

Chapter 2

Effects of land use on stormwater runoff

2.1 Urbanisation

2.1.1 The hydrological cycle

Water moves constantly between the atmosphere, ground and waterbodies in an ongoing, worldwide cycle, the hydrological cycle. Processes such as rainfall, infiltration and runoff, evaporation, freezing, and melting, continually move water between different physical phases, across regions, between fresh and saline waters and into the atmosphere. Some processes, such as freezing in polar areas or deep infiltration to slow aquifers, may keep water in one part of the cycle for long periods of time. All the time though, water is moving through the cycle.

The total volume of water in the cycle is finite. The amount of water vapour in the atmosphere plus the amount of rainfall, freshwater, ground water, sea water and ice on the land is constant. Over time, physical factors such as climate or landform may change the volume of water at each stage in the cycle, or sub-cycles, but in total no water leaves or enters the cycle.



Plate 2-1: Typical phases of urbanisation - bush, pasture, subdivision, and mature urban

Restricting the movement of water in one stage of the hydrological cycle will proportionally increase its movement in another. This occurs during urbanisation. The photographs above show the typical phases of urbanisation; through bush, pasture, subdivision and mature urban. In a natural state, a catchment is covered

by bush, trees and grass, which intercept rainfall and let it infiltrate into the ground. Urbanisation creates impervious surfaces which reduces vegetative interception, depression storage, infiltration and surface roughness (flow retardation). The excess water now runs off more quickly and increases the flow rate and volume of stormwater for a given storm event.



Plate 2-2: 100% site imperviousness

To illustrate these changes, Table 2-1 gives estimates of the proportion of movement by each process before and after development. These figures represent proportions for the non-volcanic soils of the Auckland Region.

| <u>Component</u> | <u>Pre-development</u> | <u>Post-development</u> |
|---------------------------|------------------------|-------------------------|
| Annual rainfall | 1200mm | 1200mm |
| Total runoff | 320mm | 700mm |
| Deep infiltration | 60mm | 10mm |
| Shallow infiltration | 300mm | 100mm |
| Evaporation/transpiration | 520mm | 390mm |

2.1.2 Non-point source pollution

Impervious surfaces also collect contaminants derived from everyday urban life. These could be anything from litter, dust, decomposing vegetation or oils, to exhaust emission particles. Roads, in particular, collect by-products from vehicle wear and tear and combustion by-products. In the context of stormwater management and this manual, these by-products are all termed “contaminants.”

Stormwater runoff moves contaminants off impervious surfaces, through drainage pipes and into waterbodies.



Plate 2-3: Non point source contaminants

Litter and larger particles are washed off directly while the (very small) contaminant particles attach more to fine silt and clay particles and become readily transportable. Heavier particles drop out of suspension close to the ends of stormwater pipes while finer silts settle and accumulate further away in still, sheltered sections of water. This accumulation of contaminants from wide areas of developed urban land is termed “non point source” pollution.

The effects of non-point source pollution are diverse. Persistent contaminants such as metals and toxic organics accumulate in sediment and have toxic ecological effects. Other contaminants such as sediment physically affect habitat, for example by smothering.

In some cases, these contaminants occur naturally in the environment. However, it is important to remember that impervious surfaces and stormwater pipes collect contaminants together, transport them and allow them to accumulate in places that they would not normally end up, and in much higher volumes and concentrations.

2.2 **Key effects**

Many of the effects of stormwater are only significant when considered cumulatively. The water quality and flooding effects of stormwater from an individual site may be relatively minor. If we consider a 10% increase in peak flow from a 1 hectare site, downstream flood levels may only increase 1 mm or less. However,

allowing an increase in flood levels on an individual site basis is an ad hoc approach which neglects the sum total of all potential development in a catchment. Therefore, in addition to any site specific effects, stormwater effects must be considered on a cumulative basis.

