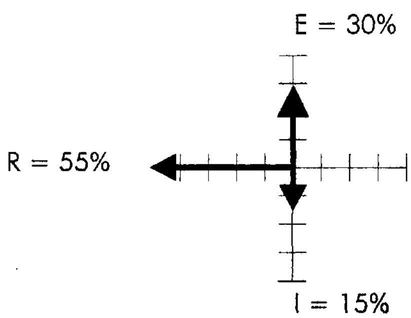
ON-SITE WATER FLOWS
IN PRE-DEVELOPMENT STATE
(NO IMPERVIOUS SURFACE COVERAGE)



ON-SITE WATER FLOWS
IN 10-20 % IMPERVIOUS SURFACE
COVERAGE OF TOTAL SITE



ON-SITE WATER FLOWS
IN 35-50 % IMPERVIOUS SURFACE
COVERAGE OF TOTAL SITE
BRENTWOOD BAY SITE
36 % IMPERVIOUS SURFACE COVERAGE



ON-SITE WATER FLOWS
IN 75-100 % IMPERVIOUS SURFACE
COVERAGE OF TOTAL SITE

Percentages of Precipitation
E = Evaporation
I = Infiltration
R = Runoff

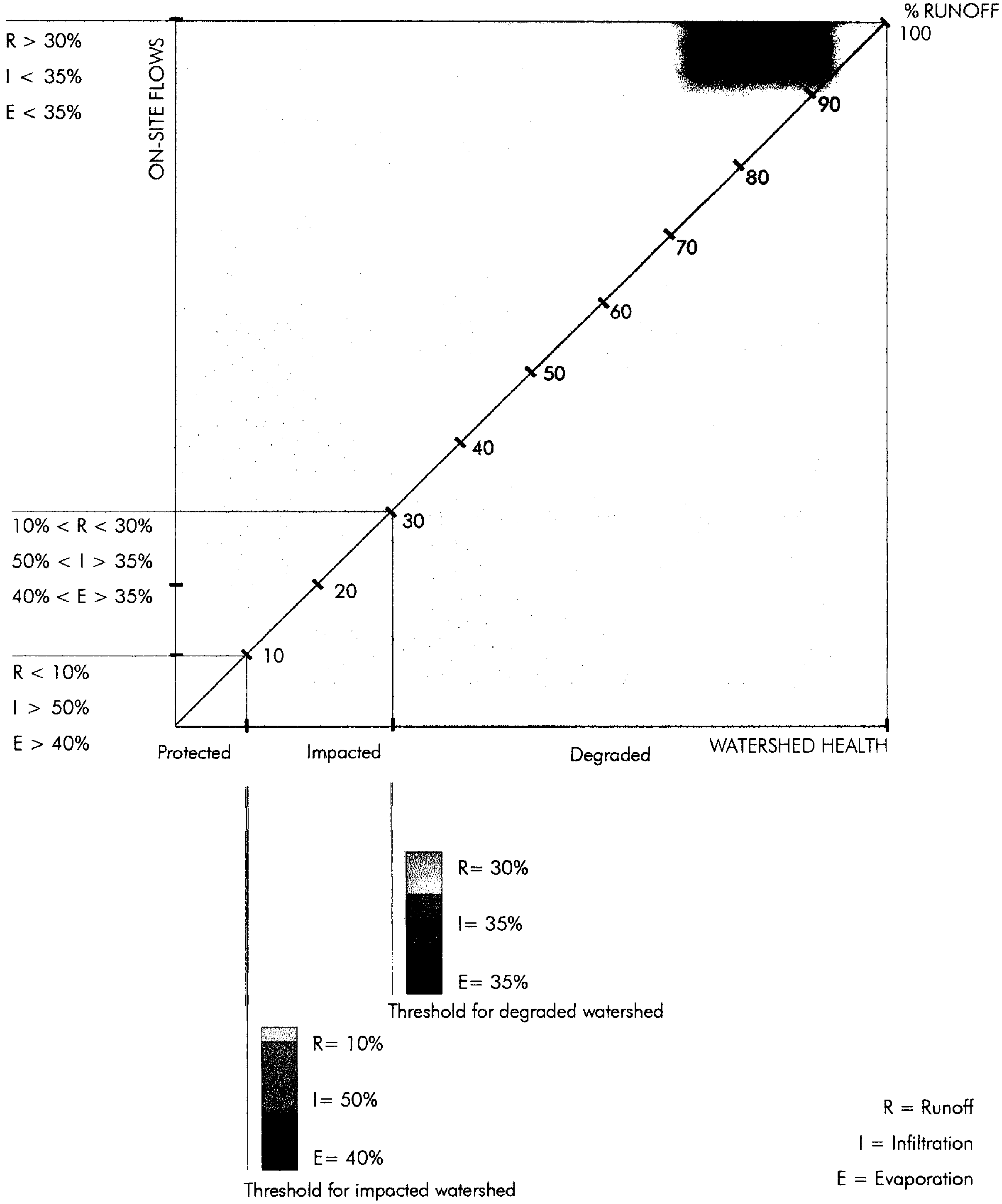
Adapted from Arnold and Gibbons, 1996

An impacted watershed has modified habitat quality, species diversity, and abundance, however it is not yet degraded since natural systems have a built-in capability to assimilate negative effects up to a certain threshold (as defined in figure 4). The degradation category has severe negative impacts on the watershed to such a degree that degradation becomes unavoidable. Categories and thresholds are often controversial and subject to change. However, significant amounts of studies acknowledge the existence of watershed degradation linked to disruption of on-site flows (Klein 1979, Griffin 1980, Todd 1989, Schueler 1994).

Arnold and Gibbons suggest that it is possible to estimate the natural on-site water cycle flow conditions and set them within the three categories of disruption: protected, impacted and degraded. These categories are defined in figure 4 which illustrates the relationship between natural on-site flows and the health of the watershed (expressing them in percentages of precipitation). For a typical site, the categories are determined by the following thresholds values: in order to protect the watershed, the natural on-site water cycle flows should be greater than 40% evaporation, less than 10% runoff and greater than 50% infiltration. To avoid degradation, the natural on-site water cycle flows must be above 35% evaporation, below 30% runoff, and above 35% infiltration. The ecological thresholds defined in the study by Arnold and Gibbons are based on typical conditions. For atypical conditions, a site-specific assessment would be necessary to determine ecological requirements. Flow quantities would significantly vary in extreme climate, soil, or topographical conditions. For example, typical values could not be applied to a site hosting a surface stream without considering the fact that runoff may be feeding this surface stream, increasing the ecological requirements for runoff.

Respecting the quantities of on-site flows necessary to protect the host watershed is vital for the health of humans and watersheds since fresh water resources are a main component to many daily ecological and human processes (Roley 1992).

FIGURE 4: ON-SITE FLOWS AND WATERSHED HEALTH



Adapted from Arnold and Gibbons, 1996

2.2.1.2. QUALITY OF NATURAL ON-SITE WATER CYCLE FLOWS

Suburban housing development should minimize polluting natural on-site water cycle flows. However, determining the quality requirements of on-site flows in order to avoid degradation of the host watershed is complex. Due to the lack of technical expertise available for this research, it is outside of the scope of the thesis to define specific and detailed water quality requirements necessary to avoid pollution. Rather, this thesis identifies current major sources of pollution that can occur due to typical suburban housing practices. These pollution sources are assessed in chapter 5, eliminating on-site degradation.

2.2.2. AVAILABILITY OF ON-SITE WATER SUPPLY

Determining the ecological requirements of groundwater sources is complex since the understanding of aquifer ecological limits to provide on-site water supply is still very limited. The British Columbia government recognizes the need for more detailed knowledge about groundwater and considers this information vital to control and to eliminate further degradation to aquifers in the province (WCSWG 1998). Due to the lack of information on this subject, this thesis does not consider groundwater as a source of on-site water supply. However, future research concerning the availability of groundwater for supply should take into account the ecological requirements of aquifers.

For the purpose of this thesis, rainwater is the only source of on-site water supply. In order to meet ecological requirements for a healthy watershed, it is necessary to identify the limit of precipitation to be removed from on-site water cycle flows and re-directed for human use. For typical conditions, the information provided by the Arnold and Gibbons study is used to define ecological requirements. The commitment to protect, impact or degrade the watershed fixes the rainwater available for supply. For an atypical site, a specific assessment is necessary to determine the limit imposed by ecological requirements.

Rainwater collection has similar consequences to those resulting from suburban runoff since collecting rainwater for human use disrupts natural on-site water cycle flows.

The precipitation collected for human use removes water available for infiltration and evaporation. Depending on the amount collected for human use, the watershed is protected, impacted or degraded. The more precipitation collected for human use, the greater the negative impact on the host watershed. For a typical site, in order to protect the watershed, the amount of precipitation collected should be a maximum of 10% of the annual precipitation. When rainwater is collected for human use, the collection of rainwater becomes a component of on-site flows. This thesis advocates for the protection of host watersheds by limiting rainwater removal for human use to the minimum.

2.3. BRENTWOOD BAY SITE

The thesis defines the Brentwood Bay selected site as a typical site. The site has no surface water bodies influencing flow conditions. In the case of an atypical site, a site-specific assessment would be required to define the ecological requirements protecting the watershed.

The Arnold and Gibbons findings are used to define the quantity of natural on-site water cycle flows of the Brentwood Bay suburban block. Accordingly, 10% of precipitation can be collected for human use and still protect the watershed. Conversely, it is estimated that watershed health becomes degraded when removal for human use exceeds 30% of annual precipitation.

3. ASSESSING THE BUILT ENVIRONMENT

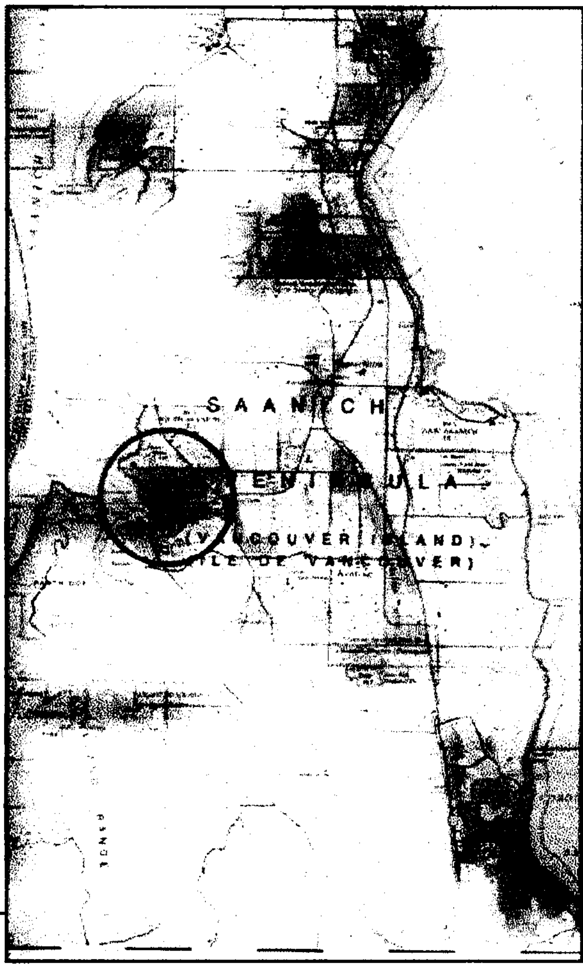
3.1. BACKGROUND

This step analyses the characteristics of the selected site. The groundcover characteristics of the selected site are important since they significantly influence on-site flows. The assessment defines the area and proportion of pervious and impervious surfaces. The specific site findings identify the natural on-site water cycle flow conditions for the Brentwood Bay site. Once the area of impervious surfaces is identified, the amount of runoff is defined using the data provided in figure 3. This classifies and determines the quantity of each of the on-site flows according to the percentage of impervious surface coverage of a given study area.

3.2. BRENTWOOD BAY SITE

The selected site is typical of Canadian suburbia. The site is located in Brentwood Bay in the municipality of Central Saanich. The site is generic: almost flat, with no surface water features and no sensitive ecosystems or ecological features. Figure 5 geographically locates the Brentwood Bay site. The houses located on the selected site are single family residences. The total population of the site is estimated at 28 inhabitants, 2.5 persons per household, which is the Canadian average (Statistics Canada 1997). Figures 6 and 7 illustrate typical views and houses of the selected site.

FIGURE 5: LOCATION MAPS



North

Saanich Peninsula
Vancouver Island, British Columbia

North

Brentwood Bay
Municipality of Central Saanich

FIGURE 6: TYPICAL SUBURBAN HOUSES

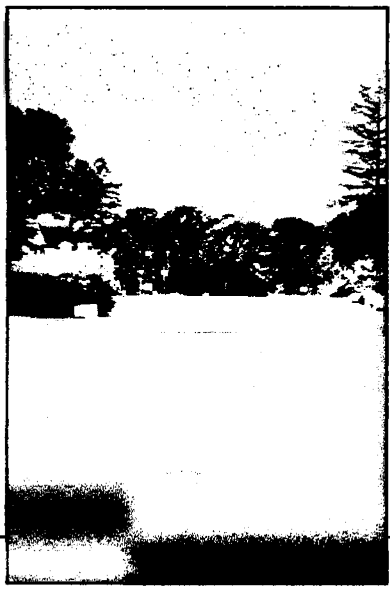
Typical House #4

Typical House #8

Typical House #11

FIGURE 7: SELECTED VIEWS

Verdier Avenue Looking East



Haggan Street Looking North

Verdier Street Looking West

3.2.1. GROUNDCOVER CHARACTERISTICS

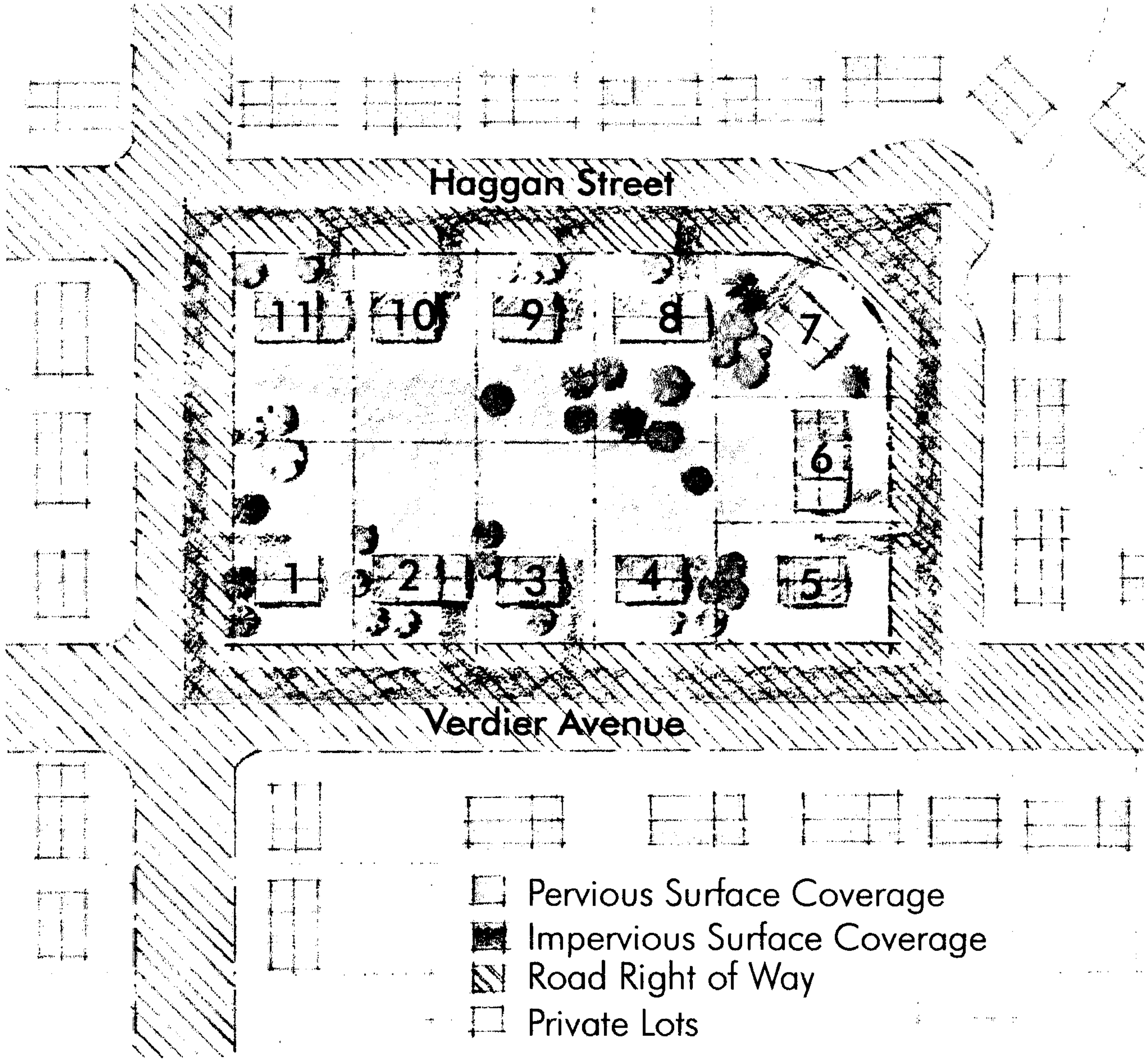
The selected suburban block consists of eleven individually owned lots and half of the road right of way. The inclusion of half of the road right of way in the study area acknowledges that addressing suburban water cycle degradation entails the consideration of attendant features of the single family residence such as impervious roads and driveways servicing suburban housing. The total area of the site is 13,535 m^2. Of that total area, 4,379 m^2 (34% of the total site area) is in the road right of way. The site also includes 11 single family lots accounting for the remaining 9,156 m^2 of the site (66% of the total site area). The average lot is 832m^2, 6% of the total site area.

