The End of the Pipe: Integrated Stormwater Management and Urban Design in the Queen's Ditch

by

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Abstract

The Queen's Ditch is located three kilometers north of Comox on Vancouver Island and is roughly 1300 hectares in size. In 1998, the watershed experienced a 1 in 200-year rain event that flooded much of the lower watershed. The Regional District of Comox-Strathcona is responsible for land-use planning in the watershed and initiated an investigation into the stormwater runoff problem. This thesis is divided into two components: a planning phase to identify problems with watershed hydrology; and a design phase to illustrate urban design that manages stormwater runoff.

Watershed assessments were conducted at the watershed and sub-watershed scale. Watershed assessments were descriptive and helped predict future trends in land-use change. These assessments were not able to identify site specific problems. Sub-watershed assessment was useful at quantifying and identifying stormwater problems. Planners should use sub-watershed hydrological performance to guide land-use planning decisions and assess hydrological and ecological effects of development. The planning phase provides planners with a process to prioritize candidate areas for development, conservation, and rehabilitation.

The design phase compares urban design and stormwater performance standards of a proposed conventional design with a sustainable design. The goal of the sustainable design was to mimic the site's natural hydrology to help reduce off-site runoff, and to ensure adequate groundwater recharge. Objectives of the sustainable design were to preserve natural vegetation; maintain ~~of~~ time of concentration; reduce and disconnect impervious surfaces, and treat~~ment~~ first flush flows.

Comparisons of conventional and sustainable designs indicate that stormwater runoff and pollution can be managed at the site level. The sustainable design provides forty-seven percent more dwelling units and exports no stormwater. The sustainable design achieves this without an expensive stormdrain infrastructure. Stormwater is managed at the site level using small infiltration depressions and swales. The design works with the natural hydrological processes of the site to generate a hydrologically sustainable design. Simulated stormwater outputs were used to test and size infiltration ponds and to assess flooding risks. The sustainable design effectively manages stormwater production, runoff, and pollution from storm events ranging from polluted first flush flows to large, flood producing rainstorms.

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Chapter 1: Introduction

As more of the world's population is moving into urban areas, the problems associated with the conversion of natural and agricultural landscapes into built environments are increasing. In North America, city planning has revolved around the automobile, resulting in an 'urban sprawl' of suburbs, roads, shopping centres and industrial zones. Development has occurred within a relatively short time frame, and with few environmental considerations, until recently. As a result, we are now beginning to see the detrimental impacts that unchecked development has had on the ecology and the livability of our region.

Two of our major natural assets in British Columbia are the abundance of clean, fresh water and our wild salmon and trout populations. Biologists are now discovering that genetic biodiversity is critically important to maintaining wild salmon populations. Unfortunately, the smaller streams, which provide habitat for genetically distinct fish populations, are the most vulnerable to habitat degradation. In Vancouver, over ninety-five percent of fish-bearing streams have been piped and paved over as the city has grown (Department of Fisheries and Oceans 1995). The hydrology of these watersheds has also been drastically altered in the process. As natural areas are paved over, the rain that falls during a storm cannot infiltrate into the ground, causing flooding in lower lying areas. To combat this problem, stormwater has been directed into ditches and drains to be removed as quickly as possible.

Paving, ditching and draining has had serious consequences for stream hydrology and ecology. Impervious surface coverage of as little as ten to fifteen percent has been linked to increased stormwater production and decreased stream biodiversity and habitat condition (Schueler and Galli 1992, Booth and Reinelt 1993 in, Schueler 1995). The increased volume and velocity of stormwater from urban sites has altered channel characteristics so that they are no longer favorable for fish. Runoff from roads, agricultural sites and industrial sites is contaminated with chemicals and other pollutants. In addition to habitat degradation and water quality problems, this system of stormwater management has led to increased, not decreased, downstream flooding (Leopold 1968, Goudie 1994, Marsh 1998). Flooding occurs when more stormwater is produced by the developed landscape then the stream channel can carry. Lowland areas are flooded when the stream floods and the banks are over-topped with excess water.

Although much as been learned in the last two decades about the ecological impacts resulting from urban development and associated stormwater runoff, many new developments continue to generate excess volumes of storm runoff that is delivered, untreated, to downstream channels and fish bearing streams. Recently, efforts have been made to improve the situation through better watershed planning (large scale planning) and urban design practices (small scale planning and design) (Schueler 1995, Marsh 1998, Prince George's County 1999).

Watershed based planning is a tool that can help prioritize lands for preservation, restoration, and development within our urban watersheds (Schueler 1995). The hydrological performance of watershed subunits can be used as a critical factor to establish planning objectives (Schueler 1995). Principles of sustainable design that are relevant to stormwater management include: the preservation of natural vegetation; maintenance of time of concentration; minimization and disconnection of impervious surfaces, and biological treatment of first flush flows. Low Intensity Design (LID) is a concept that uses design elements to mimic the site's natural hydrology to help reduce off-site runoff, and to ensure adequate groundwater recharge (Prince George's County 1999).

In this project, both of these tools (watershed planning and low impact design) are used to confront problems associated with past, and future, development in the Queen's Ditch watershed in Comox, BC. Watershed assessments were used to identify stormwater problem areas within the various sub-watersheds. A sustainable development design also illustrates how stormwater can be managed at the site level. Truly sustainable designs begin with an understanding of site processes and work with these processes.

The Study Area and Problem

The Queen's Ditch is located three kilometers north of Comox on Vancouver Island (Figure 1). Roughly 1300 hectares in size, the watershed encompasses areas of second growth forest, agricultural and industrial lands, and urban and rural developments. Urban, rural and industrial development has been steadily expanding since 1946, when the Canadian Forces Base (CFB) Comox was built.

In 1998, the Queen's Ditch watershed experienced a 1 in 200-year rain event. A large portion of the agricultural land was flooded which resulted in the loss of the entire potato crop. The farmer filed a lawsuit, won, and was awarded a significant amount of money. During the legal investigation an engineering firm assessed the hydrology of the watershed and concluded that the Queen's Ditch channel was not properly maintained (McElhanney 1998). The firm suggested that building wider, more efficient ditches and installing larger culverts would solve the flooding problem.

The Comox Strathcona Regional District (CSRD) was one of several defendants in the lawsuit. The CSRD is responsible for land management in the rural areas of the Queen's Ditch watershed. While the CSRD was contemplating taking over responsibility for the Queen's Ditch from CFB Comox, staff had concerns that the CSRD would be liable for property damage resulting from future flood events. They were also concerned about the engineer's solution to the flooding problem. Coho salmon have been found in a few areas of the watershed in 1998 (Terra Lotic Resources Ltd. 1998). The presence of salmonids in the watershed resulted in several ditches being reclassified as fish-bearing streams under the Federal Fisheries Act.

The CSRD needs to find a solution to the flooding problem that does not negatively affect the salmonid populations within the watershed. In addition, the Town of Comox has plans to develop a 32-hectare site with a conventional urban development and engineered stormwater drainage system. The CSRD asked for suggestions on how this development could proceed without further altering the watershed hydrology of the Queen's Ditch.

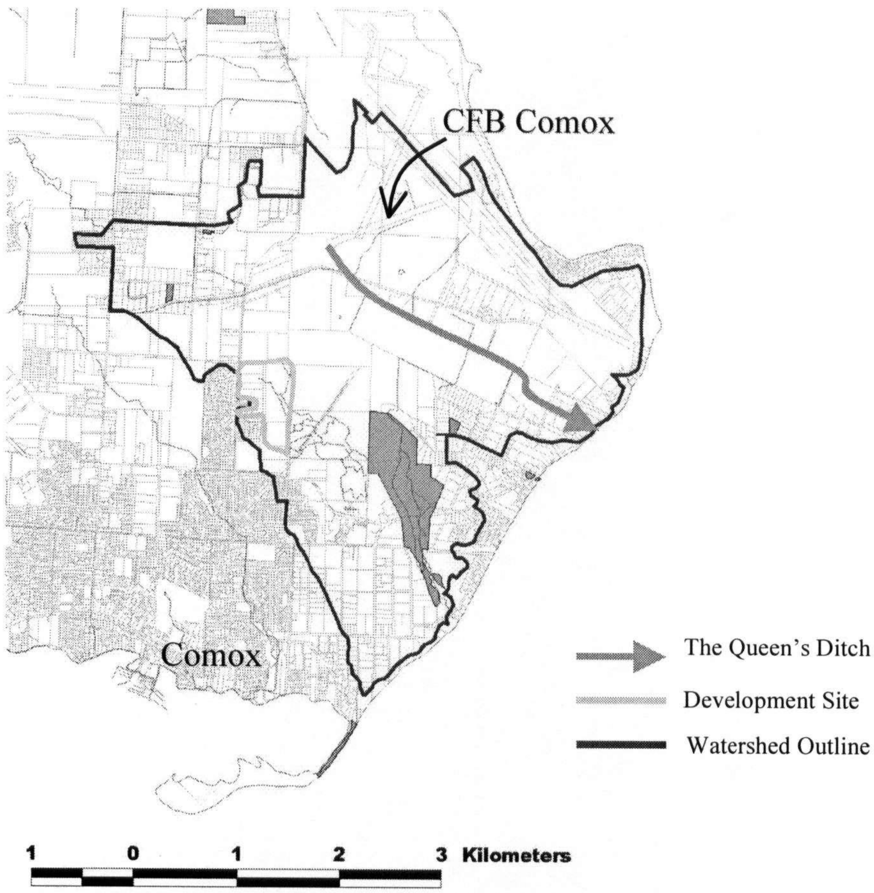


Figure 1. The Queen's Ditch watershed and surrounding area.

The project was divided into two key components: 1) a planning phase to identify problems with watershed hydrology; and, 2) a design phase to illustrate urban designs that maintain or enhance the landscape processes. The planning phase addressed inherent stormwater problems and established a methodology to identify and prioritize problem areas within the watershed. The second phase of the project compared and contrasted the proposal for conventional design with a sustainable design. Urban form and stormwater systems were used to evaluate the sustainability of each design.

Chapter 2: Watershed Hydrology

What is Stormwater?

During a rainstorm, water infiltrates into the soil. In heavier rains, or when soil absorptiveness is limited, water begins to 'runoff' or flow over the land. In natural landscapes, this runoff collects in streams and feeds river systems. In the urban landscape, this runoff is called stormwater.

Factors which influence stormwater production and delivery

The volume and rate of stormwater flow is influenced by two main factors: channel density, and the amount of impervious surface area (Leopold 1968). Watershed hydrology is also influenced by soil composition and distribution.

Impervious surface area

Figure 2 demonstrates the correlation between runoff volume and the percentage of impervious surface area.

As impervious surface area increases, infiltration rates decrease and runoff increases. Therefore, as the landscape becomes more urbanized, and impervious surface area increases, so too does stormwater production.

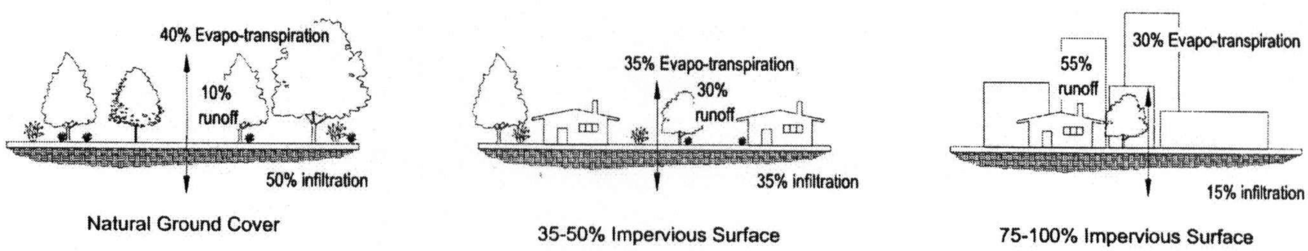


Figure 2. Relationship between impervious surface area and runoff, infiltration and evapo-transpiration rates. (Prince George's County 1999)

The amount of impervious area directly affects watershed hydrology. Under normal conditions, stream channels are naturally designed to carry runoff generated by the 1 in 2 year storm (Leopold 1968). When land within a watershed is developed, the increase in paved surface area generates more runoff than the stream can handle, causing the channel to flood. Watersheds with fifty percent impervious cover would flood four times more frequently than the same undeveloped watershed (Leopold 1968); however, changes in stream hydrology have been noted with only ten to fifteen percent impervious area (Schueler and Galli 1992; Booth and Reinelt 1993; Prince George's County 1999).

Watershed Hydrological Zones

Watersheds typically have three distinct hydrological zones, which influence the movement of water through the landscape: the recharge; transition; and, discharge zones (Figure 3). In the recharge zone, precipitation infiltrates into the soil and 'recharges' the aquifer. Water that infiltrates and travels through the soil is called interflow. Interflow generally travels at rates of less than one metre per minute, taking several days, or weeks, to reach the stream outlet. Thus, rainwater that falls in the recharge zone does not contribute to the stormwater runoff immediately following a rainfall. Interflow is an important source of water for streams during the dry summer months. Just as the water that falls on the recharge zone fills the aquifer, so too does water from the aquifer feed the streams and riparian habitats. Without this slow release of cold water, many streams would go dry, stranding and eventually killing any trapped fish.

The transition zone is an area where water begins to flow over the surface of the landscape, typically when soils become saturated. This is not a concentrated flow but rather a thin sheet of moving water with velocities of less than half a metre per second. Overland flow contributes to stormwater production, but it takes hours to reach the stream.

The discharge zone is the area where water is 'discharged' into a channel or other waterbody. When overland flow concentrates, it forms small rivulets or channels. Channel flows comprise the fastest flowing water in the landscape with velocities reaching two to three metres per second. Channels can deliver stormwater within minutes to the stream. Streams, ditches, swales, stormdrains, and drainage tile all carry channel flow.

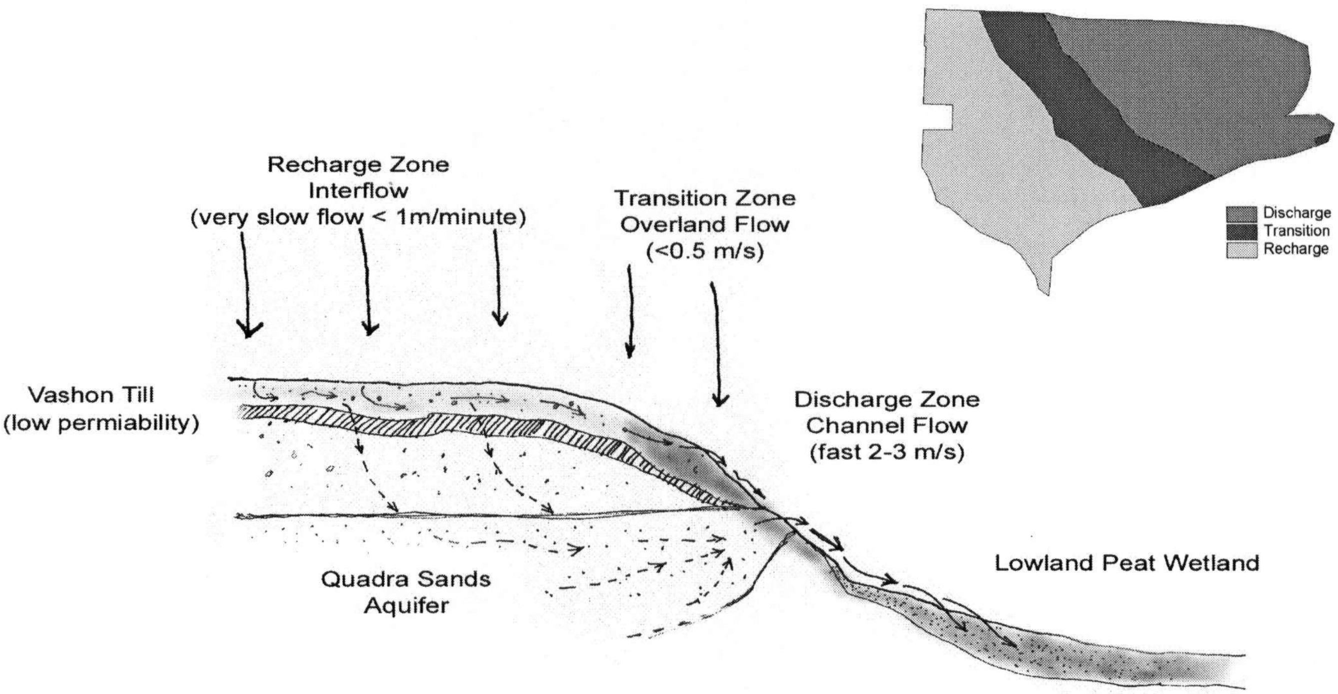


Figure 3. Hydrological function and water movement in sub-watershed seven of the Queen's Ditch.

Channel density

The third factor which affects urban hydrology is the rate at which stormwater is produced, also known as the conveyance rate. The more quickly stormwater is delivered to the stream, the more likely the stream will be to flood. A watershed with no channels will only convey water through interflow and overland flow, which are both very slow. Adding a drain, ditch, or channel to this watershed will reduce the distance that water has to travel as interflow or overland flow. Since channel flow is an order of magnitude faster than interflow (Marsh 1998), the rate of stormwater produced by the watershed will increase. The volume of water that the watershed generates during a given storm remains the same, but the delivery rate or velocity increases (Goudie 1993). A dense network of channels or high channel density will result in a faster rate of stormwater production (Figure 4).

These three factors, impervious surface area, hydrological zones, and channel density, act in concert to alter watershed hydrology in urban settings. Figure 5 demonstrates how a flood hydrograph changes as imperviousness and channel density are increased. In highly developed watersheds, the volume of water generated and the speed at which it is delivered are vastly greater than in undeveloped watersheds. Severe flooding problems usually occur downstream of these highly developed areas.

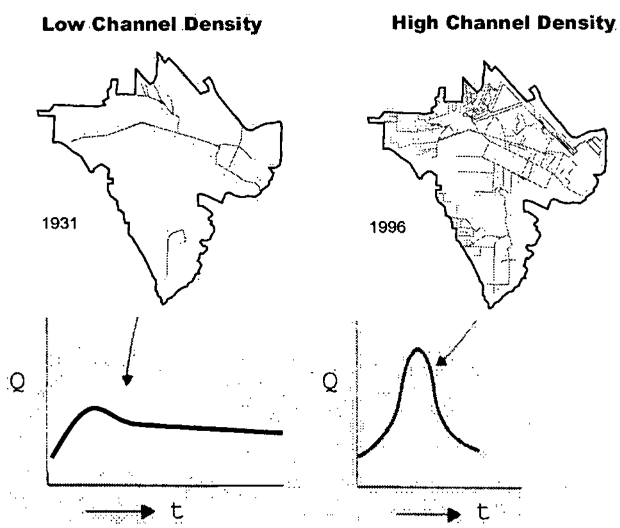


Figure 4. Hydrological response of the watershed to increased channel density (adapted from Goudie 1993).

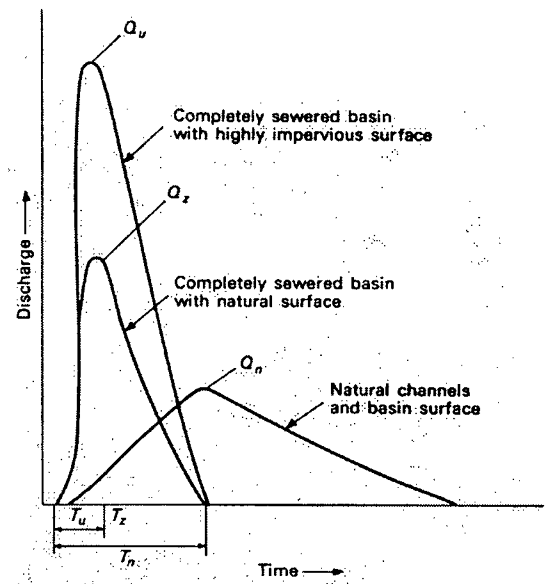


Figure 5. Volume and rate of delivery of stormwater generated in natural and built environments (adapted form Fox 1979, in Goudie 1994).

How stormwater affects stream ecology

Changes in watershed hydrology as a result of urbanization, significantly affect stream ecology. As the volume and speed of stormwater increases, channel flooding becomes more frequent. In time, the stream channel widens to accommodate the additional flow (Figure 6). Channel widening causes a corresponding decrease in channel depth. The physical structure of the stream is simplified as floodwaters remove, bury, or destroy structural elements (logs, boulders, undercut banks, etc.), reducing the amount of rearing habitat available for salmonids. Ditching and draining also reduces infiltration rates to underground aquifers. Normally, cold, clean water is slowly released from these aquifers during the summer months, thereby maintaining base flows in smaller streams. Stream can run dry during the months of July to September without this constant supply of cool, clean water.

Thus, the hydrological "health" of a watershed is linked to the amount of impervious cover and channel (Leopold 1968, Goudie 1994). Others have recently linked impervious cover to the ecological "health" of a watershed (Schueler and Galli 1992, Booth and Reinelt 1993).

