BEFORE THE ENVIRONMENT COURT

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of appeals against the decision of the North Shore City Council on Proposed Plan Change 6 and Variation 66 to the North Shore City District Plan under Clause 14(1) of the First Schedule to the Act
BETWEEN	**LONG BAY-OKURA GREAT PARK SOCIETY INCORPORATED** (ENV-2006-AKL-000894)
AND	**AUCKLAND REGIONAL COUNCIL** (ENV-2006-AKL-000901)
AND	**LANDCO LIMITED** (ENV-2006-AKL-000902)
AND	**S B & L A SINGLETON** (ENV-2006-AKL-000903) **Appellants**
AND	**NORTH SHORE CITY COUNCIL** **Respondent**

STATEMENT OF EVIDENCE OF THOMAS SCHUELER

1. INTRODUCTION

1.1 My name is Thomas R. Schueler. I hold a Bachelor of Science from the George Washington University (1982) and have 25 years experience in urban stream research, stormwater design and watershed management. I am currently employed as the Director of Practice at the Center for Watershed Protection, which is an independent, non-partisan non-governmental organization dedicated to the protection of aquatic resources through improved management of the land. Prior to founding the Center in 1992, I worked for ten years at the Metropolitan Washington Council of Governments where I directed research on the performance of stormwater management practices as well as practical stream protection practices.

Urban Stream and Stormwater Research

1.2 I have been continuously involved in research to better understand the dynamics of urban streams and their response to stormwater runoff and land development. I developed and refined the Impervious Cover Model (ICM) which is a widely recognized watershed planning tool. I helped develop the U.S National Stormwater Quality Database which contains pollutant event mean concentrations for more than 3800 storm events. I have also directed the creation of a National Stormwater Best Management Practices (BMP) Pollutant Removal Database, and have conducted extensive research on the construction costs of stormwater treatment practices, retrofits and low impact development (LID) technology.

Experience with Stormwater Practices

1.3 I have written or co-written more than a dozen local and state stormwater engineering design manuals, and developed or refined the first design specifications for bioretention, wet ponds, constructed wetlands, filtering systems, and dry swales. The manuals have directly led to greater adoption of more effective stormwater practices and LID technology. I have applied the designs to numerous retrofit and developments projects at a conceptual design level, but I am not a professional engineer. I created the Simple Method which is widely used to compute stormwater loads.

Watershed Management Experience

1.4 I have authored several widely-used references, including *The Practice of Watershed Protection, Rapid Watershed Planning Handbook, and the Impacts of Impervious Cover on Aquatic Systems*. I have directed more than 30 watershed plans in diverse settings such as the Chesapeake Bay, Pacific Northwest, Midwest, Southeast, Northeast, the Caribbean, Hawaii and Canada to protect sensitive aquatic resources. I have written seven volumes of the *Small Urban Watershed Restoration Manual Series* including *Restoration Methods*, *Stormwater Retrofit Practices*, *Stream Repair Practices*, *Source Control Practices* and the *Unified Stream Assessment*.

1.5 I have taught undergraduate and graduate courses at the University of Maryland, and have been a guest lecturer at Herriot Watt University (Scotland), University of Virginia, Virginia Polytechnic Institute, Cornell, North Carolina State University, Johns Hopkins University, University of Washington, Oregon State University, Georgetown, Princeton and University of Alabama. I have also conducted more than 200 watershed and stormwater workshops across the country, and presented more than 50 keynote addresses to international, national or regional conferences. I have served on two US National Research Council panels on stormwater and watershed management, and have been retained by the U.S. EPA, various states, territories and provinces to provide technical expertise, training and guidance on watershed planning. I served as the editor of the journal *Watershed Protection Techniques* for eight years.

Knowledge of New Zealand Issues

1.6 I inspected the Long Bay catchment in March of 2007 to get a better sense of stream and catchment conditions to prepare more accurate evidence. I have made two prior visits to New Zealand in a technical capacity, most recently as an invited speaker to the First South Pacific Stormwater Conference held in Auckland 1999 and was also retained by the Auckland Regional Council to recommend guidelines for stormwater best management practices in 1991.

Experience in Similar Aquatic Environments

1.7 In addition to my prior work in the Auckland regional area, I have had experience in working on watershed and stormwater issues in island environments such as Maui (Hawaii), Molokai (Hawaii), Guam, U.S. Virgin Islands and Puerto Rico.

Engagement as Expert Witness

1.8 Since December, 2006 I have been engaged by the North Shore City Council as an expert witness in urban stream impacts, stormwater design and watershed management. I have reviewed all of the supporting material developed to support the Long Bay Structure Plan and Variation 66 (2007), and have participated in three stormwater and freshwater ecology caucusing meetings. My role is to bring an international and North American perspective to the scientific and engineering issues involved in the Long Bay Structure Plan, and evaluate the overall capability of that plan to protect water resources in the future.

Expert Witness Code of Conduct

1.9 I have read the Code of Conduct for expert witnesses outlined in the Environment Court's practice note and have complied with it in preparing this evidence. I also agree to follow the Code when presenting evidence to the Court.

1.10 I confirm that my evidence is within my area of expertise and that I have not omitted to consider material facts known to me that might alter or detract from my expressed opinions.

2. SCOPE OF EVIDENCE

2.1 My evidence will address the following matters:

(a) The Impervious Cover Model – which generally predicts future quality of freshwater and tidal streams in response to land development and is specifically used to show the extreme vulnerability of streams in the Long Bay catchment.

(b) The Importance and Sensitivity of Zero Order Streams - review of the recent science on why such small streams that often lack flow are so critical to the health of the downstream network.

(c) Impact of Earthworks on Stream Hydrology – review of science on how soil compaction, earthworks and stream enclosure during construction alters the hydrologic response of pervious areas.

(d) Effect of Stormwater Mitigation: Ponds and Wetlands – international review of the current science and engineering data as to their capability to remove pollutants, reduce runoff volumes, and protect aquatic life downstream, as well as specific notes as to their applicability in the Long Bay catchment.

(e) Effect of Stormwater Mitigation: Low Impact Development – A similar review of the current science and engineering data on the emerging new stormwater technology known as Low Impact Development (or LID), profiling new research on its capability to remove pollutants, reduce runoff volumes, prevent stream warming and protect aquatic life. This part also summarizes why it is more appropriate and protective of water resources in the Long Bay catchment than "conventional" approaches.