3.2.2. IMPERVIOUS SURFACES

The percentage of impervious surfaces of the Brentwood Bay site is 36% of the total site area. Impervious surfaces on the site consist of building roofs and automobile related infrastructure (roads and driveways). Of the total percentage of the site's impervious surface coverage, 10% is from the roofs of the single-family residences, and 26% from the automobile infrastructure. The impervious automobile infrastructure is composed of the municipal road, which accounts for 19% of the total site area, and private driveways, which account for 7%.

It is interesting to note that the road included in the municipal right of way accounts for more than half (53%) of the total impervious surface coverage. Inclusion of half the road right of way gives a more accurate assessment of on-site flow conditions of the entire suburban fabric since it significantly increases the total area of impervious surfaces of the selected site. Figure 8 illustrates the built environment's groundcover characteristics of the Brentwood Bay site. The next chapter assesses the OSSHWC flows of the existing Brentwood Bay site.

FIGURE 8: THE SELECTED SITE'S BUILT ENVIRONMENT



<u>Percentage of Site Area</u>

Half the municipal right of way = 34%

Average private lot = 6% *11= 66%

<u>Impervious Surface Coverage</u>

Total Impervious = 36%

Road = 19%

Driveway = 7%

Roofs = 10%

4. ASSESSING THE SUBURBAN WATER CYCLE FLOWS

This step defines the quantities for each of the OSSHWC flows. For the purpose of this thesis, OSSHWC flows are classified in three components: in-flows, water use, and out-flows. This thesis assumes typical characteristics of Canadian suburban conditions for the selected site. In order to assess OSSHWC, a flow diagram is used representing the monthly flows of water in the OSSHWC derived from this site assessment. The flow diagram also illustrates the inter-connections between each element of the OSSHWC and the connection between the on-site flows and their host watershed and aquifer.

4.1. IN-FLOWS

In-flows for typical suburban housing conditions are composed of precipitation and municipal water supply. (For the Brentwood Bay site, water is supplied by a regional system, however, for the purpose of this thesis the term municipal refers to both municipal and regional systems.) Precipitation is not typically collected for any use. The municipal water supply system is commonly the only water supply for all uses inside and outside single family houses.

Monthly precipitation for the selected site is calculated by multiplying the total site area by the monthly average precipitation. For the Brentwood Bay site, monthly variations are significant; December receives an average of 79,325 litres per day (l/d), whereas July receives an average of 8,077 l/d. The annual average of rainwater is equal to 33,010 l/d. This is the total amount of rainwater available for both ecological flows and human collection and use.

The second in-flow is the municipal water supply. The water supply infrastructure is sufficient for current municipal demand, however a significant increase in total demand would require regional upgrades. The municipal water supply infrastructure provides an average of 404 litres per person per day (l/p/d) through its piped water system. This number assumes that the municipal water supply meets the entire estimated water demand of this block. The peak water supply occurs in July averaging 726 l/p/d.

4.2. WATER USE

Water use is composed of interior water use and exterior water use. The use of standard water fixtures and the low cost of water contribute to making the Canadian average indoor water consumption one of the highest daily averages in the world. Current Canadian average indoor water use is estimated at 350 l/p/d, compare to a United States averages of 220 l/p/d and a United Kingdom average of 160 l/p/d (CMHC 1993). In addition, current landscaping strategies using large areas of lawn amplify the high exterior water demand. The Canadian average for exterior irrigation of a typical lawn is 100 000 litres per summer, an equivalent of 54 l/d (CMHC 1993).

The Canadian average of 350 l/p/d is used for daily interior water use (Friedman et al. 1993). Since both exterior and interior water use are provided by the municipal water supply, this assumes that water used defines the amount of municipal water supply. The annual average demand (interior and exterior) is 404 l/p/d with a peak July demand of 726 l/p/d. Water demand of housing related uses (interior and exterior) represents 40% of the total precipitation.

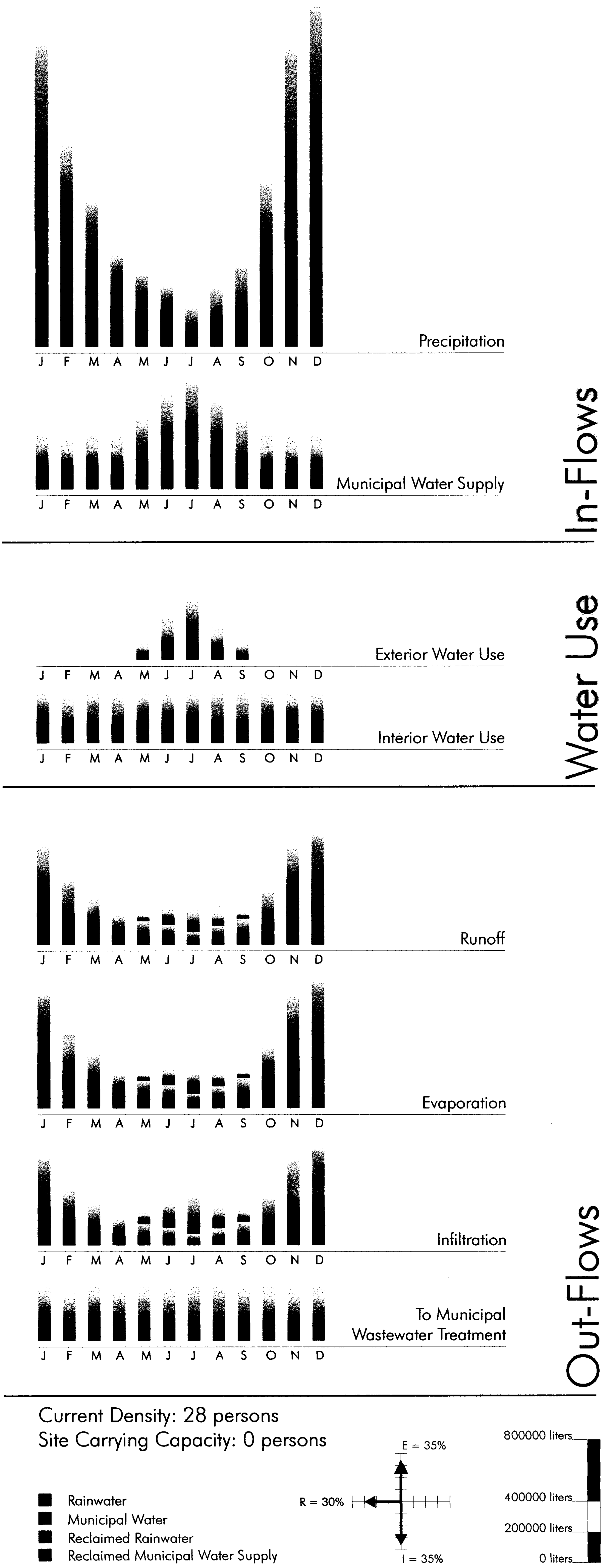
4.3. OUT-FLOWS

Out-flows are composed of runoff, infiltration, evaporation, and municipal wastewater treatment. Suburban housing is significantly disrupting natural on-site flows and substantially influencing the human made flows of municipal water systems. Runoff, infiltration and evaporation are naturally occurring flows that take place on any given site. However, suburban fabric significantly disrupts them; it amplifies runoff and reduces infiltration and evaporation. The quantities of flows are determined using the percentage of impervious surface coverage of the selected site. Since the percentage of impervious surface coverage of the site is 36%, according to figure 3 (page 18), runoff accounts for 30% of the annual precipitation whereas evaporation and infiltration claim 35% of annual precipitation.

Municipal wastewater treatment is another out-flow of suburban housing water cycle. The water directed to municipal wastewater treatment is typically equal to the interior water use with a Canadian average of 350 l/p/d. However, it is important to note that some older systems have a combine wastewater and runoff collection system. An increase of wastewater influenced by the incorporation of runoff considerably pressures the treatment plant during heavy rainfalls leading to possible overflows of raw wastewater into water bodies. This is not the case of the Brentwood Bay site.

The description of the OSSHWC Brentwood Bay site is illustrated in the flow diagram of figure 9. This flow diagram represents the OSSHWC flows of the current density of 28 persons. Disruption of natural flow conditions and on-site degradation of the Brentwood Bay site are assessed in detail in the next chapter.

FIGURE 9: EXISTING CONDITIONS OSSHWC FLOW DIAGRAM



5. ASSESSING ON-SITE DEGRADATION

5.1. BACKGROUND

This step first defines on-site degradation as used in this research and second, identifies the specific on-site degradation present on the Brentwood Bay site. It is important to eliminate on-site degradation since it assists in protecting natural water resources by minimizing cumulative negative effects of small sites on the host watershed. On-site degradation results from a disruption to the quantity and quality of natural on-site water cycle flows.

5.2. ON-SITE DEGRADATION

5.2.1. QUANTITY OF ON-SITE FLOWS

The quantities of flows necessary to avoid impact or degradation on the host watershed are determined by the ecological requirements of a given site. The most common disruption of natural on-site water cycle flows is suburban runoff. The typical design of suburban fabric collects and disposes of runoff off site quickly and efficiently via storm sewers. The starting point of this problem is the design of each individual lot. Because of the consequences of disrupting on-site flows on the host watershed and aquifer (see chapter 2, defining ecological requirements), the cumulative effects of on-site reduction of infiltration on individual lots leads to regional degradation (Richman 1997).

Impervious surfaces per se are not the problem, it is the amount of water that they collect and transport off site and/or beyond the watershed that creates negative impacts on the natural water cycle. This runoff is displacing water from infiltration and evaporation flows. Lack of infiltration leads to species depletion and degradation of marine ecosystems (Arnold and Gibbons 1996). Therefore, sufficient groundwater recharge is essential to the health of the host watershed. Impervious surfaces can exist without reducing infiltration if design strategies direct runoff to on-site permeable surfaces permitting its infiltration. In order to protect the watershed, a minimum of 50% of all precipitation must return to groundwater.

The other direct impact on the natural on-site water cycle flows of suburban housing is the reduction of evaporation. Reduction of evaporation is mainly due to the removal of vegetation during land development. Vegetation is the main contributor of evaporation through the process of evapo-transpiration (Roley 1992).

5.2.2. QUALITY OF ON-SITE FLOWS

The second factor causing on-site degradation is diminished quality of on-site flows. There are two well-documented sources of on-site pollution in suburban fabric: on-site wastewater treatment and suburban runoff.

Common wastewater treatment technologies, such as septic tanks, have a high rate of failure (Environment Canada 1992). It is therefore important to eliminate the risks of polluting groundwater or surface water sources from inadequate on-site wastewater treatment.

Runoff is a significant contributor to on-site and off-site water resource pollution (Richman 1997). At the storm sewer point of discharge, major disruption to the hydrologic cycle occurs such as increased flooding, erosion, loss of streamside habitat, and toxic contamination. Runoff from automobile infrastructure is especially polluted. In many cases, pollution created by suburban runoff, due to large volumes and concentrated pollutants, is a significant generator of surface water system contamination (Richman 1997).

5.3. BRENTWOOD BAY SITE

The Brentwood Bay site's on-site degradation is mainly due to the substantial amount of runoff amplified by suburban housing fabric. This runoff creates a significant negative impact by disrupting quantity and lowering quality of the on-site flows.

5.3.1. QUANTITY OF ON-SITE FLOWS

An analysis of the existing condition flow diagram as illustrated in figure 9 reveals a disruption of natural on-site flows for the Brentwood Bay site. The percentages of precipitation that are directed to the OSSHWC flows are as follows: runoff at 30%, infiltration at 35% and evaporation at 35%. These natural on-site water cycle flow conditions approach the threshold between impact and degradation of the host watershed identified in figure 4. Infiltration at 35% is significantly lower than the 50% necessary to protect the watershed. Evaporation is reduced to 35% compared to 40% for a protected watershed.

The above percentages indicate a significant reduction in groundwater recharge. It is interesting to note that the selected region is dealing with aquifer problems that would benefit from an increase of groundwater recharge. The Saanich aquifer is one of the eight aquifers on Vancouver Island, British Columbia facing a shortage of water (WCSWG 1998).

Disruption of natural on-site flows also affects evaporation. Existing conditions have a direct impact on on-site evaporation, reducing it by 5%. The reduction of evaporation impacts the larger hydrological cycle and leads to changes in the microclimate of a given site area. It is difficult to identify direct negative impacts associated with the on-site reduction of evaporation; however, minimizing the on-site flows' disruption in order to protect the natural water cycle is an approach advocated in this research.

5.3.2. QUALITY OF ON-SITE FLOWS

The pollution source of on-site flows in the Brentwood Bay site is suburban runoff (the Brentwood Bay site has no on-site wastewater treatment). Runoff collected from connected impervious surfaces are a source of pollution as they accumulate and concentrate pollutants such as oil, heavy metals, pesticides, sediments, and nutrients (Wilson 1994). For the selected site, roofs, driveways and roads are all connected to a storm sewer; the water collected is not filtrated before reaching its point of discharge. The pollution associated with suburban runoff discharge amplifies surface stream degradation and overall watershed degradation. These design features are illustrated in figure 10.

