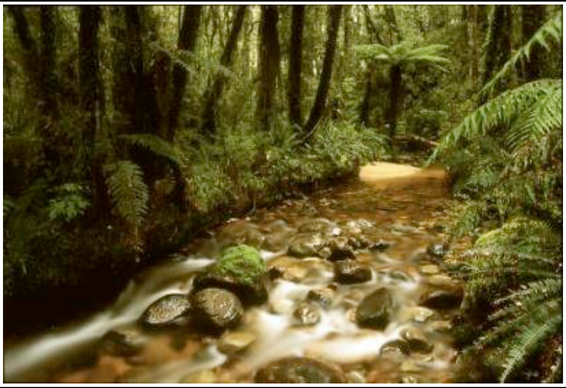
INTRODUCTION TO STORMWATER ISSUES

3. *Streams and the effects of increased imperviousness*

Stream morphology and stability

Morphology refers to the study of forms or variants of form and shape that something might take. Stream morphology concerns itself with the response of streams and their surrounding catchments to changes in adjacent land use. The form of a stream needs to be considered within the context of its **floodplain**.

Floodplains are natural areas where flood waters can be stored along a stream. These areas are important for biodiversity and include wetlands, ecosystem corridors, and riparian forests. The floodplains function in association with the stream; natural streams tend to be narrow with overhanging banks and vegetation that creates shade (regulating water temperature), and provides nutrients, habitat, and refuge.



Example of a stream in a predevelopment condition
Source: Nature Photography Society of New Zealand.

An increase in imperviousness will increase the peak discharge rate of any storm event. The direct effect on the stream is the elevation and expansion of its floodplain (refer Figure 3.1). This basic relationship is one of the key reasons properties, land, and structures that have never been subject to flooding can develop an increased risk over time as the areas around them develop. This risk can be further exacerbated as the floodplain extends into the urbanised area by secondary effects (e.g. buildings or road embankments within the new floodplain; themselves creating an obstacle).

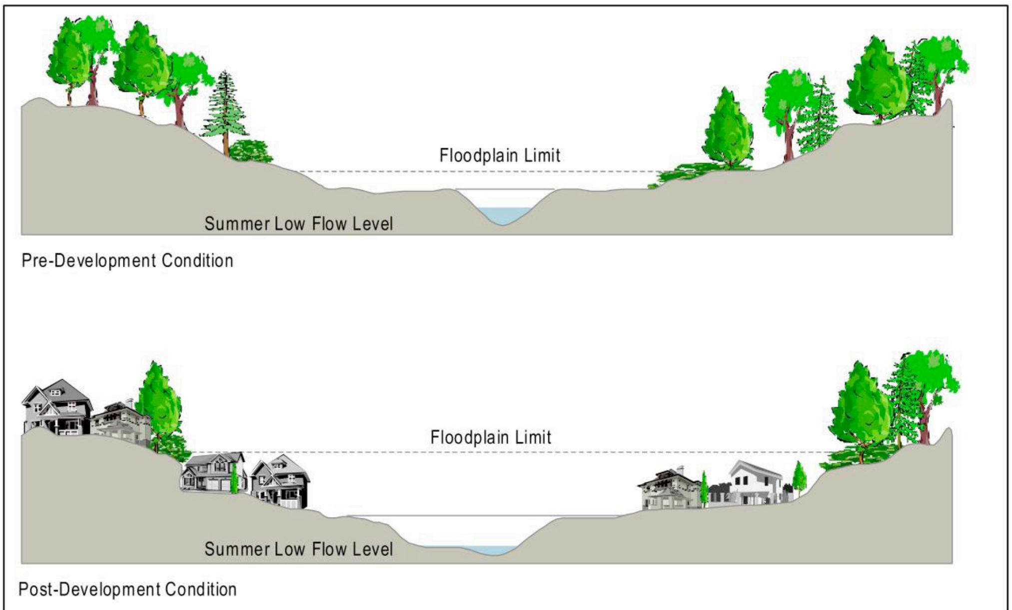


Figure 3.1: Response of stream morphology to urbanisation
Source: USEPA from Schueler, 1987

As imperviousness increases and the hydrology modified, a number of changes occur:

- Water levels rise higher, and more often;
- The upper bank of the stream undergoes more erosion, starts to become unstable, and slumps;
- Sediment loads increase (and increase scour); and
- The streambed widens and the depth of the stream decreases (refer to Figure 3.2).