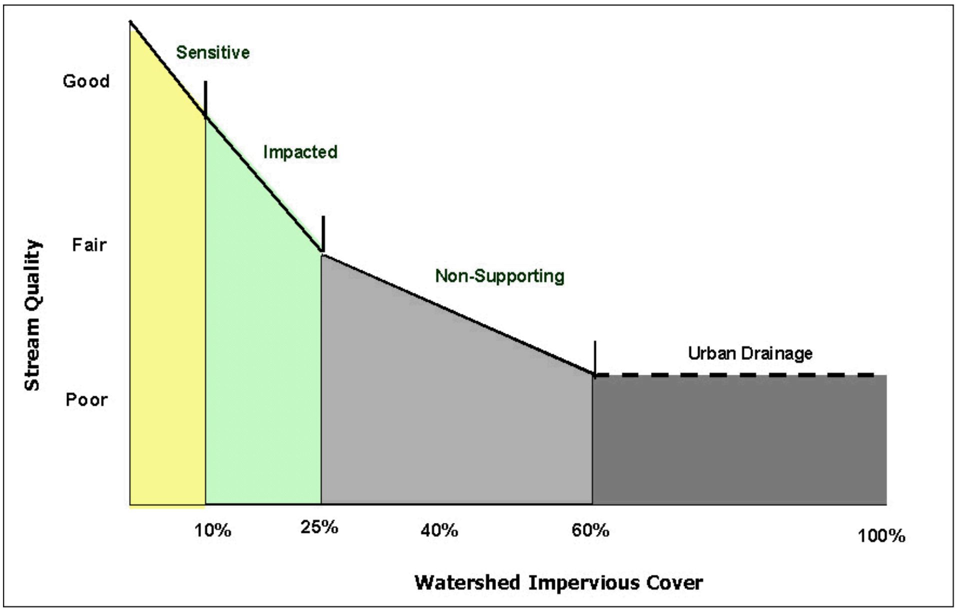
(f) Adoption and Economics of Low Impact Development – A brief summary of the Australian and North American economic research on the economics of LID in comparison to conventional development, which indicates while LID has slightly higher construction costs, its savings in other stormwater infrastructure costs makes it a cost-effective overall option for most sites.

(g) Summary Review of the Current North Shore Structure Plan – summary of why the current version is the most appropriate and effective land use and stormwater mitigation strategy to protect freshwater and tidal streams in Long Bay.

3. THE IMPERVIOUS COVER MODEL

3.1 The Impervious Cover Model (ICM) is a useful tool to diagnose the severity of future stream problems in a subwatershed. The ICM defines four categories of urban streams based on how much impervious cover (IC) exists in the subwatershed: *high quality streams*, *impacted streams, non-supporting streams* and *urban drainage*. The ICM is then used to develop specific quantitative or narrative predictions for stream indicators for each stream category (Figure 1). These predictions define the severity of current stream impacts and the prospects for their future restoration. Predictions are made for four kinds of urban stream impacts: changes in stream hydrology, alteration of the stream corridor, stream habitat degradation, declining water quality and loss of aquatic diversity.

Figure 1: Impervious Cover Model

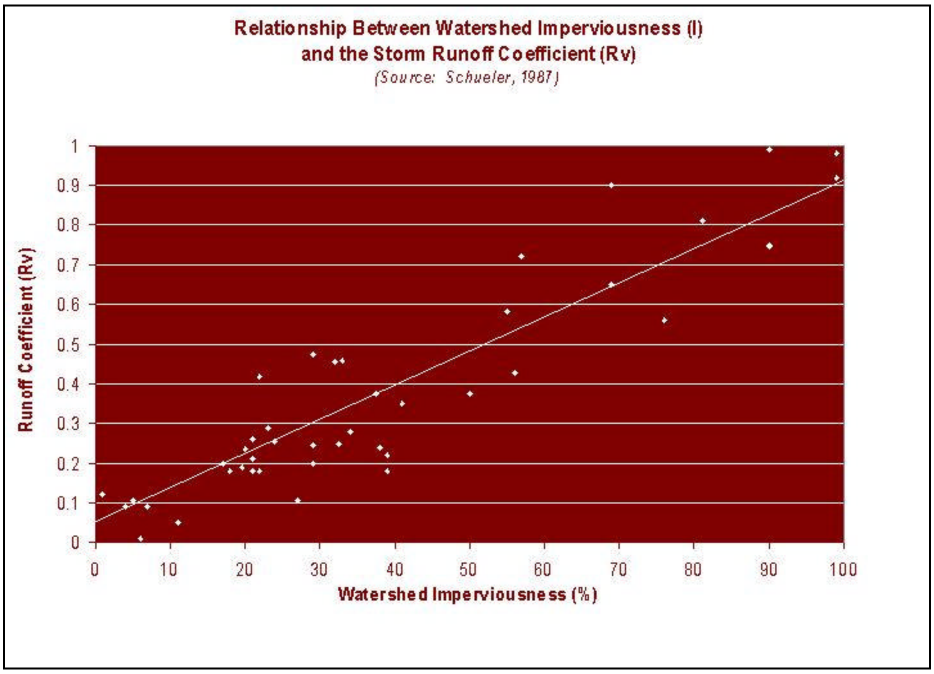


Hydrological Impacts and Physical Alterations

3.2 The combination of impervious cover, storm drain pipes, compacted soils, and altered floodplains dramatically changes the hydrology of urban streams. During storms, urban watersheds produce a greater volume of stormwater runoff and deliver it more quickly to the stream compared to rural watersheds. The urban stream hydrograph has a much higher and earlier peak discharge rate, compared to rural or undeveloped streams. In addition, stream flow drops abruptly after storms, and often steadily declines during dry weather due to a lack of groundwater recharge.

3.3 Perhaps the single most important alteration associated with land development is the effect of impervious cover on increasing the runoff coefficient of a site or catchment. The runoff coefficient (Rv) represents the fraction of each rainfall event that is converted into stormwater runoff. This phenomenon is illustrated in Figure 2, which shows the strong relationship between catchment IC vs. the Rv for more than 40 catchments in the U.S. (Schueler, 1987). The sharp increase in stormwater runoff volumes is the primary causal agent for the decline in most urban stream indicators, and is also the primary focus of the differences in the effectiveness of various stormwater mitigation efforts analyzed later in this evidence.

Figure 2: Relationship Between Watershed Imperviousness (I) and the Storm Runoff Co efficient (Rv)



3.4 This basic hydrologic response occurs during every storm, but the effect is most pronounced during smaller, more frequent storms. Consequently, urban streams experience an increased frequency and magnitude of flooding. Frequent flash flooding occurs after intense rain events and often causes chronic flood damage. The increased frequency of flooding from smaller storm events often has the greatest impact on streams, as it transports sediments and causes channel erosion. The severity of changes to the hydrology and physical character of urban streams can be predicted by the ICM, as described in Table 1.

