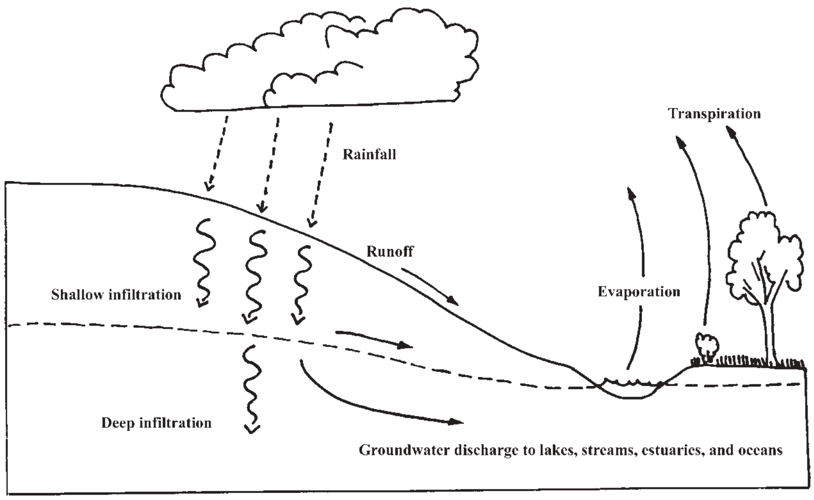
Chapter 2
Importance of Water Cycle in Stormwater Management

Understanding the water cycle concept is essential if there is to be any understanding of cause and effect as it relates to stormwater management.

The Water Cycle

Any discussion on stormwater related issues must begin with a discussion of the water cycle. Understanding the water cycle concept is essential if there is to be any understanding of cause and effect as it relates to stormwater management. Figure 2-1 illustrates, in a very simplistic form, the essential elements of the water cycle. The water cycle arrows make the point of continuous movement and transformation. Of all aspects of the water cycle, its dynamic quality - the never ending cycling from atmosphere to the land and then to surface and groundwater and back again to the atmosphere, must be emphasized. That we drink the same water today that the Maori drank hundreds of years ago is a graphic example of the continuous cycling and recycling of water. The concept of continuous movement is essential in order to understand the water cycle system.

Figure 2-1
Elements of the Water Cycle



When looking at those components of the water cycle for the Auckland Region, the following information contained in Table 2-1 can be approximated for undeveloped and urbanised catchments. This information must be placed in the context of being generally applicable for the Region. If the Auckland isthmus is considered, the deep infiltration figures become much greater. These figures are presented for the Region excluding the Auckland isthmus.

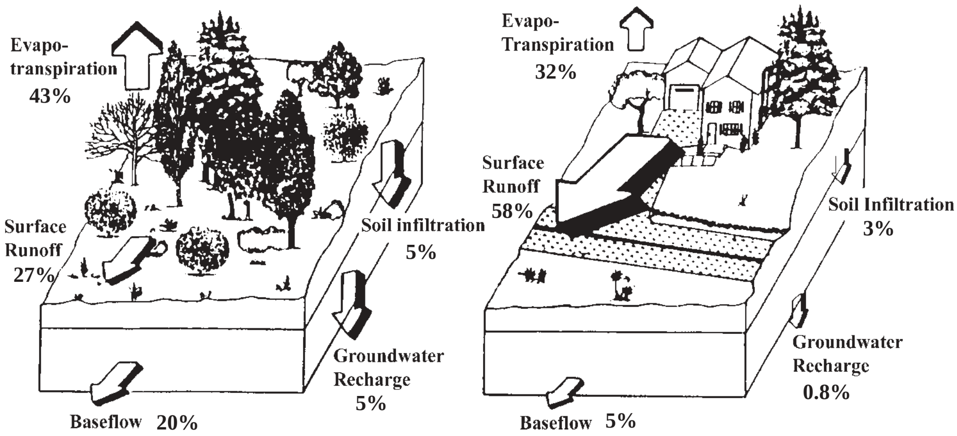
Table 2-1
Components of the Hydrologic Cycle