The three key effects of urban stormwater on the environment are:

1. Water quantity - flooding and erosion risks to humans and their property from altered hydrology and development too close to existing watercourses.
2. Water quality - threats to human health and receiving systems from changes to the physical-chemical nature of water and sediment.
3. Aquatic resources - loss of freshwater aquatic resources due to both altered hydrology and non point source pollution. In particular, this considers the physical effects of stormwater on the freshwater environment.

2.3 Water Quantity

2.3.1 General

Stormwater drainage systems are generally designed for a moderate level of risk and adopt approximately a 10% AEP event for pipe sizing. However, the importance of more severe, less frequent events is acknowledged and allowance is made for overland flow paths for events up to 1% AEP. These two systems are termed the primary and secondary drainage systems. To protect the public and their property, habitable building floor levels are required to have a contingency freeboard above the 1% AEP flood levels.

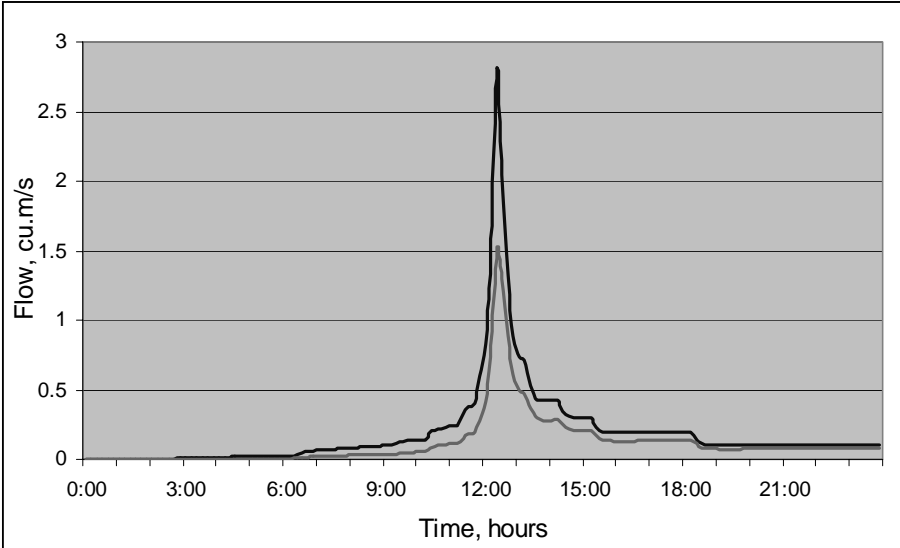
Flooding adjacent to waterways naturally occurs but urbanisation can increase flood potential due to either a gradual increase in peak flows (as a result of upstream development described in the example below), or, where a constriction in the drainage channel (culvert, pipe drainage system) or stream channel reduces the flow capacity. However, the safe passage of flood flows is not always a case of “making the pipes big enough.” Water flow changes with the location along the channel due to changes in topography, channel dimensions, roughness, pools and other factors. The flood level at a given point is therefore determined by how quickly upstream conditions deliver water and how quickly downstream conditions allow it to get away. The equilibrium sets the flood level. However, the flow rate also changes with time, as the flood passes down a catchment. The flood level will therefore constantly change as both the physical- spatial factors and the variation of flow with time balance.

2.3.2 Case study:

Figure 2-1 sets out the predevelopment and post development 50% and 10% AEP hydrographs for a 27.7 hectare residential development, which was previously pasture. The site changed from two houses to 297 lots of about 600 square metres. For average sized houses, garages and driveways and subdivision roading, the imperviousness increases from less than 1% to 54%.