FIGURE 10: TYPICAL CONNECTED IMPERVIOUS SURFACES

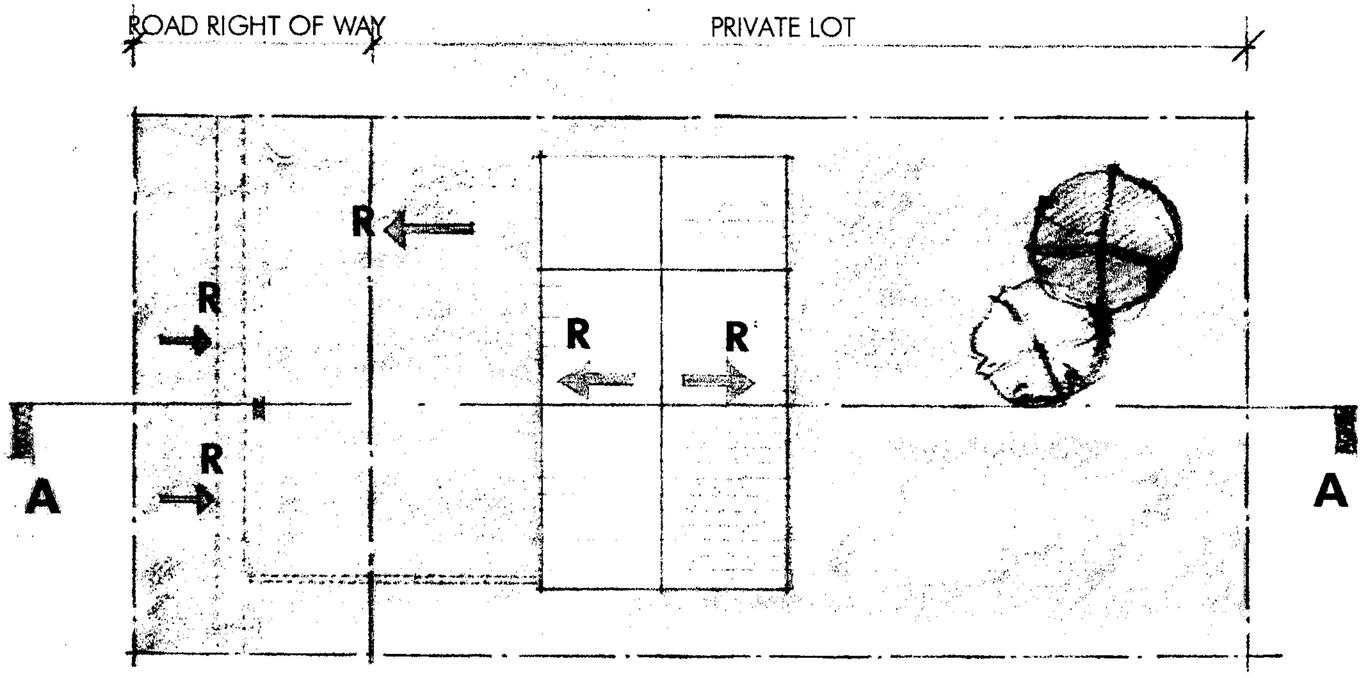


Figure 10a: Plan view of typical connected impervious surfaces

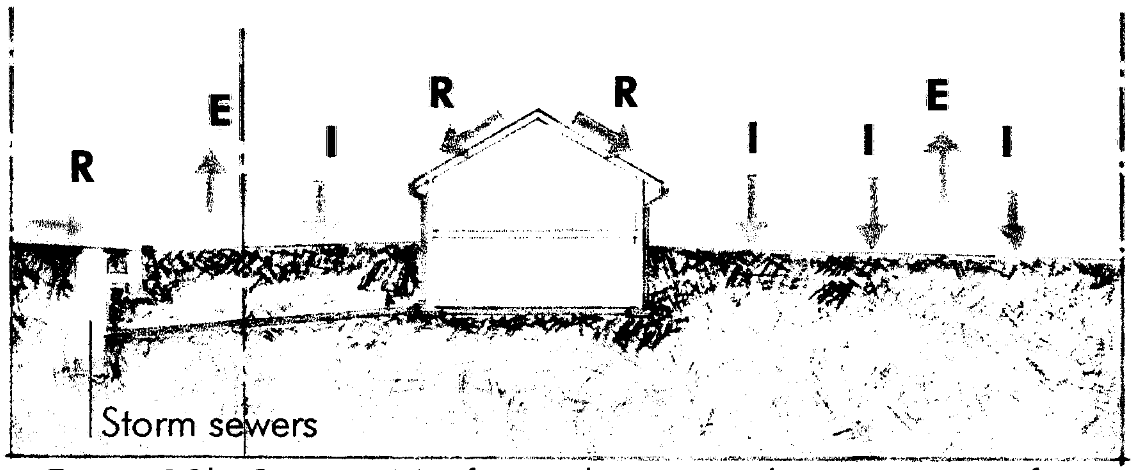


Figure 10b: Section AA of typical connected impervious surfaces

E = Evaporation
I = Infiltration
R = Runoff

6. ASSESSING LOADING ON MUNICIPAL SYSTEMS

6.1. BACKGROUND

For the purpose of this thesis, municipal loading is defined as the amount of water imported on-site and exported off-site by municipal services. This step analyses typical municipal loading for suburban fabric.

6.2. GENERAL CHARACTERISTICS

For most typical suburban sites, loading of municipal water supply and wastewater treatment systems represent major flows of the suburban water cycle. It has been documented that both municipal infrastructures for water supply and wastewater treatment have significant negative effects on the natural water cycle (Environment Canada 1992). However, the loading of municipal wastewater treatment systems causes considerably more degradation, such as chemical and bacterial contamination, than the loading of municipal water supply.

6.2.1. MUNICIPAL WASTEWATER TREATMENT

Municipal wastewater treatment systems remove a significant amount of pollutants from wastewater. However, some pollutants such as nutrients and heavy metals remain in the wastewater (Environment Canada 1992). Wastewater is pumped to the treatment plant where it is partly treated and released into the ecosystem to become part of the water supply for other humans or life forms (Environment Canada, 1992). In fact, most municipal treatment plants are currently releasing water that pollutes natural resources. Pollutants included in treated wastewater may be chemicals used for treatment or high levels of nutrients at the point of discharge. Moreover, during peak demand, some systems may overflow; discharging untreated sewage into the natural water cycle. Since the water cycle is a dynamic process, pollution created by wastewater can contaminate current and future water supply sources leading a reduction of fresh water available for supply or additional costs of treatment for human use. Surpassing the capacity of water resources to assimilate the amount of wastewater is a major problem facing current municipal wastewater treatment systems (WCSWG 1998). For example, Canadian cities, such as Victoria and Halifax, have no advanced wastewater treatment facilities in place; such a situation amplifies degradation of their surrounding water systems.

6.2.2. MUNICIPAL WATER SUPPLY

Many municipal suburban housing water systems are facing shortages of water available for supply. In a municipal supply system, water is pumped from a surface or a groundwater source, treated to become potable, and distributed within the municipality for use.

Water supply loading causes ecological pressure on its host watershed due to the large infrastructure necessary to provide water to municipal users (Roley 1992). Although municipal water supply loading has negative impacts on the watershed ecosystems, it does not create as much direct pollution as wastewater treatment. However, reducing water supply loading is important since water is not as plentiful as the majority of Canadians think. For example, in British Columbia, there is a common misconception that water is an unlimited resource, "Despite the apparent abundance of water in BC, our water supply is not as plentiful as we would like to think. Over 17% of our surface water sources have reached or are nearing their capacity to reliably supply water for extractive uses" (WCSWG 1998, 9).

6.3. BRENTWOOD BAY SITE

The Brentwood Bay site has both municipal loading of wastewater treatment and water supply. In cases where both types of municipal loading are present, the priority is to reduce the wastewater treatment loading since regardless of typical or atypical conditions, wastewater loading remains more problematic than that of water supply.

On the selected site, the loading of wastewater is estimated at 350 l/p/d. This loading represents the average indoor water use. The municipal water supply loading is estimated at 404 l/p/d; a combination of interior and exterior water uses.

7. ASSESSING CARRYING CAPACITY

7.1. BACKGROUND

This step analyses the natural on-site water cycle's carrying capacity. It defines the general concept of natural on-site carrying capacity as used for the purpose of this research, and second, it estimates the natural on-site water cycle carrying capacity of the existing Brentwood Bay suburban block.

7.2. GENERAL DEFINITION

The natural on-site water cycle's carrying capacity is a concept borrowed from ecology. It refers to the maximum population of a given species that an area can support without reducing its ability to support the same species in the future. For this study, carrying capacity is defined as the number of persons that can be supported on-site without exceeding the limits protecting the watershed from significant degradation. This thesis defines a formula that permits the calculation of the inhabitant carrying capacity using rainwater as the source of on-site water supply. Two factors influence natural on-site water cycle carrying capacity: the limit of available rainwater for human use, and the inhabitant's water demand. The quantity of rainwater available is determined by the ecological requirements of the given site. These requirements determine how much water can be removed from infiltration and evaporation flows without impacting the watershed (see figure 4, page 20). A typical efficiency factor for rainwater collection and storage system of 75% is included in the carrying capacity equation. This efficiency factor is a commonly accepted 'rule of thumb' used by the industry to estimate the required size of rainwater collection systems (Wilson 1997).

$$\text{Carrying Capacity (persons)} = \frac{\text{Available rainwater (litres/day) X Efficiency factor}}{\text{Water demand (litres/person/day)}}$$

As explained earlier, rainwater available for supply should be less than 10% of precipitation to protect the watershed, and less than 30% of precipitation to avoid degradation. The limit fixed at 10% of the annual precipitation is used in this definition of carrying capacity. The demand for water is effected by the quantity of water required to fulfill human needs as well as the level of water efficiency used to fulfill these needs. Therefore, the carrying capacity can be increased either by a reduction of the daily activities requiring water or by an increase in the efficiency of water use.

Acknowledging this, the carrying capacity of a typical suburban block is variable. However, there are advantages to increasing carrying capacity by reducing water demand rather than collecting more rainwater. This permits the protection of the watershed and enables densification of the selected site.

7.3. BRENTWOOD BAY SITE

For the Brentwood Bay site, the carrying capacity calculation is as follow:

$$\text{Carrying capacity (persons)} = \frac{\text{Available rainwater (litres/day) X Efficiency factor}}{\text{Water demand (litres/person/day)}}$$

$$\text{Carrying capacity} = \frac{0\ \text{l/d X } 0.75}{404\ \text{l/p/d}} = 0\ \text{persons}$$

No water is available for human use since the limit of water permitted to be removed by the ecological requirements from infiltration and evaporation flows is already surpassed. Runoff on the Brentwood Bay site is 30% of annual precipitation (9900 litres per day), three times the limit of 10% of the total annual precipitation estimated at 3300 litres. Thus, the carrying capacity of the existing conditions is estimated at 0 persons. The first step required to increase the carrying capacity is to reduce runoff in order to make precipitation available for human use. Since the assessment of existing conditions is complete, the following step prioritises strategies for transformation of the selected site.

8. PRIORITISING STRATEGIES FOR TRANSFORMATION

8.1. BACKGROUND

In any situation, retrofit or new construction, selecting strategies that efficiently transform existing conditions to an OSSHWC is a difficult task. A variety of ways exist to modify existing conditions designed and built with little or no concern given to the health of the host watershed.

Prioritising water cycle decisions to efficiently reduce the overall natural water cycle degradation is crucial since many retrofit projects and/or new construction may apply only a limited number of the possible ecologically sensitive strategies. This limited number of strategies applied may be due to economic reasons, municipal regulations, or a simply lack of interest in, or knowledge about, the health of the natural water cycle. Therefore, selecting the strategy that addresses the most pressing problem is crucial to the efficient transformation of existing conditions.

Two factors drive the need for a prioritised process (see 1.6. defining the thesis process). First, water cycle degradation caused by suburban housing varies according to site-specific conditions. Second, the transformation must acknowledge that the order in which strategies are applied profoundly affects the outcome.

The first factor influencing the prioritisation is that it is not appropriate to propose a process that does not take into consideration possible atypical site-specific characteristics. For example, in one area, runoff could be a major source of degradation; however, in other areas, a malfunctioning on-site wastewater treatment system such as a septic tank could be the source of significant on-site degradation. The factors amplifying on-site degradation are significantly different in these two cases. In addition, different site conditions would have specific ecological requirements and carrying capacity. Therefore, different strategies are used to address different site conditions.

A second factor to consider is that the order in which strategies are applied profoundly affects the outcome. The transformation process must acknowledge the most pressing issues to address and the most efficient order in which to apply the strategies in order to efficiently achieve a feasible transformation.

It is important to remember that the process is iterative; the use of feedback loops is required to avoid implementing incompatible strategies. Looking backward and forward at each step of the process enables a balance of trade-offs and achieves an optimum outcome.

Strategies leading to an OSSHWC are obtained by analysing the direct negative effects of suburban housing water cycle and their respective elimination. The three major direct negative impacts identified by this thesis are on-site degradation of quality and quantity of on-site flows, the municipal wastewater treatment loading, and the municipal water supply loading. For a typical site (in this case Brentwood Bay suburban block), the most pressing negative impact to address is on-site degradation, followed by municipal loading of wastewater treatment and water supply respectively.

Acknowledging the most pressing direct negative impact leads to the following prioritisation: first, eliminating on-site degradation; second, reducing water demand; third, treating and using wastewater; and lastly, collecting and using rainwater. For typical or atypical sites, the priority is similar but the strategies may differ. For example, a malfunctioning on-site septic tank wastewater treatment system may require an immediate replacement. In this particular case, on-site wastewater treatment with reclamation of wastewater may be an appropriate strategy to eliminate on-site degradation. However, this modification (for an atypical site) to the prioritisation respects the elimination of the most pressing direct negative impact of on-site degradation.

8.2. PRIORITISING FOR TRANSFORMATION

8.2.1. ELIMINATING ON-SITE DEGRADATION

Eliminating overall watershed degradation is a priority. It has been identified that both on-site degradation of natural water cycle flows and municipal water and wastewater infrastructure loading are significant sources of overall watershed degradation for the Brentwood Bay site.

Considerable public attention is given to the reduction of negative ecological impacts of municipal wastewater treatment. Degradation occurring with the municipal wastewater treatment system is centralised and therefore easier to address with single strategies such as wastewater treatment plant upgrades. For this reason, reducing the negative impacts of municipal wastewater treatment loading is considered a lesser priority by this thesis.

On-site degradation to the natural on-site water cycle is the first step to address in the transformation of existing conditions. This research advocates that, for a typical site, on-site degradation is the most pressing problem to eliminate due to the cumulative negative effects of all suburban sites on the host watershed.

On site disruption of the quantity and quality of natural on-site flows amplifies degradation to the host watershed. The situation is extremely difficult to reverse once a degraded watershed or aquifer is established. For example, the intrusion of salt water in a coastal aquifer due to the lack of on-site infiltration is a complex problem to solve (Environment Canada 1992). In such a case, the reduction of the quantity of precipitation reaching groundwater creates a void that is filled by seawater. Once an aquifer is contaminated with saltwater, it may contaminate other water bodies. Moreover, it is no longer available for human water supply. Therefore, this thesis proposes that elimination of on-site degradation at a local scale is the first priority to address.

8.2.2. REDUCING THE DEMAND FOR WATER

The reduction of water demand is defined as an essential second step of the transformation process. This step extensively reduces the flows in the entire OSSHWC. Reducing water demand reduces both water supply and wastewater treatment loading. A key factor in successfully replacing the municipal water system with an on-site system is the reduction of demand flows. The reduction of flows decreases the size of the wastewater reclamation and rainwater collection system significantly. Therefore, strategies to reduce on-site demand for water should be implemented prior to on-site treatment and reuse of wastewater as well as on-site collection and use of rainwater.

8.2.3. TREATING AND USING ON-SITE WASTEWATER

The third step of the transformation is to eliminate municipal wastewater treatment system loading. This step precedes elimination of the municipal water supply as the municipal wastewater treatment loading creates substantially greater direct negative impacts on the host watershed. Since municipal wastewater treatment does not remove all pollutants from wastewater, it is important to reduce or eliminate the municipal loading of wastewater treatment. Municipal wastewater treatment is a well documented factor contributing to the overall degradation of water resources (see chapter 6, assessing municipal loading).

Looking at water requirements in a residential setting demonstrates that there are two different types of water needs: potable water and non-potable water. The use of reclaimed water as a non-potable source significantly reduces the demand for treated potable water. Reusing water is a major factor in facilitating the increase of the natural on-site water cycle's carrying capacity. Therefore, treatment and reuse of wastewater facilitates the next step of the transformation process, the collection and use of rainwater.

8.2.4. COLLECTING AND USING RAINWATER

The last step of the transformation is the use and collection of an on-site water supply. This step eliminates the loading of municipal water supply service. The collection of rainwater for on-site water supply is more feasible having already achieved the maximum reduction of water demand in the previous transformation steps. It permits the achievement of an OSSHWC within carrying capacity. However, this step may re-introduce disruptions of the natural on-site water flows and potentially increase negative impacts on (or degradation to) the host watershed. Therefore, respecting the limit of rainwater available for supply fixed by ecological requirements (as define in figure 4) is necessary to protect the watershed and to avoid overall water resource degradation.