Table 1 Hydrologic and Physical Predictions According to the ICM

Stream Hydrology Indicator	ICM Stream Classification			
	High Quality	**Impacted**	**Non-Supporting**	**Urban Drainage**
Stormwater Runoff as a Fraction of Annual Rainfall	2 to 7%	10 to 30 %	25 to 60 %	60 to 90 %
Ratio of Post to Pre Discharge 100 Year Storm	1.0 to 1.05	1.1 to 1.5	1.5 to 2	2 to 3
Frequency of Bankfull Flood Events	1.0 to 1.2 per year	1.5 to 3 per year	3 to 7 per year	7 to 10 per year
Fraction of Original Stream Network Remaining	90 to 95%	60 to 90%	25 to 60%	10 to 30%
Fraction of Riparian Forest Buffer Intact	70 to 90%	50 to 70%	30 to 60%	less than 30%
Stream Crossings	0 to 1 per stream mile	1 to 2 per stream mile	2 to 10 per stream mile	No stream to cross

Adapted from Schueler (2004)

Impact on Stream Habitat

3.5 The increased magnitude and frequency of stormwater flows give urban streams more power to transport sediment and cause channel erosion. Most urban streams respond by enlarging their channel cross-section to accommodate the increased flows. Channel enlargement occurs through a combination of widening or down-cutting, depending on the stream type. The cross-section of the current channel can become two to 10 times larger than the pre-development channel, although the full adjustment process may take many decades to complete. Consequently, channel erosion is severe in urban streams, and causes extensive damage to both public infrastructure and private property.

3.6 The active phase of urban channel erosion greatly increases the sediment supply to urban streams. Urban streams commonly transport two to 10 times more sediment than rural streams. As this sediment moves through the stream network, it exerts a strong influence on the streambed, causing many alternating cycles of sediment deposition and erosion. The severity of changes to stream habitat can be predicted by the ICM and are summarized in Table 2.

Table 2 Stream Habitat Predictions According to the ICM

Stream Habitat Indicator	ICM Stream Classification			
	High Quality	**Impacted**	**Non-Supporting**	**Urban Drainage**
Ultimate Channel Enlargement Ratio	1.0 to 1.2 times larger	1.5 to 2.5 times larger	2.5 to 6 times larger	6 to 12 Times larger
Sediment Yield	Rural Background	2 to 5 times greater	5 to 10 times greater	possibly lower
Typical Stream Habitat Score	Good to excellent	fair, but variable	consistently poor	poor, often absent
Presence of Large Woody Debris	5 to 10 pieces per 30 m	2 to 3 pieces per 30 metres	Scarce	absent
Increased Summer Stream Temperatures	0 to 2 degrees F	2 to 4 degrees F	4 to 8 degrees F	8 + degrees F

Adapted from Schueler (2004)

Urban Stormwater Pollution and Water Quality

3.7 Just about any pollutant deposited from the atmosphere or generated within a subwatershed is likely to be washed off in urban stormwater runoff. As a result, stormwater runoff contains a wide range of pollutants that can degrade local or downstream water quality. Pollutant concentrations tend to vary with each storm event, and may depend on the prevailing land use and type of precipitation (Pitt et al, 2004). In general, however, the unit area pollutant load delivered to a stream always increases in direct proportion to subwatershed IC. The increased pollutant load associated with subwatershed development can be predicted by the ICM and is summarized in Table 3.

Table 3 Stream Water Quality Predictions According to the ICM

Water Quality Indicator	ICM Stream Classification			
	High Quality	**Impacted**	**Non-Supporting**	**Urban Drainage**
Annual Nutrient Load	Same as rural background loads	1 to 2 times higher than rural background	2 to 4 times higher than rural background	4 to 6 times higher than rural background
Violations Violations of Bacteria Standards	Infrequent violations only during wet weather	Frequent violations during wet weather	Continuous violations during wet weather; Episodic violations during dry weather	Continuous violations during wet weather, frequent violations during dry weather
Aquatic Life Aquatic Life Toxicity	No toxicity	Acute toxicity rare	Moderate potential for acute toxicity during some storms and spills	High potential for acute toxicity during dry and wet weather
Contaminated Sediments	Clean sediments	Sediments enriched but not contaminated	Sediment contamination likely, potential risk of bioaccumulation	Contamination should be presumed
Fish Advisories	None	Rare	Potential risk of bioaccumulation	Should be presumed
Trash and Debris	Less than 1 ton	1 to 2 tons per square mile	2 to 5 tons per square mile	5 to 10 tons per square mile

Adapted from Schueler, 2004

Impacts on Aquatic Diversity

3.8 Hydrologic, physical, and water quality changes caused by urbanization stress the aquatic community and collectively diminish the quality and quantity of available habitat. As a result, these stressors generally cause a decline in biological diversity, a change in trophic structure, and a shift towards more pollution tolerant organisms (Table 4). Under current patterns of development, urban streams lose their potential to have excellent biological diversity at about 10% subwatershed IC, and lose the potential to achieve “fair” diversity scores at about 25% subwatershed IC. This basic pattern in aquatic insect diversity has been reinforced by more than 20 urban stream studies (CWP, 2003).

Table 4 Aquatic Diversity Predictions According to the ICM

Aquatic Diversity Indicator	ICM Stream Classification			
	High Quality	**Impacted**	**Non-Supporting**	**Urban Drainage**
Aquatic Insect Diversity	Good to excellent	fair to good	Poor	very poor
EPT Taxa	70 to 90%	40 to 70%	20 to 50%	0 to 20%
Fish Diversity	Good to excellent	fair to good	Poor	very poor
Riparian Plant Diversity	Fair to good, depending on grazing	stressed, with reduced native plant diversity	simplified community with many exotic species	isolated remnants; dominated by exotics
Adapted from Schueler (2004)				

Scientific Basis for Impervious Cover Model

3.9 I first proposed the Impervious Cover Model that projects that hydrological, habitat, water quality and biotic indicators of stream health begin to decline sharply at around 10% total impervious cover in smaller catchments in a 1994 paper (Schueler, 1994). The ICM has since been extensively tested in ecoregions around the US, Canada, New Zealand and Australia and more than 200 different studies have confirmed the basic model for single stream indicators or groups of stream indicators (CWP, 2003). Since this comprehensive review was published, several major stream research studies have reinforced the ICM as it is applied to first to third order streams (Cianfrina et al. 2006, Coles et al, 2004, Deacon et al, 2005, Fitzpatrick et al, 2005, King et al, 2005, Urban et al 2006). The Auckland Regional Council (2004) has taken a similar approach to the basic ICM model as part of its urban stream classification framework, based on monitoring studies that have documented a similar decline in aquatic indicators in a range of Auckland streams.

Applicability of the ICM Predictions to Vaughans Stream

3.10 The ICM is a powerful predictor of stream quality, but it must be used appropriately. It is restricted to first to third order alluvial streams with moderate gradient and no major point sources of pollutant discharge. The ICM is most useful in projecting the behavior of numerous stream health indicators, but it is not intended to be accurate for every individual stream indicator. In addition, management practices in the contributing catchment or subwatershed must not currently be poor (e.g., no deforestation, acid mine drainage, intensive row crops, etc.). The last point is important; just because a subwatershed has less than 10% IC does not automatically mean that it will have good or excellent stream quality if past management were poor.