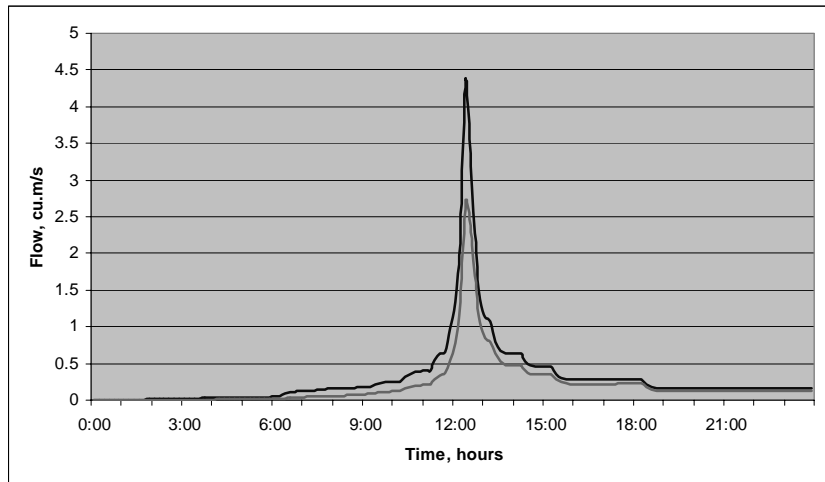
The hydrographs show that the peak flow rate for

**Figure 2-1
Pre-and post-development 50% and 10% hydrographs**



the 50% AEP event increases from 1.51 m³/sec to 2.80 m³/sec and for the 10% AEP event increases from 2.7 m³/s to 4.37 m³/s. The volume of stormwater runoff for the 50% AEP event increases from 10,200 m³ to 16,800 m³.

Stormwater from the development discharges to a stream. The extra peak flow in the watercourse raises the flood level. The flood level equivalent to the predevelopment 50% AEP event, now occurs more frequently, resulting in more frequent bankfull flows. This results in more stream bank erosion.



2.3.3 Examples of effects

1. Extent of flooding

Flood levels are determined by equating the rate of inflow, outflow and available storage. Where the outflow is smaller than the inflow, levels rise. In Plate 2-4 the flooding has risen above the stream channel and spread across large sections of land - the natural floodplain.

Increased imperviousness upstream and loss of storage volume, by filling in the flood plain, would make the flood level higher still.

Plate 2-4



2. Channel constrictions

Channel constrictions such as culverts and bridges are potential flooding points. Constrictions usually include an overland flow path to pass events more severe than the design event and make allowance for blockage.

The risks to the property in Plate 2-5 are multiple, including development greater than expected upstream, debris in the flood channel, weakening of foundations and an event greater than the design flood.

Plate 2-5



3. Lack of freeboard

To calculate freeboard and allow for the safe passage of flood flows, the ultimate development scenario upstream must be considered.

The consequences of getting it wrong are evident in Plate 2-6. A further rise in flood level will cause the bridge to become a constriction and raise upstream flood levels significantly.



Plate 2-6

4. Channel erosion

As bankfull flows increase in frequency with development, the channel erodes to become stable for the increased flow and velocity. As shown in Plate 2-7, this often results in a wider, “U” shaped channel, the most efficient shape for transporting the flow. During this process, aquatic habitat is lost.



Plate 2-7

5. Bank slumping

Stream flows are generally deepest and fastest on the outside of a bend. When flow velocities increase, the toe of a bank is often eroded, removing bank support. Eventually, the bank slumps. The recent slump is also susceptible to erosion and, unless stabilised, can keep retreating as shown in Plate 2-8.



Plate 2-8

6. Channel Incision

Plate 2-9 shows a stream where high velocity and frequent high flows erode the channel base. The clay channel invert here has been cut down 0.5 m to 1.0 m

Channel erosion is a significant source of sediment which affects water quality and downstream habitat.



Plate 2-9

2.4 Water Quality

2.4.1 General

Evidence of the effects of urbanisation on water quality may be direct but is often indirect. When considered from a number of perspectives, a clearer picture of effects emerges. Three common methods for observing water quality effects include visual assessment, contaminant level measurement, and biological surveys.

A very simple way to note stormwater effects is to walk along an urban stream and note the changes as the land use changes. Areas with greater levels of imperviousness discharge higher quantities of contaminants and water volumes which quickly change the structure and quality of the stream. Effects are particularly evident where the upper reaches of a catchment are undeveloped. A visual survey can document comparative downstream changes, such as channel erosion locations, fish pass blockages, and areas of sedimentation.



