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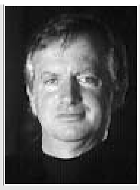

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Green municipal engineering for sustainable communities

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The East Clayton Neighbourhood Concept Plan, initiated in January 1999, had the vision of planning a community where sustainability policies were applied to the design of a site in the form of tangible practices. This paper details the design and function of the East Clayton green infrastructure plan, focusing on stormwater management, pedestrian and bicycle movement and lowered infrastructure costs, and illustrates the vital and expanding role of the engineer in the move towards liveable, affordable and ecologically sound communities.

1. INTRODUCTION

Low-density, highly paved residential communities are not only costly, but increasingly threatening to natural systems.[1–3] This trend must be addressed in light of projected growth rates and consequent demand for developable land; the population of British Columbia alone is expected to grow from 3·9 million to beyond 4·7 million over the next ten years.[4] The integration of green infrastructure into our built environments is a viable solution to this apparently intractable conflict. We offer a case study of the East Clayton Neighbourhood Concept Plan (NCP), which incorporates green infrastructure into the design of a 250 ha site, located in the rapidly expanding municipality of Surrey, British Columbia, Canada.

The East Clayton NCP's green infrastructure system builds on existing waterways to create an integrated and multifaceted network of streams, green streets, greenways, self-mitigating parcels, and park and riparian areas. This green infrastrucuture system maintains infiltration rates akin to predevelopment conditions, and thus maintains stream health. At the same time, greener infrastructure creates more walkable neighbourhoods and is cheaper to build and maintain. Lower infrastructure costs in turn lead to lower housing and long-term maintenance costs. For all of these reasons, green infrastructure needs to be recognised as a key component of more sustainable new communities. This paper details the design and function of the East Clayton green infrastructure plan, focusing on stormwater management, pedestrian and bicycle movement and lowered infrastructure costs, and illustrates the vital and expanding role of the engineer in the move towards liveable, affordable and ecologically sound communities.

2. THE CREATION OF THE EAST CLAYTON PLAN

The East Clayton project was initiated in January 1999, with the vision of planning a community where sustainability policies were applied to the design of a site in the form of tangible practices. In an effort to translate policy to practice, the City of Surrey formed a partnership with the University of British Columbia (UBC) James Taylor Chair and a multi-constituency advisory committee. Interests, such as a landowner's concern over the economic value of land, a developer's hopes for a fair return on a residential development, an environmentalist's desire for quality streams, and a city's fear concerning its ability to cost-effectively maintain what is built, can affect how a plan evolves and how it is implemented. These discrete interests were identified and grouped under 'constituencies' and were involved in the 'charrette' process (see later).

This partnership distilled seven sustainable planning principles which were generated during the 1998 City Council discussion and published in the *East Clayton Neighbourhood Concept Plan*.[5] The seven principles are as follows.

(*a*) Increase density and conserve energy by designing compact walkable neighbourhoods.
(*b*) Provide different dwelling types (a mix of housing types, including a broad range of densities from single-family homes to apartment buildings) in the same neighbourhood and even on the same street.
(*c*) Communities are designed for people; therefore, all dwellings should present a friendly face to the street in order to promote social interaction.
(*d*) Ensure that car storage and services are handled at the rear of dwellings.
(*e*) Provide an interconnected street network, in a grid or modified grid pattern, to ensure a variety of itineraries and to disperse traffic congestion; and provide public transit to connect with the surrounding region.
(*f*) Provide narrow streets shaded by rows of trees in order to save costs and to provide a greener, friendlier environment.
(*g*) Preserve the natural environment and promote natural drainage systems (in which stormwater is held on the surface and permitted to seep naturally into the ground).

These principles were then used to guide a four-day design workshop named the *charrette* process. The collaborative and integrated nature of the charrette allowed municipal officials, designers and representatives of local residents and landowners to circumvent the usual impediments to local policy innovation (impediments such as institutional barriers, regulatory gaps, and resistance surrounding both real and perceived risks of adopting alternative design and engineering standards). The four-day charrette, along with extended additional consultation, eventually yielded the East Clayton Neighbourhood Concept Plan.[5]

3. STORMWATER MANAGEMENT

3.1. Infiltration versus conveyance

Key among the seven sustainability principles was the preservation and promotion of riparian areas and the drainage regimes that support them. Ultimately, this required a change in basic stormwater management strategies. Current standards require that rain falling on impermeable surfaces such as roads and parking lots be drained into grates, conveyed by pipes and deposited directly into waterways. This polluted stormwater is deposited at velocities and volumes many times greater than predevelopment rates, scouring stream beds and resulting in uneven base flows. Green infrastructure reverses this trend by encouraging the infiltration of rainwater into the ground, where it is filtered naturally by the soil before it reaches streams. Infiltration also regulates the rate at which water enters the stream system, mimicking predevelopment forest land hydrology.