3.11 However, based on my review of project maps, the stream ecology data contained in the ecological values report prepared by Kingett Mitchell (2005), and my personal inspection of Vaughans Stream and the Long Bay catchment on March 1, 2007, I can assert that it does in fact conform to the assumptions of the ICM, and its future quality will be extremely vulnerable to future catchment development, unless the exceptional mitigation measures outlined in the Long Bay Structure Plan are effectively implemented.

3.12 Therefore, the following future stream health predictions for Vaughans Stream are predicted in the absence of effective stormwater mitigation:

(i) Existing high quality stream segments having less than 10% IC in their contributing drainage area will continue to function as **high quality streams**, and should be able to retain their hydrologic function and support good to excellent aquatic diversity. It may even be possible to improve stream condition as riparian cover increases and cattle grazing ceases.

(ii) Stream segments that have 10 to 25% IC in their contributing drainage area will behave as **impacted streams** and show clear signs of declining stream health. Most indicators of stream health will fall in the fair range, although some segments may range from fair to good as riparian cover improves. The decline in stream quality will be greatest towards the higher end of the IC range.

(iii) Stream segments that range between 25 and 60% subwatershed IC will become **non-supporting streams** (i.e., no longer supporting their designated uses in terms of hydrology, channel stability habitat, water quality or biological diversity). These stream segments will be so degraded that any future stream restoration or riparian cover improvements would be insufficient to recover stream function and diversity (i.e., the streams would be so dominated by subwatershed IC that they cannot attain pre-development conditions). It is also highly probable that a biological decline would be observed in the tidal portion of the stream and portions of the marine reserve (see paragraph 3.13 of my evidence).

(iv) Stream segments whose subwatersheds that exceed 60% IC would be eliminated or physically altered so that it merely functions as a conduit for flood waters. These **urban drainage streams** will have consistently poor water quality, highly unstable channels and very poor habitat and biodiversity scores. In many cases, the stream segments would be eliminated altogether by earthworks or enclosure.

Application of ICM to tidal streams and coastal waters

3.13 Only within the last five years have researchers examined whether the ICM applies to tidal coves and streams influenced by tidal conditions, such as the lower section of Vaughans Stream that has tidal influence. The primary work by Holland et al (2004), references cited in CWP (2003) and Lerberg et al (2000) indicate that adverse changes in physical, sediment and water quality variables can be detected at 10 to 20% subwatershed impervious cover, with a clear biological response observed in the range of 20 to 30% impervious cover. The primary physical changes involve greater salinity fluctuations, sedimentation and greater pollutant contamination of sediments. The biological response includes declines in diversity of benthic macroinvertebrates, shrimp and finfish.

3.14 More recent work by King et al (2006) reported a biological response for coastal plain streams at around 21 to 32% urban development (which is usually about twice as high as impervious cover). The thresholds for important water quality indicators such as bacterial exceedances in shellfish beds and beaches appears to begin at about 10% subwatershed IC, with chronic violations observed at 20% IC (Mallin et al, 2001). Algal blooms and anoxia resulting from nutrient enrichment by stormwater runoff also are routinely noted at 10 to 20% subwatershed IC (Mallin et al, 2004).

3.15 The primary conclusion to be drawn from the existing science is that the ICM does apply to tidally influenced streams, tidal coves and streams, but that threshold values for biological response appears to be higher (20 to 30% IC) than freshwater streams, presumably due to their greater tidal mixing and inputs from near-shore ecosystems.

Effect of riparian forest cover on the ICM

3.16 Riparian forest cover is defined as canopy cover within 100 metres of the stream, and is measured as the percentage of the upstream network in this condition. Riparian forest cover is important in maintaining stream health at low levels of catchment IC (less than 15%). Numerous researchers have evaluated the relative impact of riparian forest cover and impervious cover on stream geomorphology, aquatic insects, fish assemblages and various indexes of biotic integrity. As a group, the studies suggest that indicator values for urban streams increase when riparian forest cover is retained over at least 50 to 75% of the length of the upstream network (Urban et al 2006, Wang et al, 2003, Allan, 2004, Cianfrina et al 2006, Sweeney et al 2004, Moore and Palmer, 2005 and Morley and Karr, 2002). Given the many different ecoregions in which these studies were undertaken, it appears that a 65% riparian forest cover is a reasonable threshold to assure good to excellent stream health.

3.17 The beneficial impact of riparian forest cover is lost when catchment IC exceeds 15%, at which point degradation by stormwater runoff overwhelms the benefits of the riparian forest according to Roy et al (2005), Roy et al (2006) and Walsh et al (2007).

Effect of stormwater management practices on the ICM

3.18 The primary stormwater management strategy to mitigate the effect of the ICM is to maintain the predevelopment runoff **volume** delivered to the stream following full catchment development. In its simplest terms, this means achieving the same predevelopment runoff coefficient for each storm (cf Figure 2 in Section 4.1 of this evidence). Prior engineering design criteria have sought to maintain predevelopment peak discharge **rates** for a select set of infrequent large rain events, but it is now widely accepted that the peak discharge approach cannot replicate predevelopment hydrology across the entire range of the rainfall frequency spectrum. Runoff reduction is needed to reduce the increased frequency and duration of runoff events that streams experience and maintain groundwater recharge that supports baseflow when it is not raining.

3.19 In sensitive subwatersheds such as Long Bay, it is essential to take a runoff volume reduction approach to maintain the same hydrology from pre to post development. Some LID practices such as infiltration, bioretention, permeable paving and water harvesting have good to excellent capability to reduce runoff volumes, whereas ponds and wetlands have little or no ability to do so (see paragraphs 7.5 and 6.3 of my evidence respectively).

4. IMPORTANT OF SENSITIVITY OF ZERO-ORDER STREAMS

4.1 Zero-order streams are channels with defined banks that emanate from a hollow or ravine with convergent contour lines (Gomi et al 2002). They represent the uppermost definable channels that possess temporary or intermittent flow. They terminate when the channel becomes a defined perennial stream that supports flow during at least one-third of the year. These transitional streams have only recently received scientific scrutiny (Meyer et al 2003) but recent reports indicate they possess exceptional value in the ecology of stream network. Quantitatively, zero order streams represent the largest stream length of any stream order (Freeman et al 2007). In Long Bay subwatershed, they comprise nearly 5 kilometres of stream length.

4.2 In most cases, zero-order streams correspond to Category 2 streams referenced in the various Long Bay reports and maps, but I will use the term zero-order throughout my evidence, since I lack the local freshwater ecology experience to make a precise determination of specific stream segments in question for Long Bay. Dr. Ian Boothroyd will present more specific evidence on this topic in his evidence.

4.3 Functioning zero-order channels provide major watershed functions, including groundwater recharge and discharge (Schollen et al, 2006 and Winter 2007), important nutrient storage and transformation functions (Groffman et al 2005 and Bernot and Dodds, 2005), storage and retention or eroded hill-slope sediments (Meyers et al, 2003), and delivery of leaf inputs and large woody debris. Alexander et al (2007) recently reported the importance of zero-order streams on downstream water quality in the stream network. Freeman et al (2007) also note the importance of zero-order streams in promoting the hydrologic connectivity of down stream channels.