Component	Predevelopment	Postdevelopment
Annual rainfall	1200 mm	1200 mm
Total runoff	320 mm	700 mm
Deep infiltration	60 mm	10 mm
Shallow infiltration	300 mm	100 mm
Evaporation/transpiration	520 mm	390 mm

It is important to appreciate that the system itself is a closed loop. What goes in must come out. Impacts on one part of the cycle create comparable impacts elsewhere in the cycle. If inputs to infiltration are decreased by 250 mm per year, then inputs to surface runoff must be comparably increased by this amount. Stormwater programmes which focus on one aspect of stormwater (detention or channelisation) without paying attention to the other aspects of the water cycle, will not function effectively.

Land development has come to mean a significant change in the natural landscape, including creation of impervious surfaces. When we pave areas we increase surface runoff. Figure 2-2 demonstrates that impact. The arrows in the illustration are drawn to suggest size or extent of impact (in this case, total quantities of water involved year after year). Note that when we move from the predevelopment to post-development condition, the three medium-sized arrows become one increased surface runoff arrow with both evapotranspiration and infiltration substantially reduced. Increasing surface runoff total volumes translates into significantly reduced total volumes reduced from infiltration with significant consequences later in the water cycle.

Figure 2-2
Change in Natural Landscape Resulting from Site Development



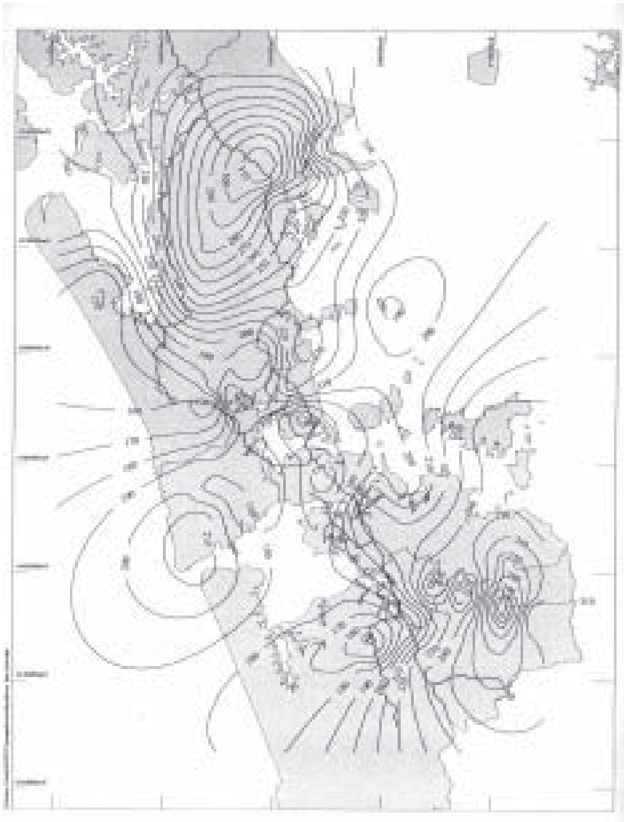
Only through understanding full water cycle dynamics can we hope to achieve some sort of system balance and minimise water cycle impacts when managing stormwater

In the past, stormwater management programmes have focused on peak rate management or water quality treatment. Because such efforts are so partial in concept and in effect, this approach fails to acknowledge and plan for critical systemwide water cycle impacts which can mean that the stormwater management approach itself becomes a problem, rather than a solution. Only through understanding full water cycle dynamics can we hope to achieve some sort of system balance and minimise water cycle impacts when managing stormwater.