This alternative approach to stormwater management was particularly crucial on the East Clayton site, which drains into three of the region's most significant rivers: the Serpentine, the Nicolmekl and the Fraser Rivers. Experience in other neighbourhoods allowed City of Surrey engineers to predict that conventional infrastructure would not only lead to stream erosion and base flow reduction, but it would also increase the duration and frequency of already chronic flooding in agricultural lands (the city was successfully sued by lowland farmers for $60 million for flood damages caused by conventional upstream storm drain systems). Engineers participating in the East Clayton design process were therefore faced with how to apply principles of infiltration and pavement reduction to this very sensitive site.

3.2. Streets

One of the largest generators of excess stormwater in any municipality is the paved street system. The typical 'curb-and-gutter' street section, which has become mandatory for even the most lightly travelled suburban street, prevents rainwater from being absorbed into roadside soils. If this typical curb-and-gutter detail were multiplied by the thousands of miles of paved streets typical to most metropolitan areas, the simple curb would look like an environmental disaster in the making.

Recently, retention ponds have been required in many jurisdictions as an answer to peak discharges generated by curbed road systems. These ponds may help mitigate peak flows, but they do nothing to protect base flows during dry seasons and are only partially effective in filtering pollutants. They can also operate in unpredictable ways such that flooding can even be exacerbated, rather than relieved.[6] A significant emphasis was therefore placed on the design of the streets themselves.

Infiltration is encouraged on the 'green' streets of East Clayton both through the use of permeable surfaces (e.g. on laneways and driveways) and by eliminating curbs, thereby allowing water to infiltrate directly into the infiltration zone, or swale. Swales will absorb most street runoff, up to 24 mm per day during winter conditions. Only when swales become saturated does water drain into a system of shallow perforated pipes laid into the infiltration zones. This pipe system connects all infiltration devices and moves water to retention/treatment ponds or artificial wetlands. The system has been sized to convey the two-year event (a downgrade from the traditional five-year event system, made possible by a decrease in overall site runoff due to infiltration measures used elsewhere on the site). (See Fig. 1.)

Paved street widths for local and collector streets in the plan range from 6 m to 11·3 m. Rights of way for these streets range from between 17 m (56 ft) and 22 m (72 ft), depending on specific infrastructure, servicing and amenity requirements of each individual corridor. Street trees are planted within these rights of way such that 60% of the street section will be shaded at maturity (20 years from date of planting). These 'urban forest' street trees will be an important element of the streetscape and a significant factor in the maintenance of watershed health, specifically through their ability to moderate hydrologic fluctuations (evaporation, transpiration, retention of water in root zones, increased soil permeability and water retention capacity, etc.). (See Fig. 2.)

3.3. Parcels

Almost 70% of the watershed is comprised of parcels. Each parcel has on-lot drainage areas, making the development of individual parcels another crucial part of the 'green infrastructure' system. Building roofs, driveways and other on-lot impermeable surfaces have to be minimised and their runoff infiltrated into yards instead of into street systems. As

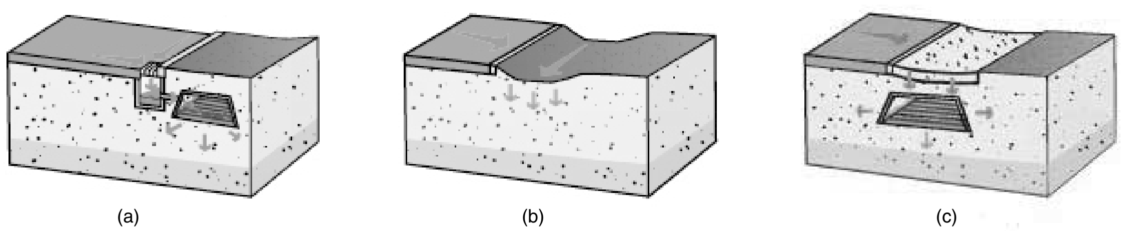

Fig. 1. (a) Conventional curb and gutter; (b) roadside swale; and (c) crushed stone infiltration trench