4.4 Meyer et al (2007) provide an international review of ecological studies confirming that zero order streams are a major reservoir supporting downstream diversity in aquatic insect communities. Many zero order streams contain rare or endemic species found nowhere else in the stream network. Lastly, freshwater ecologists now recognize that headwater streams are important areas that influence sediment and solute transport to downstream segments, and are a critical location where coarse organic carbon is processed into finer forms that serves as the base of downstream detrital food chain.

4.5 Recent research has also indicated that zero-order are more susceptible to the impacts of upstream development than first and second order streams, particularly in terms of channel geomorphology and sediment delivery. For example, recent research on California streams by Coleman et al (2005) discovered enlargement and other geomorphic responses with as little as 3% total impervious cover.

4.6 As part of my field reconnaissance of March 1, 2007, I inspected several of the zero-order and first order streams in question. Despite a lack of rain for at least a month, the streams were clearly providing important functions to Vaughans Stream as a whole. Although I did not assess every stream in the catchment, I did examine streams 1 and 4 and consider them to be an important element of the stream network to retain.

5. IMPACT OF EARTHWORKS ON STREAM HYDROLOGY

Impact of Earthworks on Soil Compaction and Infiltration Rates

5.1 Numerous researchers have documented the impact of construction earthworks on the compaction of soils, as measured by increase in bulk density, declines in soil permeability, and increases in the runoff coefficient (Pitt et al, 1999, Schueler, 2001a, Schueler, 2001b, Lichter and Lindsey, 1994, Legg et al, 1996 and Pitt, 1992). These areas of compacted areas pervious cover (lawn or turf) have a much greater hydrologic response to rainfall than forest or pasture.

5.2 Based on a conservative analysis, the existing clay soils prevalent in the catchment are expected to have runoff coefficients in the range 0.15 to 0.25 (Pitt, 1992, Legg et al 1996 and Pitt et al (1999). The effect of earthworks and soil compaction nearly doubles the runoff coefficient, as shown in Table 5. When compared to the runoff coefficient for impervious areas, the compacted pervious areas in the catchment can be reasonably argued from a hydrological standpoint to be equivalent to 45 to 50% impervious cover (e.g., One acre of turf = 0.5 acres of impervious cover).

Table 5.
Effect of Earthworks and Soil Compaction on Runoff Coefficient for Clay Soils*

Soil Condition	Runoff Coefficient
Native Bush	0.15 to 0.25
Disturbed Soils	0.40 to 0.50
Impervious Cover	0.90 to 0.95

* Volumetric runoff coefficient for storms 25 mm or less drawn from various sources

Effect of Earthworks on Zero-Order Streams and Stream Hydrology

5.3 Zero-order streams have not generally been subject to special protection under most wetland, buffer or stream protection requirements. Consequently, zero-order streams are disproportionately disturbed by mass-grading, enclosure or channelization, compared to high order network streams (Meyer et al 2003 and Gomi 2002).

5.4 No research has yet directly explored the relationship between upland impervious cover and zero-order stream loss, or between zero-order stream loss and changes in to higher order stream integrity. The most conservative assumption is to link the benefits of zero-order streams with the larger IC/stream quality relationship, and posit that no more than 10% cumulative loss of zero order stream mileage is acceptable to maintain downstream quality. David Kettle will present evidence later that indicates the Long Bay Structure Plan will eliminate less than 10% of zero-order stream length, whereas the LandCo plan will eliminate about 25% of the length of these streams in the catchment.

Sensitivity of Long Bay Catchment to Earthworks

5.5 The North Shore Structure Plan clearly outlines a strategy to minimize soil compaction and protect many zero-order streams from severe impacts of earthworks. I do recommend that the Practice Notes be amended to require soil amendments at the time of final stabilization at the end of construction. The basic approach would be scarify existing soils and incorporate 10 to 20 cm of topsoil mixed with compost to improve the post development hydrologic properties of grass areas, or at least reduce their post development runoff coefficient. More information on this approach can be found in Pitt et al (2005) and Schueler (2001b).

6. EFFECT OF STORMWATER MITIGATION: WET PONDS/CONSTRUCTED WETLANDS

Design Evolution of Stormwater Ponds and Wetlands

6.1 The design of stormwater ponds has evolved over time to meet management objectives to reduce stormwater pollutants and maintain pre-development peak discharge rates to prevent flooding (Schueler, 1987). In the last decade, the basic design has evolved to extend detention times to protect downstream channels (ARC, 2003 TP-10). This section of my evidence will review the overall capability of ponds and wetlands to mitigate the effects of increased IC in the Long Bay catchment.

Capability to Remove Stormwater Pollutants and Detain Floodwaters

6.2 Performance monitoring of wet ponds and constructed wetlands in the Auckland Region are limited to four research efforts and less than 30 storm events. It is therefore helpful to infer their broad capability from a much larger North American database of pond and wetland pollutant removal capability (see shaded cells in Table 6). When designed and maintained properly, both wet ponds and constructed wetlands can provide moderate to high removal rates for many of the common stormwater pollutants. It is important to note that reported removal rates are variable (e.g., wet pond total nitrogen removal ranges from -12% to +76%). Ponds and wetlands are also subject to a maximum level of treatment, known as the irreducible concentration (Schueler, 1999). Based on my inspection of several ponds constructed on private development sites in North Shore City designed in accordance to TP-10 guidelines, actual removal rates will probably be lower than those guidelines require, given that many have no incorporated suggested design features that promote higher removal rates in addition to the fact that Auckland soils have a high clay fraction that does not settle quickly.

6.3 Wet ponds and constructed wetlands can provide excellent downstream flood control (ARC, 2003), but this benefit depends on where they are located. Based on my field recon of the Long Bay catchment and analysis of project mapping, there are very few acceptable sites in the upper catchment to locate stormwater ponds (primarily due to steep topography). The very few potential pond and wetland sites that do exist contain important existing wetlands and high quality Category 1 and 2 streams, and are therefore not suitable for pond construction.

Table 6: Comparative BMP Capability to Reduce Pollutant Concentrations in Runoff [1]

Practice	Sediment (%)	Nitrogen (%)	Total P (%)	Zinc (%)	Bacteria (%)
Dry Ponds (10) [2]	49	24	20	29	88
Wet Ponds (44)	80	31	52	64	70
Wetlands (37)	72	24	48	42	78
Bioretention (10)	59	46	5 [3]	79	85
Infiltration (8)	89	42	65	66	nd [4]
Swales (17)	81	56	24	71	nd

Notes: 1: Median values from CWP Pollutant Removal Database Version 3.0 (Schueler, 2007)

2: number in parentheses is number of practices that have been monitored using acceptable methods

3: Low P removal due to leaching from soil media. When low-P soil media are used, removal climbs to 50%

4: insufficient monitoring data available to compute statistics

Capability to Replicate Pre-Development Hydrology

6.4 Wet ponds and constructed wetlands have been shown to have little value in reducing stormwater runoff volumes-- less than 5% according to Strecker et al (2004). The nominal runoff reduction they achieve is solely due to evaporation. Nearly all the runoff that enters a pond leaves the pond, albeit after a few hours or days of storage. Consequently, they have no capability to reduce the runoff volumes that stress streams.