Precipitation

Most of the Auckland region receives approximately 1200 mm of rainfall annually. The rainfall totals in the Waitakere and Hunua ranges (2200 mm max.) are about twice those on the lower parts of Auckland City, and rainfall below 1000 mm per year over the Hauraki Gulf and over a portion of the Manukau Harbour. The rainfall maximum over the ranges is due to an increase in the number of days that it rains (some 30-40 per year more than over the City) and rainfall being increased by orographic uplift. Figure 2-3 provides information on rainfall patterns in the region.

Figure 2-3
100 year, 24 hour rainfall totals



Winter is the season of maximum rainfall in the region with totals averaging about 150% of those in summer. The wettest month, July, with 135 mm has almost twice the rainfall of the driest month, January, which has 70 mm. Summer is the season with greatest rainfall variability with occasional very dry and very wet seasons. Even though drier than the winter months, summer storms can have very high intensities of rainfall. Nine of the first ten driest three month periods since 1910 occurred between November and February, and the seventh ever wettest three month period occurred during the summer of 1978.

The Botanic Gardens at Manurewa is representative of areas with about 1200 mm of annual rainfall. Statistics for that station indicate per the following Table 2-2.

Table 2-2
Rainfall Statistics (per storm)

Parameter	Mean value
Depth (mm)	6.6
Duration (hr)	3.3
Inter-event Dry Period (hr)	48.0
Intensity (mm/hr)	2.0

The rainfall distribution indicates that, on an annual basis, 95% of all storms are less than 25 mm. Recognition that the vast majority of storms are of smaller depth and short duration demonstrates that land characteristics, especially impervious surfaces, are very important in looking at the frequency and volume of stormwater runoff.

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Distribution of runoff in the Auckland Region parallels the seasonal recorded rainfall distribution. This is because of the regions small catchment sizes, relatively steep channel slopes and resultant short times of concentration.

Runoff is highest in winter and lowest in summer as shown in the following table of seasonal mean discharges from the Rangitopuni catchment. This trend is similar to other recorded Auckland catchments and highlights the fact that strong seasonal variations in stormwater flows exist.

Season	Summer	Autumn	Winter	Spring
Mean discharge (m^3/second)	0.650	0.850	3.01	1.60

Streams are less inclined to dry up over summer months if there is abundant vegetation in a catchment as groundwaters are recharged by movement of water into the soil.

A percentage of Auckland streams dry up completely during some summers. It is important to recognise the seasonal variability of rainfall and streamflow and the behaviour of various land use types on runoff generation. For instance, native vegetation provides a greater buffer and flow moderating influence on stormwater runoff than more modified environments. Streams are less inclined to dry up over summer months if there is abundant vegetation in a catchment as groundwaters are recharged by movement of water into the soil.

Groundwater Considerations

Groundwater is that part of the water cycle that has soaked into and flows through the ground. It is mainly derived from rainfall that has soaked into the ground instead of running off over the ground surface, evaporating or being used by plants. It may also be derived from water soaking into the ground from stream or lake beds. The replenishment of groundwater in this way is called groundwater recharge.

Water that soaks into the ground moves down through soil pores or rock fractures until it hits the water table. The zone above the water table is known as the unsaturated zone. Below the water table soil pores or rock fractures are fully saturated and the groundwater mainly moves laterally through these pores and fractures.

Groundwater underlies all of the Auckland Region. However, differences in geology, hydraulic properties of the soil or rock, topography, recharge rates and relationship with surface waters mean that groundwater flow and bore yields are greater in some areas than others. The layers of rock which allow groundwater flow are called aquifers. There are two main types of aquifer.