8.2.5. THE TRANSFORMATION

At this point in the thesis, assessment and prioritisation of strategies for transformation have been addressed. In the following section, the thesis transforms the existing conditions into an OSSHWC. The thesis structure follows the process step by step analysing a possible transformation of the Brentwood Bay existing conditions to an ecologically benign OSSHWC. In this next section of the thesis, each chapter represents a step in the transformation process. The consequences of a partial application of the process are identified within each chapter. An assessment of the OSSHWC flows is completed following each step of the transformation. A final chapter on densification concludes the transformation section.

SECTION 2: TRANSFORMATION

This transformation identifies key factors that require modification in order to achieve an OSSHWC. This section illustrates the flow implications of the four transformation steps to the Brentwood Bay site and briefly identifies strategies necessary for an impending architectural response to the transformation of the Brentwood Bay site.

The thesis analyses flow management strategies applicable at the block, lot, or unit level. The selected flow management strategies are readily applicable to demonstration projects such as the Brentwood Bay suburban block. The localized application of these strategies does not require a complete systematic modification of the municipal or regional flow management, nor the political, social, and economic conditions in order to be applied. Rather It can function as a demonstration project. For example, lowering water pressure of the municipal water supply system for water conservation is a not a possible strategy locally applicable for this project. Admittedly, each strategy's on-site application would be influenced by financial, social, and regulatory factors. This thesis chooses to focus on the flow implications of the transformation. The economic, social, and regulatory issues are discussed in relation to the flow implications of the transformation.

It is likely that each step of the transformation may only achieve a fraction of the potential results; factors such as financial constraints, jurisdictional regulations and social values may lead to partial results for each step. Nevertheless, this thesis looks at completing the transformation of existing conditions to an OSSHWC with the best results and efficiency possible. Once the transformation is complete, the OSSHWC of the Brentwood Bay site is completely benign to its host watershed. This illustrates the maximum potential of achieving the transformation.

9. ELIMINATING ON-SITE DEGRADATION

9.1 BACKGROUND

The proposed process identifies the elimination of on-site degradation as the first modification to transform the Brentwood Bay site into an ecologically benign OSSHWC. The purpose of this step is to eliminate on-site degradation that amplifies overall watershed or aquifer degradation. Specifically, this step addresses the re-establishment of the quantity and quality of on-site flows.

In the Brentwood Bay block, disruption of natural on-site flows is primarily due to increased runoff. This runoff is created by connected impervious surfaces that transport the water off-site via storm sewers. Eliminating runoff re-establishes infiltration and evaporation flow quantities to a level required to protect the watershed. Furthermore, filtration of this runoff through infiltration strategies averts pollution of natural on-site water cycle flows. The completion of this step diminishes the cumulative effects of the quantity and quality on-site disruption of the natural on-site water cycle flows that contribute to overall watershed degradation.

9.2. POSSIBLE STRATEGIES

Runoff to be removed from the Brentwood Bay site is created by connected impervious surfaces. There are two types of impervious surfaces that amplify suburban runoff in the existing Brentwood Bay site: automobile infrastructure and roofs. The water collected by these impervious surfaces is to be cleaned of pollutants and re-directed to on-site infiltration and evaporation in order to re-establish the quantity and the quality of on-site flows to their pre-development state. For the Brentwood Bay site, typical ecological requirements are used for the natural on-site water cycle flows (see chapter 2). Ecological requirements should be assessed on a site-specific basis when applied to an atypical site such as a site with a surface stream. In this case natural runoff may feed the surface stream, modifying the dynamic of on-site flows.

9.2.1. AUTOMOBILE INFRASTRUCTURE

Eliminating the runoff created by impervious surfaces of automobile infrastructure is necessary since this polluted runoff degrades the host watershed. Water collected from roads and driveways contain a high quantity of pollutants such as sediments, motor oils, and heavy metals. Therefore minimizing the amount of connected impervious surfaces that produce runoff (such as driveways and roads) greatly reduces on-site degradation. One possible approach is to direct localized runoff to pervious surfaces that permits the occurrence of natural filtration as water percolates slowly through soil layers. The reduction of this runoff can be achieved with design modifications at the lot and block scales such as driveways made of pervious paving materials. Filtration and infiltration can be achieved by using a grassy swale rather than a curb leading to a storm sewer. Different strategies are available that permit the reduction of automobile infrastructure runoff such as pervious paving material and enhanced on-site filtration and infiltration devices (Richman 1997, Wilson 1994).

Strategies to reduce runoff from automobile infrastructure are influenced by site-specific conditions. Conditions that may influence the choice of particular strategies are: soil infiltration rate, topography, types of pollutants contained in the runoff, and pollutant levels. Therefore, it is necessary to perform a careful selection of appropriate strategies aimed at improving on-site flows quality and maintaining appropriate on-site flows quantities (see chapter 2, defining ecological requirements).

9.2.2. ROOFS

Roof runoff is typically free of major pollutants. However roofing materials such as rusty nails, asphalt shingles and toxic preservatives on wood shingles may leach small amounts of chemical contaminants. Sediments and biological growth are also possible contaminants. However, the minute amount of pollutants that may contaminate roof runoff does not lower the water quality to a point where natural percolation of pervious surfaces is unable to clean the collected water (Roley 1992). Collected water should be directed to pervious surfaces rather than being directly connected to storm sewers via a gutter system. The key issue is to keep collected rainwater from infiltrating too close to a building's walls and foundation where water can induce damage to the envelope and structure. Temporary collection and storage of rainwater can facilitate natural on-site infiltration at a later time. In addition, collected rainwater can be used as water supply if landscaping requires more watering than the annual precipitation supplies.

9.2.3. APPROPRIATE STRATEGY SCALE

As demonstrated earlier, half of the municipal right of way accounts for a significant portion (19% for the road) of the impervious surface coverage of typical suburbia. This impervious coverage leads to on-site disruption of on-site flows. Uniquely addressing on-site disruption within boundaries of private lots would be an incomplete solution to on-site degradation. The elimination of on-site degradation should be addressed at block, lot and unit scales since protecting the watershed by respecting the site's ecological limits is a priority. On a typical site, eliminating automobile infrastructure runoff should be a priority since it is the largest and most polluted of the suburban housing fabric runoff (the road and driveway accounts for 26% of the impervious surface coverage). Reducing connected impervious surfaces in small design decisions at the unit, lot and block level can efficiently eliminate runoff at small scales. It is significantly easier to modify small design decisions in order to reduce the amount of runoff going to the storm sewer than to deal with the concentrated pollution at the discharge point of major storm sewers systems (Richman 1997).

9.3. OSSHWC IMPLICATIONS

For typical sites, eliminating on-site degradation begins with the elimination of polluted suburban runoff. Eliminating automobile infrastructure and roof runoff increases infiltration and evaporation flows sufficiently to ensure protection of the watershed's health. This step is a partial modification of existing conditions (three more steps still follow in the transformation process); it could be characterized as 'pale green' since it represents a minimum commitment to the reduction of overall watershed degradation.

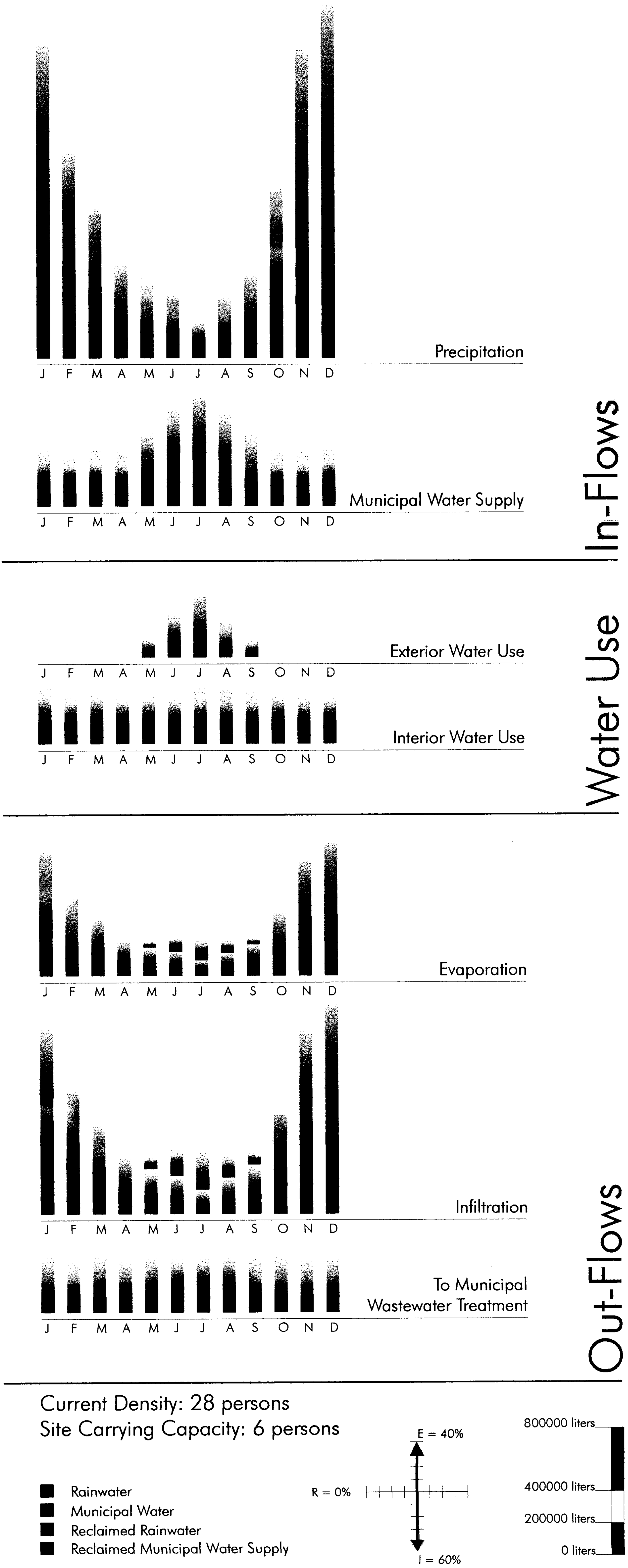
9.3.1. BRENTWOOD BAY SITE

The specific OSSHWC implications of the Brentwood Bay site are analysed using the three flow sections of the flow diagram: in-flows, water use, and out-flows. The in-flows and water use remain unchanged after the elimination of on-site degradation since only the runoff, infiltration and evaporation are modified with this step.

However, in the Brentwood Bay site, the out-flows are significantly influenced by the elimination of on-site degradation. The elimination of runoff has increased both infiltration and evaporation flows. Infiltration would increase from 35% to about 50-60%. Evaporation would also increase from 35% to an estimated 40-50%. The flow diagram in figure 11 illustrates the OSSHWC flow implications of completing the elimination of the on-site degradation for the current density of 28 persons. The exact percentages of the natural on-site water cycle flows are not calculated since there is no detailed design proposal for the Brentwood Bay site. The only certainty is that the precipitation that once contributed to runoff will be re-directed to infiltration and evaporation.

Runoff is part of the natural on-site water cycle, yet, this transformation completely eliminates them. Therefore, the infiltration and evaporation flows increase beyond their pre-development state. However, the percentage of precipitation directed to these two flows depends on the strategies selected to eliminate runoff. The flow diagram of figure 11 represents an estimate of natural on-site flows at 60% infiltration and 40% evaporation. These values represent the need to increase the groundwater recharge in order to compensate for the current lack of infiltration in typical suburban housing development. As awareness of the critical need to eliminate on-site degradation increases, practices acknowledging on-site flows' ecological requirements will become commonly accepted and the need to compensate will be eliminated.

FIGURE 11: OSSHWC IMPLICATIONS OF ELIMINATING RUNOFF



9.3.2. NATURAL ON-SITE WATER CYCLE CARRYING CAPACITY

For the purpose of this thesis, the carrying capacity is defined as the number of persons that can be supported by an OSSHWC while protecting the watershed. The implication of eliminating runoff on the on-site water cycle carrying capacity is significant since no precipitation is available for human use before doing so. Therefore, before eliminating runoff, there is no carrying capacity for the Brentwood Bay site. The elimination of runoff makes precipitation available and permits the increase of carrying capacity from 0 to 6 persons (assuming host watershed protection).

The calculation for the Brentwood Bay water cycle carrying capacity uses the limit of precipitation imposed by the ecological requirement to protect the watershed, that is to say, 10% of annual precipitation (see 2.2.1. natural on-site water cycle flows, page 16). As mentioned earlier, typical efficiency for rainwater collection and storage system of 75% is used in the carrying capacity equation. The calculation uses the existing conditions water demand estimated at 404 l/p/d.

$$\text{Carrying capacity (persons)} = \frac{\text{10\% of precipitation (litres/day) X Efficiency factor}}{\text{Current water demand (litres/person/day)}}$$

$$\text{Carrying capacity} = \frac{\text{3300 l/d X 0.75}}{\text{404 l/p/d}} = \text{6 persons}$$

The current density of the Brentwood Bay site is estimated at 28 persons. The natural on-site water cycle carrying capacity of 6 persons illustrates the disconnection between natural water cycle carrying capacity and that of the existing suburban water cycle. Current block occupants are dependent on an artificial suburban housing water cycle that amplifies overall watershed degradation in order to meet their high water demand. The transformation to an OSSHWC for the Brentwood Bay site requires an increase in carrying capacity in order to support the existing occupants, let alone densification.

Protecting the watershed limits the amount of rainwater available. The increase in natural water cycle carrying capacity needs to be achieved by reducing water demand. The next step of the transformation section analyses possible strategies and OSSHWC implications of reducing water demand.

10. REDUCING WATER DEMAND

10.1. BACKGROUND

The thesis prioritisation process has identified the reduction of the water demand as the second priority to efficiently transform existing conditions. Reducing water demand significantly reduces flows in the entire OSSHWC, including municipal water and wastewater service loading. For this reason, it is more efficient to reduce demand to a minimum before considering the substitution of on-site wastewater treatment or on-site water supply for the existing municipal systems. The reduction of water demand can be achieved by decreasing water needs and by increasing water use efficiency of both interior and exterior water use.

10.2. POSSIBLE STRATEGIES

Reducing the water demand begins by acknowledging the two categories of water use, interior water use and exterior water use. Although these two water uses differ significantly in their respective quantities and demand period, they are equally important. For the Brentwood Bay site, interior water use is constant throughout the year whereas exterior water use occurs primarily during the drier summer months. The high summer demand for exterior water use goes against natural precipitation patterns of the Brentwood Bay site where precipitation levels are lowest in the summer months, thus reducing the feasibility of using rainwater as a source of on-site water supply.

This thesis analyses the flow management strategies applicable at a block, lot, or unit scale. These strategies can be classified in two categories: interior water use and exterior water use.

10.2.1. INTERIOR WATER USE STRATEGIES

Retrofitting or specifying efficient (low flow) fixtures is the on-site flow management design strategy available for reducing interior water use. The use of efficient fixtures has a significant impact on the reduction of interior water demand (Friedman et al 1993). The reduction in water demand provided by efficient fixtures can be significant for the shower and bath as well as for toilet water use; reduction in water demand for the shower and bath can reach 50%, and for toilets 70% (Friedman et al 1993). Figure 12 compares and contrasts high flow fixtures with low flow fixtures for a typical user, assuming no change in consumption patterns. Other strategies of the social and economic realm are possible such as public education and an increase in water pricing. These strategies may influence inhabitants' consumption patterns. Moreover, possible problems with public acceptance of different technologies such as composting toilets, is a factor that would need to be addressed in the selection of more ecological technologies.

One issue concerning efficient fixtures is problematic. The problem lies in the importance of avoiding incompatible strategies. Composting toilets are water efficient fixtures; they do not require water to function. Nevertheless, the use of composting toilets is problematic with certain reclamation systems such as Solar Aquatics and Waterloo Biofilter (Waller, Mooers, Samostie and Sahely 1998). By removing fecal filled water (defined as black water) from wastewater, composting toilets eliminate essential nutrients that feed certain reclamation systems. Therefore, composting toilets are not to be used with the above mentioned black water based reclamation systems. On the other hand, composting toilets can be implemented with reclamation systems designed to reclaim water that does not include black water. This research concludes that composting toilets are a possible, yet not always desirable strategy to reduce indoor water use.