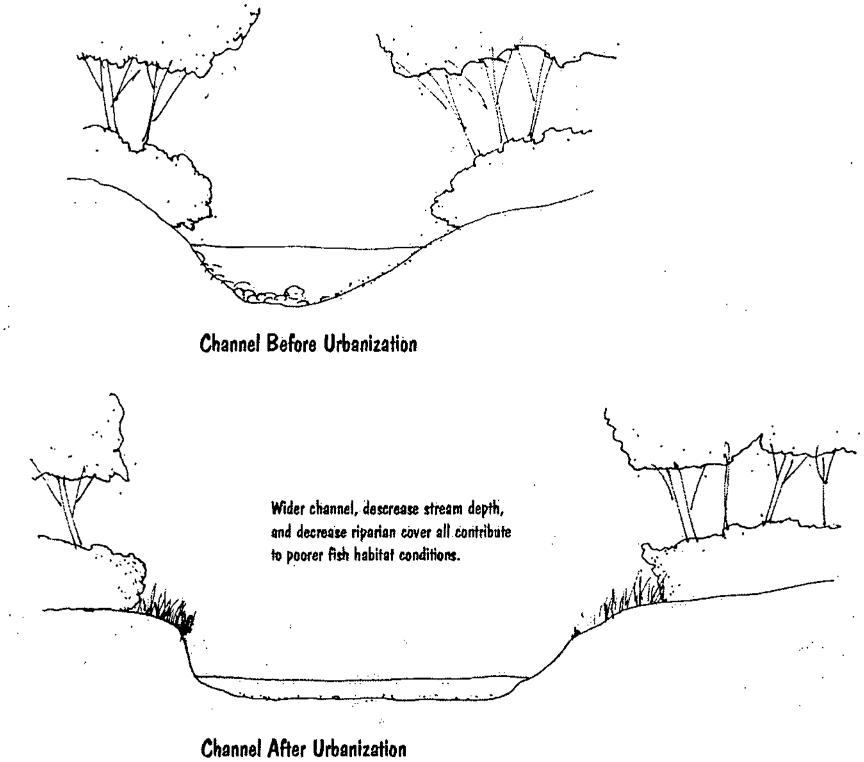


Figure 6. The effect of urbanization on stream channel morphology.

Ecological values such as stream habitat, are linked to proper functional processes and in particular; hydrological processes (Schueler and Galli 1992, Booth and Reinelt 1993, Prince George's County 1999). Hydrological "health" will therefore be used as an indicator of ecological "health", for the purpose of this study. Hydrological "health" can be quantified by plotting impervious area against channel density (Figure 7).

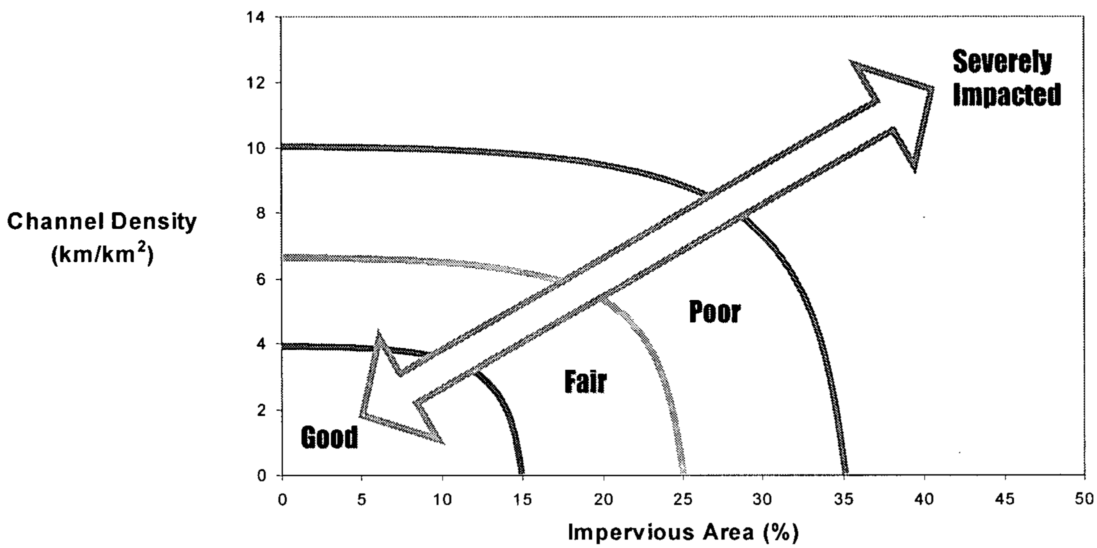


Figure 7. Hydrological variables used to quantify hydrological and ecological "health" of watershed and sub-watersheds.

Chapter 3: Watershed Planning

Land-use planning has traditionally been based on political boundaries, often resulting in conflicting management agendas and an inability to solve problems, which overlap jurisdictions. Since nothing is more likely to alter ecosystem function than changing watershed hydrology, it makes sense to use watershed boundaries to define planning unit (Mooney 1999). Watersheds are clearly definable, discrete units that are based on landscape hydrological processes. In addition, the watershed can be used as a system of organization at a variety of scales, ranging from regional to the smallest sub-watershed or neighbourhood unit (Table 1). Using the watershed as a planning unit is particularly appropriate for stormwater management.

Landscape managers and planners assess zoning, set backs and land-use but rarely assess the effect of proposed development plans on watershed ecology. Impervious cover and channel density information can be effectively used to assess and prioritize areas for conservation, development, or restoration (Arnold and Gibbons 1996). For areas in good hydrological condition, emphasis should be placed on prevention measures using open space design, vegetation retention and stream buffers to maintain infiltration and reduce imperviousness (Arnold and Gibbons 1996). For areas that are, or will be, in fair to poor hydrological 'health' the emphasis should be placed on site design that reduces runoff and increases stormwater infiltration. Finally, in severely affected areas, management of stormwater quality is the highest priority. Schueler (1995) goes further to suggest that development should be restricted, or curbed, in areas of good hydrological 'health' and focused in areas that are already severely impacted. The rationale behind such a decision is to ensure that critical or sensitive areas of the watershed remain in good condition. Rather than allowing the entire watersheds to uniformly degrade, he suggests managing development to meet watershed performance goals.

Table 1. Characteristics of five watershed management units (adapted from Schueller, 1995)

Watershed Management Unit	**Typical Area** *(ha)*	Influence of Impervious Cover	Primary Planning Authority	Management Focus
Neighbourhood	0.05 to 0.2	Very Strong	Property Owner Local Government	Site Design and BMP
Catchment	10 to 100	Very Strong	Local Government	BMP
Sub-Watershed	100 to 500	Strong	Local or Regional Government	Stream Classification & Management
Watershed	1,000 to 25,000	Moderate	Regional Government	Watershed-Based Zoning
Sub-Basin	25,000 to 250,000	Weak	Local, Regional and Provincial	Basin Planning
Basin	250,000 to 2,500,000	Very Weak	Provincial and Federal	Basin Planning

Chapter 4: Sustainable Stormwater Planning and Design

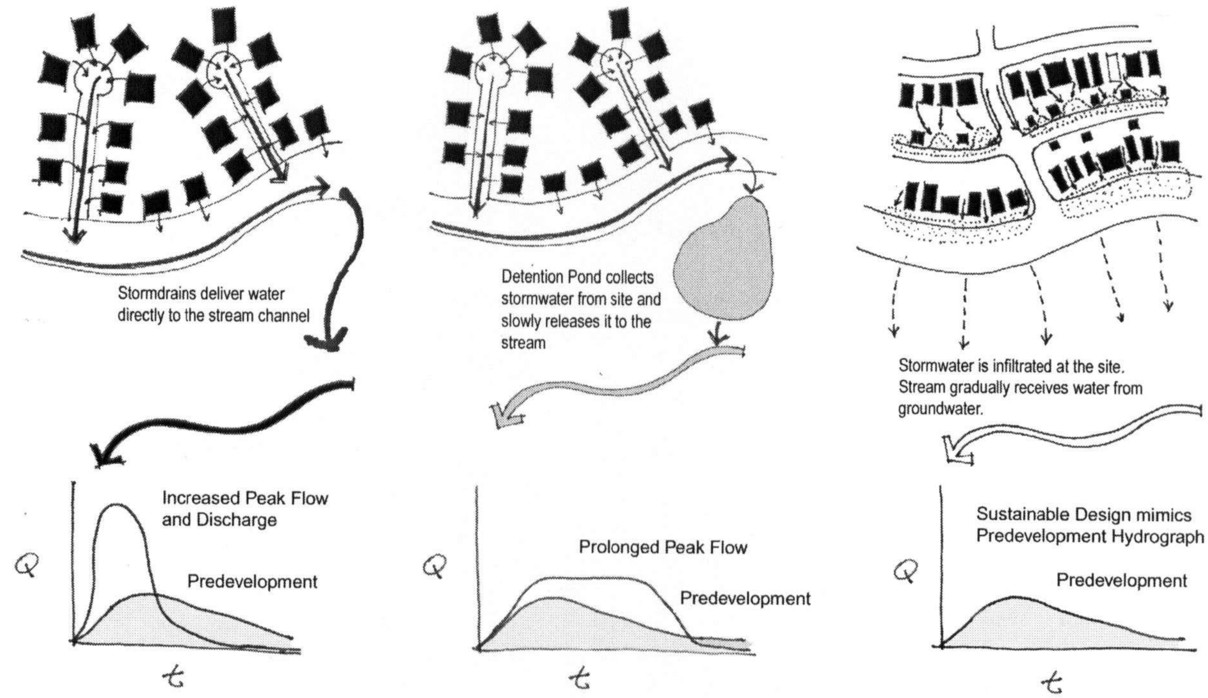
It is only within the last 30 years that stormwater management has become an issue in urban design and development. Stormwater management has evolved from simple ditch and pipe drainage systems, to detention basins that controlled peak discharge, and finally to infiltration systems that mimic the sites natural hydrological processes.

Until recently, engineered stormwater systems super-imposed stormdrains over top of the site's natural hydrological process. Historically, water that was generated by roads and buildings was simply directed into storm drains, removed from the site and discharged into the nearest stream or lake (Figure 8a). This system of stormwater production and rapid conveyance led to increased downstream flooding and habitat impacts, decreased water quality, and decreased aquifer recharge. Unfortunately, many new developments continue to generate excess volumes of storm runoff that is delivered, untreated, to downstream channels and fish bearing streams.

The next approach to stormwater management was to detain or slow down the amount of water leaving the developed site. Through the 1980's and 90's, stormwater best management practices (BMP's) were designed to reduce peak flows generated by urban development. Catch basins detain stormwater and slowly release it into the stream, reducing peak velocities to pre-development levels (Figure 8b). Several problems arise from this method of stormwater management including; 1) increased water temperature due to warming of ponded waters; 2) increased peak flow duration; 3) more frequent peak flows; and, 4) decreased ground water recharge (Ferguson 1991). These systems do not work with the natural hydrological processes of the site. Although they tend to reduce the peak flows they do little to control water volume or quality (Ferguson 1991).

In the past 10 years stormwater designers and planners started working with the natural hydrological processes of the site and watershed to achieve hydrologically sustainable designs. Sustainable design is a commonly used term in university classrooms throughout North America. For a design to be hydrologically sustainable it must maintain or enhance the watershed hydrology processes of the site, and manage the volume, velocity and quality of water produced to pre-development conditions. But, many 'sustainable stormwater designs' continue to negatively affect stream habitat and the ecological health of the watershed. Recent findings suggest site design and planning can be used effectively to reduce the stormwater problems associated with urban development (Schueler 1995, Arnold and Gibbons 1996, Prince George's County 1999).

Green infrastructure, Low Intensity Development (LID), and Smartgrowth are design and development concepts associated with sustainable development. LID is a concept that uses planning and design elements to mimic the site's natural hydrology to help reduce off-site runoff and ensure adequate groundwater recharge (Prince George County 1999). Landscape architects manipulate the infiltration characteristics of the site by paving, erecting buildings, removing vegetation, and compacting soils. They also manipulate the drainage patterns of the landscape. These manipulations usually increase watershed stormwater production and delivery, often to the detriment of the environment. The LID approach advocates working with the site's intrinsic characteristics, in combination with innovative stormwater management practices, to generate designs that sustain watershed hydrology.



A. Conventional design with stormdrain system discharging directly to a stream.

B. Conventional engineered design with stormwater detention pond.

C. Suatainable landscape design with soil infiltration system.

Figure 8. Stormwater management practices and there implications to watershed hydrological performance.

Rather than collecting all of the water produced by the site at the end of the pipe, the idea is to treat stormwater where it is generated, at the site (Figure 8c). Stormwater produced by a building or road is directed to a nearby bioretention or infiltration area. Smaller, more numerous retention and infiltration areas have been found to be significantly cheaper and less risky than large end-of-pipe retention ponds (Richman 1997).

Calculating Stormwater Production

Responsibility for calculating stormwater production before and after development is usually the responsibility of engineers. However, if landscape architects and planners are going to attempt truly sustainable design practices, then they should understand how these figures are generated. Typically 100 percent of the watershed area is used to estimate pre-development stormwater production. It is assumed that all rainfall that lands within a basin's confines, contributes to stormwater runoff. However, only a fraction of the rainfall really ends up as stormwater. Dunne and Black (1970) call this partial area contribution of storm runoff. This phenomenon occurs because some rainfall will infiltrate into the soil and slowly percolated down to either recharge aquifers or eventually enter the stream channel (see discussion p.9, recharge zone). Figure 9 illustrates how post-development designs generate more water than the pre-development condition when the entire watershed area is used to calculate stormwater production.

The implications to design and urban development are very significant as most designers use pre-development estimates based on 100 percent area contribution. Designs generated and tested with these values would be over estimating the pre-development stormwater runoff by at least forty to fifty percent. In other words, post-development runoff using 100 percent area contribution would be about forty to fifty percent greater than runoff from a design based on partial area contribution. A design that is hydrologically sustainable must mimic or produce the same hydrological conditions of the pre-development site. Many developed sites generate more water than they did prior to development even though Best Management Practices (BMP's) were used to maintain discharge at pre-development levels (Mewett 2001). In most cases, the area contributing to stormwater runoff is over-estimated resulting in designs that do not contain or infiltrate enough of the stormwater produced by the site. Designs based upon 100 percent area contribution runoff estimates will still have serious negative impacts on downstream areas as runoff volume and velocities will be significantly greater than actual pre-development conditions.

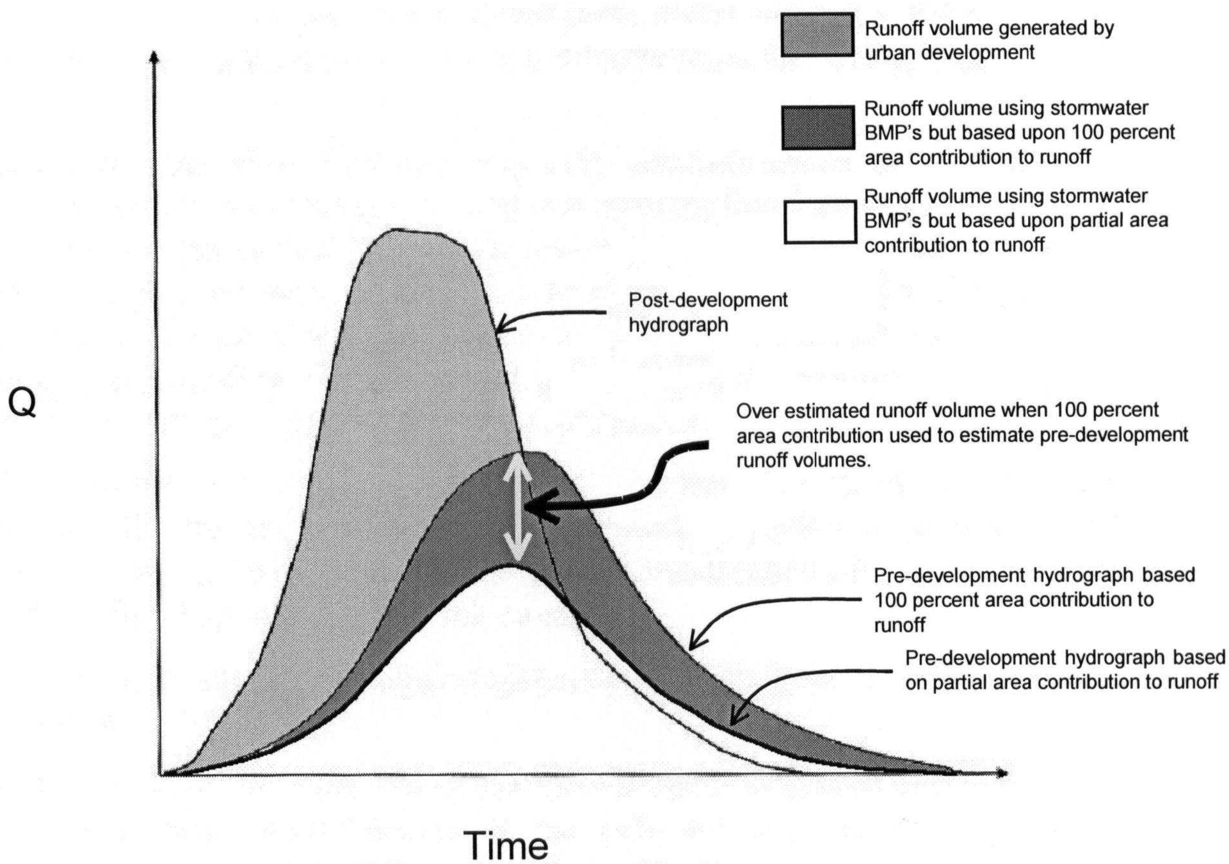


Figure 9. Significance of partial area contribution for pre-development runoff calculations and implications to stormwater management and design.

The Design Storm

The design storm is the hypothetical amount of rainfall used to simulate how a stormwater management system functions. To do this it is necessary to understand the typical rainfall pattern in the study area. For example, annual precipitation records from Comox suggest that in 1997 less than six rain events were greater than 25 mm and only one of these was greater than 50 mm (Anderson Engineering Ltd. 2001). Ninety-five percent of rain events in Comox are therefore less than twenty-five millimeters. In other words, Comox tends to have many small rain events, which generate small quantities of stormwater, with the occasional large storm event that can produce flood conditions.

Watershed managers, planners, and urban designers can use this knowledge of storm frequency to assess risk and make design decisions (Figure 10). Small storms make the largest contributions to total watershed runoff volume and have the greatest impact on water quality. The "First Flush" event is defined as the first 13 mm of runoff from an impervious surface, and is the most polluted stormwater flow (Prince George's County 1999). Designs need to treat the first flush water to remove pollutants before stormwater is infiltrated. Larger storm events do occur, but at very low frequencies. These flows tend to create the most physical damage to a stream and have the greatest potential to impact property values. When landscape architects work with water it is critical that the design solution treat the appropriate problem. Is it a problem of water quality, in which case the first 13 to 25 mm of rainfall is important ,or is it flood control and risk that we are designing for?

Finally, there are implications to ecological function and stormwater management. Too often, through our best intentions, we attempt to mitigate stormwater flooding by taming the system. For example, excess water may be diverted through a stormdrain to bypass areas of sensitive fish habitat. The stream channel no longer experiences a variety of flood flows with this bypass in place. A static flow regime leads to silted and compacted spawning beds and decreased habitat diversity. Streams are not static systems; they require change in order to remain productive. Flood flows are required to clean spawning gravel and to erode stream banks. Urbanization upsets this balance and increases the rate of these changes. Designers need to understand that for sustainability, streams need to have the full range of flow conditions that mimic the natural system.

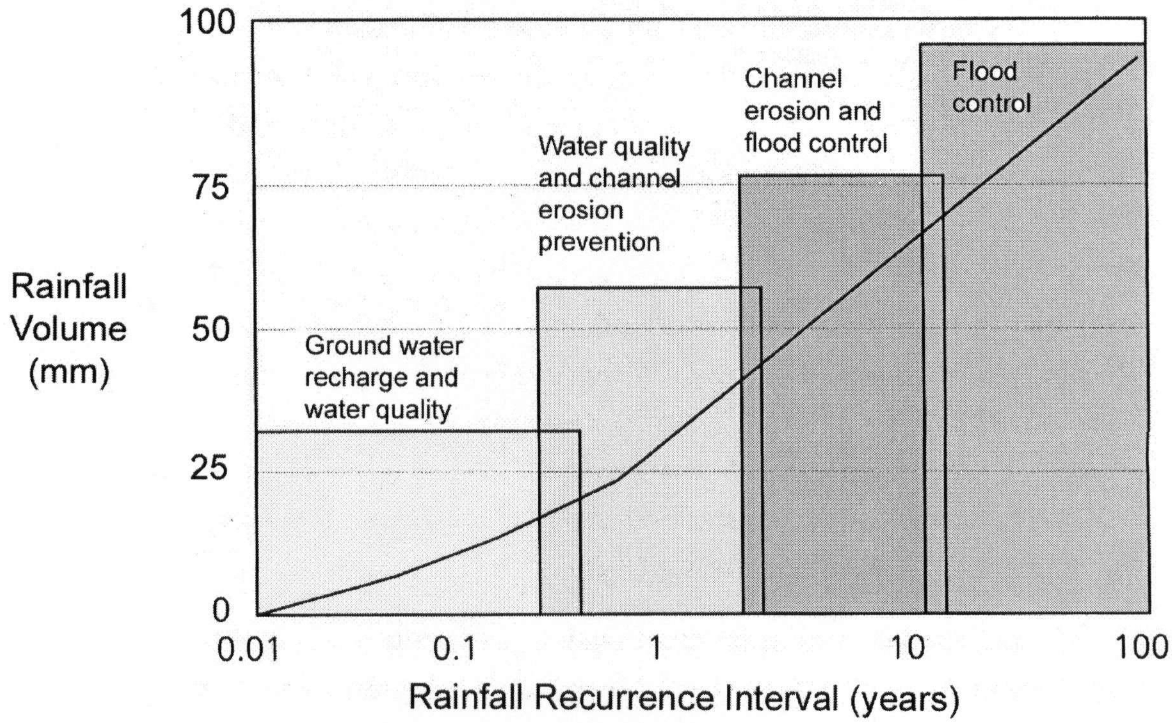


Figure 10. The design storm and its application to stormwater management (adapted from Prince George's County 1999).