- Unconfined or water table aquifers. These are recharged by rainwater percolating down from the land surface (see Figure 2-4)

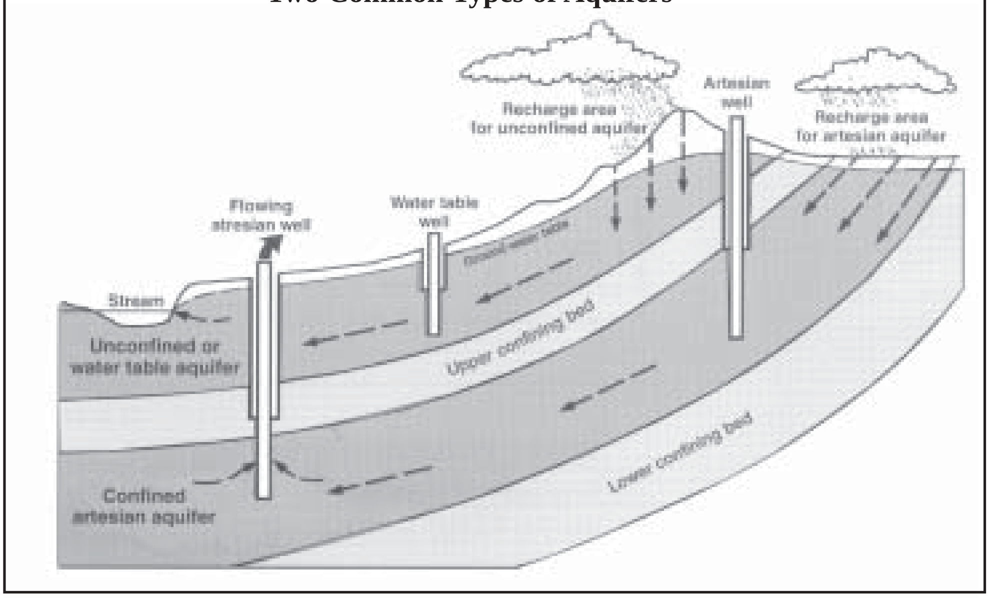
- Confined or artesian aquifers. These are pressurised and may give rise to artesian or free-flowing bores. They are recharged only where they are exposed at the land surface.

Confining beds or layers that don't allow groundwater flow are called aquitards.

Groundwater discharges from aquifers into the ocean, streams, lakes and at springs. Aquifer discharge plays an important role in providing water to streams during dry periods. This flow to streams is called baseflow.

There is a dynamic equilibrium between groundwater recharge, aquifer storage and aquifer outflow. For example recharge increases during a rainfall event and there is an increase in aquifer storage (the water tables rises) and there is a corresponding increase in aquifer outflow particularly baseflow and spring flow. This equilibrium

Figure 2-4
Two Common Types of Aquifers



Aquifer recharge is very important in maintaining stream ecology particularly during periods of low rainfall

is also changed by changes in land use. Where changes in land use reduce recharge rates there is a reduction in aquifer storage (the water table declines) and consequent reduction in baseflow in streams and in spring flow. Aquifer outflow is very important in maintaining stream ecology particularly during periods of low rainfall. During such times baseflow and spring flow is maintained from aquifer storage. If aquifer storage is not replenished by recharge a new equilibrium is reached with reduced baseflow and subsequent effects on stream ecology.

Groundwater resources in the region vary from place to place according to the characteristics of the underlying rock type. Groundwater characteristics are discussed as follows:

<u>Waitemata Group</u>

The Waitemata Group consists of interbedded siltstones and sandstones and, in places, conglomerates. These rocks are widespread. Although they have a low permeability when compared with some other rock types in the Region, these rocks form an important aquifer. The aquifer is used for irrigation, industry and municipal supply. The aquifer provides baseflow to many of the region’s streams e.g. Kaipara and Hoteo catchments.

<u>Quaternary Sediments</u>

Quaternary sediments cover large areas of valley flats and may be up to several tens of metres in thickness. These relatively thin deposits do not contain large amounts of stored water, but are important in providing local baseflow to streams.

<u>Northern Allochthon and Mahurangi Limestone</u>

This rock type is relatively impermeable, being composed mainly of mudstone and limestone. It yields insignificant amounts of groundwater. Hence, streams in these areas have very low baseflow and are often dry in the summer e.g. parts of the Rangitopuni catchment.