Conventional Fixtures		Efficient Fixtures	
Toilets		**Toilets**	
20 L/flush		6 L/flush	
5 Flushes per person per day	100 L/day	5 Flushes per person per day	30 L/day
Shower		**Shower**	
20 L/minute		10 L/minute	
6 minute shower/person/day	120L/day	6 minute shower/person/day	60 L/day
Bathroom Faucet		**Bathroom Faucet**	
13 L/minute		4 L/minute	
2 minutes/day	26 L/day	2 minutes/day	8 L/day
Kitchen Faucet		**Kitchen Faucet**	
13 L/minute		7 L/minute	
1.5 minutes/day	18 L/day	1.5 minutes/day	10 L/day
Dishwasher		**Dishwasher**	
35 L/load		21 L/load	
2.25 Loads/person/week	10 L/day	2.25 Loads/person/week	7 L/day
Clothes Washer		**Clothes Washer**	
225 L/load		175 L/load	
2.5 Loads/person/week	76 L/day	2.5 Loads/person/week	60 L/day
Total	350 L/day	**Total**	175 L/day
(Adapted from Friedman et al 1993)			

10.2.2. EXTERIOR WATER USE STRATEGIES

Flow management strategies that reduce exterior water use are associated with eliminating or reducing the need for landscape irrigation. Typical landscaping water demand is mainly due to the common suburban lawn which absorbs 100 000 litres of water during a typical summer (CMHC 1993). This irrigation demand significantly increases exterior demand in summer months. Due to this demand, the total (interior and exterior) daily water demand in Brentwood Bay for the month of July is 726 l/p/d, more than double the average daily interior water demand of 350 l/p/d (see figure 13). One design flow management strategy available to reduce the demand for exterior water use is to provide a drought resistant landscape. There are different flow management design strategies that provide a drought resistant landscape, such as xeriscaping and zeroscaping (Roley 1992).

Xeriscaping defines landscape strategies that conserve water through creative landscaping (Williams 1993). Principles of xeriscaping include soil analysis, reduced turf area, and appropriate plant selection. Such principles reduce water demand and also reduce the need for pesticides and fertilisers that may contaminate the on-site flows. Zeroscaping, on the other hand, is the replacement of vegetation by mineral materials such gravel and rocks that require no water. This latter strategy eliminates the vegetation's evapo-transpiration process that contributes considerably to the evaporation flow. In addition, zeroscaping may be difficult to implement in a typical suburban setting where vegetation is an important part of the housing typology. In the case of new construction on non-developed sites, retaining existing native vegetation would maintain the evapo-transpiration process and minimize exterior water demand.

10.2.3. APPROPRIATE STRATEGY SCALE

The reduction of on-site demand for water should be addressed at the block, lot and unit scales simultaneously. At all three scales, the reduction of water demand is a priority in order to achieve an ecologically benign OSSHWC. Water demand can be reduced at a unit level by providing efficient water fixtures and a block level by landscaping municipal land or any communally owned land (such as strata titles) in a drought resistant manner.

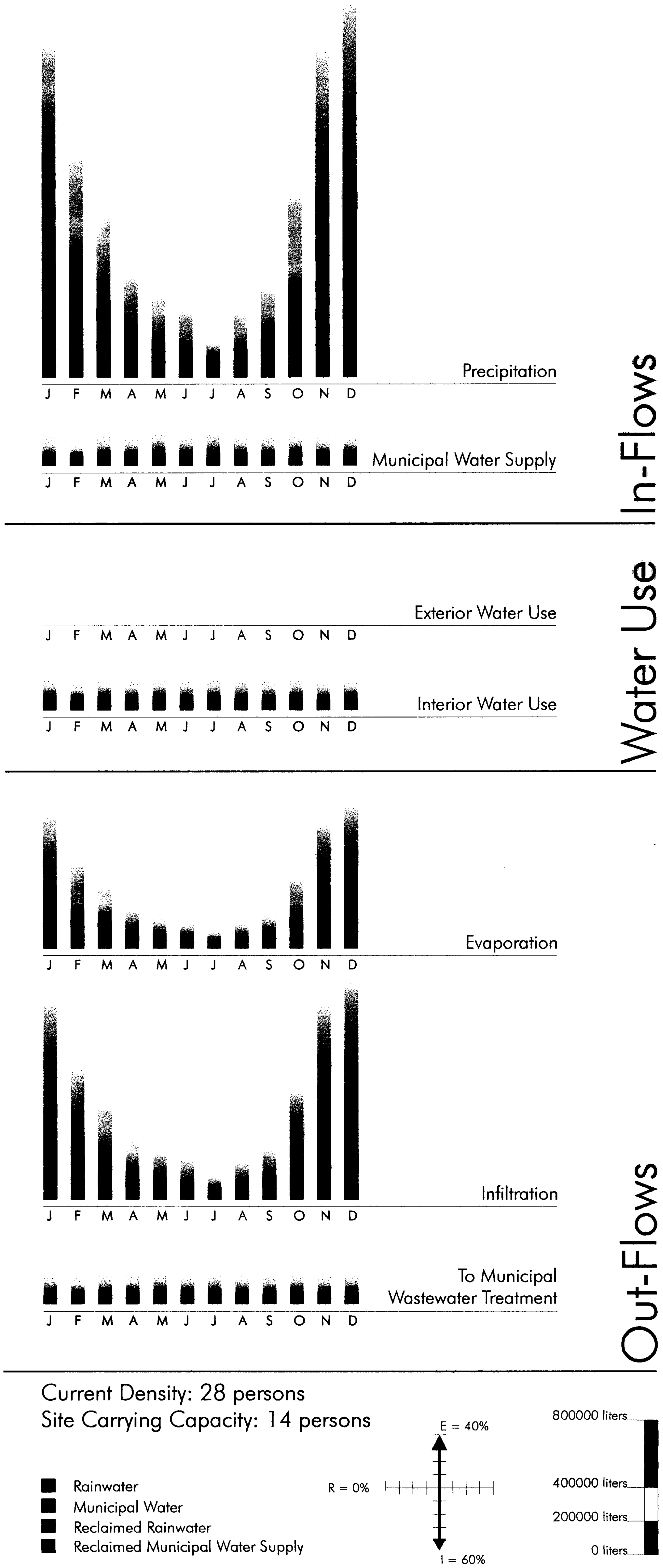
10.3. OSSHWC IMPLICATIONS

The implications of using efficient fixtures and providing a water efficient landscape is characterised by the reduction of OSSHWC flows. Reducing demand flows decreases municipal loading as well as increases the natural on-site carrying capacity by decreasing the water demand. Water demand reduction is the second step towards increasing the site's carrying capacity. In addition, it reduces the municipal loading and will facilitate the transformation to on-site systems by reducing water use and out-flows. This thesis characterizes this step as 'light green' as it provides an improved commitment toward protecting the host watershed over the previous 'pale green' step, however, the consequences of achieving these two first steps do not yet provide an ecologically benign OSSHWC.

10.3.1. BRENTWOOD BAY SITE

The OSSHWC implications on the Brentwood Bay site are considerable. Water demand reductions are achieved by eliminating the need for water irrigation and by improving the efficiency of interior water use. The elimination of the exterior water need is obtained by completely eliminating the need for landscape irrigation. Moreover, efficient fixtures reduce the daily average water consumption by 50%, from 350 l/d/p (assumed Canadian Average) to 175 l/d/p. The most significant water use reduction comes from low flow toilets; the water demand is lowered from 100 l/d/p to 30 l/d/p.
The flow diagram of figure 13 illustrates the implications of reducing water demand on the Brentwood Bay site for the current density of 28 persons.

FIGURE 13: OSSHWC IMPLICATIONS OF REDUCING WATER DEMAND



The combined effect of these strategies on the Brentwood Bay site significantly reduces the municipal water and wastewater treatment systems loading. Both the municipal water supply and wastewater treatment decrease to yearly averages of 175 l/p/d for water supply (a 57% reduction) and 175 l/p/d for wastewater treatment loading (a 50% reduction).

10.3.2. NATURAL ON-SITE WATER CYCLE CARRYING CAPACITY

This section estimates the natural on-site carrying capacity after reducing water demand. Similar to the previous transformation step, the natural on-site water cycle calculation uses the precipitation limit set by the ecological requirements of the watershed, which is 10% of the site's precipitation (see 2.2.1. natural on-site water cycle flows, page 16). The calculation also uses the current estimated Brentwood Bay water demand of 175 l/p/d. Following the reduction in water demand, the natural on-site water cycle carrying capacity of the Brentwood Bay site increases to 18 persons. The previously used equation to calculate carrying capacity is used once again at this step of the process.

$$\text{Carrying capacity (persons)} = \frac{\text{10\% of Precipitation (litres/day) X Efficiency factor}}{\text{Current water demand (litres/person/day)}}$$

$$\text{Carrying capacity} = \frac{\text{3300 l/d X 0.75}}{\text{175 l/p/d}} = \text{14 persons}$$

The natural on-site water cycle carrying capacity of this transformation increases the carrying capacity from 6 persons to 14 persons. This number remains lower than the current density of the Brentwood Bay site (estimated at 28 persons). This illustrates the need for further transformations to increase the natural on-site water cycle carrying capacity by reducing the water demand.

11. TREATING + USING WASTEWATER

11.1. BACKGROUND

Treating and using wastewater is considered the third priority in the transformation of existing conditions to an ecologically benign OSSHWC. The on-site treatment and use of wastewater precedes the collection and use of rainwater. Treating and reusing wastewater eliminates municipal loading of wastewater treatment and therefore reduces pollution to the host watershed since the assessment of municipal loading for typical sites has identified significant degradation amplified by municipal wastewater treatment. Moreover, treating and using wastewater greatly reduces water demand by introducing reclaimed water as a non-potable water substitute for some lower quality water uses.

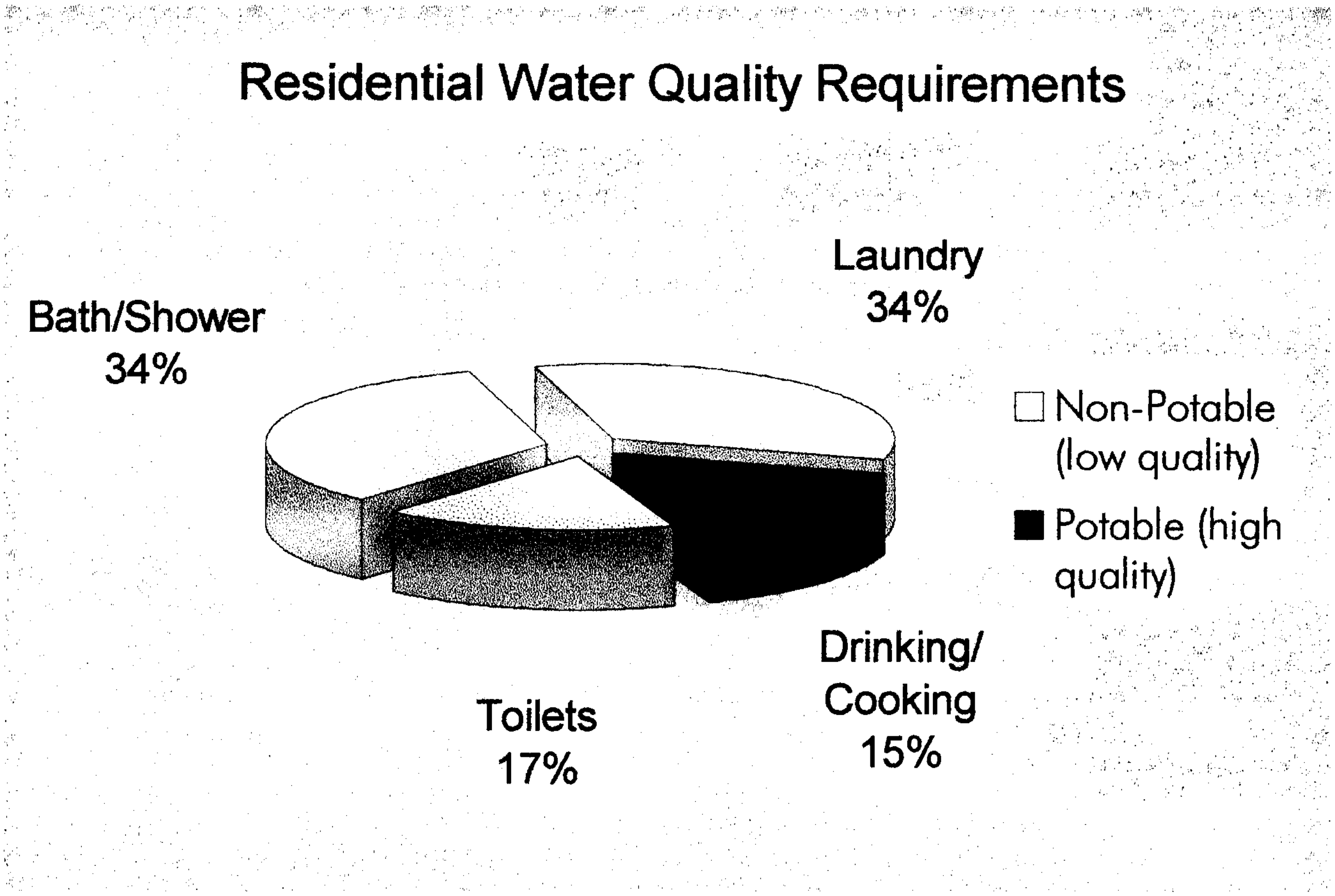
11.2. POSSIBLE STRATEGIES

Possible strategies regarding the treatment and reuse of wastewater begin by acknowledging two types of water requirements in a residential setting: potable water and non-potable water.

Using reclaimed water for non-potable needs has the potential to dramatically reduce the demand for water. Non-potable water needs are significantly larger than potable water needs. Figure 14 illustrates typical water quality requirements in a residential setting once efficient fixtures have been implemented (Friedman et al. 1993). This figure illustrates that different amounts of water can be reclaimed with a range from 17% of total water use when reclaiming for toilet use and up to 85% when reclaiming for water consumption that does not require potable water.

A significant implication associated with the reclamation of wastewater is the need for a dual piping system supporting both the potable water and the reclaimed water systems. Regardless of the type of reclamation, introducing a dual piping system may require modifications to existing plumbing regulations. The two types of reclamation processes are wastewater recycling and wastewater reuse.

FIGURE 14: RESIDENTIAL WATER QUALITY REQUIREMENTS



Adapted from Friedman et al., 1993

11.2.1. WASTEWATER RECYCLING

Wastewater recycling re-circulates wastewater many times through a reclamation system such as Solar Aquatics, Waterloo Biofilter, and Cycle-let technologies. Each time wastewater passes through a reclamation system, a certain percentage is absorbed by the system. As such, the initial amount of water is reduced during successive cycles through the system. Water is absorbed by the system's living organisms that feed off the nutrients in the reclaimed water. Wastewater recycling is the most efficient type of reclamation as it uses the same water multiple times in a closed loop system.

Despite its efficiency, recycling water has the potential to concentrate certain pollutants. Since the water is recycled many times and if the system does not remove all pollutants from the water, those left in the water after treatment accumulate in the system. This problem can be identified with a comprehensive monitoring system and resolved by providing a series of consecutive yet different treatments in order to remove all pollutants. Combining different treatments increases the efficiency of the treatment system.

On-site wastewater recycling technologies would require user involvement and possibly a modification of health regulations to be widely implemented. However, the potential water demand saving by providing recycled water to non-potable water uses can be as extensive as 85% (see figure 14). Moreover, complete wastewater recycling eliminates wastewater treatment loading, as the system outputs no wastewater.