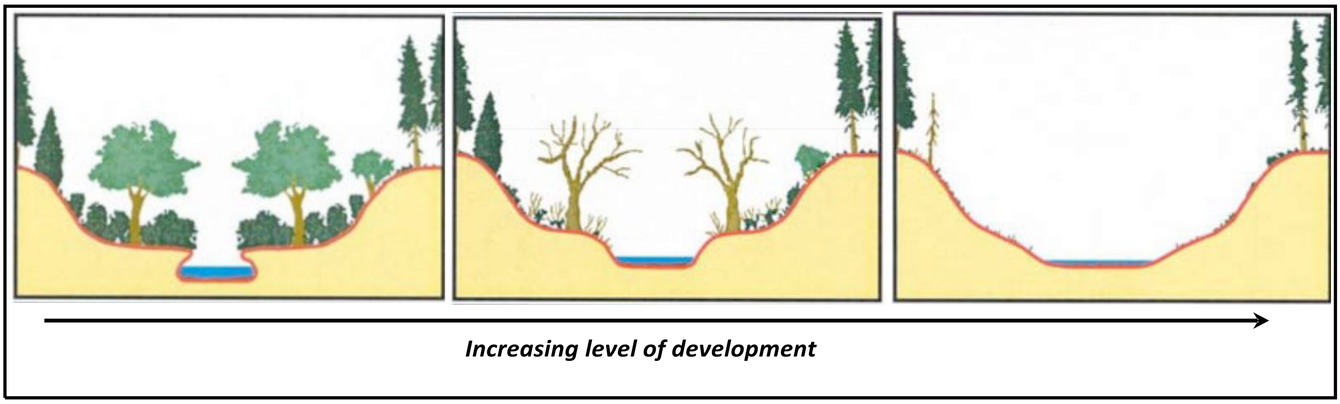


Figure 3.2: Evolution of channel degradation with urbanisation
Source UNCE

Vegetation also starts to disappear (or be replaced with weed species). With this comes a loss of essential nutrients, shading, and habitat. The disappearance of the riparian vegetation weakens the stream bank through the loss of the stabilising root mass, and the ability of the vegetation to slow flows and reduce scour in larger events.

Overseas studies (e.g. Booth and Reinelt, 1993) indicate a threshold for urban stream stability exists at about ten percent imperviousness of a catchment, below which most channels are stable. The rate and severity of channel instability appears to be a function of less than full-bank floods, whose frequency can increase by a factor of ten even at relatively low levels of imperviousness (Hollis, 1975; Macrae and Marsalek, 1992; Schueler, 1987). Within New Zealand, NIWA has explored methods for assessing such channel widening in order to better quantify the effects of urban development on stream habitat. NIWA proposes guideline values (refer to Figure 3.3 and Table 3.1) which express the degree of channel enlargement as an area enlargement ratio (calculated from the post-development bank-full channel cross-sectional area divided by the pre-development value).