Auckland Volcanic Field

The Auckland volcanic field is an important aquifer with an ability to produce a substantial volume of potable water. Groundwater is used for municipal supply and industry. The aquifer outflow provides important spring flow in Onehunga and Western Springs, as well as baseflow in Motions, Meola and Oakley Streams.

The source of the recharge is precipitation. Rapid urban development has drastically changed the runoff-evapotranspiration pattern and consequently, recharge to the aquifer. In pre-urban situations, most of the rainfall was evapotranspired with only a small portion recharged into the volcanic aquifers. Significant use of soakholes for stormwater disposal can increase recharge by up to 300%.

Kaawa Formation

Kaawa Formation sediments consist of several shell rich layers (shell beds) occurring near the base of a Pliocene sequence. The Kaawa aquifer is an important source of irrigation water particularly in Franklin District.

South Auckland Volcanic Field

The South Auckland volcanic field is similar in character to the volcanics of the Auckland field. They have very high groundwater flows, and are important sources of water for irrigation and water supply. Aquifer outflow provides spring flow and baseflow to the streams of the Franklin District. Baseflow from the volcanics is much higher than other aquifer types in the region.

Geothermal Fields

Geothermal fields occur in the Region at Parakai, Waiwera, Whitford and Great Barrier Island. Hot water rapidly rises from depth through fractures in the rocks to provide bore production temperatures of up to 65^0 C.

Stormwater Quantity

Changing the surface of the land from native vegetation or pasture to urban land use increases site and catchment impervious surfaces, by increasing rooftops, roads, driveways, patios, and pathways. Typical levels of imperviousness which can be found for various types and levels of development include the following:

Type of Development	Percent Impervious
Residential housing	
500 square metres	65
1000 square metres	38
1300 square metres	30
2000 square metres	25
4000 square metres	20
8000 square metres	12
Commercial and business	85
Industrial	72

The greater the level of development in a catchment, the greater the level of impervious surfaces, and the greater the runoff.

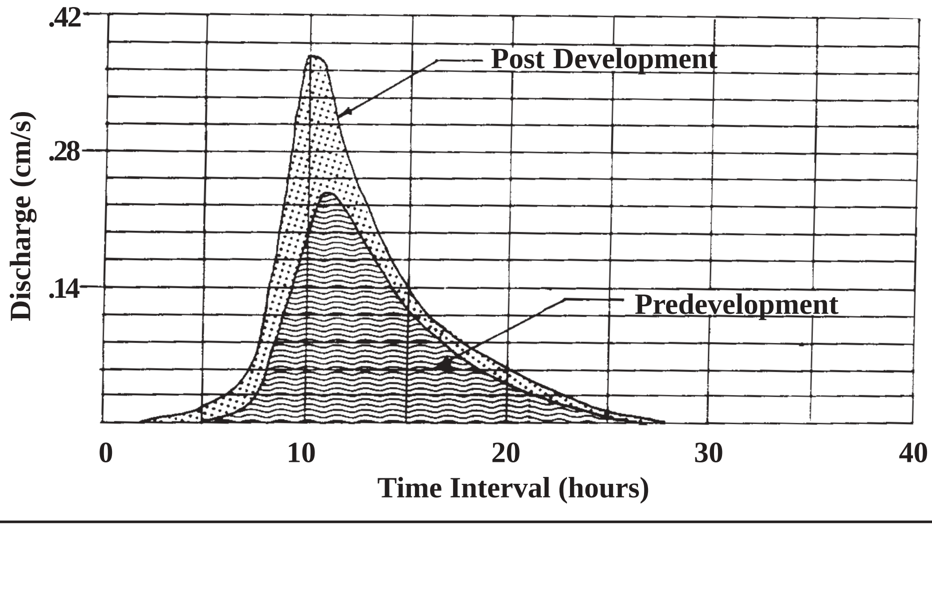
The greater the level of development in a catchment, the greater the level of impervious surfaces, and the greater the runoff. Impervious surfaces, other than having a small wetting factor, directly convert rainfall into runoff.