Plate 2-10

Urban stream where stability issues cause economic effects

Measuring water or sediment quality chemical parameters for comparison against accepted threshold values can also indicate effects on organisms. A number of studies of such urban runoff have been carried out in Auckland to monitor water quality effects. In addition, a number of biological studies have monitored chemical parameters in situ and attempted to correlate the contaminant levels against the observed species condition and abundance. There is increasing evidence that catchment development strongly impacts on aquatic resources.

This section presents an introduction to common stormwater contaminants and includes an overview of visual and biological effects that are linked to development and non point source pollution. The ARC has carried out a significant amount of work on quantifying water quality effects and this information is available through a number of ARC technical publications. A summary of available information was collated in 1995 in ARC TP 53 - "The environmental impacts of urban stormwater runoff".

2.4.2 What are the contaminants?

(a) **Suspended sediments:** These are soil, organic particles, and breakdown products of the built environment entrained in stormwater flow. They can be silt sized ($63 \mu\text{m}$) or smaller. Sediments reduce light transmission through water, clog fish gills, affect filter feeding shellfish, smother benthic organisms, change benthic habitats and fill up estuaries. Larger soil particles above silt sized are also contaminants, but typically exhibit different physical characteristics and settle much more quickly. These particles are sometimes termed "bed load" sediment.

For the purposes of TP 10, the definition of suspended sediments is that provided in the ALW Plan.

(b) **Oxygen demanding substances:** These are soil organic matter and plant detritus which reduce the oxygen content of water when they are broken down by chemical action and by bacteria. Chemical oxygen demand (COD), total organic carbon (TOC) and biological oxygen demand (BOD) are three measures of the consumption of oxygen in water. Fish generally need at least $5 \text{ gO}_2/\text{m}^3$ to stay alive. A large proportion of fish kills in the Region are caused by spills and oxygen demanding substances such as sewage.

(c) Pathogens: Pathogens are disease-causing bacteria and viruses, usually derived from sanitary sewers. Organisms such as faecal coliform and enterococci are often used as indicators of the presence of pathogenic organisms. However, the presence of an indicator organism does not necessarily prove a pathogen is present; merely that the risk is higher.

Concentrations of indicator organisms in stormwater in the pipe before discharge may exceed Ministry of Health guidelines for contact recreation and shellfish collection. However, dilution with receiving waters will usually mean public health criteria are not exceeded.

(d) Metals: A variety of trace metal compounds are carried in stormwater in both solid and dissolved forms. The most commonly measured metals of concern are zinc, lead, copper and chromium. Metals are persistent; they don't decompose and they accumulate in sediments, plants and filter feeding animals such as shellfish. Elevated levels of metals cause public health issues and organisms avoid the affected habitat area (leading to a reduction in the number and diversity of fauna.) At higher levels still, intergenerational deformities and tumours may occur, as has been recorded overseas.

(e) Hydrocarbons and oils: The hydrocarbons in stormwater are generally those associated with vehicle use. They may be in the form of a free slick, oil droplets, and oil emulsion, and in solution or absorbed to sediments.

(f) Toxic trace organics and organic pesticides: A large range of trace organic compounds has been found in stormwater in Auckland. Polyaromatic hydrocarbons (PAHs) are one major group. PAHs are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil, and gas. Soot is a good example of a PAH. Organo-chlorine pesticides such as dieldrin, Lindane and Heptachlor constitute another main class of toxic organics.

(g) Nutrients: Nutrients in stormwater are usually nitrogen and phosphorus compounds that stimulate plant and algal growth. This can cause daily fluctuations in oxygen concentrations, including phases of aerobic decomposition, which removes dissolved oxygen from the receiving waters.

(h) Litter: Litter in stormwater is often referred to as gross pollution. It has a high visual and amenity impact, but limited effect on public health and ecological standards.

In addition to the above contaminants, stormwater discharges have other physical and chemical effects which affect aquatic organisms and change how contaminants react. These include changes to temperature, pH, dissolved oxygen, alkalinity, hardness and conductivity.