Chapter 4: Methodology

The Process

Due to the complexity and scale of the project, it was undertaken in two phases. Phase one entailed conducting an assessment of watershed hydrology and land-use to identify problem areas. Phases two consisted of the design of a hydrologically sustainable development, illustrating stormwater best management practices. Phenomenology and scientific or rationale design methodology were used to develop and test the design. Phenomenology was used as a tool to try and understand how the site functioned, to discover how water moved through the site, and to assess the "feel" of the final design. Scientific methodology was used to assess the hydrological "health" of the watershed, to compare and contrast design options and to test the hydrological performance of the designs. The entire project process is demonstrated in Figure 11. At each step of the process, a smaller unit was assessed/designed, from watershed to sub-watershed to catchment to neighbourhood.

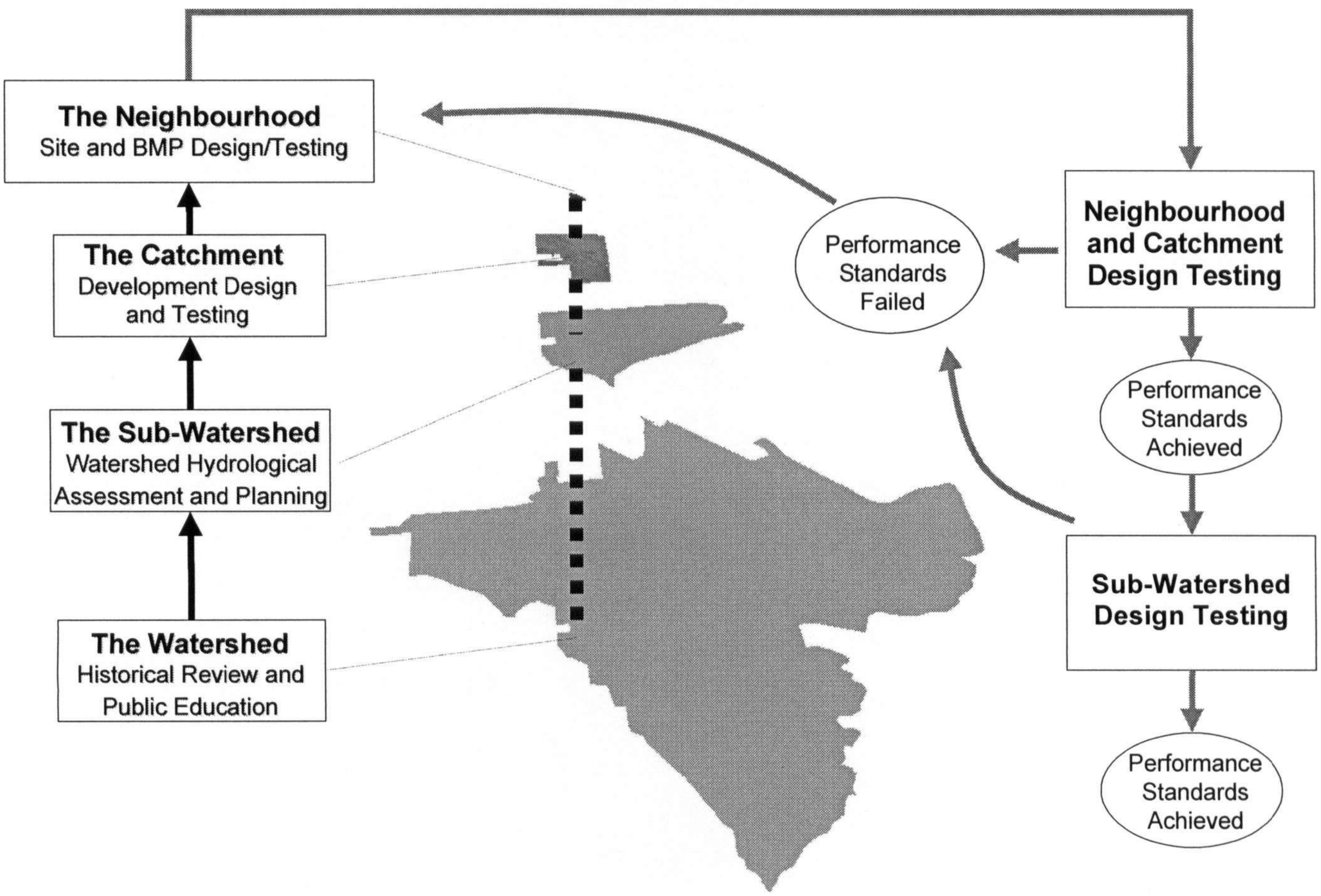


Figure 11. The watershed planning and design process.

The Watershed Level

In the watershed assessment phase, land-use and channel density changes over time were measured. Historical aerial photographs (from 1931, 1944, 1954, 1964, 1975, 1984, 1991, and 1996) were digitally scanned and rectified such that the images were now digitally geo-referenced to the site. Land-use coverage was digitized from air photographs using ARCview

GIS software. Land-use was classified into forests, wetlands, urban and industrial development, and agricultural lands. Channel location and type was obtained from aerial photos. The 1996 channel and stormdrain locations were obtained from the Regional District of Comox Strathcona (Bainbridge et. al. 2000), CFB Comox stormdrain maps, and the Town of Comox stormdrain maps (Town of Comox 1999).

The watershed boundary was estimated using two metre contour data, visual assessment of stereo pair aerial photographs, stormdrain and ditch mapping, and field assessment. Changes in the watershed shape and area were noted. Land-use statistics are based upon the area of the watershed for the given year of assessment.

Land-use statistics were obtained from an ARCview summary of the land-use polygons. Forested cover and impervious area were estimated by calculating the amount of forest or impervious area in each land-use type (see Chapter 5, pg 16).

The Sub-Watershed Level

Assessment at the sub-watershed level involved analysis of the 1996 land-use information for the watershed. The watershed was then divided into smaller, discrete hydrological units, called sub-watersheds. A total of nine units were identified and assessed.

The portion of each land-use type within the nine sub-watersheds was assessed. The 1996 land-use polygon theme was converted to a GRID them of one metre units within the same outline as the original polygon. This enabled easier calculation of land-use coverage figures using Spatial Analyst. Forest and impervious cover data were calculated using the same methods described in the watershed section above. Channels were manually selected from each sub-watershed, and their length calculated with ARCview software.

The sub-watershed hydrological performance was tested using two simulation models. A hydrological model developed by the Soil Conservation Section (SCS model) of the US Department of Agriculture (USDA 1986) was used to test conditions that would be created by the sustainable design. The SCS model uses soil infiltration characteristics to estimate how much water a particular land surface produces for a particular rainstorm event. It is based on overland and open channel flow, but not piped flow. It was therefore not appropriate to test the conventional design with the SCS model, since the design is based on a piped stormwater system.

Land-use cover was used to obtain the 'Curve Number' for all hydrological estimates. The curve number represents the amount of water that is shed by a particular land-use type. This value was obtained from Table 2-2 in the SCS report (USDA 1986). The curve number is positively related to the amount of stormwater produced by each land-use type. As imperviousness increases, less water infiltrates, resulting in larger curve numbers. Soil infiltration rates are incorporated into the model via the curve number (see Table 2-2, USDA 1986). Each particular land-use type has a range of curve numbers that are inversely related to the soil permeability.

Two estimates of discharge were generated for the pre-development sub-watershed. The first used 100 percent of the watershed area to calculate discharge. The second excluded land within the recharge zone from the stormwater production calculation. All pre-development simulations were based on 100 percent forest cover for curve number selection. Hydrographs were generated for all estimates. The hydrographs produced by the SCS model hydrographs are truncated, as the model is only able to generate values for the first twenty-four hours of stormwater production.

The conventional design was assessed using (Hydsis for Drainage, Version 6.0) which combines the SCS model with an engineering component designed to model piped drainage systems. Pre-development and post-development discharge calculations for the conventional design assume that 100 percent of the sub-watershed contributes to stormwater production. The sustainable design was assessed at the neighbourhood level (see below).

The Catchment Level

The catchment refers to the area of land that has been developed. Site hydrology and design opportunities and constraints were assessed at this scale. Stormwater output from the conventional design catchment was calculated in order to determine the size of a stormwater detention pond that would be necessary to capture all stormwater generated from the 100 year storm event.

Slope, vegetation, soil and surface water patterns were used to assess site and design opportunities and constraints. ARCview Spatial Analyst was used to generate a slope map from two-metre contour data. Areas with twenty percent gradient or higher were considered too steep for building. Forest cover information for a portion of the site was digitized in order to prioritize important forest habitats (Ayers 1999). Mature stands of coniferous forest along with young western red cedar and spruce forests formed the high-priority forest class. All remaining forest types were considered to be of lower priority.

The Neighbourhood Level

Small scale design, including lot layout, building orientation, cluster development layout, and pond layout was done at the neighbourhood scale. Single family, commercial, and cluster development designs were hydrologically tested at this scale. Small discrete hydrological units were defined for each neighbourhood unit. Stormwater runoff was calculated for the one inch and 100 year storm event using the SCS model. Stormwater mitigation swales and ponds were then designed to treat and manage these flows. Runoff for the entire catchment was not completed since the designed ponds capture all stormwater runoff from storms up to the one in 100 year rainstorm.

Chapter 5: Watershed Assessment Results

Watershed Assessment

Between 1931 and 1996 significant changes in forest and wetland cover, urban development and agricultural land expansion were observed in the Queen's Ditch watershed (Figures 12 and 13). Prior to development in the watershed, approximately ninety percent of the land was forested and remaining ten percent consisted of wetlands. Since development began, most of the watershed has been altered by logging, land clearing, gravel extraction, agriculture, and urban development. Over ninety percent of the watershed's wetlands were drained and converted to agricultural land by 1996. Forest cover also significantly declined to less than half of its original level. Almost all of the existing forest is second or third growth, with only a few old growth trees remaining in the watershed (Ayers 1999).

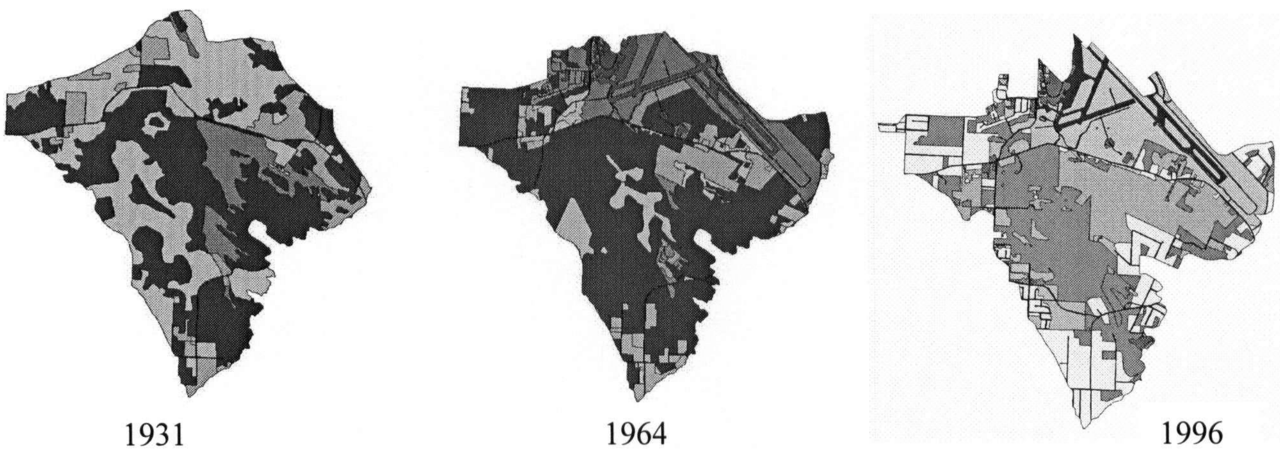


Figure 12. Land-use changes over time in the Queen's Ditch watershed.

Both impervious surface area and channels increased with development of the watershed. Impervious cover increased to over eleven percent by 1996. This level of impervious cover has been shown to result in decreased stream biodiversity and negatively impact stream habitat (Booth 1991, Schueler and Galli 1992). Channel density also increased significantly from 0.5 km/km^2 in 1931 to over 5.2 km/km^2 in 1996. Plotting impervious area against channel density (as described in Chapter 2) indicates that the Queen's Ditch watershed is rated as 'Fair' for hydrological health (Figure 14).

Impervious and forested areas used in the land-use analysis (see Chapter 4, pg 14) were based on the following ratios. Industrial, urban, rural residential, and roads themes had roughly ninety, forty, ten and 100 percent impervious area respectively. Urban, rural residential, and forests had roughly five, seventy and 100 percent forested area respectively. The remaining area was classified as grass cover.

An examination of the soil distribution of the Queen's Ditch watershed indicates that there is a surficial peat layer that varies in depth from 3 to 5 metres in the low-land area of the watershed (agricultural lands). Much of the water that falls on the upper part of the watershed (recharge zone) infiltrates into the ground and does not contribute to stormwater production.

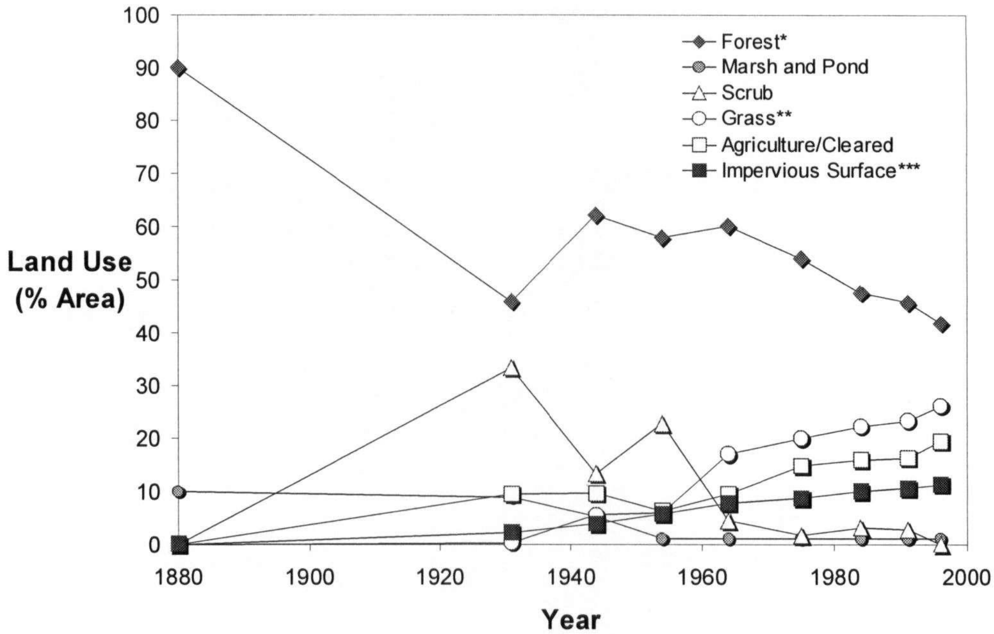


Figure 13. Land-use changes within the Queen's Ditch watershed, from 1880 (estimated) to 1996.

Hydrologically, the watershed has gone from being a very slow system, where much of the stormwater is absorbed and slowly released from large wetlands, to a very fast system, designed to transport water quickly and efficiently from areas of stormwater production to the system outlet. The watershed will continue to be affected by larger than normal flows and stream velocities as a result of development.

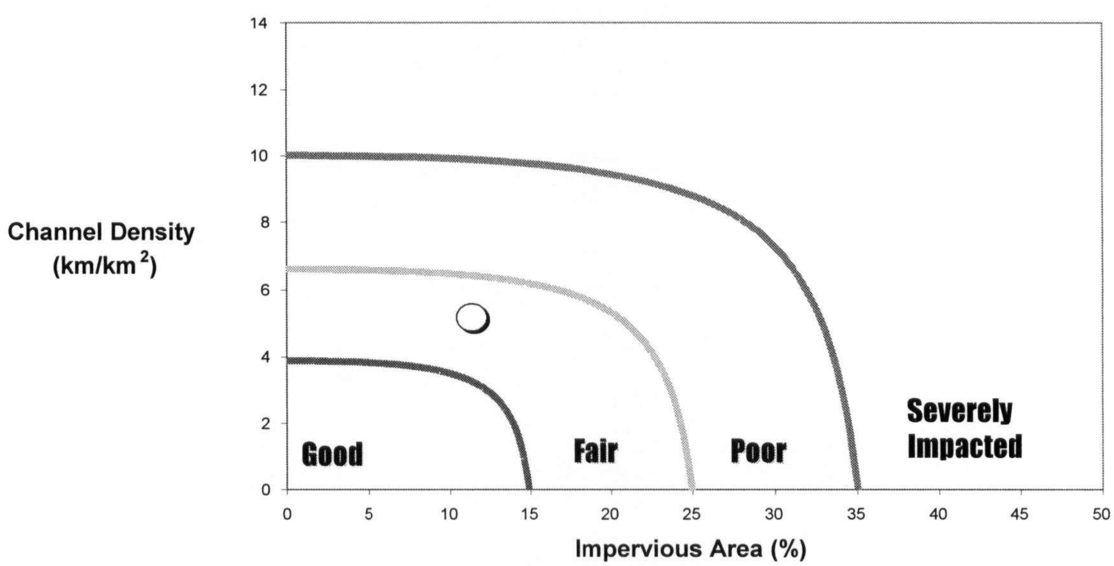


Figure 14. Hydrological health of the Queen's Ditch watershed based on 1996 land-use and channel information.

Sub-Watershed Assessment

Hydrological assessment of the watershed at the sub-watershed level was undertaken to help identify and prioritize areas for conservation, development and restoration. The watershed was divided into nine discrete hydrological units or sub-watersheds, ranging from 60 to 377 hectares (Figure 15). The assessment is based upon the 1996 land-use and channel patterns, but the scale of analysis is almost an order of magnitude smaller than in the full watershed assessment.

Analysis of the sub-watersheds indicates that there is a large variation in impervious area and channel density within the Queen's Ditch (Figure 16). Impervious area ranged from 2.6 to 45.8 percent and channel density from 2.0 to 12.1 kilometres of channel per square kilometre of land (for sub-watersheds six and seven respectively). Only two of the sub-watersheds were found to be in good hydrological health (Figure 17). Agrcultural land and forests dominate these units. Sub-watersheds one, five, and six were the most severely impacted. Much of units five and six is CFB Comox, with paving, built structure, and associated stormdrains. Unit one however is relatively pervious and pre-dominantly rural in nature. High channel density in this sub-watershed poses a stormwater problem.

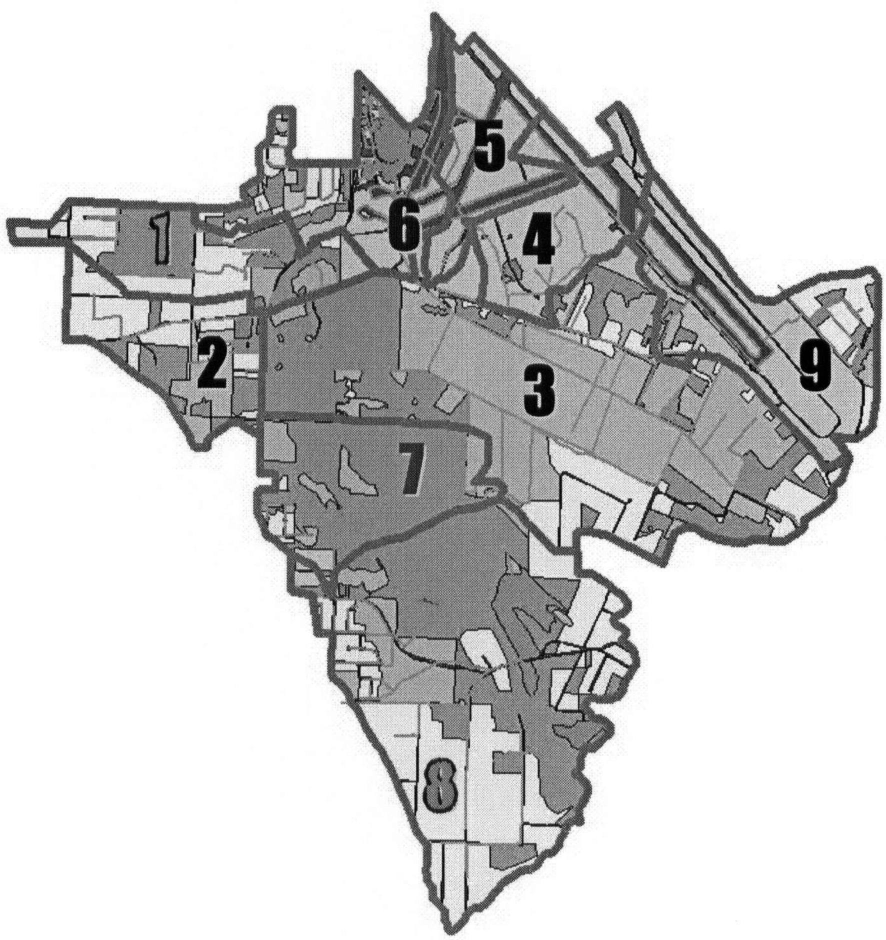


Figure 15. Hydrolgically discrete sub-watershed areas used to assess hydrological impacts within the watershed, 1996 land-use and channel data.