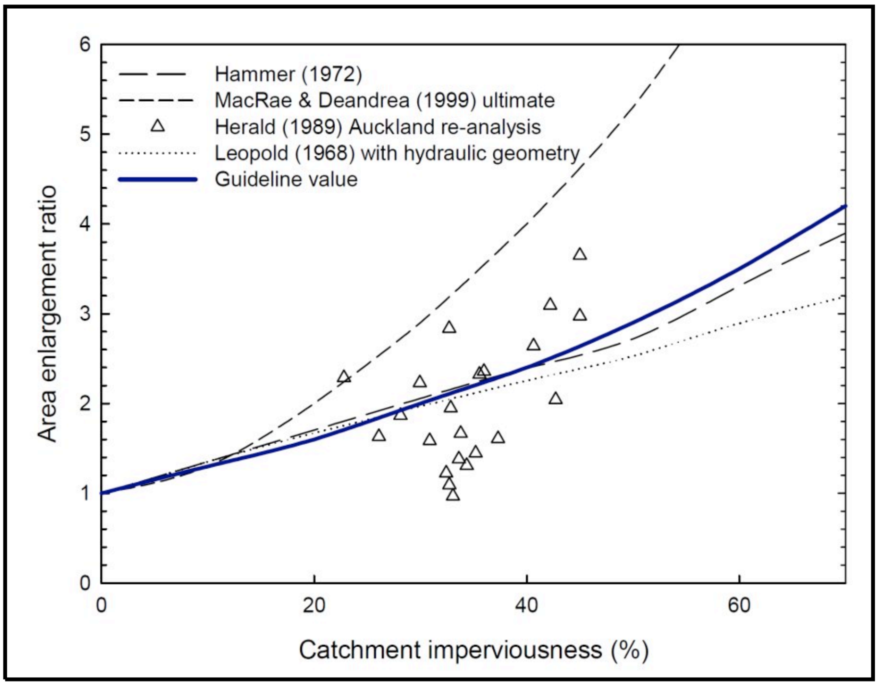


Figure 3.3: Channel enlargement as a function of catchment imperviousness
Source: NIWA (2004)

Table 3.1: Guideline values for channel enlargement (NIWA, 2004)

Imperviousness (%)	0	10	20	30	40	50	60	70
Area enlargement ratio	1.0	1.3	1.6	2.0	2.4	2.9	3.5	4.2
Width enlargement ratio	1.00	1.19	1.36	1.57	1.77	2.00	2.26	2.54

The NIWA guideline aims to establish a method that takes into account the difficulties in measuring the bank-full area, as well as bed and bank materials, channel slope, the pre-development hydrology, the type of development, the degree of formal drainage, the amount of time since development started, and difficulties in estimating what the pre-development area would have been. The guideline is intended to establish typical values.

Imperviousness and Water Temperature

Temperature changes are another factor influenced by development and the increased level of imperviousness. Changes to the temperature regimes of watercourses generally arise from the disappearance of riparian vegetation (which provides a natural buffer against background climate fluctuations), and / or the effect of rainfall on heated paved surfaces (such as roads) which can release a pulse of heated water into an ecosystem – often from multiple sources (refer to Figure 3.4).

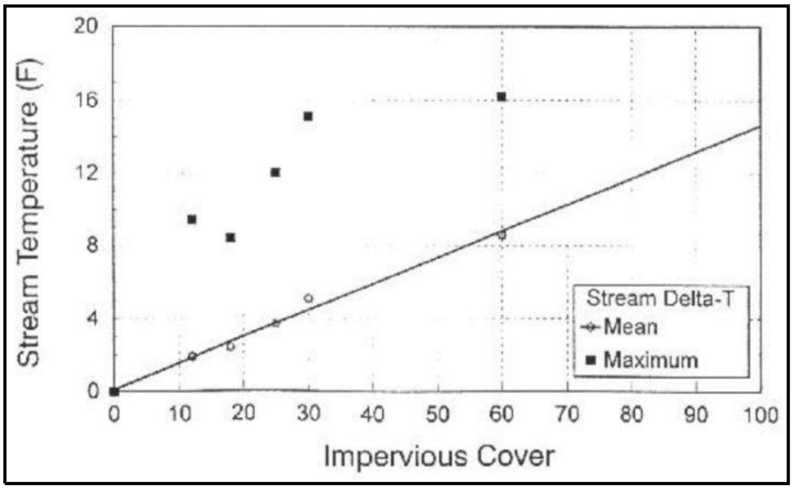


Figure 3.4: The effect of imperviousness covers on stream temperature
Source Galli, 1990

Many aquatic organisms are sensitive to temperature fluctuation, and even if the pulse of hot water dissipates, the effects may continue. Effects can range from decreased egg survival, retarded growth, increased susceptibility to disease, and decreased ability of young fish to compete for food and to avoid predation.