2.4.3 Measurement of water quality effects

The concentration of contaminants in stormwater varies during a storm, from storm to storm, and from catchment to catchment. The event mean concentration (EMC) is a measure of the average pollutant concentration during a storm. It is the pollutant load for the storm divided by the volume of runoff and will vary from storm to storm. The variation of pollutant concentration with time through a storm is termed a pollutograph.

When comparing concentrations with water quality criteria, it should be borne in mind that individual samples may exceed the EMC by a large factor. Exceeding water quality guidelines does not necessarily lead to effects on the environment. An EMC value in stormwater may exceed water quality guidelines "in pipe" but may not following dilution in receiving water. Water quality criteria are therefore more often used as an indicator of receiving environmental health rather than a regulatory standard.

Once contaminated sediments accumulate, their effect depends on factors such as spatial distribution, duration of exposure, dilution from deposition with cleaner sediments, and the rate at which the contaminants are assimilated (or bioavailability) by organisms in the receiving environment.

Pollutant toxicity is described as chronic (effects are the result of a gradual accumulation over time) or acute

(effects are the result of a sudden pulse).

2.4.4 Examples of effects

The following photographs illustrate the issues discussed.

1. Stream contaminants

Plate 2-11 shows the urban stream water and sediment quality in an inner city stream. Effects include litter, inorganic material, some turbidity in the water column, vegetative detritus, and sediments.

Plate 2-12 is a close-up of the same environment.



Plate 2-11

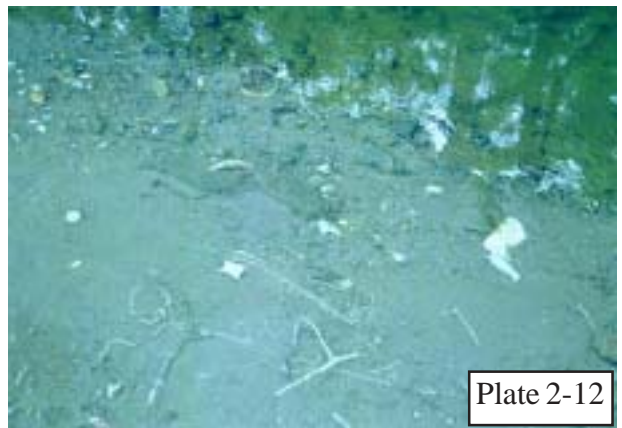


Plate 2-12

2. Sediment

Sediment from urban land uses and stream channel erosion often settles in estuaries. Low velocities and the saline environment assist particulate settling. Continual sediment delivery reduces light penetration and prevents plant food sources growing in the estuary, thereby affecting bottom dwelling organisms such as worms, crabs and shellfish, the base of the marine food web.

The sediments in the upper and right of plate 2-13 are predominately coarse sand and gravel sized particles transported from nearby roads.



Plate 2-13

3. Litter

Stormwater systems typically receive inflow via a catchpit. "Back entry" catchpits have a slot set into the kerb behind the grate to improve the hydraulic capacity. However, the size of the slot (50 mm minimum) is sufficient to pass pieces of litter into the stormwater system and waterbodies. Plate 2-14 shows a gross pollutant trap to catch litter.