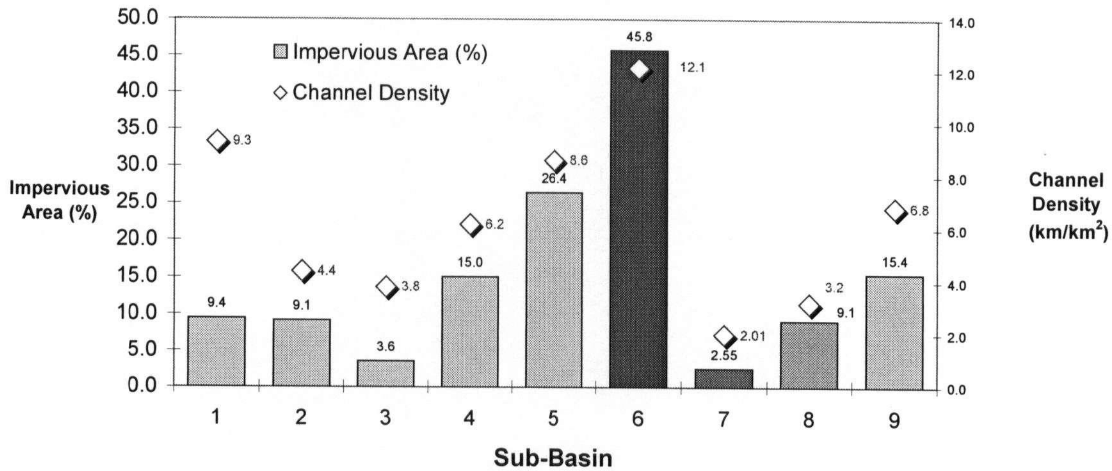


Figure 16. Impervious area and channel density for the nine sub-watersheds of the Queen's Ditch (1996 data).

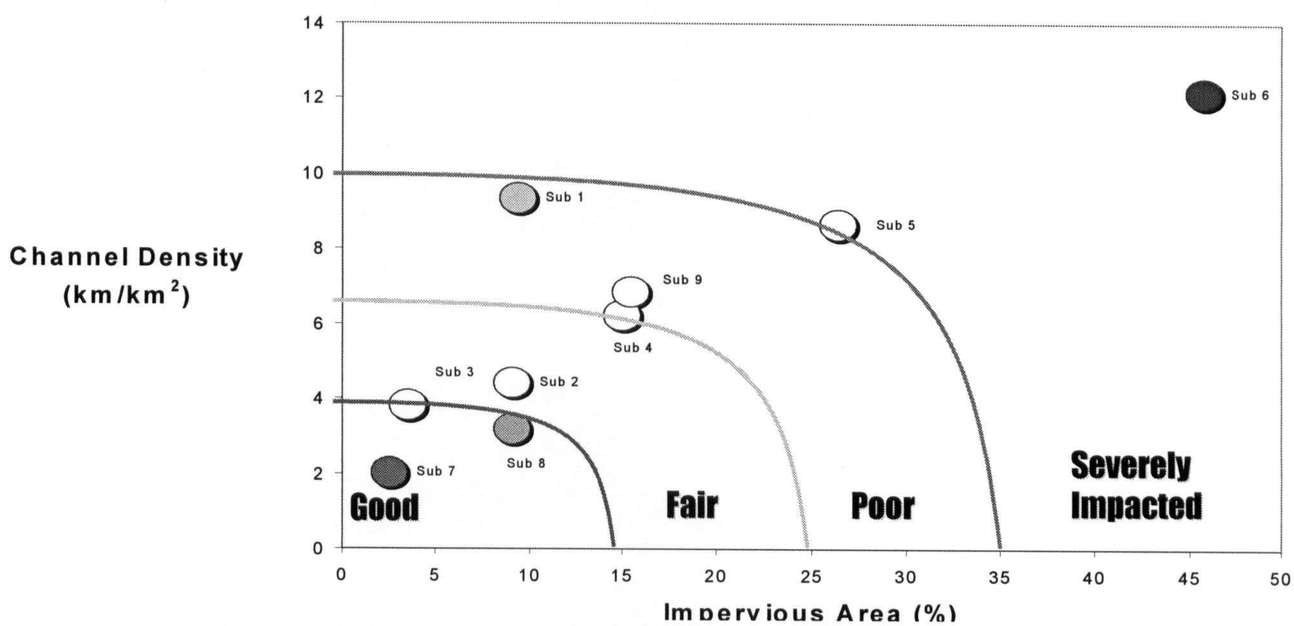


Figure 17. Sub-watershed hydrological conditions for the Queen's Ditch (1996 data).

These estimates of the hydrological condition of the sub-watersheds help determine planning options for future development. For example, if a limited amount of funding were available for stormwater mitigation, it would be appropriate to concentrate work on sub-watersheds two, three, and eight. Although these are within the good to fair range, with a small amount of investment their hydrological condition could be improved. There is a high probability of success that these sub-watersheds could be "shifted" to good, or even very good condition, compared to the probability of doing the same for sub-watersheds five or six. Sub-watershed six is so severely impacted that remediation is not feasible. Instead, efforts should be made to mitigate water quality in this basin.

Sub-watershed eight has the same amount of impervious area as number one but its channel density is three times greater. Sub-watershed eight would tend to flood more frequently with higher peak discharges than unit one. These floods would cause significant channel erosion and damage to downstream habitat. Rehabilitation in this area should focus on disconnecting roads and houses from ditches through the creation of several strategically located infiltration ponds. These ponds will slow water velocities, increase infiltration, and increase aquifer recharge, resulting in less erosion to downstream channels. The same intervention could be used to improve the hydrology of sub-watersheds two and three.

The sub-watershed assessment also provides information valuable to future land-use decisions in the Queen's Ditch watershed. For example, sub-watershed seven is a good candidate for conservation measures as it is the least impacted sub-basin. These might include stringent development standards (see Design Phase) or outright protection. Schueler (1995) has proposed that new development should be concentrated in areas with altered hydrology rather than existing natural areas. As the Official Community Plan (OCP) indicates, extensive development planned for sub-watershed seven. This plan should be re-examined in light of these findings.

Chapter 6: Site Design

Two development scenarios, conventional and sustainable (or green) development, were used to assess stormwater management practices and urban design in sub watershed 7.

Conventional Site Design

The conventional design (Figure 18), including road alignments, zoning and density, was obtained from the Town of Comox OCP (Town of Comox 1997). The OCP indicates the study area is zoned for two schools; however, one of these schools has since been built outside the study area. For the purposes of this project, the land that was allocated to the school has been reallocated to single-family housing.

The conventional design is built around existing property lines and a small buffer zone around the artesian Hilton Spring. Roads and paths are aligned north/south or east/west with no consideration given to the site's hydrological processes, topography, or vegetative cover. A piped stormwater system is super-imposed over the landscape (based on observations from other local developments). This stormwater system over-rides the natural hydrological processes of the site.

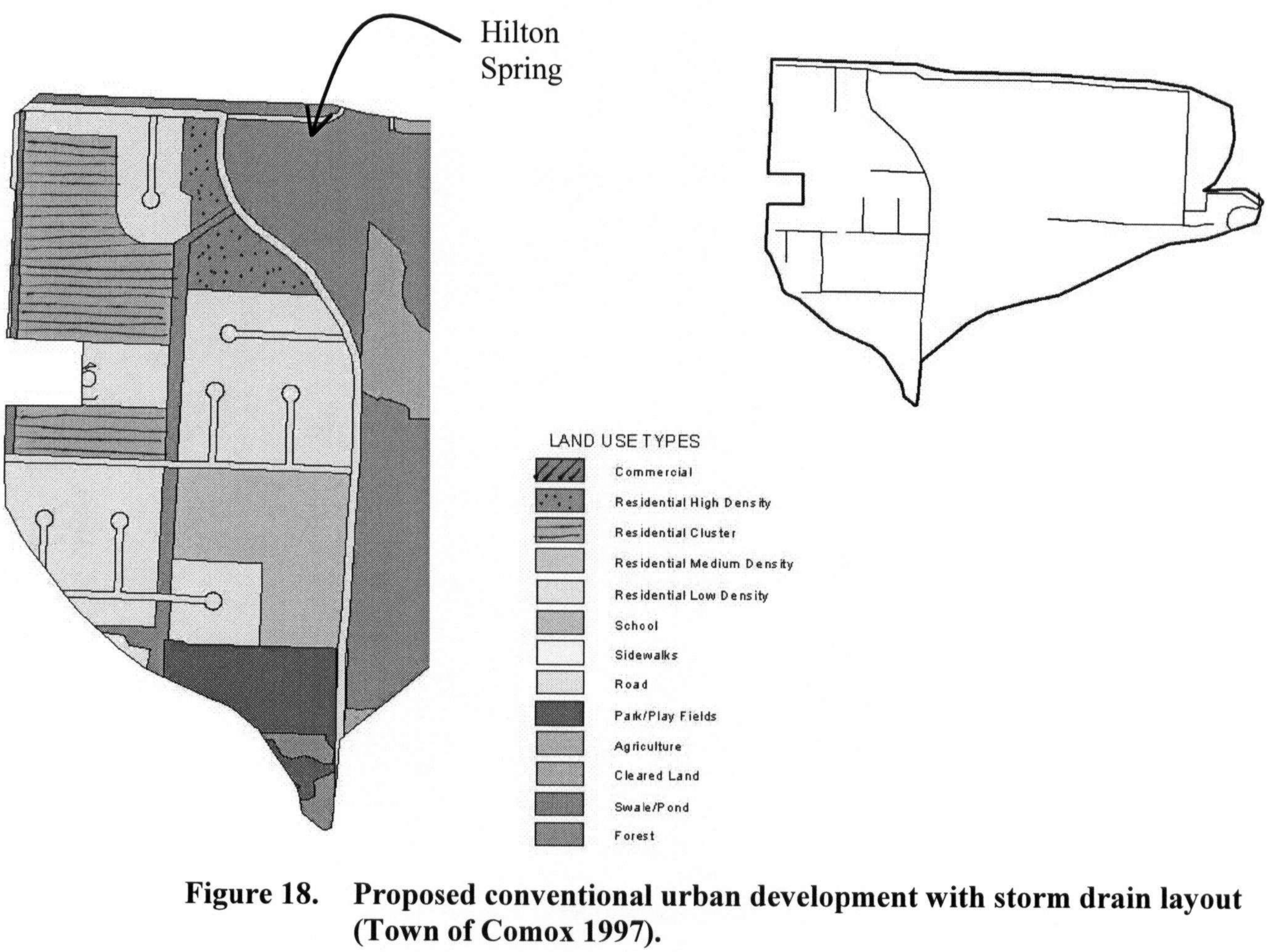


Figure 18. Proposed conventional urban development with storm drain layout (Town of Comox 1997).

If this design were fitted with an end-of-pipe stormwater detention pond, the pond would have to hold just over 6,300 m^3 of water to contain the 100-year storm event. The pond would be roughly 12,700 m^2 covering the equivalent of 10.4 single-family lots to a depth of half a metre of water. Obviously, this would be a significant economic investment.

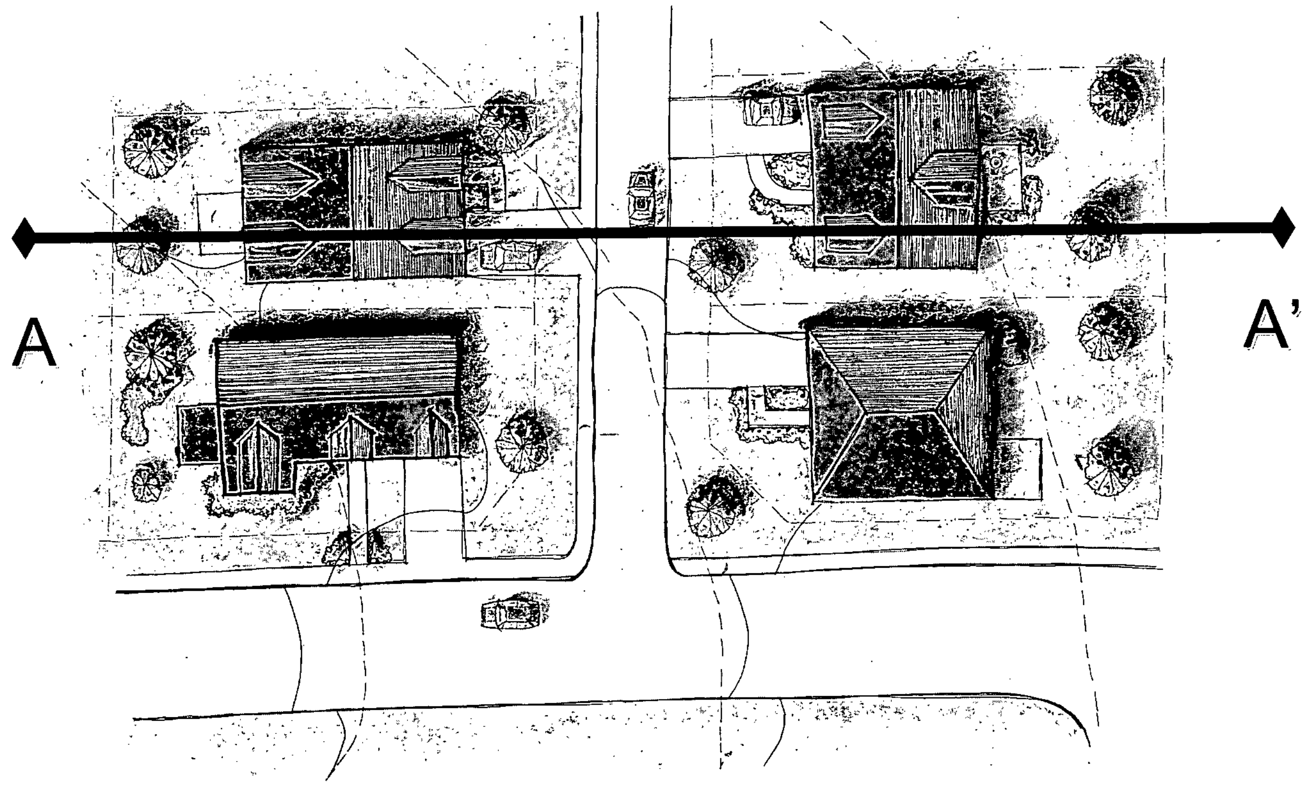
If the development proceeds like other existing developments in the area, forest cover would be removed prior to development and the site would be completely regraded. Excessive grading would obliterate all of the small surface depressions that, under natural conditions, store stormwater. The site would become a smooth, sterile, and somewhat static landscape. The hydrological processes of the site would be altered. Since the ecological systems depend upon the physical habitat and processes of the site, they too would be negatively affected. In essence the site becomes ecologically non-functional.

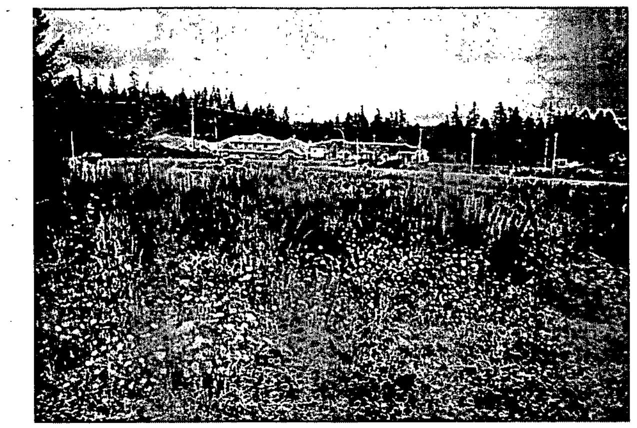
Structurally, the urban form is very weak with numerous dead-end roads, or cul-de-sacs, that limit movement through the site and that continue to encourage vehicular use. Circulation patterns are inappropriate for all modes of transportation, particularly for pedestrian and bicycles. The layout of the roads is based on existing property lines, rather than site conditions. Many of these roads are over eight percent gradient and would therefore not be universally accessible. In addition there is no community node or activity hub in this design. The nearest commercial area is over two kilometres away. This lack of proximity to commercial areas will continue to foster reliance on the automobile. Urban park space is also lacking, or isolated, from most inhabitants of this community. One greenway trail leads to a park in the north portion of the site however, very few dwelling units have direct green space access.

The design also lacks experiential qualities. Landscape processes have been manipulated to such an extent that the community is disconnected from the environment and the processes that shaped it. Because stormwater is hidden underground, the residents of this community will not be able to make the connection between their actions, and the environmental consequences. For example, few residents will realize that when they wash their car, fertilize their lawn, or change their car's oil, that they are contributing to water pollution just downstream.

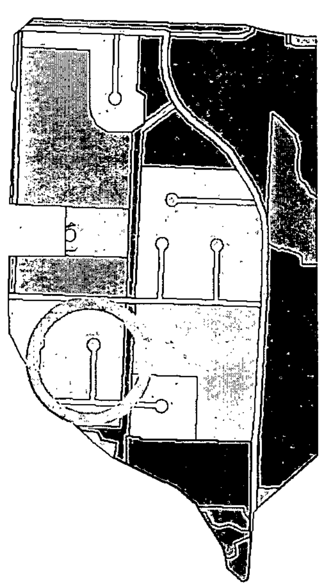
Within the area zoned for single-family residences, there is very little urban space that has been created (Figure 19). The large road widths and housing setbacks create a space that is neither aesthetic nor hospitable to people. The scale is too large and the landscape too barren. There is no surprise in this landscape. It seems that these spaces would be best experienced from a car moving quickly through the area. It is not a place of exploration or intrigue and definitely not a place for pedestrians. All of the forest cover has been removed with the exception of a few token trees left behind. High maintenance lawns and impervious, double car driveways have consumed much of the remaining landscape.

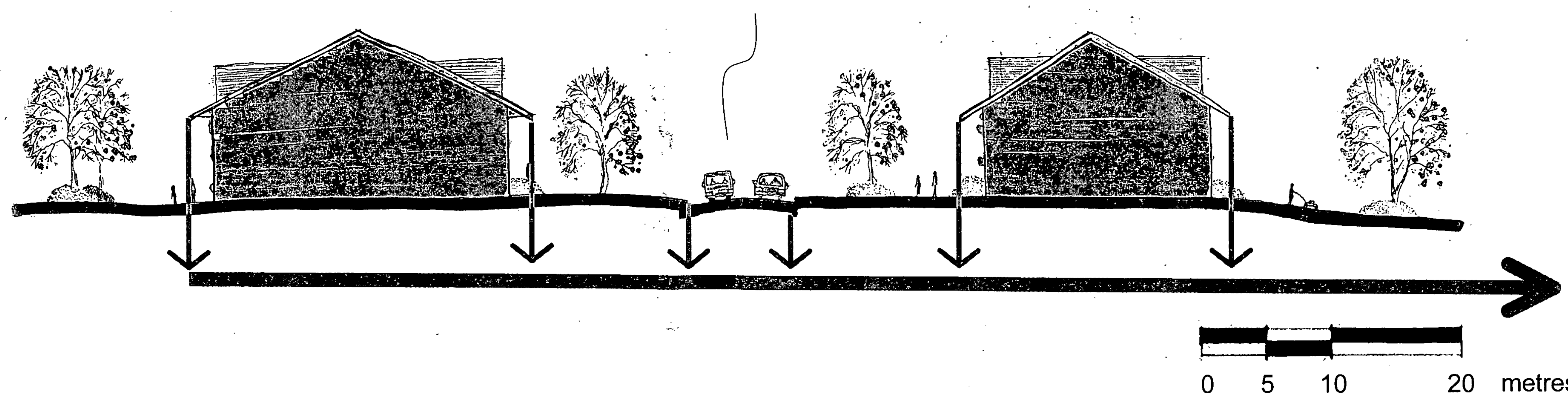
Ecologically, this form of urban development is a disaster. The natural hydrological processes have been replaced by a piped conveyance system. Storm drains quickly convey stormwater produced by the site to downstream channels. Water no longer infiltrates into the ground; instead, it is quickly removed via area drains, catch basins and drainage tiles. The polluted stormwater is conveyed untreated to downstream fish habitat. The increased frequency and velocity of peak flows generated by this form of development would degrade stream channels and fish habitat downstream of the site, decrease water quality, and decrease summer flows. The net result is a degraded ecological system that is not sustainable over the long term.