6.5 The other concern about ponds is related to their downstream location in the catchment. Simply put, all of the upstream channels in their contributing drainage area would be untreated and essentially sacrificed (Schueler, 2000). Given the topography of the Long Bay catchment, this would mean that many sensitive streams (e.g., 1, 3, 4 and 9) would be subject to severe degradation even if they were preserved during development.

Stream Warming by Ponds

6.6 Summer stream temperature is an important organizing element in freshwater stream ecology. Stormwater ponds act as a heat sink and have been shown to contribute to stream warming. This effect is typically defined as the delta-T, or the additional increment of summer water temperature compared to an undeveloped forested reference stream. Numerous researchers have shown that stormwater ponds and wetlands increase downstream daily water temperatures by at least three degrees Celsius (Galli, 1990, Maxted et al, 2005). Despite many efforts, there are no promising technological fixes to solve the pond stream warming problem.

Capability to Protect Downstream Aquatic Life

6.7 Seven research studies have evaluated whether stormwater ponds and wetlands are capable of preserving the quality of aquatic biota in streams. These studies have uniformly shown that ponds and wetlands are unable to prevent the degradation of aquatic life in downstream channels (MNCPPC, 2000, Maxted, 1999, Stribling et al, 2001, Galli, 1990, Horner and May, 1999, Horner et al, 2001 and Jones et al, 1996). The primary reasons that are cited for this phenomenon are stream warming (amplified by ponds), changes in organic matter processing, the increased runoff volumes delivered to downstream channels, and habitat degradation caused by channel enlargement.

6.8 Once again, the downstream location of ponds exacerbates the aquatic diversity problem in the Long Bay catchment. Ponds act as AN effective barrier to upstream fish migration and also effectively isolate the upstream aquatic life community (Schueler, 2000). By interrupting the connectivity of the stream network, the ponds may sacrifice zero and first order streams that are critical to sustaining freshwater diversity in the catchment.

Proper Use of Ponds and Wetlands in the Long Bay Catchment

6.9 Ponds and constructed wetlands do have a role to play as part of the overall treatment train for the Long Bay catchment. Off-line constructed wetlands are appropriate to treat runoff from intensively developed subcatchments in the lowermost portion of the catchment (Stream Protection Area B) as well as the Awaruku stream, and off-line locations in subcatchment 9.

7. EFFECT OF STORMWATER MITIGATION: LOW IMPACT DEVELOPMENT

Definition of LID and BSD in context of the Long Bay

7.1 The terminology related to new and innovative stormwater practices can be somewhat confusing. In my evidence, I use the terms Low Impact Development (LID) and Better Site Design (BSD) to define two complementary runoff reduction strategies. LID refers to the systematic application of small on-site practices across the subwatershed to treat the quality and quantity of runoff at its source.

7.2 The Long Bay Structure Plan and the accompanying Practice Notes outline a series of LID practices such as revegetation (SW-3), rainwater harvesting (SW-4), rain gardens (SW-6), permeable pavers (SW-5), swales and filter strips (SW-7, biofiltration trench (SW-11) and related practices. These small LID practices are sized and designed to treat the runoff from a few hundred square metres of impervious cover.

7.3 Better Site Design (BSD) is a term for non-structural practices employed during site design and construction to minimize the creation of new impervious cover, prevent the compaction of pervious cover and conserve natural areas that are critical in maintaining predevelopment hydrology (CWP, 1998). Examples of BSD techniques include minimizing impervious areas (SW-2), lot-level erosion control (SW-13), riparian management (SW-14), conditioning of surface soil (SW-17), streambank management (SW-20), and ephemeral stream management (SW-21). These techniques are all geared to conserve natural and pervious areas in the catchment that are currently producing the natural hydrology that maintains the freshwater diversity in Vaughans Stream.

7.4 I have extensively reviewed the design criteria and modeling used to develop the Practice Notes, and have concluded they are technically justified, current and consistent with similar guidance produced in Australia and North America. As a whole, I regard the Long Bay Practice Notes as one of the best examples anywhere on how to apply LID and BSD practices together in the context of a specific sensitive catchment. The remainder of this section details the scientific evidence as to ability of these LID and BSD practices to mitigate the effects of increased IC in the Long Bay catchment.

Capability to Remove Stormwater Pollutants and Detain Floodwaters

7.5 As with any emerging technology, the track record on LID and BSD practices has only become established in the last few years. The research studies that have evaluated the pollutant removal capability of individual LID practices are shown in the un-shaded cells of Table 6. In general, LID practices are capable of reducing most stormwater pollutant concentrations as well as or better than stormwater ponds and wetlands. LID practices are considered even more effective in reducing pollutant loads when their impressive runoff reduction benefits are taken into account (since loads are the product of both stormwater flow volume and the treated pollutant concentration).

7.6 Numerous modeling studies have also demonstrated the pollutant reduction benefits associated with BSD at the scale of the individual site (CWP, 1998a, 1998b, 2002) and two monitoring studies have confirmed it in paired catchments in the USA (Bedan and Clausen, 2006 and Cheng et al, 2005).

Capability to Replicate Pre-Development Hydrology

7.7 My understanding is that while there are two ongoing monitoring studies investigating LID practices in the Auckland area, there is no performance data yet available. A group of new research studies from North America, however, have demonstrated the value of BSD and LID practices to replicate pre-development hydrology at the site and catchment level through impressive levels of runoff reduction. As noted in paragraph 3.3, runoff reduction is the primary stormwater management strategy to mitigate the effect of IC on sensitive streams; effectively achieving the predevelopment runoff coefficient for each storm. Table 7 reviews 17 recent studies on the runoff reduction capability of LID practices, ranging from bioretention, biofiltration swales, permeable pavers and rain tanks from elsewhere in the world. As can be seen, the reduction in runoff volume achieved by LID practices is impressive—ranging from 40 to 99%

with a median reduction of about 75%. When this is compared to the nominal runoff reduction achieved by ponds and wetlands (>5%), the superior performance of LID is evident. Less research is available to define the runoff reduction benefits of BSD practices, but modeling studies consistently show a 10 to 45% reduction, compared to conventional development (CWP, 1998a, 1998b, 2002).