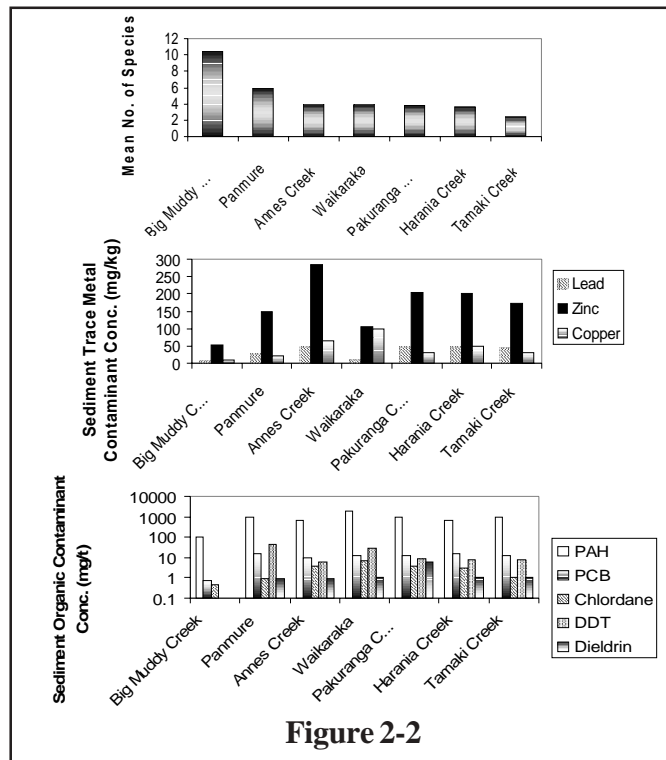
Litter will then travel downstream from where it is generated and is an obvious example of how far stormwater pollutants may travel. Litter affects recreational amenity values and may compromise species habitat.



Plate 2-14

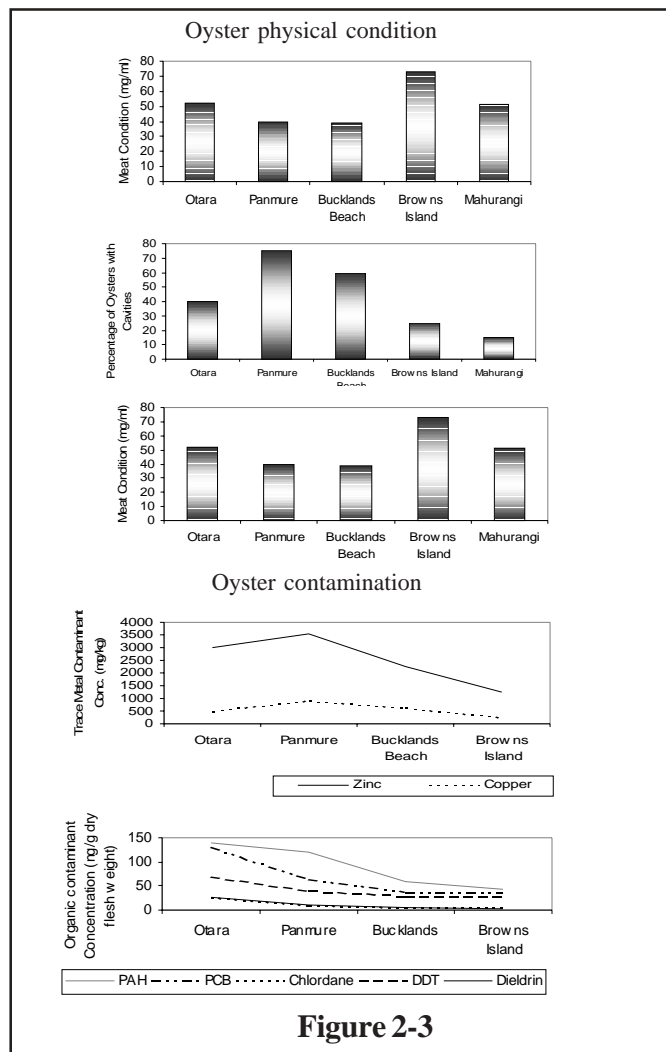
4. Benthic community health

Benthic species are creatures living in aquatic bottom sediments. Figure 2-2 gives an indication of benthic community health in a number of urbanised estuarine areas around Auckland by looking at the species diversity and frequency. Big Muddy Creek can be thought of as a control site as most runoff is from the water supply catchments west of Laingholm. Sites adjacent to the urbanised parts of the region have fewer number of species and a corresponding higher level of metal and organic chemical sediment contamination.