Changes which modify stream morphology directly affect **riparian** vegetation and the associated fauna and their habitat. Aquatic insects are a useful environmental indicator of this effect as they form the base of the stream food chain. Commonly two measures of stream health based on aquatic insect populations are used:

- **Macro invertebrate** community index (**MCI**):
  The MCI assesses the whole macro invertebrate population and provides a score that indicates general water quality. The Ministry for the Environment (**MfE**) advises that in general, an MCI score of less than 80 indicates poor water quality and a score of greater than 119 indicates excellent water quality;
- Percentage of **Ephemeroptera**, **Plecoptera**, and **Trichoptera taxa** (% **EPT**):
  Ephemeroptera, Plecoptera, and Trichoptera are mayflies, stoneflies and caddisflies respectively.
  Low % EPT indicates a river is under pollution stress, while high % EPT indicates good water quality.

Further information on the applicability and use of biotic indices can be obtained from the MfE website at **http://www.mfe.govt.nz/publications/water/mci-user-guide-may07**.

Because macro-invertebrates are such good indicators, many studies have focused on the aquatic insect community; using their **abundance** and **species richness** to evaluate the quality of urban streams. Even in the earliest studies (Klein, 1979), it was shown that **macro-invertebrate** diversity drops sharply in urban streams at approximately the same trigger point as for stream bank and channel instability, around 10% imperviousness, and this has been subsequently verified by numerous other studies (e.g. Benke, 1981; Steward, 1983; Pederson and Perkins, 1986; Jones and Clark, 1987; Limburg and Schmidt, 1990; Booth, 1991; Schueler and Galli, 1992; Shaver et al, 1994; and University of Maine, 2003 – refer to Figure 3.5).

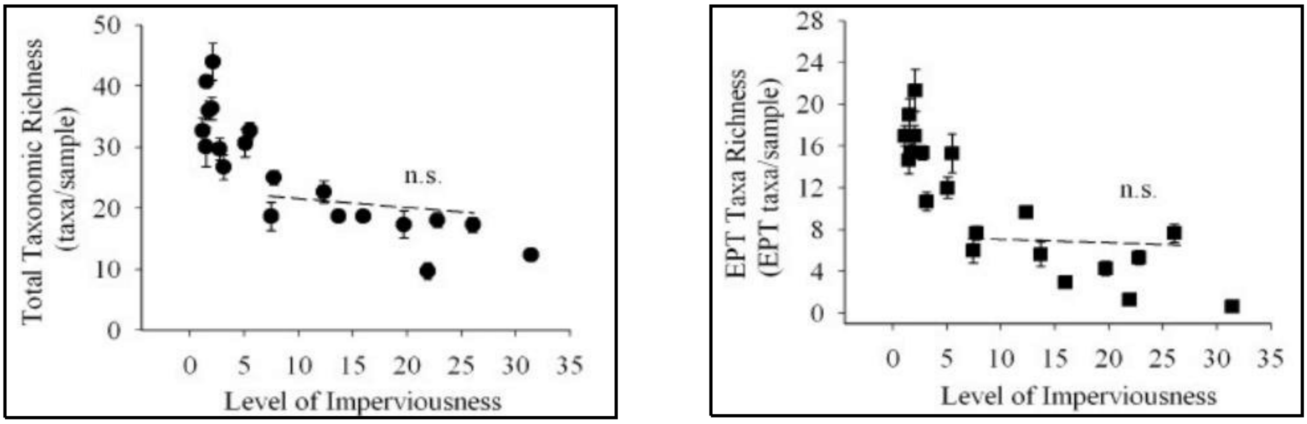


Figure 3.5: Influence of increasing urban intensity on macro invertebrate communities
Source : University of Maine USA, Measuring the Impact on Maine Surface Waters, 2003