11.2.2. WASTEWATER REUSE

Wastewater reuse systems reclaim wastewater for a purpose other than that for which it was initially used (Waller, Mooers, Samostie and Sahely 1998). These systems treat wastewater from the original use sufficiently to permit its reutilisation in a lower quality water use. For example, water from showers and baths can be treated and reused for toilet flushing. This research suggests that there are two major disadvantages to implementing a water reuse system: the amount of wastewater produced and the low water demand reduction.

The principal disadvantage of wastewater reuse is that it does not reduce water demand as greatly as wastewater recycling does, therefore decreasing the site's potential carrying capacity. Wastewater reuse is a process that does not include the complete recycling of wastewater. For example, with a per person water demand of 175 l/d, where the reuse is for the lower water quality toilet use (30 litres), the high quality water demand (145 litres) must come from municipal or rainwater supply. Although water demand reduction is minimal when compared to wastewater recycling, wastewater reuse may be easier for consumers to accept since changes, such as using treated wastewater in daily bathing and showering, may be subject to public apprehension.

The second disadvantage of wastewater reuse is that the process produces more wastewater than water recycling. Wastewater reuse produces a significant amount of wastewater since wastewater from lower quality uses is not recycled into the system. The area necessary to dispose of this wastewater may be problematic in the design of OSSHWC within suburban fabric. Disposal of wastewater back into the natural water cycle requires a considerable area, such as drainfields or sand filter systems, for proper filtration and infiltration of the treated wastewater. In addition, wastewater produced by the lower quality water use contributes to municipal wastewater treatment loading.

11.2.3. APPROPRIATE STRATEGY SCALE

Many technologies that permit wastewater recycling are based on the reproduction of natural process in a small, compact environment. Thus, many of these technologies are space efficient. Recycling of water is the most space efficient of the two types of reclamation systems since it produces almost no wastewater whereas wastewater reuse technologies require large areas for the disposal of wastewater produced.

The appropriate scale for the treatment and use of wastewater would vary considerably depending on strategies implemented, site specific soil types, and topography conditions. The smaller the scale, the easier the retrofit for the privately owned lot of the typical suburban fabric. On the other hand, retrofit at the suburban block permits central control and easier system monitoring. Furthermore, following this reasoning, retrofit at a municipal level would facilitate the monitoring and control of the system. The factors that influence the appropriate scale for on-site wastewater treatment and reuse are site and project specific.

11.3. OSSHWC IMPLICATIONS

This section analyses the general implications of on-site waste water treatment and use on the OSSHWC as well as the specific Brentwood Bay OSSHWC implications. These implications are threefold: it reduces the water demand, eliminates the municipal loading of wastewater treatment systems, and increases the natural on-site carrying capacity.

11.3.1. GENERAL IMPLICATIONS

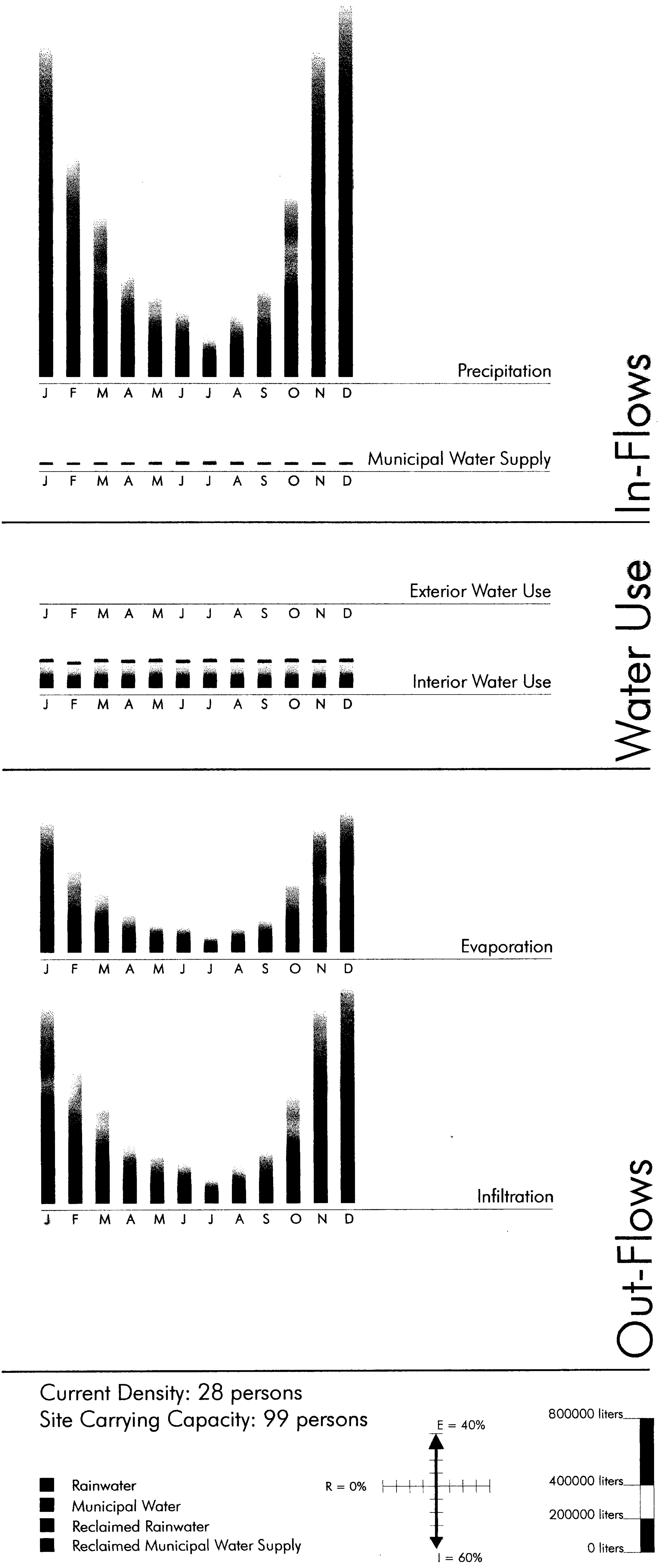
The treatment and use of wastewater has the potential to significantly reduce water demand. Furthermore, the introduction of on-site wastewater treatment and reclamation eliminates loading on municipal wastewater treatment systems. Following this step, the only remaining municipal loading is on water supply, although this too is significantly reduced by the use of reclaimed water for non-potable water uses. Water demand for this step is defined solely by the potable water demand. Since the demand for water is significantly reduced, this step represents an important increase in the natural on-site water cycle carrying capacity. This step is characterized 'medium green' as it represents a significant commitment to watershed protection.

11.3.2. BRENTWOOD BAY SITE

The OSSHWC implications on the Brentwood Bay site of treating and recycling wastewater are significant. One benefit of this transformation is the elimination of municipal wastewater treatment loading. This leads to a reduction of the overall watershed degradation. The completion of this step also reduces water supply loading significantly; the municipal water supply is reduced to about 6% of the initial existing conditions. In order to achieve such a significant reduction, the reclamation process recycles wastewater many times rather than reusing it once. Recycling of wastewater eliminates the need for disposal of wastewater on the Brentwood Bay suburban block. The recycling of wastewater for all non-potable water uses lowers the 175 l/d/p of municipal water supply down to 25 l/d/p. The total daily per person water use remains 175 l/p/d. Out of these 175 litres, 25 litres are supplied by the municipal water system for potable uses, the remaining 150 litres are provided by recycling reclaimed water for non-potable uses.

The reduction of municipal water demand is considerable; annual daily demand is reduced to 25 l/p/d, a significant reduction from the previous 'light green' step (175 l/p/d) water demand reduction. The flow diagram of figure 15 illustrates the OSSHWC flow implications of treating and recycling wastewater for the current density of 28 persons.

FIGURE 15: OSSHWC IMPLICATIONS OF TREATING AND USING WASTEWATER



11.3.3. NATURAL ON-SITE WATER CYCLE CARRYING CAPACITY

Similar to previous transformations, the calculation for the natural on-site water cycle carrying capacity uses 10% of the site's precipitation, which is the limit of precipitation imposed by ecological requirements to protect the watershed (see 2.2.1. natural on-site water cycle flows, page 16). The calculation uses the reduced water demand of 25 l/p/d achieved by treating and recycling wastewater. With the completion of this step, the natural on-site water cycle carrying capacity of the Brentwood Bay site increases to 99 persons.

$$\text{Carrying capacity (persons)} = \frac{\text{10\% of Precipitation (litres/day) X Efficiency factor}}{\text{Current water demand (litres/person/day)}}$$

$$\text{Carrying capacity} = \frac{\text{3300 l/d X 0.75}}{\text{25 l/p/d}} = \text{99 persons}$$

99 persons represents a significant increase of the natural on-site water cycle carrying capacity from the 14 persons achieved in the previous 'light green' step. Compared to the existing density of the Brentwood Bay site, estimated at 28 persons, the natural on-site water cycle carrying capacity of this step of the transformation, estimated at 99, represents more than three times the current density. This increase illustrates the importance of wastewater recycling in order to achieve an ecologically benign OSSHWC.

12. COLLECTING + USING RAINWATER

12.1. BACKGROUND

Collecting and using on-site water supply permits the complete elimination of municipal water supply loading. However, this last step of the process re-introduces disruption to the natural on-site water cycle flows that may lead to negative impacts on the host watershed. Consequently, it is important to respect the limit imposed by the ecological requirements in order to avoid impact or degradation to the host watershed.

12.2. POSSIBLE STRATEGIES

Rainwater as a source of water supply has significant variation during the year therefore providing a variable and limited amount of water each year. On the Brentwood Bay site, rainwater supply is categorised as heavy in the winter and light in the summer. Rainwater supply depends on variations in rainfall that is intermittent and unpredictable. Thus, rainwater collection systems must be designed to support these variations. The collection and use of rainwater begins by defining collection areas as well as storage characteristics.

12.2.1. AREA OF COLLECTION

Rainwater is collected by impervious surfaces connected to a storage tank. As mentioned previously, two types of impervious surfaces exist on the Brentwood Bay site: automobile infrastructure and roofs of buildings. Automobile infrastructure constitutes a significant proportion (26%) of the impervious surface coverage of the selected site. The municipal roads alone represent 19% of the total area of the site. Roads, which are fairly permanent surfaces, could be converted to collection areas, however, the low quality of water collected by the car infrastructure (see chapter 5 assessing on-site degradation, page 33) does not make it appropriate for potable water supply. Therefore, automobile infrastructure runoff should be minimized, cleaned and returned to on-site infiltration. The strategies leading to a reduction of car infrastructure runoff are discussed in chapter 9, eliminating on-site degradation (page 50).

12.2.2. COLLECTING WATER FROM ROOFS

Roofs are the most appropriate rainwater collection surface for high quality potable water supply necessary for the OSSHWC transformation. Roofs collect less polluted water relative to roads. However, there is a possibility of biological growth on roof surface such as mold, algae and bacteria. In addition, chemicals may leach from roofing materials such as asphalt shingles and metal roofing. These contaminants may pollute the collected water. Proper roofing materials such as clay tiles, roof-wash system and filtration system are necessary to control the quality of roof collected rainwater. There are many design considerations related to the design and management of roof collection systems such as roof finishing materials, filters and distribution systems (Wilson 1997).

For the reduced water demand achieved so far in the transformation, only a portion of the roof is necessary to collect sufficient water for supply. The remainder of the water collected by roofs should be directed to pervious surfaces in order to minimize disruptions to on-site flows.

12.2.3. STORAGE

Storage is an important component of the OSSHWC. Once collected, rainwater should be stored in order to meet yearlong water demand, particularly during dry summer months. The size of storage necessary to achieve an OSSHWC is substantial for typical water demand. Reducing water demand through strategies such as those discussed in the first three steps of this transformation permits a significant reduction of the storage size. Without the reduction achieved in previous transformation steps, the storage of rainwater for human use would require an unfeasible storage size. In order to be functional, a rainwater collection system requires a storage tank. The water demand defines the necessary amount of collected rainwater which in turn defines the storage tank size. The amount of collected rainwater and storage size are influenced by the fact that rainwater collection systems are not 100% efficient and that rainfall is intermittent, varies monthly, and is somewhat unpredictable.

The amount of rainwater collected and the storage size can be translated into many different combinations; for example, a specific water demand can be met with a different combination of collection areas and storage sizes. For given water demand one can either maximize the size of collection area or storage. Maximizing the collection area permits a reduction of the storage size since more water is collected during the dryer summer months. In contrast, maximizing storage size permits a reduction of collection area since more water can be store in the wet winter months. With regard to the health of the watershed, collection areas should be kept to a minimum in order to minimize the amount of water removed from the natural on-site water cycle during the dry summer months. It is during this period that the watershed is most sensitive to a disruption of on-site flows (Roley 1992).

12.2.4. APPROPRIATE STRATEGY SCALE

In the Brentwood Bay suburban block, rainwater collection and use can be achieved at the block, lot, or unit scale. The selected scale would vary depending on site-specific conditions such as land and system ownership. If the rainwater collection is communally achieved, a single system may be more feasible since the larger the scale of storage of rainwater collection system, the more the system can support variation of demand. In addition, a single system facilitates control and maintenance of quality of collected water. On the other hand, if lot owners all individually own systems, separate systems may be more feasible to implement. Smaller scale systems have the advantage of permitting unit by unit or lot by lot retrofit.

12.3. OSSHWC IMPLICATIONS

This step represents the complete transformation from existing conditions to an ecologically benign OSSHWC; it has no direct on-site degradation and no municipal water services loading. This transformation from existing conditions demonstrates that is it possible to use on-site rainwater as the only water supply for the selected Brentwood Bay site. This is principally due to the reduction of water demand achieved in previous steps such as the use of reclaimed water for lower quality water uses. This OSSHWC rainwater demand is solely for potable water demand. The recycled wastewater completes the water use. This step can be characterized as 'dark green'; it represents a high commitment to the reduction of overall watershed degradation.

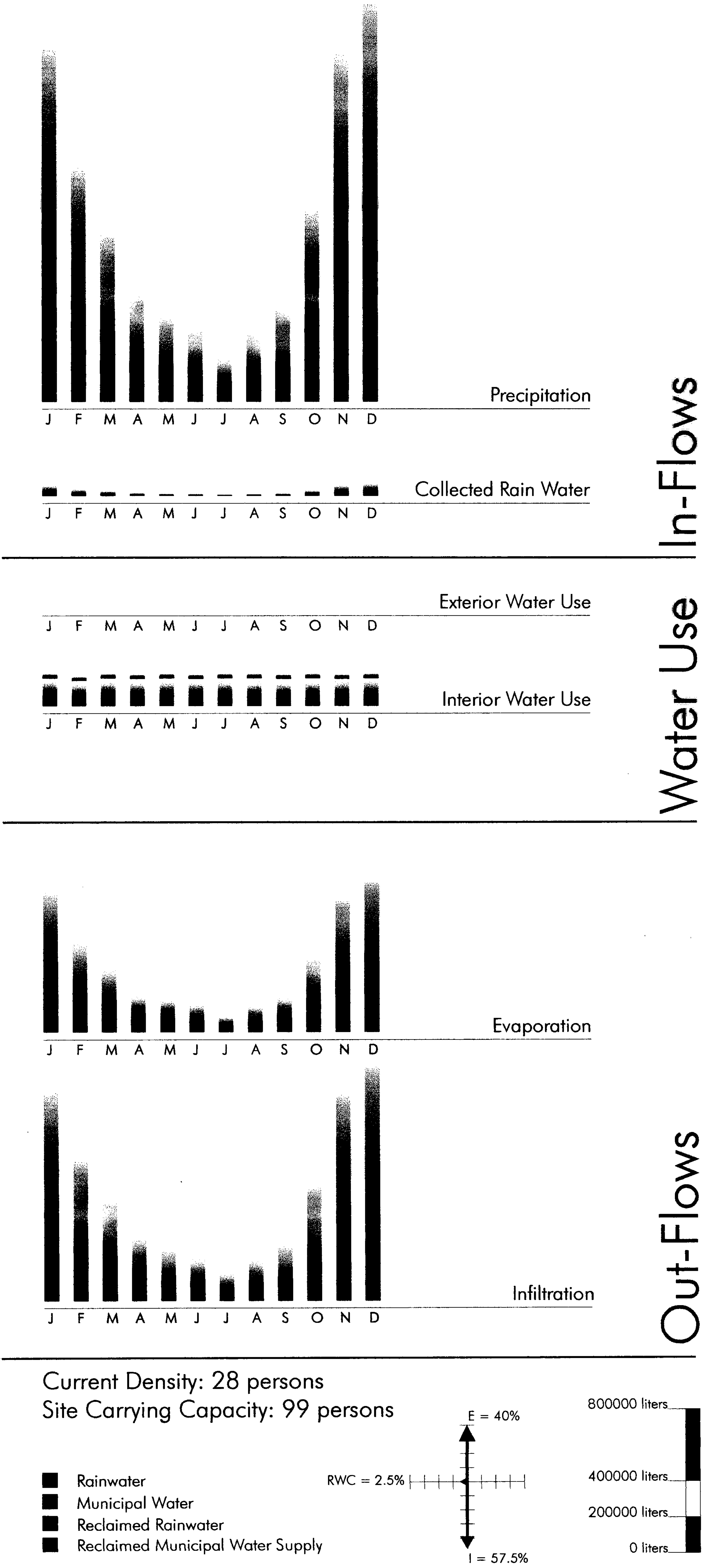
The rainwater collection system size is determined by the total water demand. After the transformation of the Brentwood Bay site, the total water demand is significantly reduced. The use of an efficiency factor of 75% introduced earlier is necessary to acknowledge when sizing a rainwater collection system in order to meet the water demand. For the Brentwood Bay site, the limit of rainwater available for use that enables watershed protection is determined to be 10% of the site's precipitation.

$$\text{Carrying capacity (persons)} = \frac{\text{10\% of Precipitation (litres/day) X Efficiency factor}}{\text{Current water demand (litres/person/day)}}$$

$$\text{Carrying capacity} = \frac{\text{3300 l/d X 0.75}}{\text{25 l/p/d}} = \text{99 persons}$$

99 persons represents the limit of persons that the site can support without impacting the watershed. However, the flow diagram in figure 16 illustrates the OSSHWC flow implications of collecting and using rainwater for the existing density of 28 persons.