5. Tamaki River contamination gradient

Figure 2-3 shows a possible relationship between oyster contamination and body condition. Commercial oysters were taken from the Mahurangi Estuary and deposited in locations along the Tamaki River for a twelve month period. The level of contamination is worst in the reaches of the river with greatest contamination (Panmure Basin) and decreases toward the open coastline. The condition of oysters in the upper reaches of the Tamaki River is significantly worse than those in the lower reaches. This is thought to be due to increased flushing characteristics of the river as the tidal influence increases.



2.5 Aquatic habitat

2.5.1 General

Stream health is affected by all the water quality and water quantity factors that have been discussed in the previous sections. Hydrological factors are thought to be key factors in causing sedimentation and erosion of physical stream structure. However, it is very difficult to identify the combination of different factors that cause specific problems in stream health. Surrogate indicators are therefore used to indicate stream health.

One form of life that exists in streams is macroinvertebrates. Macroinvertebrates are aquatic insects that include grazers, shredders, collectors/browsers, piercers, suckers, and filter feeders on detritus and predators. The presence of a diverse macroinvertebrate community indicates consistently good water quality and a stable stream structure (available habitat). Any alteration of either of these parameters will be reflected in the macroinvertebrate community. So where they are present, they are extremely valuable.

Fish are another barometer of health with their absence or presence providing a picture of the overall health of a stream. Typical fish found in Auckland streams include banded kokopu, inanga, common bully, as well as eels and freshwater crayfish.

The increased frequency and magnitude of peak flows destabilises stream banks and increases sedimentation. Sedimentation can smother stable and productive aquatic habitats such as rocks, logs, and aquatic plants. The roots of large trees are undercut and fall into the stream while new growth has less opportunity to become established. Deliberate removal of vegetation exposes soil on stream banks, a common feature of urban streams that makes them more vulnerable to erosion. The structural stability of the stream channel has a significant effect on the health of the aquatic ecosystem.

The effectiveness of structural practices at protection of stream aquatic resources was assessed by Horner, (2001) from a catchment-wide perspective. Horner makes a number of interesting statements although they need to be further documented. Key findings were:

- > Until catchment total impervious area exceeds 40%, biological decline was more strongly associated with hydrologic fluctuation than with chemical water and sediment quality decreases. Accompanying hydrologic alteration was loss of habitat features, like large woody debris and pool cover, and deposition of fine sediments.
- > Structural BMPs at current densities of implementation demonstrated less potential than the non-structural methods (riparian buffers, vegetation preservation) to forestall resource decline as urbanisation starts and progresses. There was a suggestion in the data, though, that more thorough coverage would offer substantial benefits in this situation. Moreover, structural BMPs were seen to help prevent further resource deterioration in moderately and highly developed catchments. Analysis showed that none of the options is without limitations, and widespread landscape preservation must be incorporated to retain the most biologically productive aquatic resources.
- > Structural BMPs can make a substantial contribution to keeping stream ecosystem health from falling to the lowest levels at moderately high urbanisation and, with extensive coverage, to maintaining relatively high biotic integrity at light urbanisation.

The following pictures and text detail aquatic resource impacts related to stream channel modification, barriers to migration, and sedimentation.

1. Stream structure

Urban streams are often straightened and “improved” to increase the hydraulic capacity as seen in Plate 2-15. This process removes habitat such as stream meanders, pool/ riffle structures. Food sources from in stream vegetation and sediments are lost.



Plate 2-15

2. Barriers

Culverts, weirs and other in-stream structures form barriers to fish passage. This culvert is above the base flow water level preventing fish migration. Climbing fish species cannot pass through the culvert because it overhangs the stream and the shallow depth of water inside the pipe gives high velocities. The culvert shown in Plate 2-16 has also caused channel and stream bank erosion, producing turbulence which discourages migration by slow swimming fish species.



Plate 2-16

3. Sedimentation

Low flowing sections of streams are susceptible to sedimentation as seen in Plate 2-17. This can remove habitat in a similar way to channel lining, by infilling pool and riffle stream stretches and smothering food sources and bottom dwelling animals.



Plate 2-17

2.6 Bibliography

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