New Zealand research is consistent with the above-mentioned examples. Between 2005 and 2007, the Ministry for the Environment monitored 66 sites as part of its National River Water Quality Network and found that the three poorest sites were down gradient of developed land (being hydro dams, urban areas, or farming), and those with the best MCI scores tended to be in the headwaters of catchments with upstream catchments dominated by native forest (MfE, 2007). Refer to: **http://www.mfe.govt.nz/publications/ser/enz07-dec07/html/chapter10-freshwater/index.html**

Although freshwater macro invertebrates are a more commonly used bio-indicator, other biological assessment methods may also be appropriate. For example, an abundance / biomass comparison (referred to as **ABC**; refer to Figure 3.6. after Warwick, 1986) may provide a ready indication of the relative ecosystem health in estuarine environments. The methodology used should obviously reflect the nature of the habitat and purpose of the assessment.

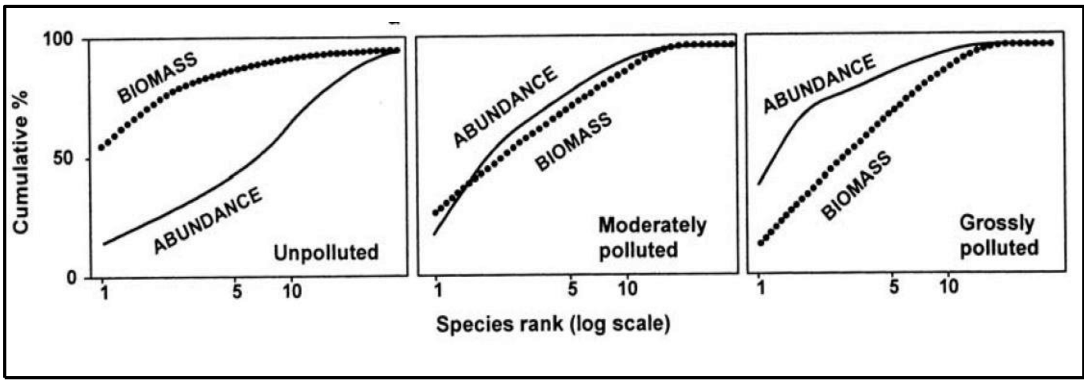


Figure 3.6: Abundance / Biomass Comparison (ABC) Plots
Source Canadian Environmental Assessment Agency, 2001 (after Warwick)

Figure 3. Abundance-Biomass Comparison (ABC) method of determining levels of disturbance, based on a comparison of (species) biomass and abundance k-dominance curves, showing relative positions of curves at different levels of pollution (from Clarke and Warwick, 2001a).

Fish populations also provide another useful environmental indicator. In a 1983 report, the USEPA reported that increased erosion in urbanised channels is a significant cause of fish habitat degradation, and American research more generally appears to point to fish species that swim up rivers and streams to spawn (**anadromous** species), and trout and salmon especially, as being most negatively affected by impervious cover (refer to Figures 3.7 and 3.8), such that trout were seldom present in catchments where imperviousness exceeded 15%, and spawning success declined above 10% imperviousness.