Table 7:
Review of Recent Research on Volumetric Runoff Reduction by LID Practices

LID Practice	**% Runoff Reduction**	Reference
Bioretention	99	Dietz and Clausen (2006)
Bioretention	58	Seters et al (2006)
Bioretention	98	Rushton (2002)
Bioretention	50	Hunt et al (2006)
Bioretention	40 to 60	Smith and Hunt (2006)
Bioretention	75	Ballestro et al (2006)
Bioretention	80	Traver et al (2006)
Bioretention	73	Lloyd et al (2002)
Biofiltration Swale	98	Horner et al (2003)
Biofiltration Swale	94	Jefferies (2004)
Bioflitration Swale	46 to 54	Stagge (2006)
Permeable Pavement	75	Rushton (2002)
Permeable Pavement	99	Seters et al (2006)
Permeable Pavement	95 to 97	Traver et al (2006)
Permeable Pavement	60 to 90	Hunt and Lord (2006)
Permeable Pavement	50	Jefferies (2004)
Rainwater Harvesting	60 to 90	Coombes et al (2004)

7.8 The next question is whether the runoff reduction benefits of individual LID and BSD practices have a cumulative benefit at the neighbourhood or catchment scale. Four monitoring studies have clearly documented a major reduction in stormwater runoff from development that employ LID/BSD compared to those that do not (see Table 8). These are some of the most difficult monitoring studies to complete, but all four -- Jordan Cove and Somerset Heights, Fig Tree Place and Lynbrook Estate -- provide an affirmative answer.

7.9 In addition, a half dozen studies have documented the runoff reduction benefits of LID at the catchment or watershed scale using a modeling approach, as has been done in the North Shore Structure Plan (Maunsel Ltd, 2004).

Table 8 Review of Recent Monitoring and Modeling Research on Catchment Scale

Location	**Type**	**Practices**	**Runoff Reduction**
Jordan Cove, USA Bedan and Clausen (2006)	Mon	Permeable pavers, bioretention, grass swales	84%
Somerset Heights USA Cheng et al (2005)	Mon	Grass swale, bioretention, and rooftop disconnection	45%
Figtree Place AUS Coombes et al (2005)	Mon	Raintanks, infiltration trenches, swales	100%
Lynbrook Estate AUS Lloyd (2002)	Mon	Biofiltration swales	75%
North Ryde, AUS Coombes (2004)	Mod	Rainwater harvesting (roof only)	24%
Heritage Mews AUS Hardy et al (2004)	Mod	Raintanks, infiltration trenches, swales	100%
Ralston Creek USA Dodds et al (2003)	Mod	On lot bioretention and infiltration on impermeable soils	60%
Portland, OR USA Huber et al (2006)	Mod	Rooftop disconnection and rain gardens in ultra urban catchments	50%
Boulder, CO USA Alexander (2003)	Mod	Biofiltration swales along streets	96%
Vancouver BC CAN Stephens et al (2002)	Mod	Retrofit of urban watersheds with green rooftop, bioretention and compost amendments	40 to 50%

Mon = demonstration through hydrologic monitoring
Mod = demonstration through hydrologic modeling studies.

Stream Warming Impact

7.10 The use of LID practices such as bioretention has been shown to reduce stream warming in recent research (Hunt, 2007 personal communication) or at least be thermally neutral. When compared to the stream warming caused by ponds, this is a very important difference in stormwater mitigation.

Capability to Protect Downstream Aquatic Life

7.11 Given their proven capability to reduce post-development increases in runoff volume, LID has the greatest potential of any practice to mitigate the impacts of increased impervious cover if used on a widespread basis.

Proper Use of LID/BSD in the Long Bay Catchment

7.12 The available science clearly indicates that runoff reduction is the most critical variable influencing the post-development stream, as it replicates the pre-development hydrology, uses soils to filter pollutants, reduces stream warming, and minimizes stream habitat degradation caused by channel enlargement and/or incision. The clear definition of where, how and what LID/BSD practices to use in stream protection areas A and B is major difference between the two Long Bay development scenarios before the Court.

7.13 It is also important to introduce a cautionary note in regard to LID. While it is clearly the best approach to use in the catchment, no stormwater mitigation scheme can ever be 100% effective. For example, full runoff reductions may not always be achieved due to clay soils, winter ET rates or poor installation. This is implicitly recognized in the North Shore Structure Plan, since it also produces a lower level of subwatershed IC as an additional level of insurance in case the proposed stormwater mitigation is not fully achieved.

8. ADOPTION AND ECONOMICS OF LID AND BSD PRACTICES

8.1 The adoption of any new technology raises concerns about its feasibility, life cycle costs maintenance needs, longevity, and community acceptance. Over the past decade, communities in North America and Australia have gained experience in implementing low impact development. This section reviews the available science with respect to the economics, feasibility and acceptance of these practices.

8.2 In general, the on-site approach to stormwater management embodied by LID has been shown to be economically superior to the centralized off-site stormwater management that it replaces, despite the fact that initial installation costs are slightly higher. Kloss and Calarusse (2006) in a more comprehensive review of LID economics notes that their capital and life-cycle costs are generally equally to or less than the costs for conventional stormwater practices when applied to new development sites (i.e., greenfield development). By contrast, LID construction and life cycle costs are greater when they are retrofitted into existing urban catchments. The central premise of the structure plan is to systematically install them in a new development context.

Initial Construction Costs

8.3 In general, the initial construction costs for LID practices are slightly higher than for conventional stormwater practices, such as ponds and wetland. The magnitude of the construction cost premium largely depends on two factors: 1) whether LID is applied to new development or retrofitted after the fact and 2) whether they are applied to low or high density development. In my own research, I have generally found that LID construction costs are slightly higher than stormwater ponds or constructed wetlands, primarily due to economies of scale involving drainage area – ponds and wetlands treat larger drainage areas and have a lower unit cost for treatment (Schueler, 2007).

8.4 Table 9 reviews 17 case studies that have compared the costs associated with conventional stormwater management versus low impact development on actual development sites. Given the many differences in site design, currency rates, and design criteria among the studies, the specific dollar results cannot be directly compared, and are not shown. As can be seen, initial construction costs for LID practices are often, but not always higher. This is consistent with the LID economic analysis conducted for Long Bay (Kettle et al 2004).

Savings in Overall Stormwater Infrastructure

8.5 The primary economic value of LID/BSD practices is that they reduce post-development runoff volumes and therefore reduce the size and cost of the stormwater conveyance system (curbs, gutters, storm drain inlets, storm drain pipe, and downstream stormwater ponds). Additional savings are produced by reductions in paved areas (narrow street widths etc.). As can be seen in Table 9, the majority of case studies indicate an overall project savings related to stormwater and other development infrastructure (less paving, sidewalks, etc.).