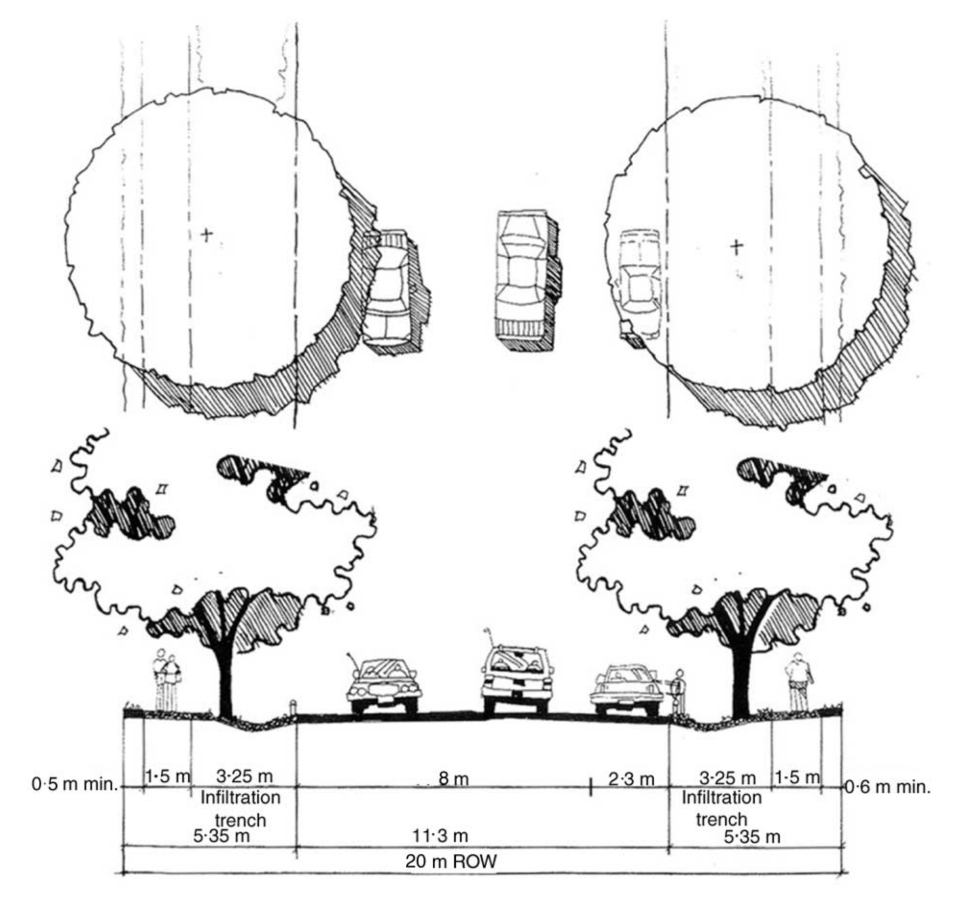

Fig. 2. Residential collector street section (taken from Figure 5.2.3.2 of the East Clayton NCP)

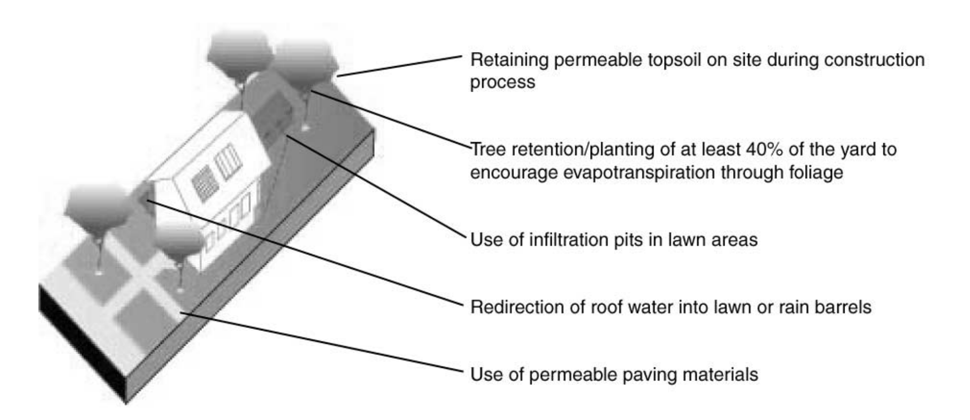

Fig. 3. Land infiltration methods

illustrated in Fig. 3, there are several ways to facilitate yard infiltration.