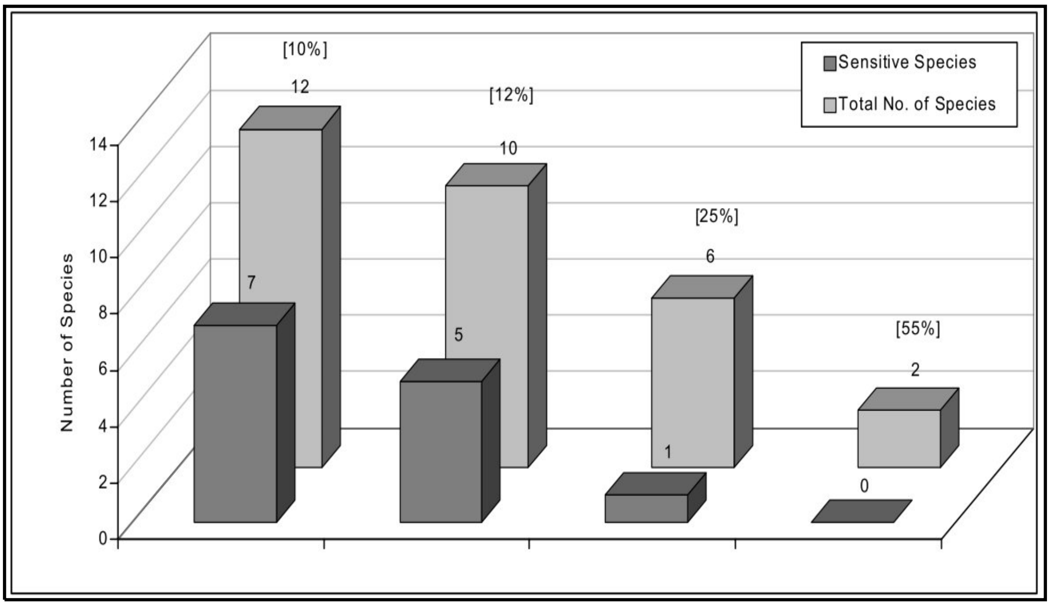


Figure 3.7: Fish diversity in four subcatchments with differing levels of imperviousness
Source: Schueler and Galli, 1992, as cited in Schueler, 1995

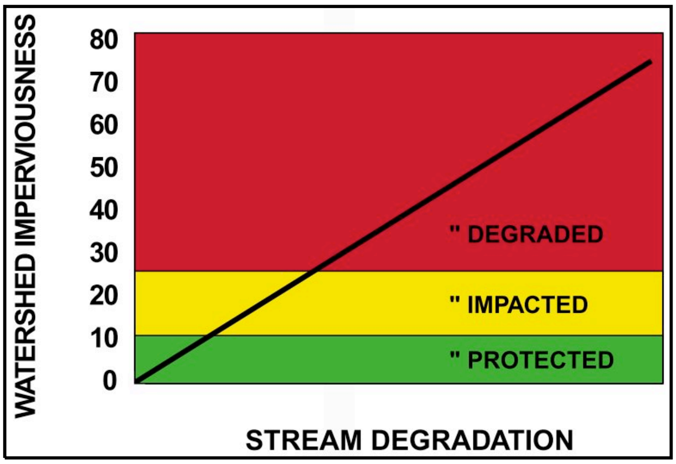
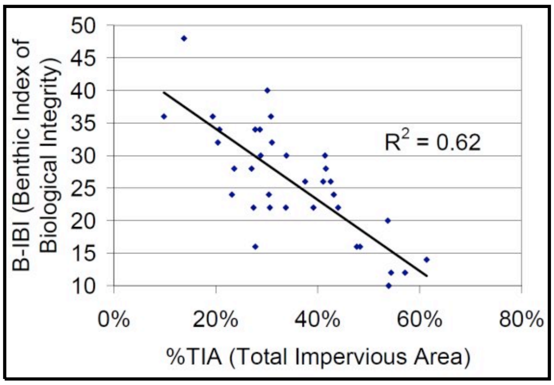


Figure 3.8: Relationship between watershed imperviousness and receiving stream impact
Source : Planning with power 1996, adapted from Schueler, 1992

New Zealand **diadromous** fish species, meaning fish that migrate between fresh and salt water, are predominantly **catadromous,** rather than **anadromous**, meaning that they migrate downstream to the sea to spawn (e.g. eels), in contrast to the US, but the general findings of local research paints a similar picture (Hanchet, 1990; Allan, 2004; Suren & Elliott, 2004; and Scott, 2006). Of particular relevance to New Zealand fish species (which tend to be poor climbers), Doehring (2010), found fewer fish species than expected at sites with numerous downstream barriers than at sites with uninterrupted access and concluded that urbanisation not only determines fish communities in waterways immediately surrounded by a city, but it also determines fish community composition of the entire upper catchment above the urban area.