Large Set backs from the road creates “car space”. This is not a human space. It’s too wide and open.





Section A-A’ Typical Single family residential area in conventional sub-division

Figure 19. Single family development for conventional design with hydrological process map insert.

Sustainable Development Design

Site Layout and Design

The second design scenario is based upon a sustainable design approach that worked with the site's natural processes and features rather than replacing them with super-imposed engineered systems (Figure 20). The design, which includes single-family residences, cluster development and commercial-urban development, addresses both the urban form and the natural site processes, achieving a sustainable solution. Topography, vegetation cover, hydrology, soils, urban form and structure, circulation, and connection to green space were all factors which influenced the design. A summary of the land-use and hydrological statistics can be found in Table 2 (see page 38).

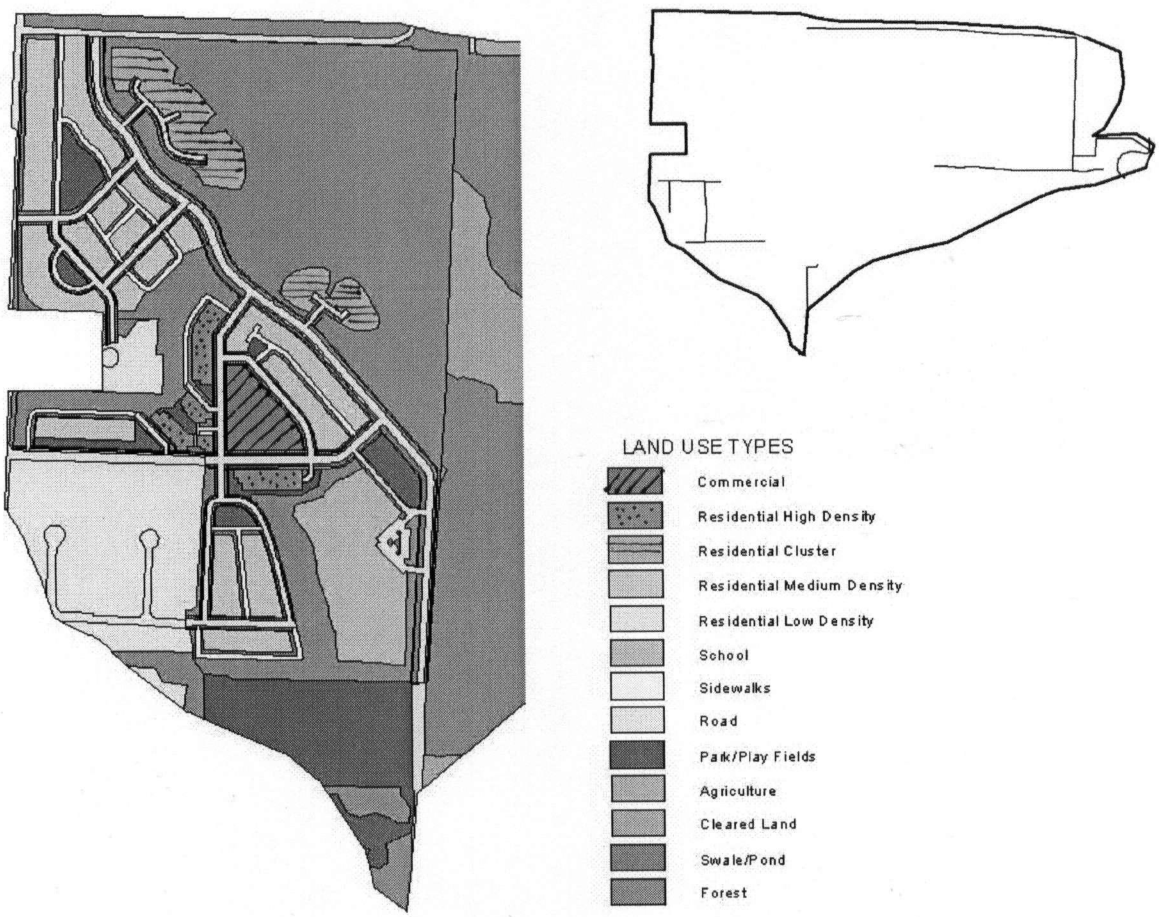


Figure 20. Proposed sustainable urban development plan and stormwater system.

Topography

Site topography plays a significant role informing site design. Roads have been designed to run along the upper contour of several steep embankments (Figure 21). Locating the roads here helps preserve these steep landforms and also helps maintain road gradients at less than eight percent. Furthermore, by pitching the road surfaces in the up-slope direction, the roads can be used as interim detention ponds (Figure 22). The steep, continuous slopes to the east of the site are not developed because of steep slopes as well as high spring and seepage activity.

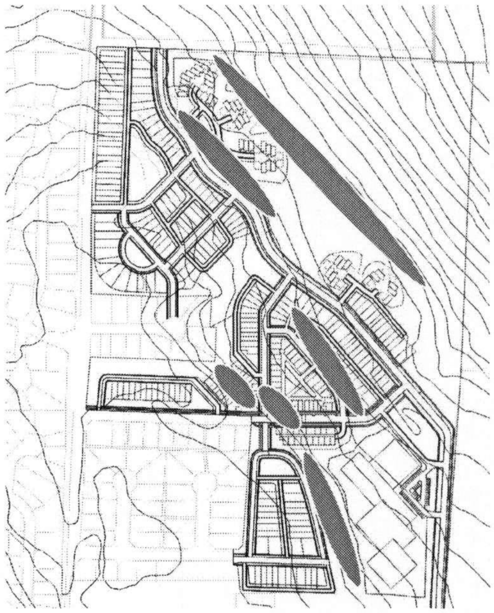


Figure 21. Steeply sloped embankments in the study area.

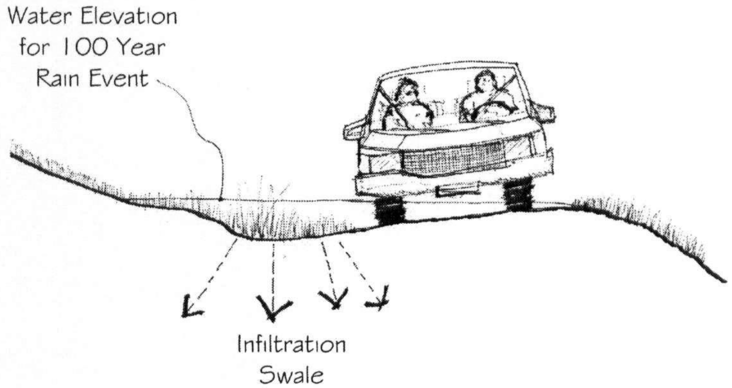


Figure 22. Road section showing water retention and infiltration functions.

Vegetation Cover

The site is currently covered with mixed-age stands of Douglas fir and alder, abandoned fields that have been taken over by scotch broom, and cleared land which marks the location of old gravel pits. Where possible, mature stands of Douglas fir are preserved as green space. Development that infringes upon this zone is limited to small cluster developments. The main road also passes through this forest area. Trees that needed to be removed have been replaced in order to meet a goal of twenty percent canopy cover in the development. In addition, regrading has left small depressions that are designed to store stormwater. These take the form of stormwater gardens, park and school stormwater infiltration areas, and bioretention areas.

Hydrology and Soils

Hydrologic zones were assessed but it was impossible to map ground water or aquifers. The proposed development lies within the recharge zone (Figure 23) and sits upon moderately permeable Bowser and Dashwood soils, consistent with the hydrological soils group B (USDA 1986). Channels were not present in the study area even though the site experienced a 1 in 200 year flood event in 1998. Since the last glaciation event, about 8,000 years ago, the area would have experienced about 40 such storm events. There would be physical signs including small channels or eroded surface materials if these storms generated surface flow. Since there is no evidence of erosive flows we can assume that all of the water that falls on the site is infiltrated. The only flowing water observed was from Hilton Spring, a small artesian spring with a flow of just under 0.1 cubic metres per second (Figure 24), and from another seep located 200 metres east of the site.

Discrete hydrological units were used to assess stormwater production and to design spaces for it to be infiltrated at the site. The premise of the design is that all stormwater produced at the site should be treated at the place it is produced. Only the largest flows are redirected to nearby park spaces when retention capacity is surpassed, but in no circumstance is stormwater piped off-site. In addition to performing an important hydrological function in the watershed, these stormwater infiltration systems are also designed to help link the community to the landscape and to educate people about landscape processes.

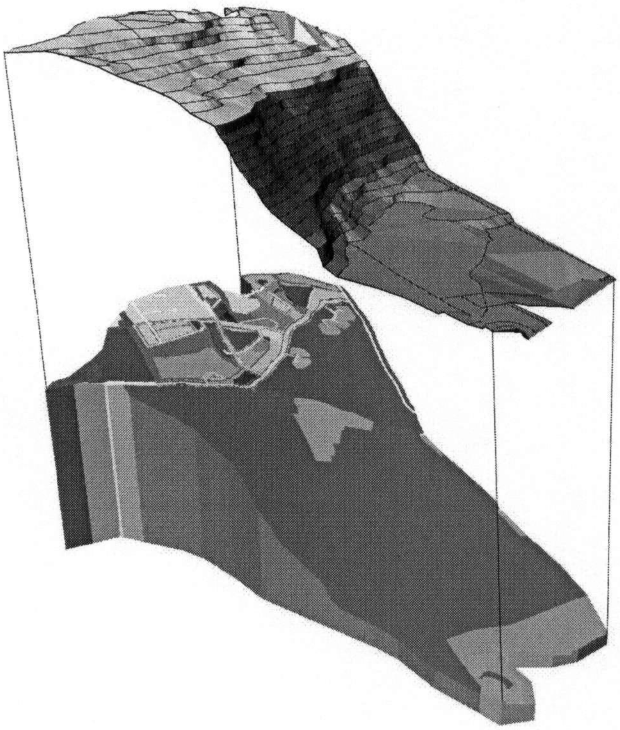


Figure 23. Site design and sub-watershed hydrological processes.

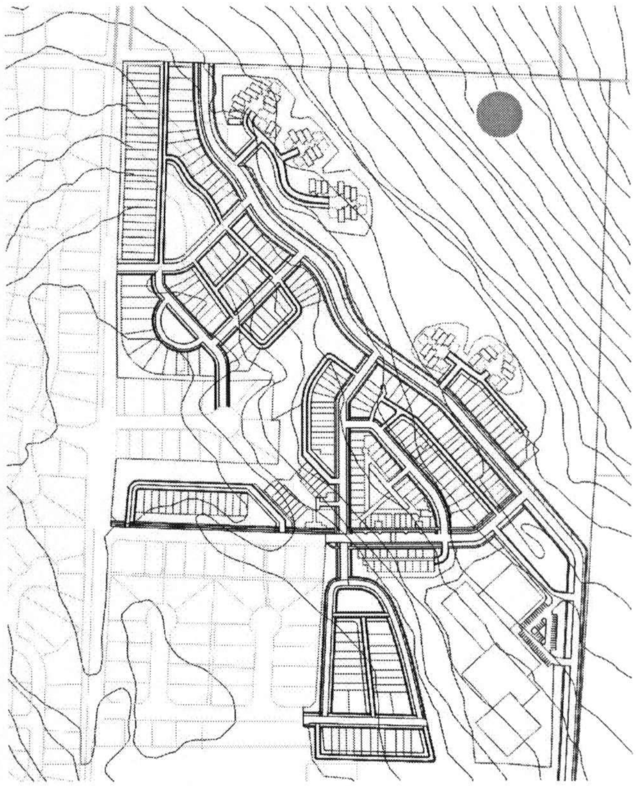


Figure 24. Location of Hilton Springs.

Urban Structure

The urban structure is partially based on the physical characteristics of the site as previously mentioned. Other guiding principles, or features of sustainable designs, that are incorporated into the design are: increased urban density; pedestrian and bicycle connectivity; decreased automobile reliance; and, community access to commercial/work-office space. About ninety percent of the new development lies within a fifteen minute walk (400 metres) of the community node and all of it lies within a 10-minute bicycle ride (Figure 25). According to Condon (2001) this can significantly reduce the number of automobile trips in the community, thereby reducing fuel consumption and greenhouse gas production. The existing development around the site has also been provided with increased access to open space and the commercial centre. In the sustainable design there are no new dead-end streets. In fact, one of the existing cul-de-sacs has been connected via a road into the new development.

Circulation

The development's circulation system is built upon the notion of accessibility, connectivity and spatial hierarchy. The trail and street pattern work together to increase pedestrian and bicycle connectivity within, and outside, the new design community. As previously mentioned, road gradients are less than eight percent, providing universal accessibility. Through streets are the widest (nine metres with additional parking on either side), queuing streets are four metres wide, with additional parking on each side, gravel alleys are four metres wide, and gravel trails are two metres wide. In all design schemes the roads perform several functions in addition to transportation. They also function as water-damming devices to hold back stormwater. This water is infiltrated by associated swales along the road, and in stormwater gardens. Alleys serve as pedestrian walkways and are connected to adjacent trail networks

Figure 25. Fifteen-minute pedestrian walking distance from the commercial node of proposed and nearby developments.

Parks

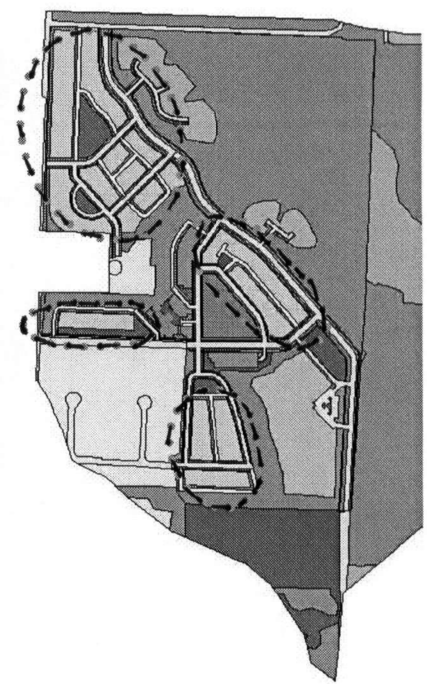
In addition to greater access to open space, there are more urban park spaces in the sustainable design. These parks serve several purposes, including social gathering places; recreational spaces, and, infiltration basins for larger storm events. Most are located at the downstream end of the smaller hydrological units in the development, where they can receive and infiltrate stormwater.

Three development types

The design phase of the project continued as an exploration of three urban development types to assess stormwater management problems in a variety of urban design situations. These types were: 1) single family; 2) cluster; and, 3) mixed urban-commercial development. Differing stormwater management issues and site characteristics resulted in a different solution for each development type. The following sections outline principle design issues and general stormwater management goals for each development type.

Single Family Development

Single-family units account for about sixty percent of the residential dwelling units in the new sustainable design (Table 2, pg 38). They are situated in areas with less than fifteen percent gradient, on previously cleared land or areas of young forest. The sustainable design contains a total of 134 single-family dwelling units with an average lot size of 290 m^2. These lots are about seventy five percent smaller than single-family units in the conventional design and building footprints are similarly reduced. Impervious area of the house, garage, and driveway ranged from 113 m^2 to 150 m^2 in the sustainable design compared to 297 to 443 m^2 in the conventional scenario. Housing densities of thirty four dwelling units per hectare are significantly higher compared to eight dwelling units per hectare in the conventional design.



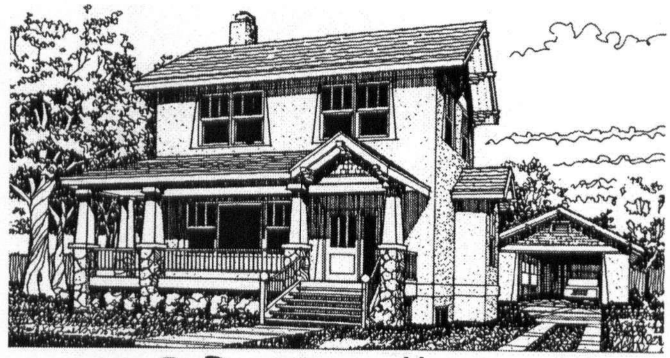
Single Family Development Areas.

The rural character of the site was maintained even at these higher densities. Rural aesthetics were maintained by incorporating appropriate housing architecture styles and landscape design. All buildings are constructed in the craftsman style (Figure 26) to reflect the design of older buildings in the area. Small gravel alleys and narrow, tree-lined roads calm traffic while still maintaining rural character (Figure 27). Limiting curbed roads to the core commercial area distinguished the commercial core from the surrounding residential areas. Rather, residential streets and alleys slope towards open swales and bioretention gardens. Sidewalks are present along both sides of all paved roads but not along alleys.

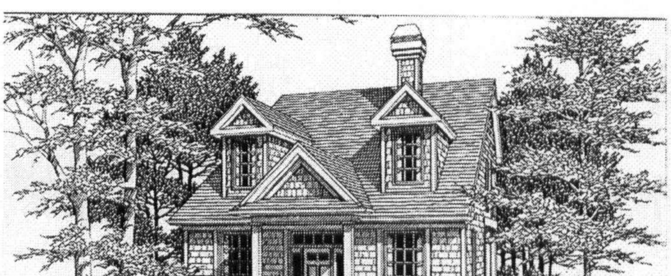
Social interactions between neighbours should be higher than in a conventional development since narrow roads and small front yard setbacks encourage social interaction (Alexander et. al. 1977). Higher densities will also contribute to increased social activity.

Each single-family dwelling is part of a neighbourhood stormwater management unit (see stormwater process diagram Figure 27). Stormwater produced at the site is managed at the site (Figures 27 and 28). Runoff that is generated at each home is directed to an infiltration stormwater garden (Figure 29) or a soak-away pit (Figure 30). These will treat the first 13 mm of rain, considered to have the highest contamination load. In heavier rainfalls, excess water will flow to the road and infiltrate into the associated swale. The road and swale are designed to create a small catch-basin to slow the downstream movement of water and allow it time to infiltrate (Figure 28). Although portions of the road will experience puddling during heavy rain events, there will be no risk of flooding to local houses. All of the water that is produced is infiltrated at the site. Impacts to downstream stream habitat will be much reduced. In addition, the stormwater generated will recharge the local aquifer, that will feed streams during low flow periods. The design has taken stormwater, considered to be waste by many, and turned it into an ecological resource.