Although infiltration pits are the most expensive option, they were incorporated into the East Clayton plan due to their predictability. (This is a key point, as many decisions are driven by fear of nuisance or unpredictability, often resulting in more costly components.) Infiltration pits are capable of infiltrating 12–24 mm/day and are designed to ensure at least 30 years of trouble-free operation. They are usually located at property lines to provide a minimum of 3 ft of distance from building foundations and are filled with crushed rock or prefabricated infiltrators.

3.4. School and park sites

The NCP's green infrastructure also comprises linked open spaces, including major parks, smaller neighbourhood parks and school sites. In addition to offering educational and recreational opportunities, these areas provide ideal locations for naturalised wetland habitat and overflow ponds.

The NCP proposes 9·53 ha of combined park and school sites, which provide forest cover, habitat and on the eastern school site, a naturalised wetland. This wetland will act as a retention and biofiltration area for surface water from other parts of the site and with its native plantings and small islands, extensive bird habitat. The centre depth of the pond is constructed to a maximum of 1 m, with peripheral areas accepting the five-year storm. In the event of a 100-year storm, adjacent playing fields would be flooded to a maximum depth of 1 m. As already mentioned, these wetland/retention facilities are effective for dealing with peak flows; however, they cannot substitute infiltration measures elsewhere on site.

Smaller neighbourhood parks also contribute to this system, as they accept drainage from surrounding street surfaces and, in certain locations, provide sites for deep well infiltrators. The infiltrator's main function is to accept stormwater produced by peak flows and discharge this water into regional groundwater aquifers. The capacity of each well will be dependent on its location in the area, ranging from 60 l/s down to 10 l/s. (See Fig. 4.)

3.5. Riparian parks

Riparian parks perform the vital function of preserving existing or rehabilitated riparian zones. These zones are left untouched during the development process and are incorporated into leaf areas. The size of leave area is determined by the need to maintain a continuous canopy over stream zones, such that streams are shaded from potential overheating and to ensure a steady supply of leaf litter and insect food for fish. By preventing the removal of vegetation, banks continue to be

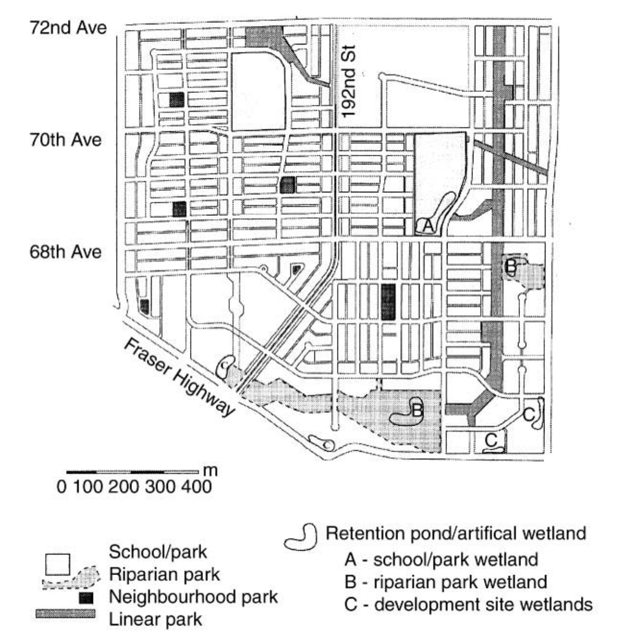

Fig. 4. Schools, park sites and riparian parks as part of the infiltration system

stabilised by roots, and snags or dead trees become part of the stream debris, creating crucial salmon habitat and locations for cavity-nesting birds and small mammals.

Activity in leave areas is limited to passive recreation in the form of low-impact walkways. Access corridors necessitating the removal of vegetation or soil disturbance would be built on the outer 5 m of the leave area, as far away from the stream as possible. Corridors passing through sensitive riparian areas are limited to a maximum trail width of 1·5 m and constructed of permeable gravel or raised boardwalk to aid infiltration.