Table 9. Summary of Cost Benefits of LID vs. Conventional from Case Studies

Case Study	LID Costs More	LID Reduces Infrastructure Costs	Faster home sales	Overall Project Savings *
Laurel Springs	No	Yes	Yes	Yes
SEA Streets	Yes	Yes	--	Yes
Rivergate	--	Yes	--	Yes
South Kingstown	--	--	Yes	Yes
WSSI	Yes	No	--	--
Pembrook Woods	No	Yes	Yes	Yes
Somerset	No	Yes	Yes	Yes
Jordan Cove	--	No	--	--
Forest Ridge	--	--	Yes	--
Forest Brooke	Yes	Yes	Yes	Yes
Boulder	Yes	Yes	--	Yes
Figtree Place	--	Yes	--	Yes
Glencourt	Yes	Yes	--	Yes
Rappahanock	Yes	Yes	--	Yes
Henrico	Yes	Yes	--	Yes
Frederick Retail	Yes	Yes	--	Yes
Germantown Office	Yes	Yes	--	--

Sources: CWP (2006), Coombes (2004), CWP, (1998), Alexander and Heaney (2002), Hardy et al (2004), and Huber at (2006)

--: study did not examine this benefit

Life cycle costing for both conventional and LID stormwater practices remains in relative infancy due to the fact that most municipalities have not regarded either as an important infrastructure asset to manage for the public good (Taylor, 2003 and WERF, 2004).

Maintenance and Community Acceptance of LID/BSD Practices

8.6 The track record for LID/BSD practices is relatively short so it is difficult to make strong assertions in regard to their longevity and maintenance (WERF, 2004). The key difference is that many of the LID practices would be privately maintained, as opposed to the public maintenance of stormwater ponds and wetlands. Experience so far in North America indicates they are maintained well since they often also serve a landscaping function. LID practices are also consistently popular in the community, compared to their pond and wetland counterparts. They tend to be more aesthetic and safe and encounter fewer nuisance problems (e.g., mosquitoes, odors, vermin).

9. SUMMARY REVIEW OF THE CURRENT NORTH SHORE STRUCTURE PLAN

9.1 In my professional opinion the current version of the Long Bay Structure Plan is the most appropriate and effective land use and stormwater mitigation strategy to protect freshwater and tidal streams in Long Bay. Vaughans Stream is considered a regionally important reference stream and currently has very high ecological function and biological diversity despite grazing pressures. As noted earlier, it is particularly vulnerable to future catchment development. Based on my review of all of the key documents and my field reconnaissance, I am very confident that the Structure Plan and Practice Notes provide greater assurance that the resource will be protected in the future. I am currently unable to review major elements or the capability of Landco's alternative structure plan because of a lack of detail in many of its stormwater mitigation elements.

9.2 My reasons as to why the Long Bay Structure Plan is more appropriate are in summary:

(i) *Relevance of Model and International Data:* Based on my own investigations of the Long Bay site, I can confidently state that it does conform to the assumptions of the impervious cover model that now has widespread international acceptance. I see no reason by the international data on which I rely in this evidence would not provide an accurate indicator of hydrological and ecological effects in Long Bay under different development scenarios.

(ii) *Subwatershed Impervious Cover*: The Long Bay Structure Plan will yield much lower levels of total and effective impervious cover throughout the freshwater portion of the catchment, and will stay below critical threshold levels. It will result in less total impervious cover draining to the sensitive tidal portions of Vaughans Stream, as well, which will be close, but below IC thresholds to protect coastal resources. According to calculations provided in Dave Kettle's evidence, the Landco plan will exceed critical IC thresholds in major portions of the subwatershed, endangering future stream health in both the freshwater and tidal areas.

(iii) *Non-Compacted Pervious Area*: The Long Bay Structure Plan will minimize earthworks, and protect important zero-order streams in the Vaughan stream network. The more extensive earthworks proposed by Landco will increase runoff coefficients from turf and lawn area, increasing the effective impervious cover across the subwatershed. By amending the Practice Notes to incorporate scarification and compost amendments, the Long Bay Structure Plan may be able to recover soil porosity and infiltration that will be lost during project construction.

(iv) *Riparian Forest Cover*: The Long Bay Structure Plan has a more aggressive plan to restore riparian cover in the stream corridor in both category 1 and category 2 streams. Current grazing pressures have impacted on the riparian forest especially in the lower catchment, so this plan element has potential to improve stream quality within the expected level of subwatershed impervious cover.

(v) *Category 2 Stream Protection*: The Long Bay Structure Plan does a better job at protecting the capillaries of the stream network in Long Bay – the nearly 5 kilometres of zero-order streams that provide major hydrologic and ecological services to the downstream system. According to evidence presented by David Kettle, the

Long Bay Structure Plan would fill, disturb or cause degradation to less than 10% of these stream lengths, whilst the Landco plan would eliminate about 25% of their total length.

(vi) *Category 1 Stream Protection*: In a sensitive subwatershed such as Long Bay, it is essential to take a comprehensive and "redundant" approach to protect stream quality that seeks to minimize impervious cover, protect and restore key natural areas and reduce runoff volumes from new impervious cover to maintain predevelopment hydrology. The Long Bay Structure Plan gets high marks in all three areas. The key point is that if one element fails, the others provide a safety backup. Thus, I would consider the Long Bay Structure Plan to be a much more reliable and appropriate subwatershed strategy because of this management redundancy.

(vii) *Stormwater Mitigation Approach*: In my opinion, the Long Bay Practice Notes and Long Bay Structure Plan are one of the best examples I am aware of on how to apply LID and BSD practices together in the context of a specific high quality catchment. The NSPP provides specific guidelines on when, where and how practices will be organized into a treatment train. As noted earlier, an exceptional stormwater mitigation approach is needed to protect Long Bay, and the approach set forth in the Long Bay Structure Plan is based on the best science and engineering to manage stormwater. While LID/BSD is relatively new to New Zealand, experience in Australia and North America has proven it to be an effective and practical stormwater management strategy.

(viii) *Limitations of Ponds and Wetlands:* The Landco approach to stormwater mitigation, to the extent that its detail can be discerned from its alternative structure plan, is ambiguous and appears to rely heavily on the use of ponds and wetlands. As noted earlier, conventional stormwater management approaches, such as ponds and wetlands, do not appear to have sufficient capability to protect high quality streams from degradation, and it is highly doubtful that their extensive use in Long Bay catchment will be effective in maintaining stream integrity.

(ix) *Implementation:* A key differences between the two plans is that the Long Bay Structure Plan presents a comprehensive and coherent approach toward the implementation of development mitigation measures, particularly with respect to stormwater management. Instead of getting such measures piece-meal through the subdivision process, the NSSC plan and accompanying Practice Notes present a common roadmap on how, where and what kind of LID/BSD practices will be installed in the catchment. This approach assures greater cumulative implementation of effective LID practices to address the cumulative impacts of land development. The Landco approach, on the other hand, appears to rely heavily on many individual decisions throughout the subdivision process, where implementation can be limited by many factors.

(x) *Risk of Failure*: The foremost issue is which plan has the least risk of failure, defined here as a loss of future stream or coastal quality. Vaughans Stream is predicted to be exceptionally vulnerable to future development, and only an extraordinary commitment to watershed protection measures can prevent the degradation. The Long Bay Structure Plan, if properly implemented, appears capable of protecting aquatic resources in the future.

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