3 Bedroom house
8 metre lot



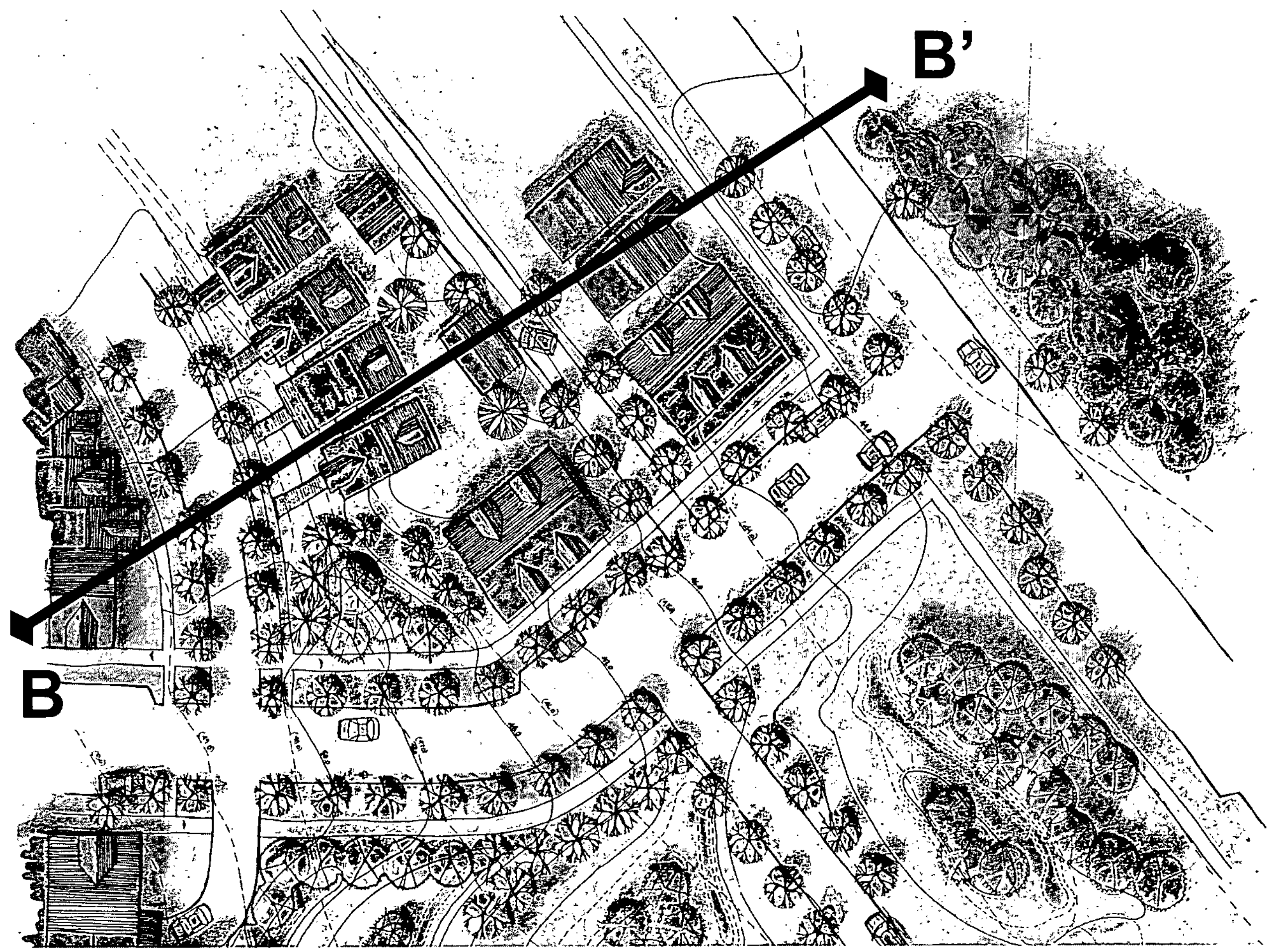
3 Bedroom House
10 metre lot



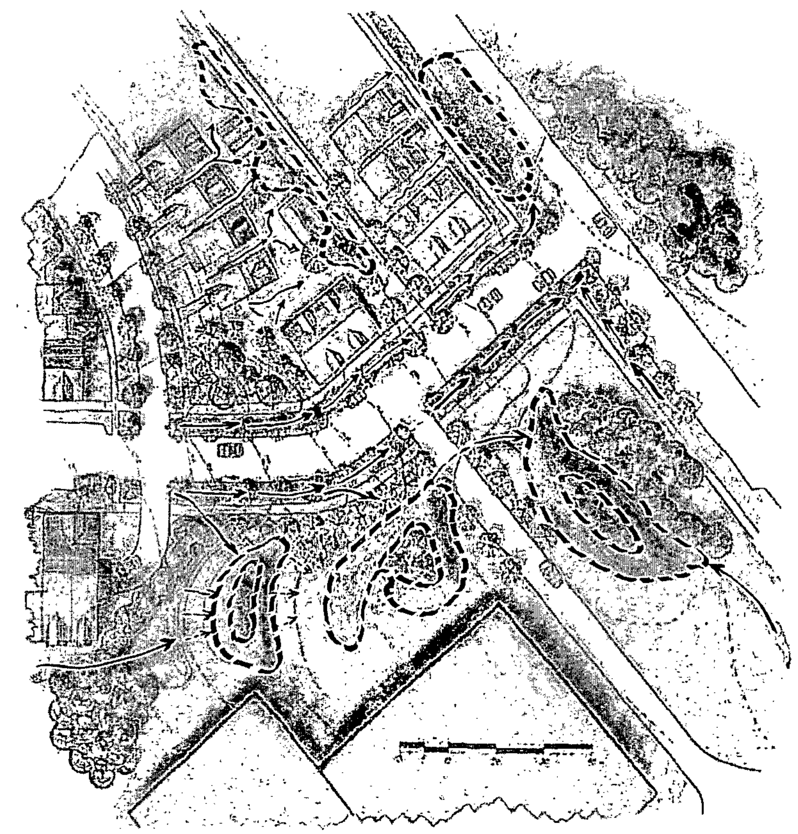
3 Bedroom House
10 metre lot

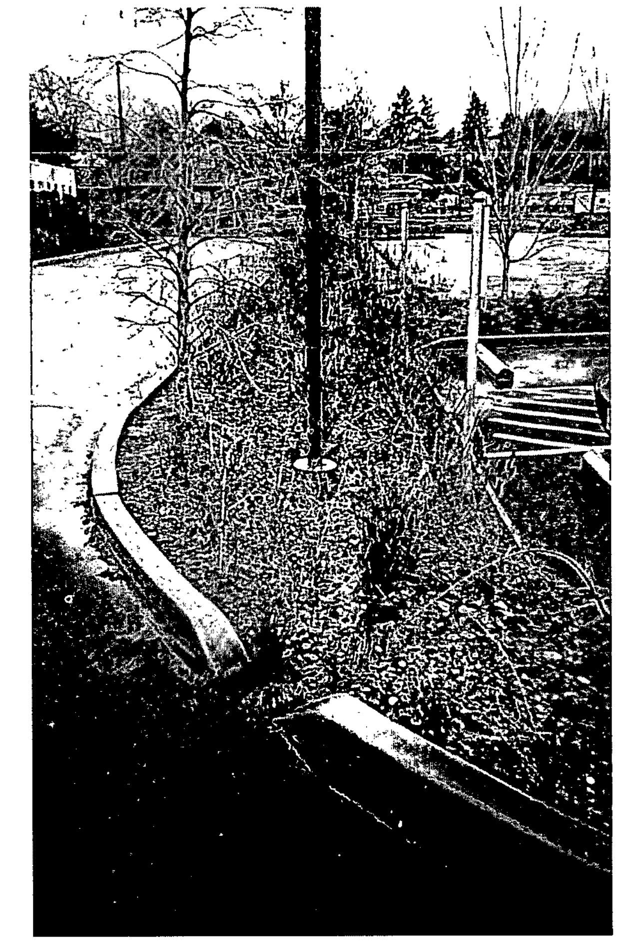
4 Bedroom Duplex
15 metre lot

Figure 26. Examples of architectural style for proposed single-family dwelling units.

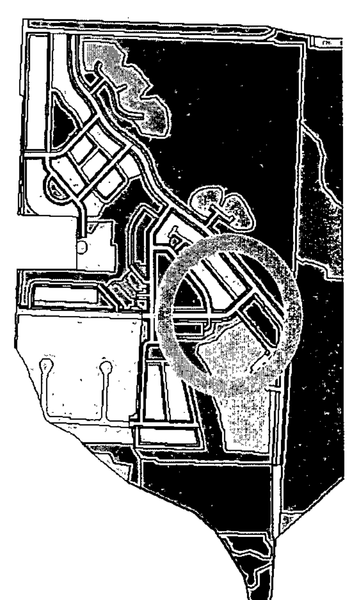


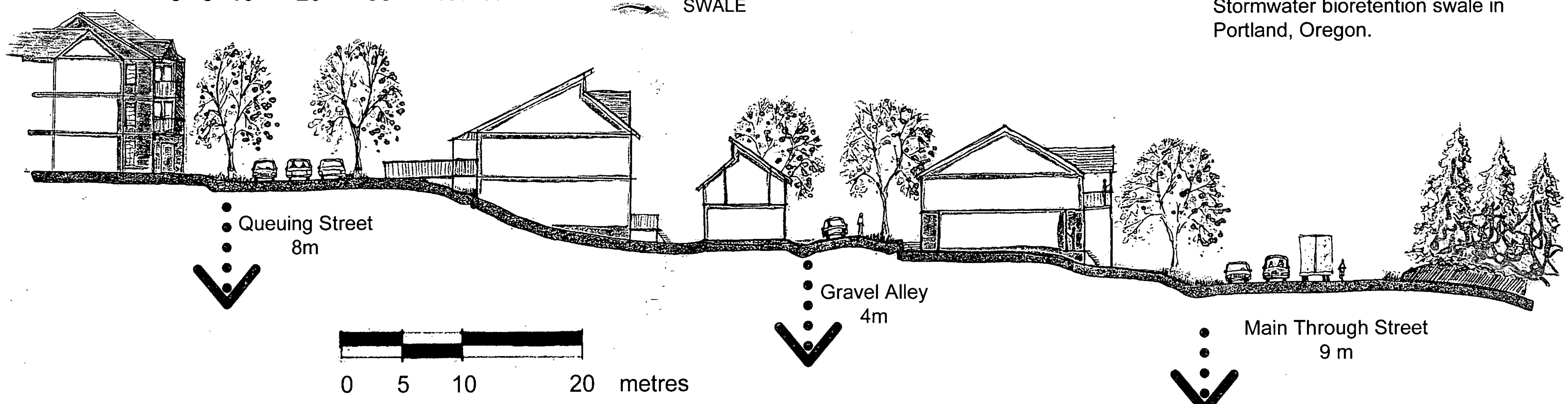
Stormwater Process Diagram





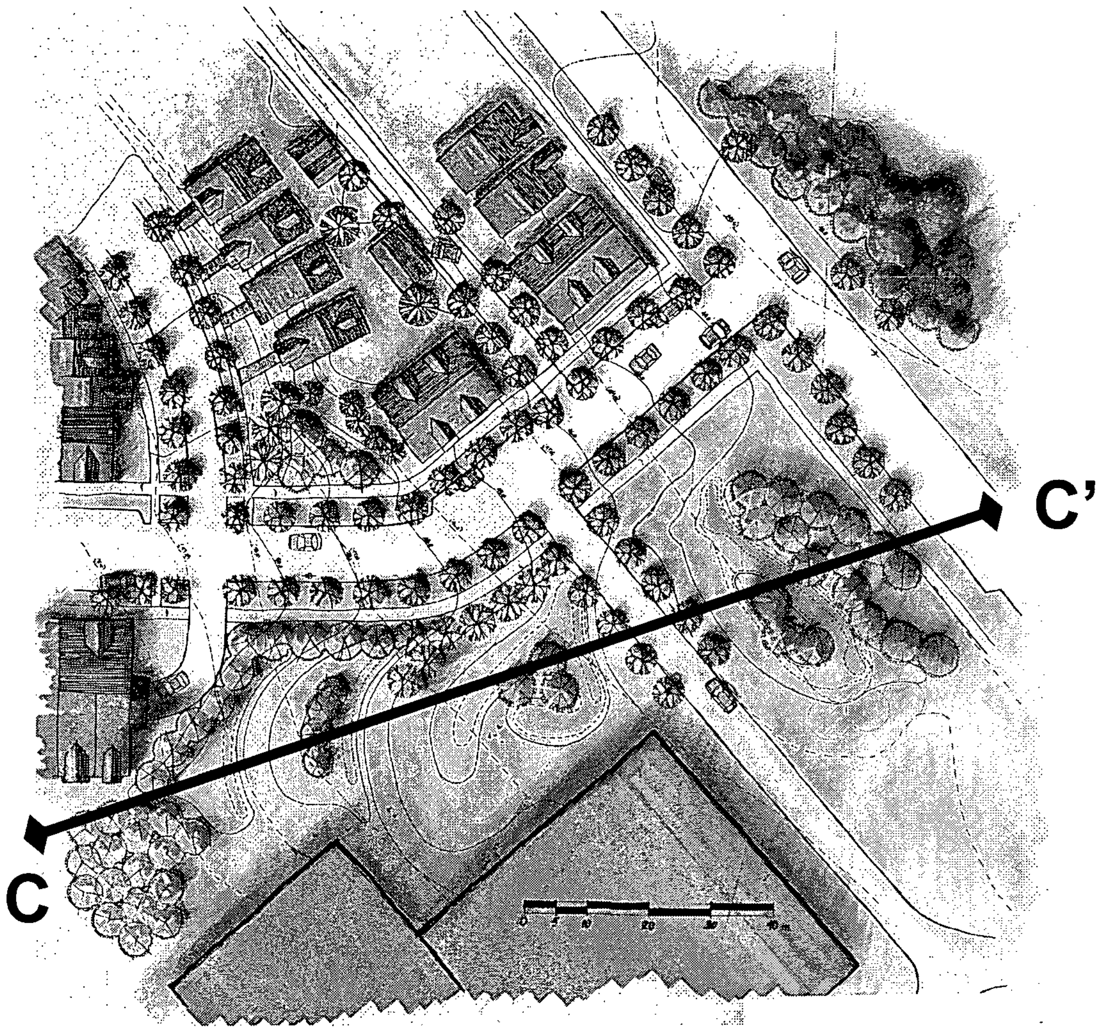
Stormwater bioretention swale in Portland, Oregon.

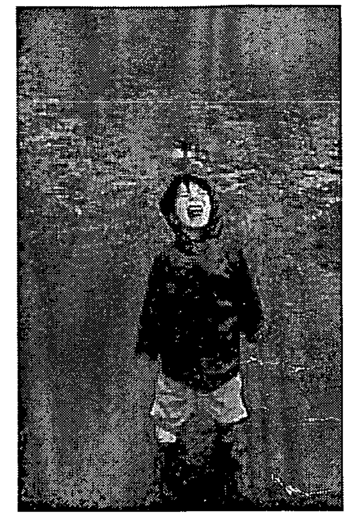


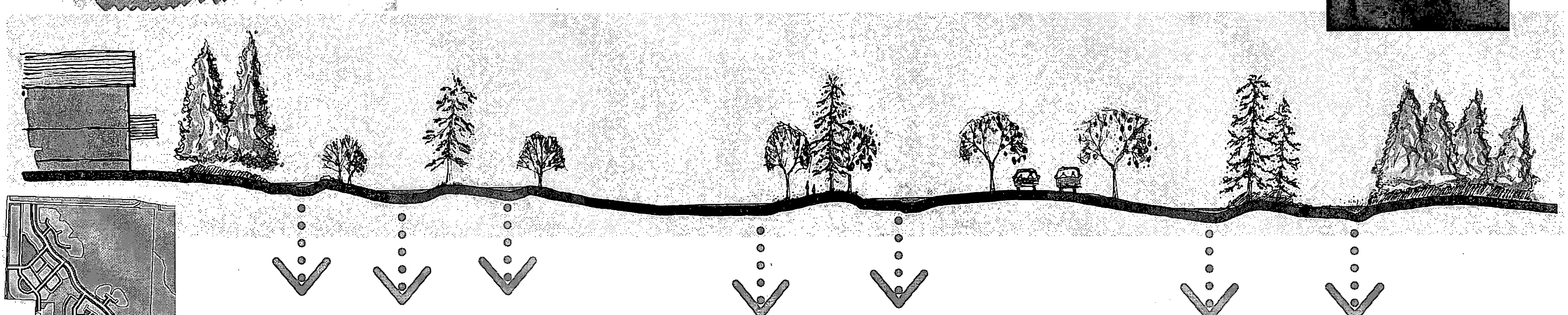


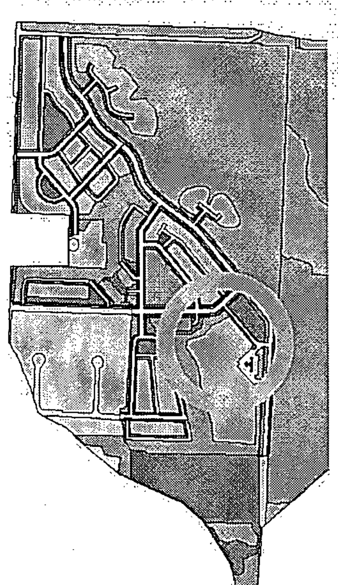
Section B-B' Single-family development stormwater system.

Figure 27. Typical single-family neighbourhood design.









Section C-C' School infiltration play-ground

Figure 28. School yard infiltration system associated with single-family neighbourhood.

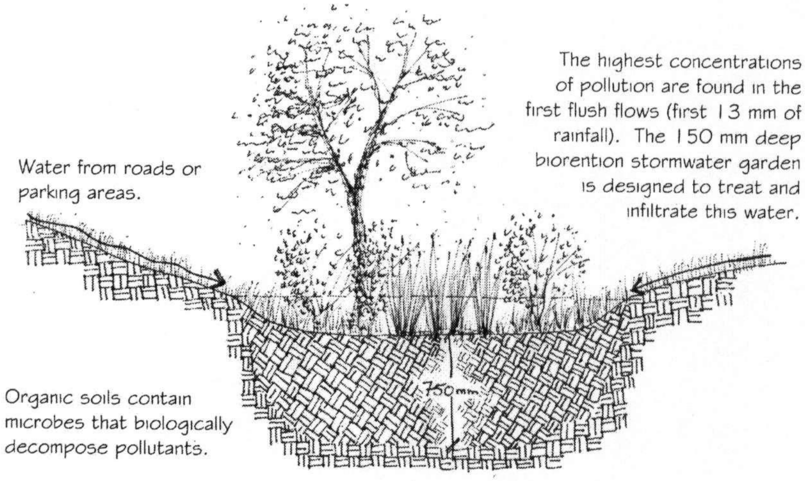


Figure 29. Stormwater bioretention garden.

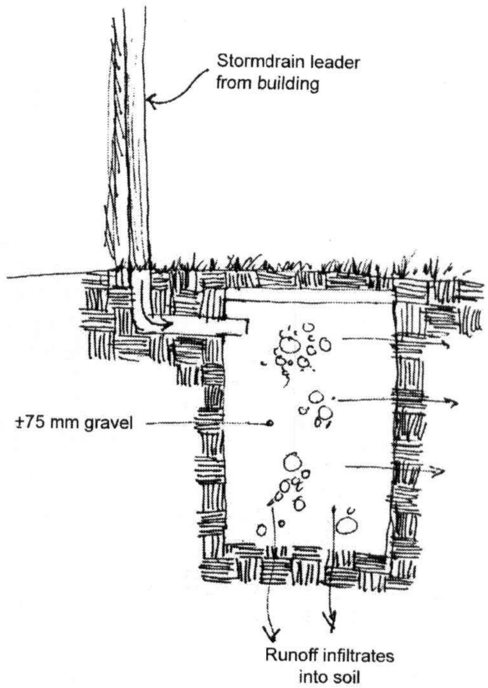
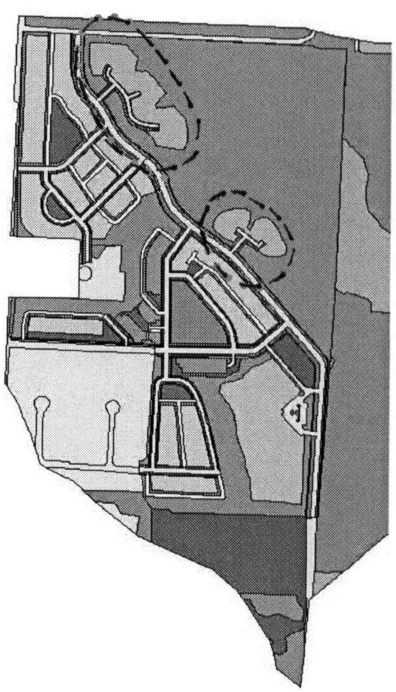


Figure 30. Stormwater infiltration dry well.

Cluster Development

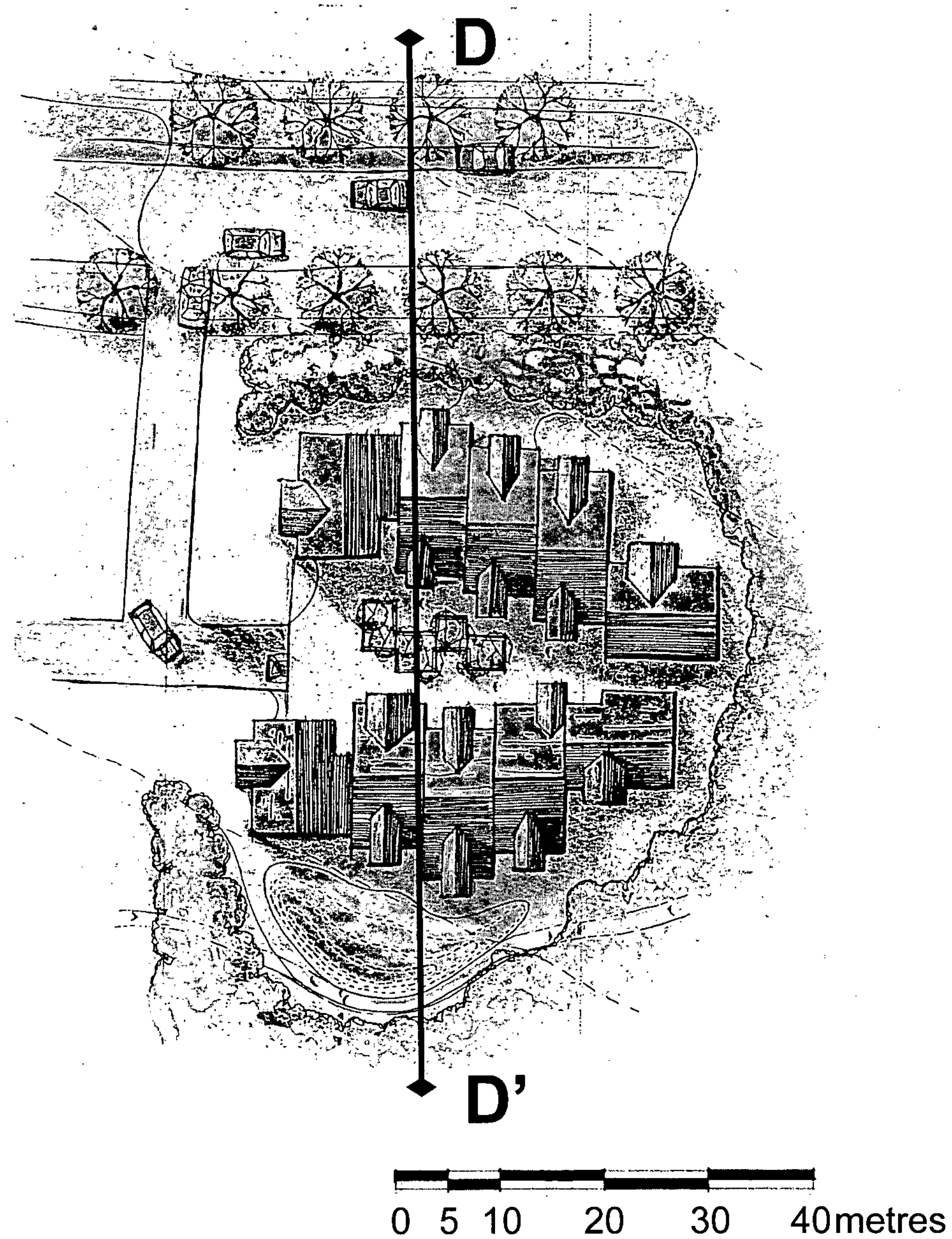


Cluster development areas.