3.6. Greenways and riparian parkways

The greenways and riparian parkways are a system of multi-use transportation corridors which also facilitate infiltration and movement of stormwater. Greenways replace what would have been storm drain interceptor pipes with green pedestrian and cycle ways, which are also sites for infiltration, habitat zones and migration corridors. Rights of way for greenways do require more space than storm drain interceptor pipes; however, this is balanced by reduced lane width of adjacent arterials. Within the greenway there is also opportunity for the naturalisation of stream flows, achieved by adjusting the depth of swales to pick up interflow across glacial hardpan. (See Fig. 5.)

Riparian parkways are multi-use transportation corridors built around constructed riparian areas. As with the greenway, the storm drain interceptor pipe is replaced, this time by the artificial stream running alongside travel ways. These artificial streams manage stormwater from surrounding districts, emulating natural processes and occasionally aided by deep well infiltrators to infiltrate as much water as possible while still managing to convey the 100-year storm to retention ponds.

3.7. Benefits to water quality and base flows

East Clayton's infiltration-based system is specifically designed to improve water quality by allowing runoff to be filtered by the soil before it replenishes the aquifer or seeps into streams. Roadside infiltration trenches, on-site infiltration devices and artificial wetlands will sequester silts and pollutants from first-flush runoff.

Water quantity regimes are also maintained at predevelopment levels. Rainfall data for the Surrey area indicate that the majority of rain falling on the site is from frequent, but small, storm events (i.e. those smaller than 24 mm per day). By capturing up to 24 mm of rainfall per day (including the first 24 mm of larger storm events), almost 90% of total rain that falls on the site will be absorbed naturally in the infiltration zones of the various components of the green infrastructure system explained above. Once in place, the system will maintain current 'predevelopment' annual total water volume discharged into streams and protect existing dry season base flows. Thus the impact on stream hydrology and morphology will be reduced by over 90% when compared to conventional infrastructure systems (based on performance objectives and the ecological infrastructure standards and guidelines outlined