Collateral Effects

Increased imperviousness can arise as a consequence of measures intended to avoid, remedy, or mitigate stormwater quantity related effects. Conventional controls have tended to focus on the protection of assets with little regard for effects upon biological systems or amenity. Research on the local impacts of road crossings on Puget Lowland creeks in Washington state, USA (Avolio, 2003) explored a number of these issues, and investigated the overall effect of increasing imperviousness, as well as the effect of an increasing number of road crossings (and related structures such as **scour protection**) on streams (refer to Figure 3.9). The study found that at 60% imperviousness or at four road crossings per km of stream, the biological integrity and health of these streams was so reduced as to be negligible.



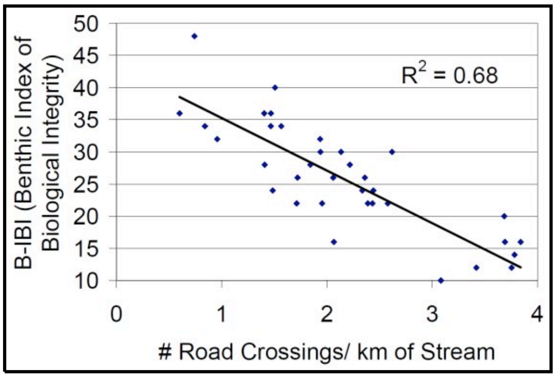


Figure 3.9: Urban stream health as a function of disruption
Source: Avolio, 2003

The principal findings from this study were:

- Road crossings can significantly alter the physical features, flows, and volumes of downstream channels;
- Road structures crossing and confining streams, and related bank changes, such as reinforced edges and embankments, can degrade downstream channel complexity and decrease the variety of channel units by removing the natural curves and bends, or sinuosity, from the stream; and
- Stormwater outfalls were found to correlate with altered downstream physical conditions, including increased erosion.

Stream stabilisation
Source: Picasaweb.

The conclusion was that, the greater the length of any artificial banks (whether as part of the road crossing itself or through the stabilisation of down-gradient stream banks), the greater the subsequent length of unmodified stream that will be physically degraded. The type of crossing, whether culvert or bridge, and the length of stream disrupted by stabilisation works will be significant factors in the correlation between land development and stream degradation.

The natural form of the water body frequently requires both erodible banks and the physical space needed to make lateral channel changes. A lack of space and an innate discomfort with allowing natural water bodies to change are often vital issues for streams in urban areas. Often the banks of a stream in a development will be legally defined and fix the boundaries of private property. To protect private property, banks inurban or suburban settings are often lined with concrete and **riprap.**

This can produce a cascade of downstream requirements for “**hydraulic improvement**” and **channel protection**, which can eventually lead to the complete loss of the habitat, and eventually to the piping of the water body.

The establishment of road crossings in New Zealand is required to comply with the relevant provisions of the **Freshwater Fisheries Regulations** (1983), with clause 42 (**culverts** and **fords**) being most directly applicable:

“Culverts and fords

(1) … no person shall construct any culvert or ford in any natural river, stream , or water in such a way that the passage of fish would be impeded, without the written approval of the Director-General incorporating such conditions as the Director-General thinks appropriate.

(2) The occupier of any land shall maintain any culvert or ford in any natural river stream, or water, (including the bed of any such natural river, stream, or water in the vicinity of the culvert or ford) in such a way as to allow the free passage of fish:

provided that this requirement shall cease if the culvert or ford is completely removed or a written exemption has been given by the Director-General.”

A range of techniques to avoid impeding fish passage are available, but these seldom address the effects of the changes to the banks and channel, put in place to manage the effects of increased imperviousness, on the stream or water body as a viable habitat

Wairau Creek
Source: North Shore City Council.

Stream armouring
Source: Armourtech Solutions.

Culvert outfall with fish ladder
Source: CalFish.

Fish ladder
Source: Environment Agency (UK).