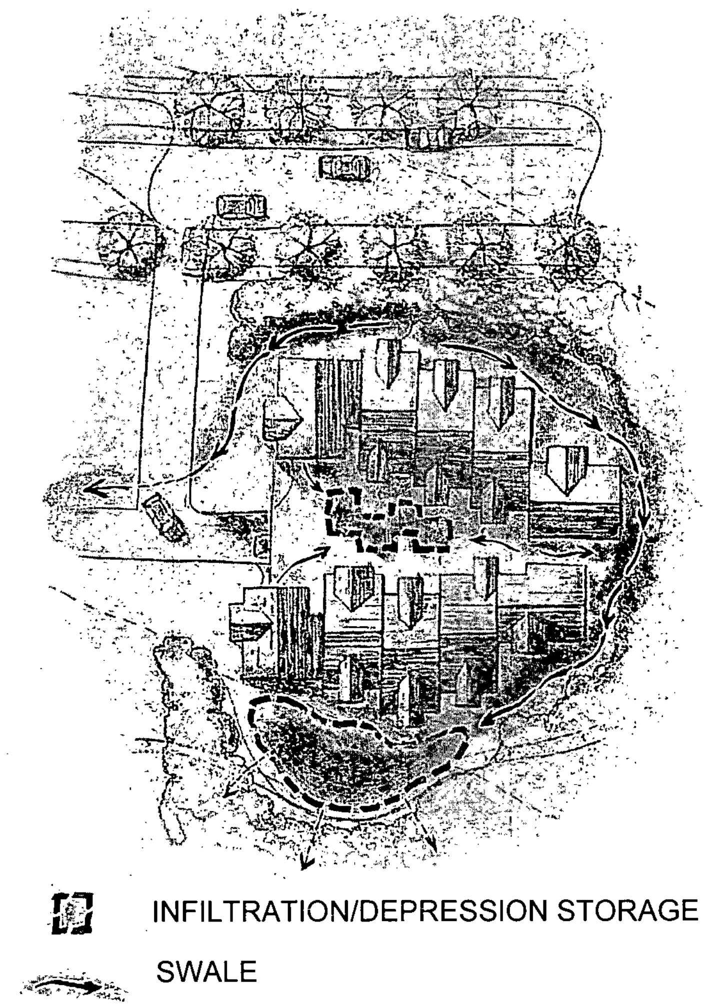
Cluster developments are situated in ecologically sensitive areas such as areas with mature forest cover, near sensitive habitats, or along visually sensitive corridors. Cluster developments reduce impacts to these types of areas when compared to single-family homes. Per dwelling unit, cluster development reduces impervious surface area, site disturbance, grading, land consumption, stormwater production, and pollution.

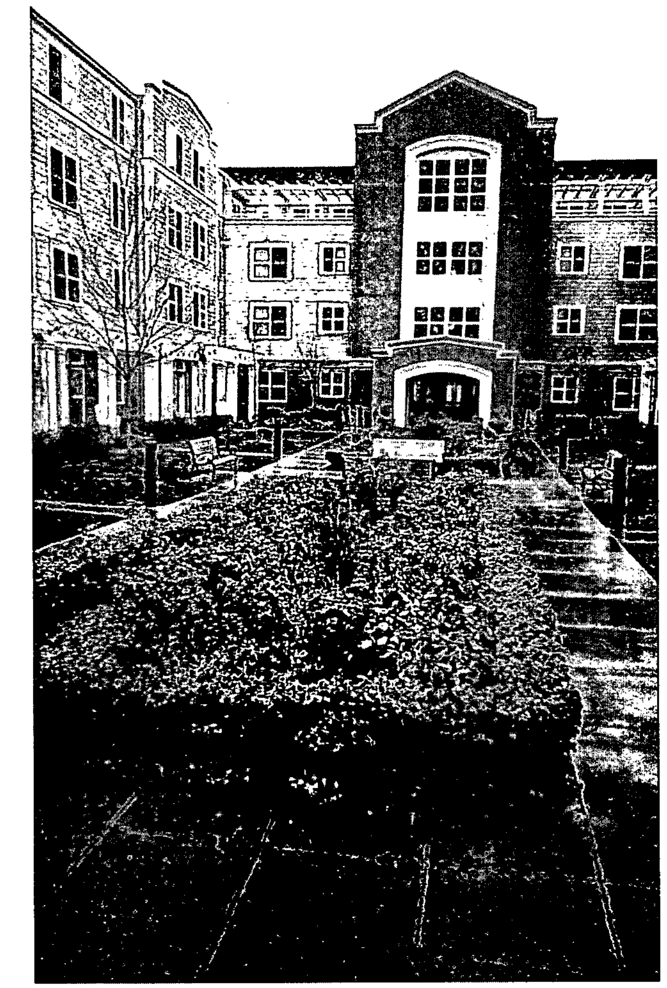
In addition, this form of housing creates a social cluster, providing space for people to meet and interact. All buildings face a common, central courtyard. Private or semi-private space is provided at the back of each unit, facing the forest. Trails to the commercial centre and nearby woods connect residents to the larger site context.

Stormwater produced at the site is managed via two types of infiltration systems: a stormwater garden and an infiltration pond (Figure 31). Water that drains towards the centre of the complex is directed into a stormwater garden. Stormwater fills the garden during rain events, and then gradually infiltrates through the organic soils. The garden also functions as a biological pollution control mechanism. Pollutants are removed through physical and biological treatment processes by the plants and soil microbes (Prince George's County 1999). Soil micro-organisms decompose most oil products, reduce nutrient levels by forty to eighty percent, and remove almost all of the mercury and lead contaminants (Prince George's County 1999). A vertical infiltration column pierces the lower parking garage so infiltrated water can recharge aquifers below.

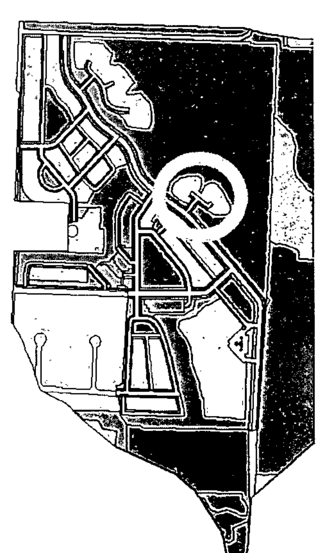


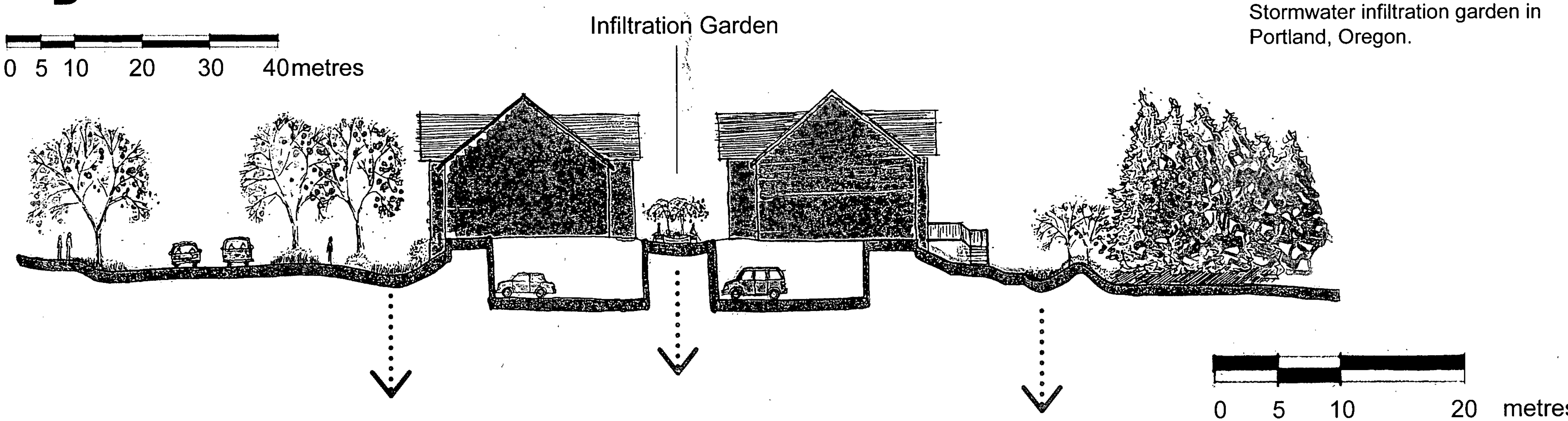
Stormwater Process Diagram





Stormwater infiltration garden in Portland, Oregon.





Section D-D' Typical cluster development with patio infiltration garden

Figure 31. Typical cluster development design.

Rainwater draining from roof surfaces is conveyed by swales to an infiltration pond. During severe storm events, excess water from the central rain garden will be diverted to the outer swale and pond system to reduce flood risk to buildings.

This pond is combined bioretention stormwater garden and infiltration trench. The lowest portion of the basin is a bioretention garden which will hold all rain falls less than one inch in twenty-four hours. Infiltration structures were tested by simulating a 100 year storm to measure their capacity to accommodate the runoff produced by such a rainfall. Additional forms of water storage were found to be necessary to contain the storm. Rather than building a large pond, which would use productive land, or deep ponds, which pose a safety hazard, the capacity was increased by designing an infiltration trench around the pond. A one metre by one metre trench filled with over 30 m^3 of gravel[1] generates an additional 12 m^3 of stormwater storage (Figure 32).

The inner edge of the infiltration trench is located at rim elevation of the ponded water created by the one-inch storm. The water level will rise above this edge during larger rain events and spill into the infiltration trench. The gravel infiltration trench is designed to detain and infiltrate flood runoff. Rapid infiltration of stormwater from larger rain events is desirable since this water is less polluted than first flush flows and the larger volumes are flood hazards.

When the designed ponds and gardens cannot contain the 100 year storm runoff, roads or parking areas will flood for a period of time until the water is able to infiltrate. Buildings did not flood in any of the design scenarios, under any conditions.

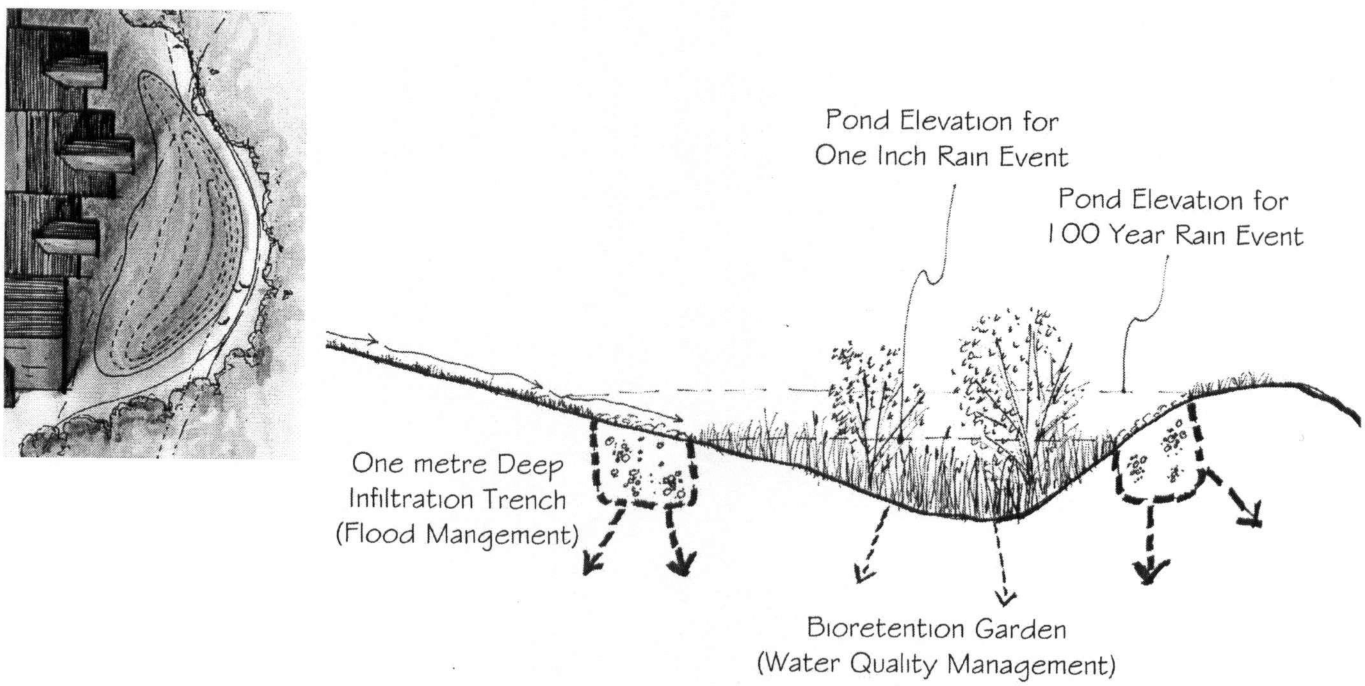
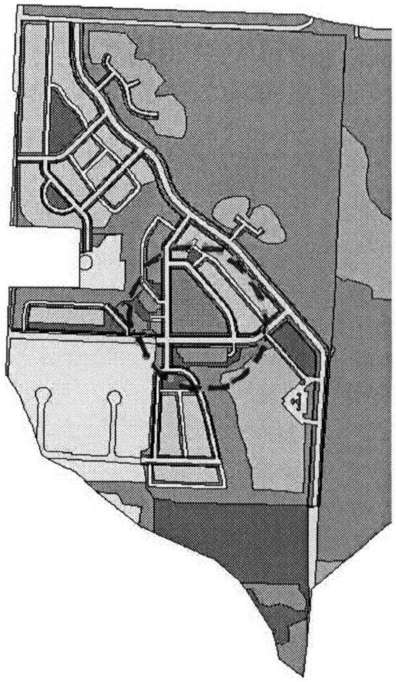


Figure 32. Infiltration pond designed to biologically treat first flush flows and infiltrate stormwater from larger storm events.

[1] ± 75 mm gravel has a pore space equivalent to about forty percent of the gravel's volume. In other words, a 10 m^3 pool filled with this gravel could hold 4 m^3 water before it over topped.

Commercial-Urban Development

Although placing the road and commercial area in this area resulted in significant site disturbance, this location is centrally located to all user groups. The centrally located commercial area is easily accessible by car, foot or bicycle from the schools, as well as from existing and new development. The commercial centre is a mixed-use area with stores and offices at street level and residential units above (Figure 33). The density of this development is not sufficient to support a large commercial area. In order to support more commercial and retail space, the density of the existing or sustainable design development would have to increase to the suggested forty dwelling units per hectare within a 400 metre radius of the centre (Condon 2001). Instead, the commercial centre will have more office space with additional retail phased in over time as needed.



Location of commercial node.

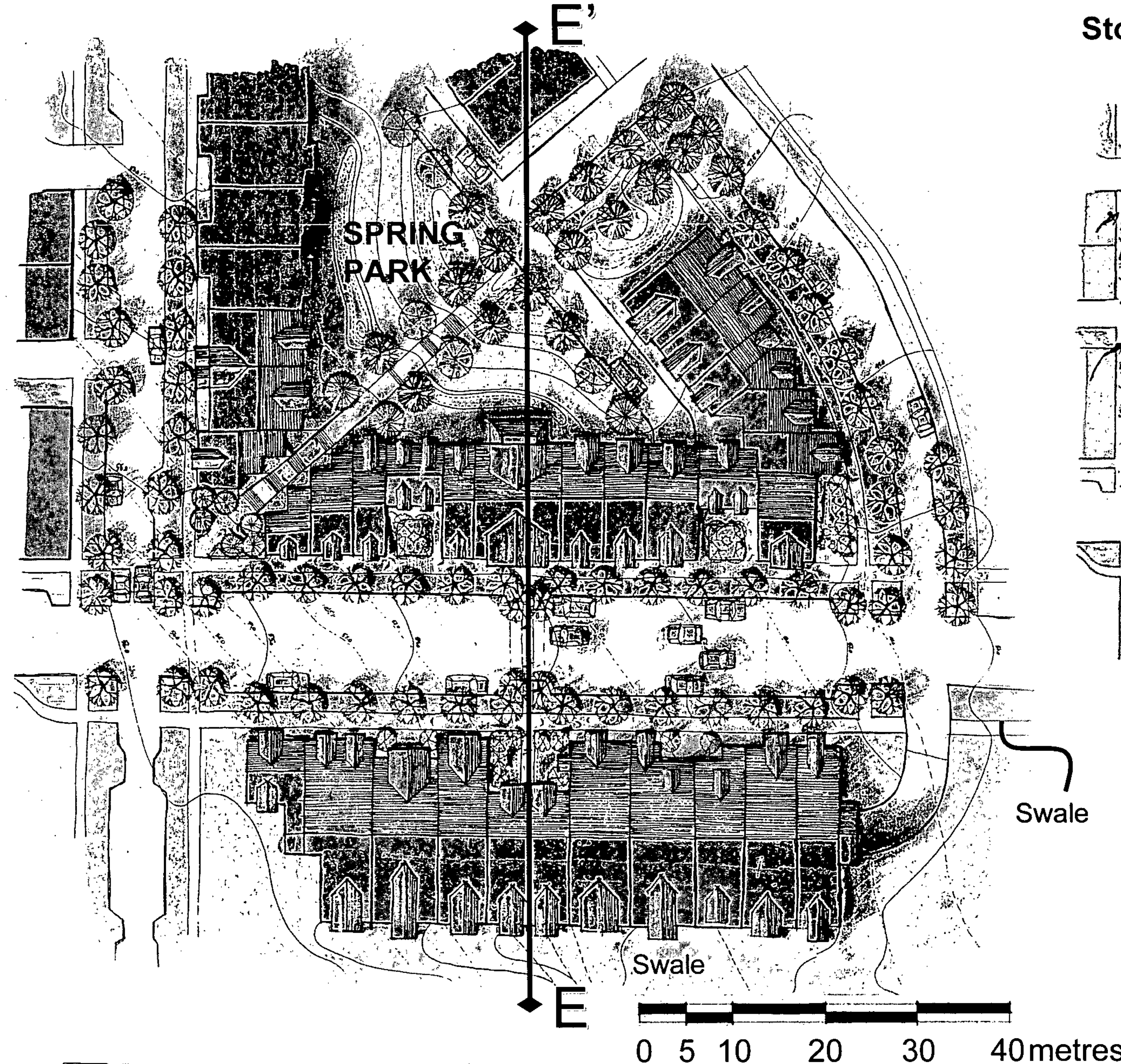
The largest site constraint was the steep slopes that ranged from ten to seventeen percent. Roads have a five percent grade and all sidewalks and buildings are universally accessible. Large quantities of fill are required to raise the roadbed elevations. The disturbance zone is large since the new grade must meet with the existing grade.

The building and stormwater system of the commercial-urban centre capitalizes on the steepness of the site. Over seventy percent of the parking is below ground and the central courtyard serves as a stormwater infiltration area.