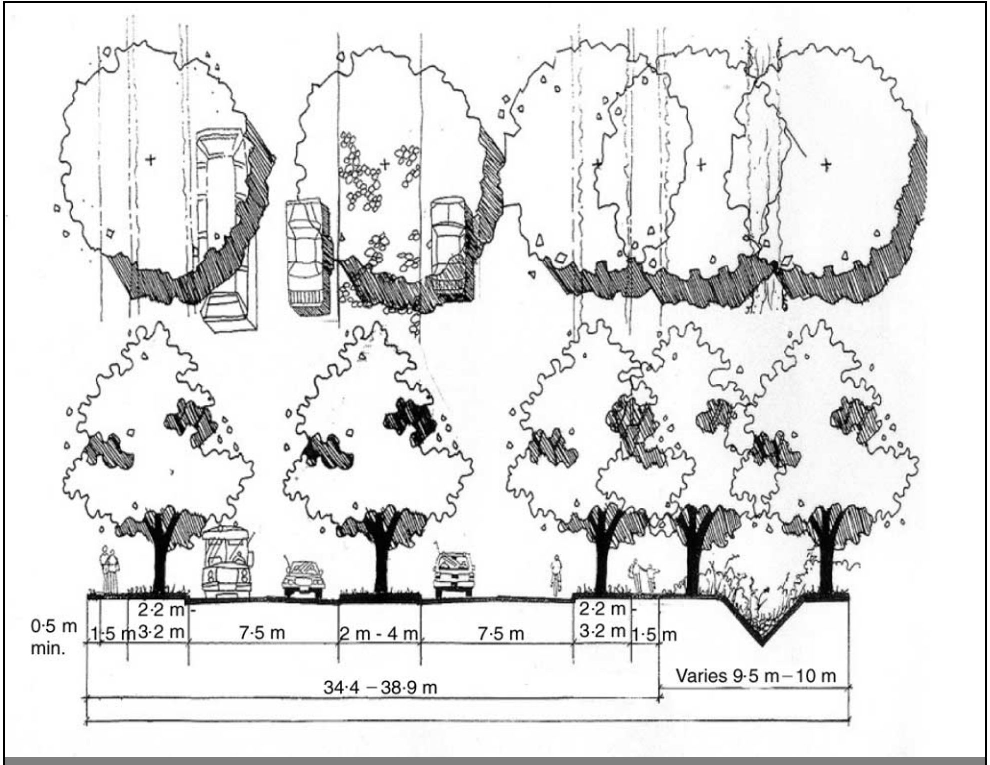

Fig. 5. Riparian parkway greenway—an artificial stream located in boulevard

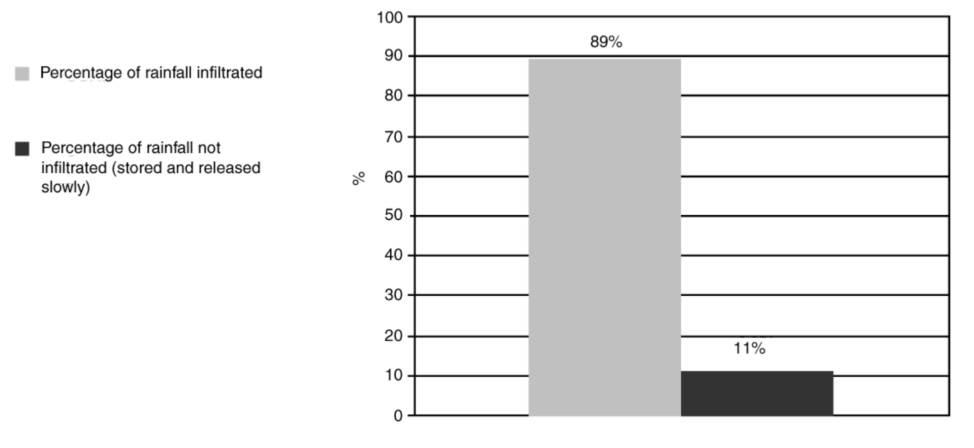

Fig. 6. Annual rainfall potentially captured with East Clayton system. (Taken from Figure 8-4 of the East Clayton Environmental Benefits Technical Bulletin. Source: Kwantien Park rain gauge data, 1 Jan. 1962 to 1 May 1995)

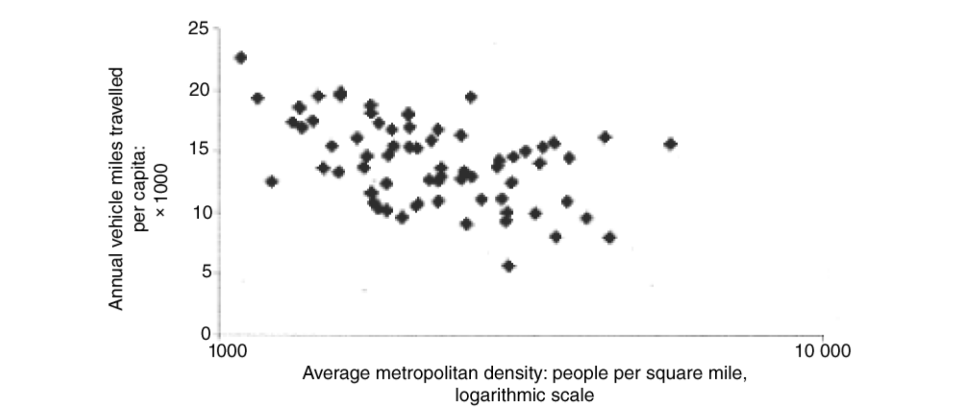

Fig. 7. Higher metropolitan densities reduce per capita vehicle travel[7]

in Section 3.1.1 and Section 5.0 of the East Clayton Neighbourhood Concept Plan (presented to the public in July 1999) and the Land-use Plan approved by the City of Surrey in November 1999). (See Fig. 6.)

4. PEDESTRIAN AND BICYCLE MOVEMENT

4.1. Interconnected street and greenway network

The streets and greenways of the East Clayton Plan are not only crucial for the movement of water, but also for the movement of people. Conventional North American suburban development is characterised by low-density housing, culs-de-sac and curvilinear streets connected to wide arterials. This hierarchical street configuration means that most trips are longer than they need to be and thus favour driving over walking or biking. Building more of these kinds of communities means that more people are forced to drive, trips get longer, and air pollution increases. In contrast, interconnected streets in a grid, or a modified grid pattern, in addition to greenways and bikeways, provide multiple and alternative routes for moving through a community. Research shows that, in combination with higher than average residential densities (i.e. above 25 units per ha), a high degree of land-use mix (including local employment opportunities) and access to a frequent transit service, interconnected street networks can greatly reduce vehicle miles travelled (Fig. 7). (For further information on urban sprawl and alternatives, see References 8 and 9.)