FIGURE 16: OSSHWC IMPLICATIONS OF COLLECTING AND USING RAINWATER



The complete transformation permits the comparison of OSSHWC flows of this step with the earlier steps of the transformation as well as with the existing conditions before transformation. For the current density of 28 persons, the collected rainwater is equal to 2.5% of the total annual precipitation. The carrying capacity is similar to the previous step since the per person water demand and the limit of available precipitation remain the same. This 'dark green' transformation represents, for the first time, the completion of the OSSHWC and the achievement of a suburban water cycle within natural on-site water cycle carrying capacity. For this complete transformation, the amount of rainwater used for supply is significantly lower than the 10% precipitation limit imposed by the ecological requirements of this typical site. Therefore, on a typical site with this density and reduced demand, achieving an OSSHWC creates no impacts to the host watershed.

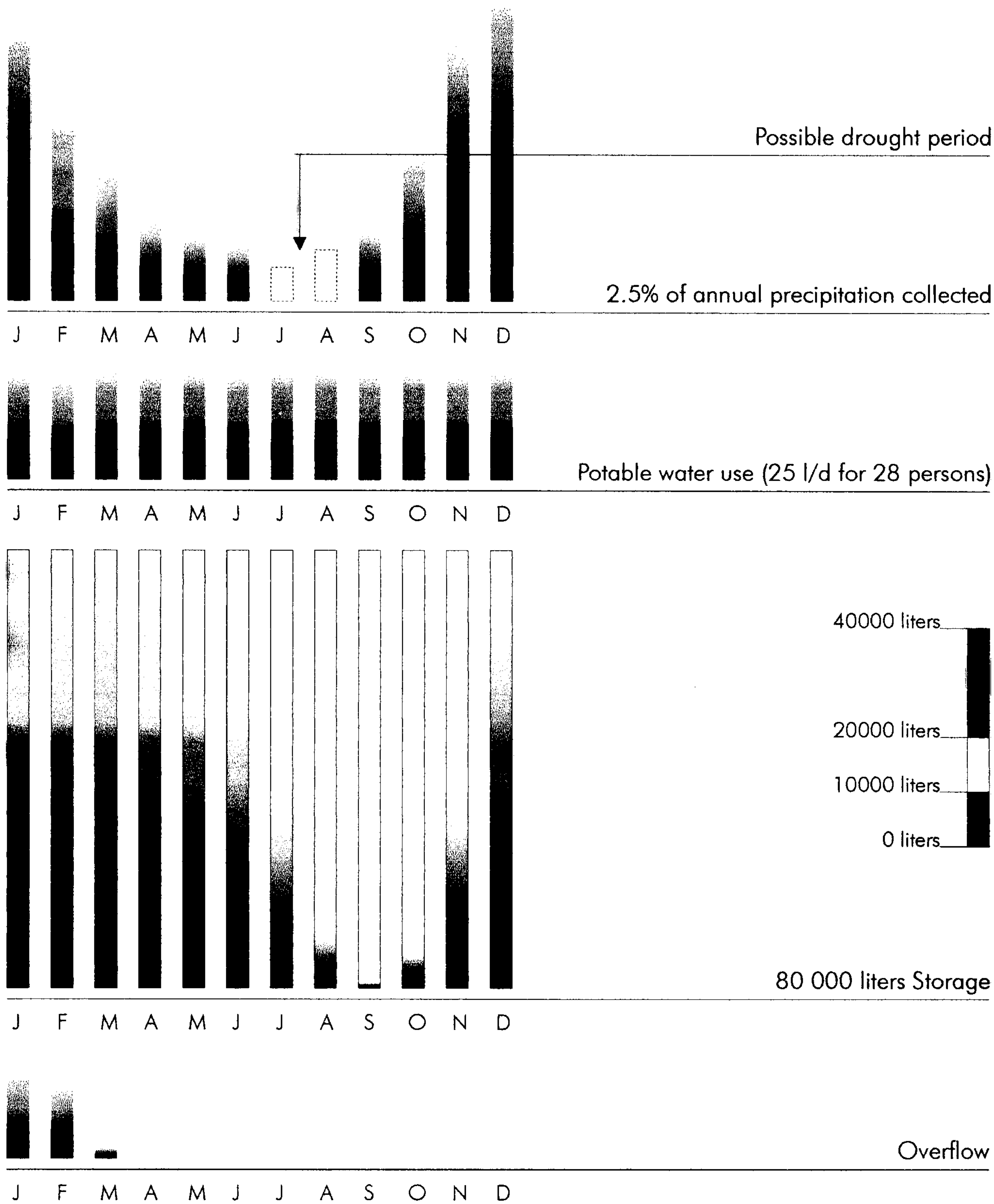
12.3.1. SIZING THE RAINWATER COLLECTION SYSTEM

The rainwater collection system needs to be designed to support rainfall variation within the year. A two month drought period is used as a typical security for reliable systems. This research assumes the drought period to be in the two driest months of the year for Brentwood Bay, July and August. This permits an estimation of the storage size. The storage tank is designed to supply 434 000 litres during the drought period. Figure 17 illustrates the amount of rainwater collected to supply the selected site at current density of 28 persons with the assumed two months drought period.

Storage size = (Water demand X Number of persons) X Days without rain

Storage size = (25 l/p/d X 28 persons) X 62 days = 434 000 litres

FIGURE 17: SIZING THE RAINWATER COLLECTION SYSTEM



This thesis uses 75% efficiency in order to calculate the amount of rainwater necessary, therefore each system should collect 25% more precipitation than the water demand. The water demand is estimated at 700 litres per day which is 2% of annual precipitation (significantly lower than the 10% or 3300 l/d limit required to protect the watershed).

Annual precipitation demand = (Water demand X Number of persons)

Annual precipitation demand = (25 l/p/d X 28 persons) = 700 litres per day

Thus, in order to meet the 2% water demand, 2.5% of precipitation is required. The storage tank size estimate derives from the fact that it must be filled during the wet winter months in order to meet water demand during a possible drought period.

The storage requirement for the Brentwood Bay block is estimated at a significant 80 000 litres, a tank of 4.3 metres (m) wide, by 4.3 m long, by 4.3 m high. Translated into a typical household storage, the storage is approximately eleven times smaller at 7 300 litres, a tank of 1.9 m wide, by 1.9 m long, by 1.9 m high. Since the storage requirement is relatively small in the Brentwood Bay site, it can be implemented at the unit, lot, or block scale. An important characteristic of the storage is that it is underground; temperature variation inside the storage tank is minimized, as is bacterial contamination.

This current low density of suburbia supports growing environmental concerns associated with suburban sprawl. These growing environmental concerns such as high energy and land use, encourages possible densifications of the Brentwood Bay site. The selected Brentwood Bay site can be densified while still respecting the 10% annual precipitation limit since the rainwater demand for the current density is estimated at 2.5% of annual precipitation. This transformation has no municipal loading. Healthy on-site flows, in percentage of annual precipitation, are estimated at 2.5% of collected rainwater, 57.5% infiltration and 40% evaporation.

13. DENSIFYING BRENTWOOD BAY

13.1. BACKGROUND

This thesis proposes that densification of suburbia may reduce overall negative ecological impacts of the suburban fabric. Maintaining low densities may lead to significant ecological stresses such as high-energy consumption and extensive use of biologically productive land. Detached homes, the most popular housing form of suburbia, consume larger amounts of operating and embodied energy per unit of floor space as compared to denser housing forms (Walker and Rees 1997). Moreover, suburban fabric solely consisting of single detached houses increases dependence on automobiles as it isolates the housing activity from other activities. Densifying suburbia permits more energy efficient housing forms, the reduction of the energy related to transportation, and a more compact and efficient land use development.

13.2. BRENTWOOD BAY SITE

Now that the transformation to an OSSHWC is complete, the thesis analyses the possibility of densifying the Brentwood Bay block. The densification process begins by defining how much impact it would inflict on the host watershed. This impact is determined by the amount of precipitation collected for supply. The general implications of densifying suburban fabric are identified as a disruption of natural on-site water cycle flows. Densifying suburban fabric may or may not introduce impacts on natural on-site water cycle flows. The ecological requirements of the Brentwood Bay site identified in chapter 2 are used to define the limits of rainwater available for housing supply. The limit to respect in order to protect and to avoid impact to the watershed is estimated at 10% of the site's precipitation. The limit to respect in order to avoid degradation is estimated at 30% of the site's precipitation. Since literature suggests that there are significant advantages to densifying current suburbia, this thesis explores possible densifications of the existing Brentwood Bay site.

13.2.1. DENSIFICATION WHILE PROTECTING THE WATERSHED

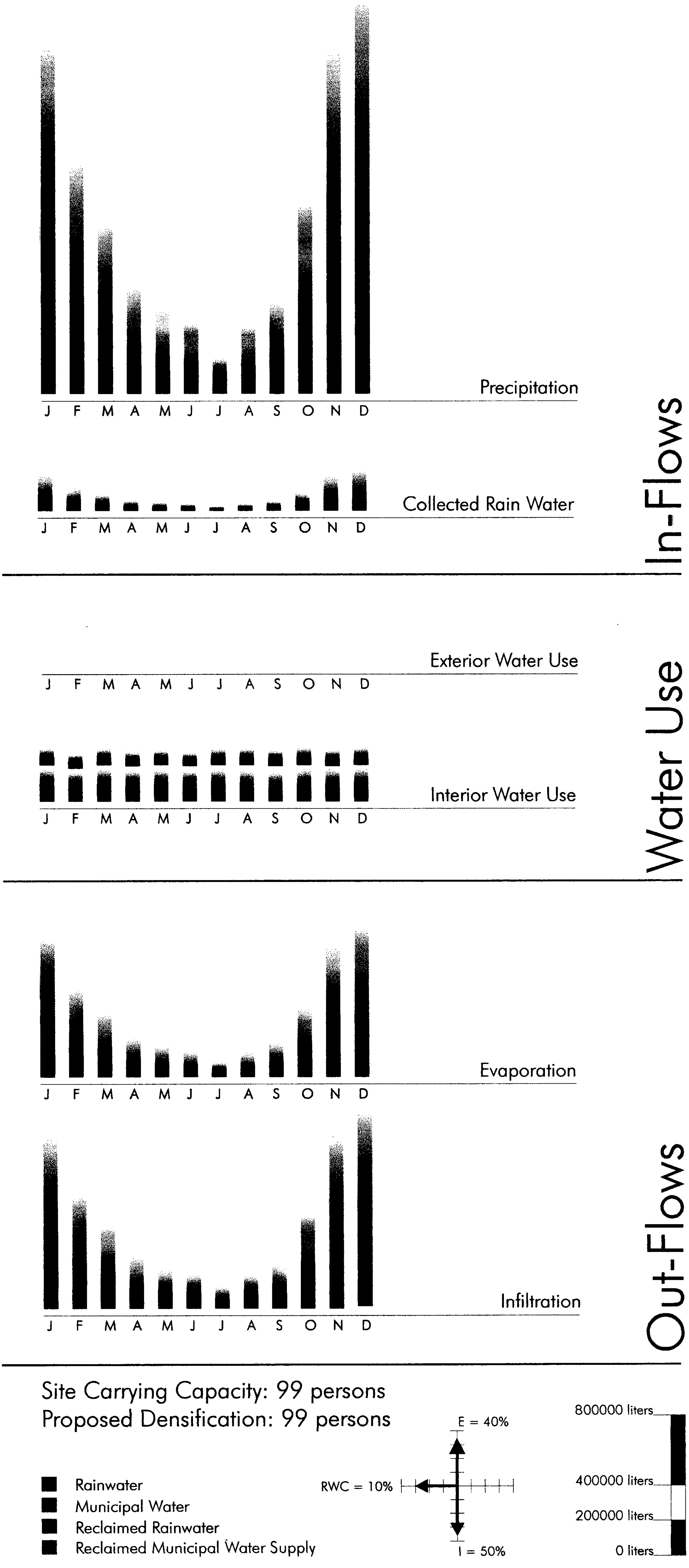
The first densification analysed protects the host watershed. Direct negative impacts can be avoided if the amount of rainwater collected is below the 10% limit of annual precipitation defined by typical ecological requirements (see 2.2.1. natural on-site water cycle flows, page 16). In this case, evaporation flow is estimated at 40% of the site's annual precipitation and infiltration flow at 60%. The potable water use illustrated in figure 18 in navy blue is equal to about 7.5% of rainwater collected. This water demand accounts for the 75% efficiency of typical rainwater collection system. The densification has no loading on municipal water and wastewater services. The calculation for the possible densification is equal to the carrying capacity. The calculation uses the reduced water demand of 25 l/p/d achieved by treating and recycling wastewater. Densification while protecting the watershed can support 99 persons.

$$\text{Densification (persons)} = \frac{\text{10\% of Precipitation (litres/day) X Efficiency factor}}{\text{Reduced water demand (litres/person/day)}}$$

$$\text{Densification} = \frac{3300 \text{ l/d X } 0.75}{25 \text{ l/p/d}} = 99 \text{ persons}$$

Assuming the Canadian average of 2.5 person per household, the density of the existing conditions is estimated at 28 persons; a typical density for suburban fabric. However, while protecting the watershed, maximum densification is estimated at 99 persons. This represents almost a factor four increase in density. For this first possible densification, the Brentwood Bay site OSSHWC flow implications are illustrated in the flow diagram of figure 18. As mentioned earlier, densifying suburban fabric can considerably reduce overall negative effects of suburban fabric. The second possible densification represented is defined by the maximum limit of collected rainwater available without degrading the host watershed.

FIGURE 18: DENSIFICATION WHILE PROTECTING THE WATERSHED



13.2.2. DENSIFICATION WITHOUT DEGRADING THE WATERSHED

In the second densification, the disruption of natural on-site water cycle flows is identical to the existing conditions prior to the transformation of the Brentwood Bay site. In the existing conditions, runoff is equal to 30% of the site's precipitation. Similarly in this possible densification, collected rainwater for water supply is equal to 30% of the site's precipitation. The collection of rainwater for water supply has replaced runoff in the natural on-site water cycle flows, infiltration and evaporation are identical in both circumstances. The densification has no loading on municipal water and wastewater services. The densification illustrates the potential for achieving an on-site water cycle in denser urban conditions.