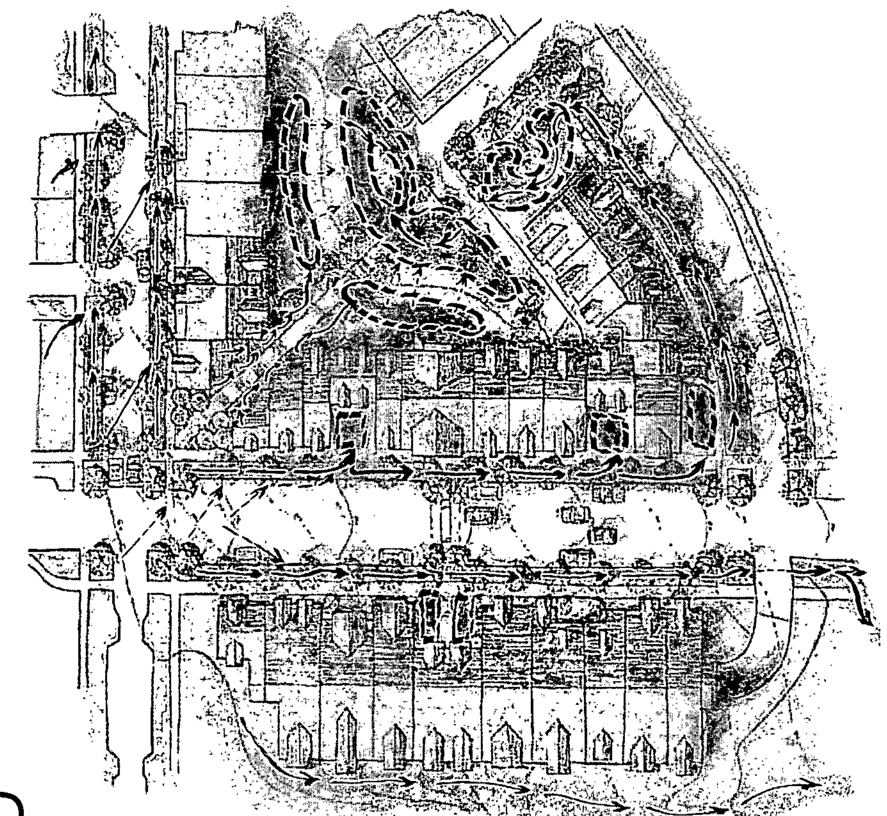
This is the best location for the commercial centre. Although excessive grading is not desirable from a low impact development perspective, in situations where high density is desired it is not always possible to preserve forest cover. Instead, extra measures must be taken to accommodate the larger volumes of water that will be produced by the site. Site disturbance and forest cover lost are compensated for with extensive street tree plantings, stormwater gardens, and neighbourhood stormwater park space.

A significant concern is this highly density area is treatment of stormwater from first flush flows. Stormwater gardens are installed every 40 metres along the street to biologically treat first flush flows. Stormwater from larger storms bypasses the garden, and is directed to a larger infiltration park located in the inner courtyard. As with all previous designs, excess water from severe storms can be diverted to adjacent infiltration areas. In this case, water would be diverted to the school grounds.

Stormwater will be utilized as a principle feature of the landscape. Spring Park mimics the watershed's natural hydrological processes. Roof water will infiltrate from a narrow basin located at the top of the slope, and reemerge as weeping springs half way down the slope, before being captured in a second infiltration area. Education of the public about ecological and hydrological principles is fundamental to this design. It is hoped that connections to the landscape will help create a sense of place within the community, something that is missing in most communities.



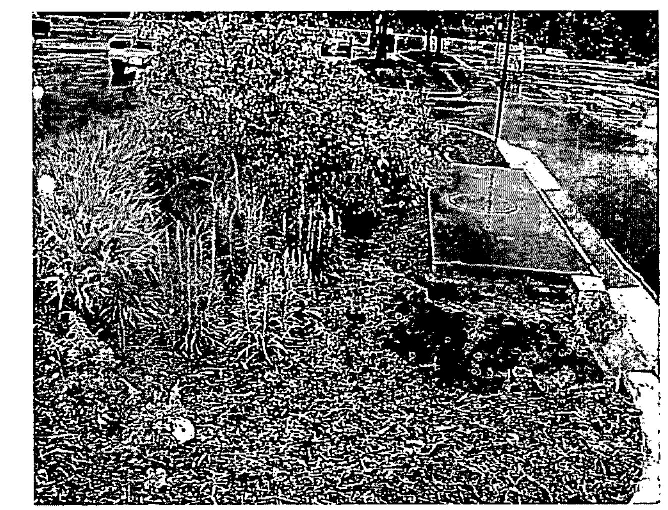
Stormwater Process Diagram



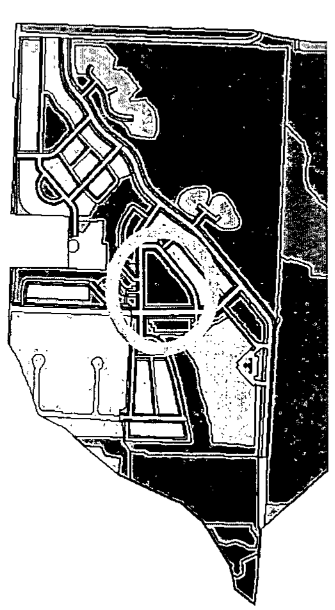
INFILTRATION/DEPRESSION STORAGE

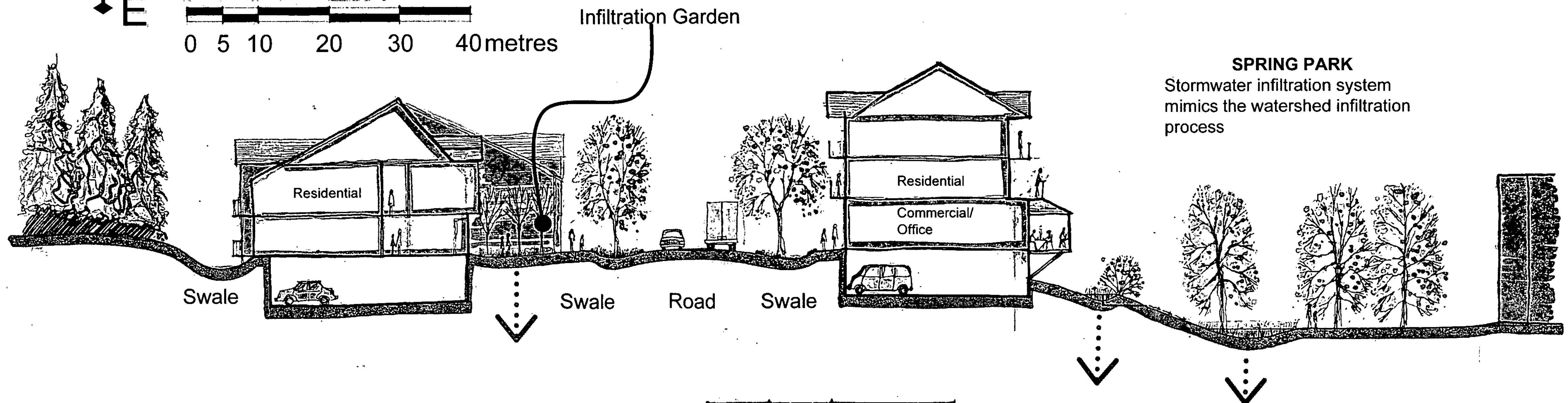
BIORETENTION GARDEN

SWALE



Stormwater bioretention garden in Maryland.





Section E-E' Mixed use neighbourhood centre

0 5 10 20 metres

Figure 33. Commercial-urban community node design.

Chapter 7: Comparisons of Conventional and Sustainable Design Scenarios

Comparisons between the conventional and sustainable designs were based upon urban structure, parks, opens space, and stormwater management (Table 2). In all categories the sustainable design out performs the conventional model. Some of these highlights include:

- Forty seven percent increase in number of dwelling units;
- Fifty eight percent more open space and park area;
- Ten percent additional forested area preserved;
- No dead end roads (not including three existing cul-de-sacs);
- No wastage of land for stormwater retention ponds (conventional system would require 1.2 ha pond to contain 100-year storm event; and
- ninety five percent increase in population density.

With respect to watershed hydrology, the sustainable design also out-performs the conventional system. Examples include:

- effective impervious cover of zero percent compared to thirty three percent for conventional
- channel density for the sub-watershed maintained at existing levels (although stormdrains from existing development still remain, water produced from those houses and streets is treated and infiltrated in the school yard infiltration area)
- average stormwater exported from the site per dwelling unit is zero for 100-year storm event compared to over twenty three cubic metres for the conventional design

Although an economic evaluation was not performed, there are several indications that suggest the sustainable design may be more profitable than the conventional design. The largest economic benefit is derived from the additional 127 dwelling units in the sustainable design (137 if end-of-pipe stormwater BMP incorporated into conventional design). Road construction costs would probably be comparable for both designs since sustainable design has more road but much less curbing and associated infrastructure. In Maryland, the use of bioretention stormwater gardens has been found to reduce construction costs by thirty five to fifty percent over conventional stormdrain installation (Prince George's County 1999)

The external cost of environmental damage is rarely considered in economic assessments of development. In the sustainable design, hydrological performance is actually enhanced while the conventional system would definitely create downstream impacts. Based on better hydrological performance it is possible that the ecological performance will also be improved (Figure 34). Finally, the sustainable design will have no negative affect on watershed hydrology. Potential developers should not be liable for any future flood damage to downstream areas since this development will not export any stormwater runoff. In fact the development actually improves the watershed's hydrological function. Although this may not seem important now, sooner or later the system will flood again. Effected properties owners will once again pursue legal action and try to seek compensation for damages.

Table 2. Comparison of land-use, urban form characteristics and hydrological variables for conventional and sustainable design scenarios.

Land-use Measures	Design Scenarios	
	Conventional	**Sustainable Design**
Total Dwelling Units	271.0	398.0
Design Land-use Summary (ha)		
Open Space	11.5	18.2
Housing	14.1	7.3
Commercial/Mixed Use	0.0	0.1
Civic	4.8	2.1
Public Streets and Paths	2.1	4.9
Site Area	32.6	32.6
Gross Density (Dwellings per unit area of entire site)		
Dwelling Units/Ha	8.3	12.2
Dwelling Units/ac)	3.4	4.9
Net Density (Dwellings per unit area of housing land including roads)		
Dwelling Units/Ha	16.7	32.6
Dwelling Units/ac)	6.8	13.2
Land Allocated to Public Open Space (ha)	11.5	18.2
Forest	11.5	14.6
Swales	0.0	2.1
Parks	0.0	1.5
Land Allocated to Roads (ha)	2.1	4.9
Paved	2.1	1.9
Gravel	0.0	3.0
Hydrological Assessment		
Impervious Area (%)	33.0	32.2
Effective or Connected Impervious Area (%)	33.0	0.0
Channel Density (km channel/km^2 land)	5.0	2.0
Q 1 Inch Storm - Site Only (m^3)	1435.6	0.0
Q 100 Year Storm - Site Only (m^3)	6364.2	0.0
Q Produced/DU I inch storm (m^3)	5.3	0.0
Q Produced/DU I00-year storm (m^3)	23.5	0.0

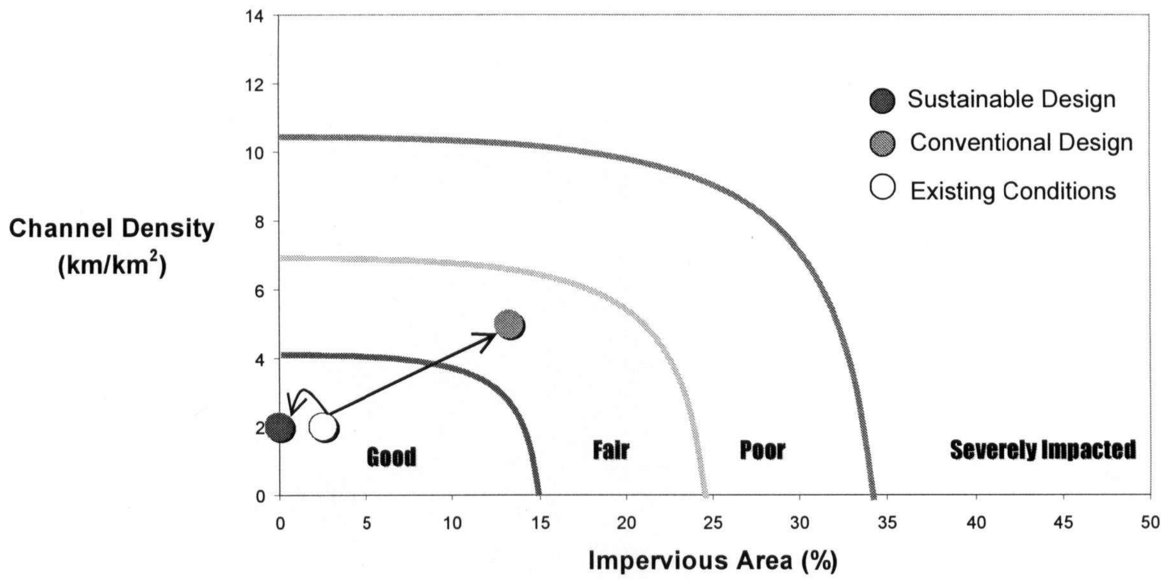


Figure 34. Design influence on hydrological health of the sub-watershed. Conventional design degrades health while sustainable design improves upon existing conditions.

The SCS method generated a slightly higher hydrograph than the engineer's model (Figure 35). When the area of land representing the infiltration zone was removed from the calculation, the unit hydrograph decreased by about one third.

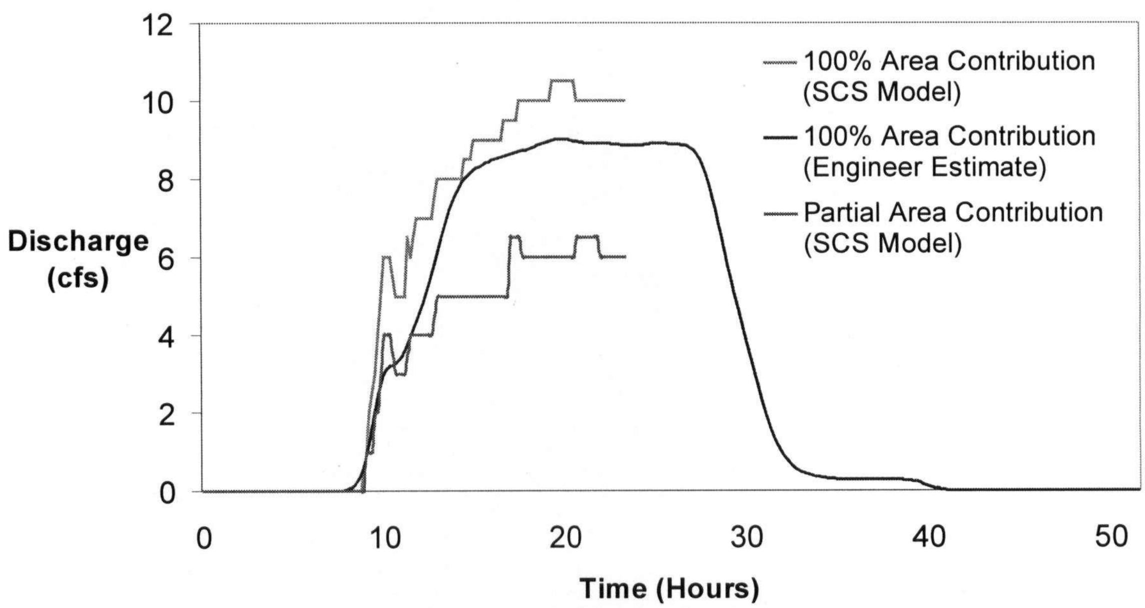


Figure 35. Comparison of pre-development stormwater production for the 100-year storm event.

Chapter 8: Evaluation of Design Methodology

It is interesting to reflect upon the research process and work that went into the actually land-use mapping and GIS analysis. There were certain hydrological problems that were evident even before analysis was started. Historical aerial photographs indicated that a significant changed in land-use had occurred within the watershed. It was easy to see the expansion of agricultural land and subsequent reduction in wetlands. It was also obvious that there was a significant amount of channel that was not present prior to development. These changes were observable and could be experience to some degree, through the use of stereo aerial photograph assessment.

Field observations suggested that certain channels were experiencing large, high energy flows while others were conveying very little. It was obvious that certain areas were producing large quantities of stormwater although how much was impossible to know. It was possible to observe the landscape and begin to understand how it was functioning. Based on these observations, it was possible to hypothesize which areas were hydrologically performing well or poorly. Field observations also indicated the recharge zone was not contributing to stormwater production.

Observations and experiences such as these help one to understand landscape processes and provides ideas for future design. They do not, however, quantify the scope of the problem or enable planners to prioritize areas for rehabilitation or potential development. Observations are useful for designer but engineers, planners, and the public needs numbers and facts to make educated planning decisions. Designers also need numbers to test their designs. Pond sizing requires precise calculations for pre-development and post-development discharge. As has been discussed, major problems result from inappropriate assessments and calculations.

It was evident that phenomenological assessment of the site was an important part of the design methodology but that it would be difficult if not impossible to use it exclusively. Scientific assessment of land-use was necessary to identify variations in sub-watershed hydrological 'health'. Testing stormwater performance of the conventional and sustainable designs could not be accomplished using phenomenology. Simulation models based on empirical relationships was necessary.

For these reasons both research methods were used in the present study. Phenomenology was used to understand how the site functioned and to begin to identify the site stormwater problems that existed. Scientific methodology was used to analyze and quantify differences in hydrological condition, to test designs and convey information to land-use managers and planners.

The Process

The following sections discuss the pros and cons of the specific scale of assessment for use in landscape planning, site design, and design testing

The Watershed Level

Pros

- Good tool to show public how landscape has changed over time
- Watershed is a discrete unit that is linked to landscape processes

Cons

- Scale is too large for public to comprehend
- Difficult to identify problem areas
- Quantifiable information means nothing at this scale
- Cannot compare the hydrological performance from one area to another
- Too large an area for effective management of the system
- Cannot design at this scale

Assessment at the watershed scale was good for descriptive and illustrative purposes but it was too large for meaningful quantitative assessment or for management purposes. Instead, we need to assess at a smaller scale, or at the sub-watershed level, to discern hydrological differences within the watershed.

The Sub-Watershed Level

Pros

- Critical scale-can identify stormwater problem areas
- Manageable planning scale
- Public can comprehend landscape at this scale

Cons

- Scale may be too large for design purposes

The critical component to watershed assessment hinges on knowing the appropriate assessment scale or the critical scale. The scale at which assessment is conducted in a watershed is of critical importance for good landscape management and design (Table 1). For example, assessment of impervious cover at the watershed level reveals that about 11 percent of the watershed was covered by impervious surface. Ecological impacts would be starting to occur at this level of watershed development. However, at the sub-watershed scale we observed impervious cover values ranging from 3 to 47 percent of the area.

The Catchment Level

Pros

- Good for site assessment and larger site level design such as road and neighbourhood layout
- Public can comprehend landscape at this scale
- Good scale to test hydrological performance of entire site design. but not to assess performance of individual design elements such as cluster development, single family groupings or commercial areas.

Cons

- Scale is still too large for smaller scale design purposes
- Cannot assess hydrological processes at this scale. Need to use smaller scale to assess performance of individual design elements such as cluster development, single family groupings or commercial areas.

The Neighbourhood Level

Pros

- Excellent scale to calculate stormwater production from smaller design units or development types
- Good scale to test hydrological performance of sub-units such as cluster development, single family groupings or commercial areas.

Cons

- Scale is too small to assess the hydrological performance of the entire development-need to go back to sub-watershed level and test cumulative design effect

Chapter 9: Conclusions

Watershed assessment at the appropriate scale is an effect tool for planners and managers to identify and prioritize stormwater problems. Assessment at the watershed scale was descriptive but was not site specific enough to identifying problem areas. Sub-watershed assessment proved to be a valuable tool to quantify and prioritize stormwater problems in the Queen's Ditch watershed. Planners can use hydrological performance to guide land-use planning decisions and assess hydrological and ecological effects of developments. The planning phase also provides planners with a process to prioritize candidate areas for development, conservation, and rehabilitation.

Comparisons of conventional and sustainable designs showed that stormwater runoff and pollution could be managed at the site level. The sustainable design provides forty-seven percent more dwelling units and exports no stormwater while maintaining the rural character of the site. The sustainable design achieves this without an expensive stormdrain infrastructure. Rather; the stormwater is managed at the site level using small stormwater infiltration ponds and swales. The design works with the natural hydrological processes of the site to generate a hydrologically sustainable design. Simulated stormwater outputs were used to test and size infiltration ponds and to assess flooding risks. The sustainable design effectively manages stormwater production, runoff, and pollution from storm events ranging from polluted first flush flows to large, flood producing rainstorms.

It is apparent that understanding how pre-development runoff is calculated has huge implications to stormwater management and sustainable design. Many stormwater designs are based on over estimated pre-development stormwater production. As a result, these developments generate more stormwater runoff than the predevelopment condition. Understanding how the site functions is probably the single most import aspect of landscape planning and design. In the case of stormwater management, over estimating pre-development runoff can double the volume and velocity of water leaving the site.

Watershed based planning combined with 'green' design can be an effective method to maintain or enhance watershed hydrology. Leopold (1968) suggests, "Of all land-use changes affecting the hydrology of an area, urbanization is by far the most forceful". This is particularly true if the site has high impervious surface coverage and is serviced by extensive stormdrain networks. But, if we begin to work with the site's landscape processes we can at least maintain the hydrological performance of the site. As Ferguson (1998) states, "Hydrological restoration is not an economic or technological imposition upon nature. It is just nature. Nature wants to work. It evolves to work…Stormwater management must re-iterated the kinds of long term environmental processes that occurred before impervious surfaces were installed."

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