The organisation of the roads, blocks, parks, parkways and riparian areas in the East Clayton Plan responds to the site's topography and the location of its sub-watersheds. The street network is organised around a four-level hierarchy of streets, which includes arterials, collectors, local streets, and lanes. This is unlike conventional developments, where traffic is routed along an exclusive and dendritic hierarchy of roads—from an arterial, to a collector, to a local, and finally to a cul-de-sac. The Plan's integrated system disperses traffic across the interconnected and modified grid, thereby reducing the strain on arterials. Major and local through-traffic is accommodated on a system of major and minor arterials, furnished according to specific requirements for servicing, utilities, drainage, pedestrian amenities, and urban forestry. (See pp. 72–88 of Reference 5 for further discussion of ecological infrastructure performance standards and guidelines.)

4.2. Improved walkability of the East Clayton Plan

In addition to the incorporation of greenways, cycle ways and improved pedestrian areas, East Clayton will contain a Main Street commercial district and a total of five commercial locations. The commercial areas are dispersed throughout the community so as to be within a 4–5-minute walk of all residences. A 'high-tech' business park, and a live–work area will also ensure local workplaces for the community's residents. Bus transfer points will eventually be located within 800 m of each residence. The integrated grid of streets and lanes ensures that pedestrians have multiple route choices to nearby destinations.

4.3. Benefits to air quality in the East Clayton Plan

East Clayton's integrated street network, together with higher than average residential densities,* mixed land uses and pedestrian-friendly green streets, is expected to curb reliance on the automobile. As a result, it is anticipated that both vehicle miles travelled per person per day and per capita

* Higher than average net residential density of approximately 14 units per acre (UPA) or10 UPA gross, more than twice the density of traditional suburban developments, which typically have no more than four dwelling units per acre.

Air quality comparison	Scenario 1 2010		Scenario 2 2040	
Neighbourhood attributes	**East Clayton**	**Suburban-type***	**East Clayton**	**Suburban-type**
Urban context	Inner suburb†	Inner suburb	Inner area‡	Inner area
Land area: ha	250	250	250	250
Road layout type	Primarily grid	Random curvilinear	Primarily grid	Random curvilinear
Total length of non-expressway roads: km	26	20	26	20
Total number of intersections	112	60	112	60
Total length of wide arterials (4-lane): km	2·5	5	2·5	5
Daily bus vehicle service: h	14·6	5	16·2	14·6
Total length of bike routes: km	7	0	7	0
Socio-demographic data	**East Clayton**	**Suburban-type**	**East Clayton**	**Suburban-type**
Total number of residential units	4928	2250	4928	2250
Total residential density: units/ha	25	10	25	10
Housing mix (1 = total mix; 0 = no mix)	0·74	0	0·74	0
Number of grocery stores: 1 km radius	8	0	8	0
Number of jobs: 1 km radius	4464	0	4464	0
Number of jobs: 5 km radius	40 000	40 000	120 000	120 000
Locational characteristics	**East Clayton**	**Suburban-type**	**East Clayton**	**Suburban-type**
Distance to central business district: km	12	12	3	3
No. of jobs: 5 km radius				
Distance to nearest rapid transit station (rapid bus): km	1	1	1	1
Distance to nearest commuter rail (Sky Train): km	8·7	8·7	3	3
	Neighbourhood performance compared			
Weekday household travel behaviour	**East Clayton**	**Suburban-type**	**East Clayton**	**Suburban-type**
Average vehicles owned/household	1·17	1·65	1·13	1·60
Average vehicle kilometres travelled generated/household	51·6	78·80	38·00	72·80
Average passenger kilometres travelled generated/household	16·20	19·70	13·00	19·80
Annual household vehicle emissions	**East Clayton**	**Suburban-type**	**East Clayton**	**Suburban-type**
Auto: l	5900	9000	4400	8300
Transit: l	220	270	180	270
Total household vehicle emissions: l	6100	9300	4600	8600

* The term 'suburban-type', as defined by the tool, refers to development with characteristics typical of modern suburban developments (including low net densities, curvilinear street patterns with culs-de-sac extending out to wide arterials). All neighbourhood characteristics relating to suburban-type development have been derived from the tool and applied to an area of similar size to East Clayton.
† Inner suburbs are defined by the model as communities that are located between 5 km and 10 km away from the CBD, which for the purposes of this study is considered the Surrey Centre, located approximately 12 km away from East Clayton. This distance also corresponds to the average distance to work for residents in this area.
‡ Inner areas are defined by the model as communities located between 0 and 5 km away from a CBD. Assuming that East Clayton's more concentrated development pattern is repeated in adjacent areas over the next 30 years, and a corresponding increase in regional services and jobs, the neighbourhood classification was changed from 'inner suburban' to 'inner area', with the CBD now being considered the municipality of Langley, just under 3 km to the east.