The calculation for the possible densification surpasses the limit imposed by the carrying capacity fixed at 10% precipitation. This possible densification imposes impacts on the host watershed while avoiding degradation. The 30% of precipitation limit is defined by typical ecological requirements. The calculation also uses the reduced water demand of 25 l/p/d achieved by treating and recycling wastewater.

The potential densification (without degradation) for the Brentwood Bay site is estimated at 297 persons. This densification goes beyond the number imposed by the carrying capacity since it imposes impacts on the watershed. The densification is calculated by using the familiar equation of the carrying capacity, however, the rainwater available for supply is increased from 10% to 30% of annual precipitation.

$$\text{Densification (persons)} = \frac{\text{30\% of Precipitation (litres/day) X Efficiency factor}}{\text{Reduced water demand (litres/person/day)}}$$

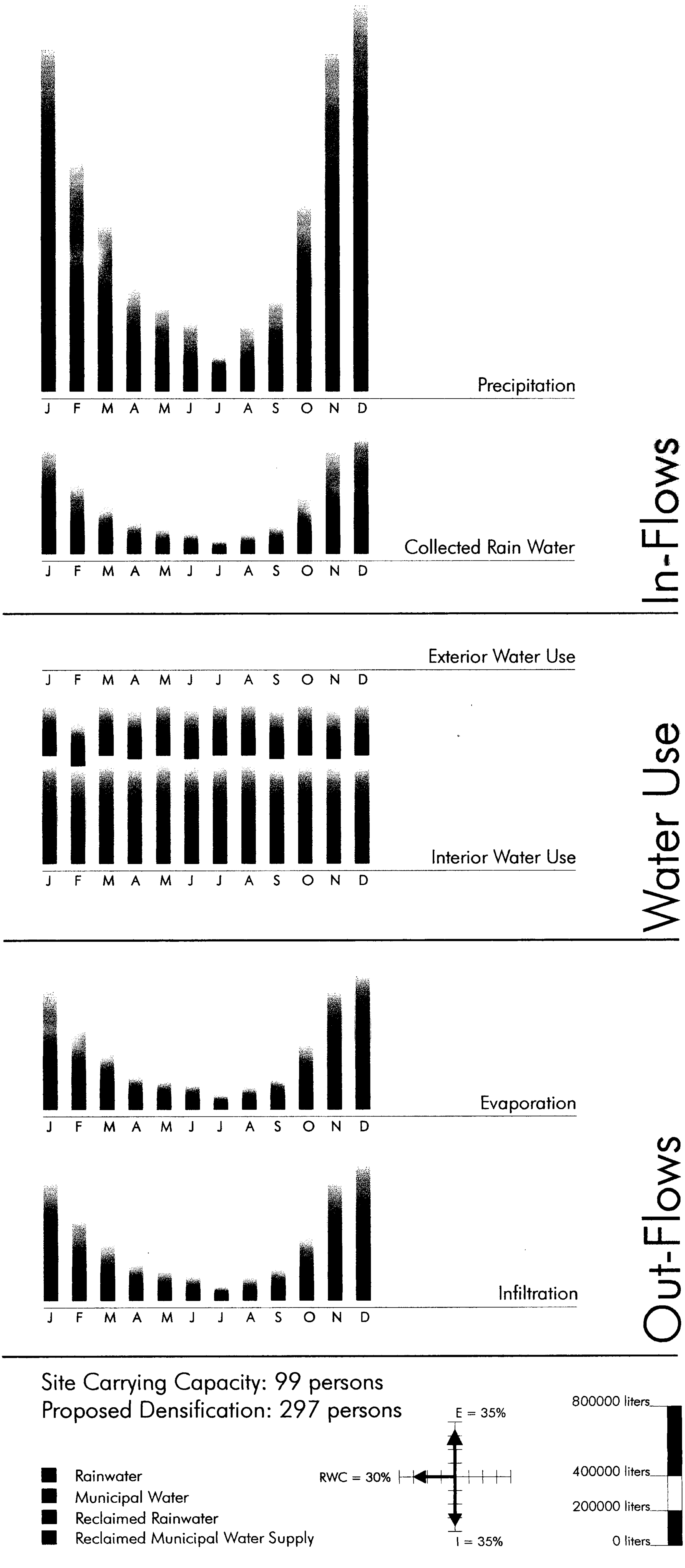
$$\text{Densification} = \frac{\text{9900 l/d X 0.75}}{\text{25 l/p/d}} = \text{297 persons}$$

The potable water use illustrated in figure 19 in navy blue is equal to about 22.5% of rainwater collected. This water demand accounts for the 75% efficiency of typical rainwater collection system. The Brentwood Bay site OSSHWC flow implications of densification are illustrated in the flow diagram of figure 19.

This potential increase in inhabitants represents a significant densification of suburbia, more than ten times existing density. It illustrates the potential of achieving an OSSHWC even in a dense urban fabric. This density could be translated into a variety of housing options; such an increased density permits the transformation from suburban to urban fabric.

This densification impacts the watershed. Such a removal of precipitation from the on-site flows would impact the ecological processes of the host watershed. The decision to impact the host watershed rather than using municipal water supply would be made at the project or regional level. It is beyond the scope of this thesis to define whether impact to on-site flows is advantageous to municipal water supply loading. In some cases, it may be more appropriate to use a municipal water supply than to impose impact on the watershed. However, this thesis suggests that disrupting natural on-site flows beyond the degradation limit should be avoided due to the complexity of restoring a damaged watershed and the multiple negative impacts associated with on-site degradation.

FIGURE 19: DENSIFICATION WITHOUT DEGRADING THE WATERSHED



CONCLUSIONS + DISCUSSIONS

14. CONCLUSIONS + DISCUSSIONS

14.1. SYNOPSIS OF FINDINGS

This thesis defines a process that transforms existing suburban water cycle conditions into an ecologically sensitive on-site suburban housing water cycle. Specifically, the thesis illustrates the process application to a typical suburban block located in Brentwood Bay, British Columbia. The application of the process permits the elimination of on-site degradation, the elimination of municipal water and wastewater service loading, as well as a significant increase of the natural on-site water cycle carrying capacity. The complete transformation of existing conditions at maximum efficiency permits the achievement of an OSSHWC with no direct negative impacts on the host watershed. Once the natural on-site water cycle carrying capacity is sufficiently increased, densification of the existing suburban fabric is possible within the limit imposed by the ecological requirements of the site. A three-fold increase in densification is possible while protecting the watershed and a ten-fold increase in densification is possible while accepting impact but avoiding degradation of the watershed.

14.1.1. APPLYING THE PROCESS

This research suggests that the process advocated here is necessary in order to successfully achieve an OSSHWC. Two factors are essential to this transformation: first, the transformation process begins with a site assessment; and second, a prioritisation of the strategies is necessary in order to achieve an efficient OSSHWC transformation.

In order to comprehensively and ecologically address water cycle issues of suburban housing, existing conditions must be assessed to determine if the site is typical or atypical. Typical conditions for Canadian suburban housing are similar the Brentwood Bay site. These conditions are characterized by municipal loading of water supply and wastewater treatment, and impervious surfaces amplifying runoff. On the other hand, the presence of on-site water bodies, on-site wastewater treatment, or on-site water supply characterizes atypical sites. These characteristics would greatly influence the on-site flows, therefore, for atypical sites, assessment must be site specific.

For an atypical site, the assessment defines the factors influencing the direct negative impacts of suburban housing on the host watershed. The assessment permits the analysis of the site's ecological requirements, the built environment, the OSSHWC flows, the on-site degradation, the municipal water and wastewater service loading and the natural on-site water cycle carrying capacity. For a typical site, the site assessment can be omitted by using the site characteristics developed in this research.

The strategy ranking for transformation follows the assessment. Prioritising the transformation process is crucial to a successful and efficient ecological design process. For many reasons such as costs, political structure or regulatory issues, the transformation toward an ecologically sensitive suburban housing water cycle is likely to be incremental. Many projects are likely to be limited in the number of ecologically sensitive strategies applied due to economic, social or political issues. Therefore, identifying and applying the more pressing and efficient strategies facilitates the elimination of direct degradation of the host watershed.

The prioritisation advocated in this research is as follow: first, eliminating on-site degradation; second, reducing the demand for water; third, treating and using wastewater; and fourth, collecting and using rainwater. For a typical or atypical site, the findings of the assessment may be different but the prioritisation remains the same. The ecological requirements, the factors influencing on-site degradation, and the amount of impervious coverage may differ significantly from a typical to an atypical site, yet the rational for the prioritisation remains. The on-site degradation must be reduced to protect the watershed, reducing water demand must be completed prior to on-site wastewater treatment and water supply. On-site wastewater treatment facilitates the future implementation of on-site water supply. However, the strategies may differ in some cases. For example a malfunctioning on-site wastewater treatment that amplifies on-site degradation may be replaced by a wastewater treatment system providing wastewater recycling. This latter example respects the prioritisation in a specific possible scenario.

This thesis details all the steps included in the application of the process to the Brentwood Bay site. However, for future application, the process can be simplified.

14.1.2. ADDRESSING DIRECT NEGATIVE IMPACTS

This research suggests that transforming the existing conditions into an ecologically benign OSSHWC requires the elimination of direct negative impacts on the host watershed. This thesis has found that in order to eliminate direct negative impacts of suburbia, it is necessary to assess the water cycle at a scale larger than the single family detached house. Considering larger scale negative impacts ensures an accurate assessment of the on-site degradation occurring at the suburban housing fabric level.

Acknowledging that all the components of suburban fabric such as automobile infrastructure, impervious surfaces, and suburban houses have negative impacts on the host watershed enlarges the focus beyond the isolated single family house. Focusing on a building's individual performance is not an accurate strategy when addressing the reduction of natural water cycle degradation since a significant amount of direct degradation occurs beyond the suburban house. The disruption of on-site flows, for example, is mainly due to the large amount (72%) of impervious surfaces (other than roofs) immediately surrounding single family residences.

This research reveals a link between small-scale site intervention and the health of the host watershed. Acknowledging the existence of this link between OSSHWC and host watersheds and/or aquifers illustrates the need for holistic watershed and aquifer management. This thesis stresses that the OSSHWC is strongly embedded in the notion that local, small-scale sites affect larger, regional scale watersheds or aquifers. Therefore, acknowledging the link between the OSSHWC and the watershed or aquifer is essential. The cumulative effects of small-scale on-site degradation are largely ignored, as a result, they continue to be major contributors to global degradation of the host watershed or/and aquifer.

14.2. DISCUSSIONS

14.2.1. RESEARCH APPLICABILITY

The process defined in this research is applicable (with various modifications) to any location, building type, and density. The objective of the process, for the Brentwood Bay block, is to transform existing water cycle conditions into an ecologically sensitive OSSHWC. Eliminating direct on-site degradation, reducing municipal water and wastewater systems loading, and increasing on-site water cycle carrying capacity are targets included in the process objective. Attaining these targets is a priority for any building, location, or density since doing so reduces the direct negative impacts of the built environment on host watersheds.

The proposed process can be applied to other building types since all buildings are built within a watershed and therefore, all buildings interact with the natural on-site water cycle flows of a watershed. The components and flows that compose an OSSHWC, are present in most buildings; within most building types potable and non-potable water is used and wastewater is produced. Moreover, for a significant number of building types, the water demand is lower in quantity and quality than that of suburban housing. Therefore, in many cases such as retail and office buildings, achieving an OSSHWC within the natural on-site water cycle carrying capacity is a feasible target.

The relationship of a building's water cycle to the natural on-site water cycle would vary drastically depending on location. Site specific conditions such as precipitation levels and amount of impervious surfaces would influence the relation of a building with its watershed. For example, the annual precipitation average may not permit the transformation to autonomous OSSHWC if the maximum reduced water demand is above rainwater supply permitted by ecological requirements. Although, factors amplifying direct negative impacts to the host watershed may be different in many locations, the objective of eliminating overall watershed degradation remains the same. The importance of the process lies in considering the entire site (including roads and driveways, for example), rather than limiting the study to isolated buildings. This permits the consideration of the site's ecological requirements as well as the link between the on-site water cycle and the health of the watershed and/or aquifer. Regardless of location, the thesis advocates that the prioritisation of strategies for transformation is similar. Eliminating on-site degradation in all small sites within a watershed is the most pressing issue to address. Protecting the health of watershed is an important objective to meet for the communal protection of global water resources.

Urban densities are producing water demand levels that are significantly greater than suburban densities. Most urban projects may not technically be able to achieve an OSSHWC. However, this prioritised process can be applied to facilitate the elimination of direct negative impacts on the natural water cycle. The research does not suggest that all sites should achieve an on-site water cycle within carrying capacity. For some building uses with high water demand, such as residential and office towers or hospitals, achieving an OSSHWC within carrying capacity is out of reach. Still, a reduction of these buildings' on-site degradation as well as a reduction of their municipal water and wastewater loading are important issues to address in order to protect the host watershed.

14.2.2. SCALE AND REDUCTION OF WATERSHED DEGRADATION

In applying the process to the Brentwood Bay suburban block, there are three different possible scales at which the flow management strategies can be applied: the block, lot, or unit. The elimination of on-site degradation and the reduction of water demand can and should be applied at all of these scales simultaneously. However, the treatment and use of wastewater as well as the collection of rainwater for supply could be applied at the unit, or lot or block scale. Decisions about appropriate scale application are not without tradeoffs. Strategies applied at the lot or unit scale may entail intensive use of resources as many features are repeated, lot after lot, unit after unit. In contrast, the unit and lot scales facilitate the retrofit of typical privately owned lots or units within the suburban fabric. At the block scale, current individual lot ownership challenges communal efforts despite the possible efficiency gained in implementing a unique system.

Future research might involve the application of the process at the municipal or regional scale. These jurisdictions have control over their water and wastewater services making it possible for them to modify existing systems at a potentially greater efficiency than at the smaller lot or unit scale.

14.2.3. CONTEXTUAL ISSUES

The reduction of a building's direct negative impacts is an important objective to meet in order to minimize the human impact on the planet. This research prioritises flow management strategies that facilitate the transformation to ecologically benign on-site water cycle. Some strategies mentioned in this research, such as wastewater reclamation, require significant changes in today's political, social, and economic realms in order to be implemented. Many examples of possible strategies facilitating the transformation exist such as: public education for water conservation and the use of reclaimed water; appropriate price structure to account for the increasing cost of water pollution; and regulations that permit water reuse and recycling.

In order to be successful, the transformation requires the implementation of more than flow management strategies. Without public will and government support, and without economic feasibility, the elimination of direct negative impacts will not be broadly achieved. The thesis suggests that social, political, and economic strategies should be implemented along with flow management strategies in order to successfully protect global fresh water resources.

Although this thesis has isolated the water cycle from its broader context in order to study the relationship between suburban housing and the natural water cycle, the findings of this research cannot be applied without considering the contextual issues present in all projects. These contextual issues will significantly influence the implementation of this research's findings. For example, safety and health concerns designed to protect citizens would influence the transformation towards an OSSHWC. Issues such as building codes, fire safety, health regulations, and engineering concerns for road right of way are contextual issues that need to be incorporated in the application of the thesis process. A second example of a contextual issue is the implication of the thesis process on the price of housing. A potential increase in the cost of housing by incorporating water cycle strategies could introduce equity issues along socio-economic lines. Moreover, applying the findings beyond the residential block introduces new factors to the process. For example, an institution, such as a hospital, could require 'borrowing' from its surroundings in order to deal with its runoff or to collect sufficient rainwater. This introduces legal and regulatory concerns to the thesis process.

This thesis advocates that a successful application of the process requires the inclusion of all contextual factors. The reduction of direct negative impacts of suburbia on watersheds needs to be considered in all levels of decisions regarding suburban housing fabric.

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