Table 1. Air quality comparison (taken from Table 8-1 of the James Taylor Chair East Clayton Environmental Benefits Technical Bulletin)

production of greenhouse gas attributable to automobile use will be reduced by over 40% when compared to conventional suburban models. In addition, the number of cars per household will be reduced by 0·6 from the typical number of cars per dwelling in conventional suburban neighbourhoods.* (See Table 1.)

* Figures are derived from the model *Greenhouse Gas from Urban Travel: a Tool for Evaluating Neighbourhood Sustainability*, CMHC/SCHL in partnership with Natural Resources Canada, 2000. This model uses daily household travel behaviour and annual household vehicle emissions to evaluate neighbourhood sustainability. Based on the input variables (from the East Clayton NCP), the total vehicles owned per household in East Clayton amount to 1·2. This translates into 59·9 km of total vehicle travel per household and 2·9 km per day of travel by foot. Low-density suburbs of a similar scale and location average 1·8 vehicles per household with a total of 100·6 total vehicle travel per household.

4.4. Infrastructure costs

In the spring of 1998, the James Taylor Chair explored the costs and benefits that might result from employing alternative community planning and engineering standards (Table 2). We presented our findings at the Alternative Development Standards for Sustainable Communities Workshop—a session that involved over 300 planners, engineers, real estate agents, developers, and federal, provincial and municipal government officials.[11] Results showed direct cost savings in the range of 35% for equal-sized units (interior square feet) in a sustainable neighbourhood when compared with similar units in a status-quo area.[11] The increased efficiencies attained in the East Clayton Plan will result in similar cost reductions. Single-family homes can be profitably supplied at sale prices 15–25% lower than conventional developments in the same area. This estimate is based on anticipated reductions in per-unit infrastructure costs related to more cost-effective land development and green infrastructure components (based on sustainable planning principles and performance objectives (Section 3.1 and Section 3.1.1 of Reference 5).

Infrastructure	Cost: $	
	Conventional	Alternative
Roadworks	218 894	256 853
Asphalt paving	24 553	38 247
Storm sewer	205 820	n/a
Surface drainage (swale pipe*)	n/a	99 945
Boulevard landscaping	30 000	36 070
Water mains	113 705	169 107
Water tie-ins and connections	18 177	49 211
Sanitary sewers	135 255	229 780
Sanitary tie-ins and connections	5000	13 536
Street lighting	44 000	64 500
Lot grading and/or swales	24 450	24 221
Hydro/telephone installlation (buried services)	54 000	146 196
Boulevard tree planting	20 000	24 052
Utilities	54 000	89 859
Walkways and emergency access	12 500	n/a
Walkways landscaping	4000	n/a
Total infrastructure cost		
Entire site	964 354	1 241 577
Per unit	23 521	11 185
Per parcel	23 521	16 778

*Assumes $150/linear metre pipe in stone infiltration system.

Table 2. Cost comparisons (taken from James Taylor Chair *Technical Bulletin No.2: Status Quo Standards vs. Alternative Technical Bulletin*)

5. CONCLUSION

Increasingly, major metropolitan areas within what we often call the 'Rain Valley', from Eugene, Oregon to Vancouver, British Columbia, are struggling with similar problems, namely: how can we build at sustainable densities without killing natural systems? The only cost-effective solution to this crisis seems to be a reconsideration of our standard approach to providing municipal infrastructure. As demonstrated in the East Clayton NCP, green engineering has to be incorporated into the planning of our communities from the very beginning. This perspective was supported in the East Clayton process by the involvement of engineers, whose role was expanded to move beyond providing dependable urban machinery to designing and managing green engineered systems. The resulting interlaced and layered systems of riparian corridors, streets and public open spaces make new and retrofitted high-density areas more ecologically sustainable, liveable, affordable and walkable.

While a number of challenges still remain in the implementation of the East Clayton NCP, the Plan offers an unprecedented blueprint for sustainable development. It is already influencing the development of lighter, greener, cheaper, smarter, and complete communities throughout the Cascadia region and beyond.

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