A common means of visualising the response of stormwater runoff to rainfall is the concept of a storm hydrograph, which is a graphical comparison of runoff being discharged from any particular site (measured in cubic metres per second) versus the time that the water is being discharged. Hydrographs can be developed for sites of any size and for all different size and duration storm events. Figure 2-4 presents a hydrograph for a typical site before land development has occurred and compares that hydrograph with the post developed runoff condition.

There are a couple of points that can be made when comparing the pre- and post development hydrographs detailed in Figure 2-5.

- The figure provides for a hypothetical development at a hypothetical site and presents a post-development hydrograph with the assumption that there is no stormwater management.
- There is a significant increase in the peak discharge from the development activity versus the predevelopment condition
- As the total volumes of the runoff are the areas under the curves, there is a significant increase in the total volume of runoff from the pre- to the post-condition.
- The post-development hydrograph rises or increases earlier in time than does the predevelopment hydrograph. Runoff starts earlier as portions of the site have been made impervious and immediately start to discharge water as rain begins.

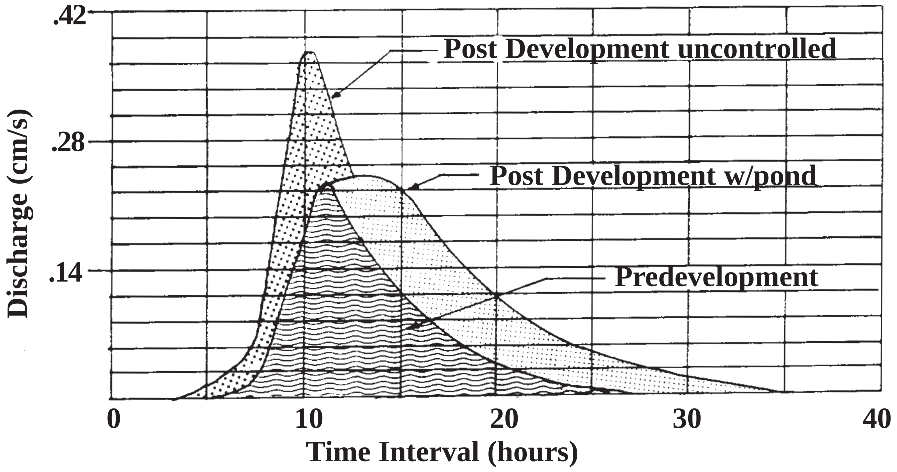
Figure 2-5
Typical pre and post Hydrographs for uncontrolled conditions



Ponds provide numerous benefits but they cannot reduce the total volume of water which must pass through them.

Under existing approaches to stormwater management a developer might be required to construct a pond for water quantity, and possibly water quality, control. Ponds provide numerous benefits but they cannot reduce the total volume of water which must pass through them. This means that water is discharged from them for a longer period of time than would have occurred under predevelopment conditions. Figure 2-6 shows hydrographs under three different scenarios now with the total volume for the uncontrolled condition being the same as the volume for the hydrograph where there is stormwater pond. Where this situation occurs, it may not always cause problems downstream of the facility but duration of flows downstream of where a number

Figure 2-6
Post Development with Detention



of ponds are located on different tributaries may aggravate existing flooding problems.

Figure 2-7 illustrates the possible flooding impacts (depending on location within a catchment) which can result when a peak rate control approach is used catchment wide. Under the assumption that they illustrate five sub-catchments within a single catchment, each of which undergoes development and relies on a peak rate control approach for stormwater ponds. Under this analysis, there is a predevelopment hydrograph which sums the individual sub-catchments, five different hydrographs from sub-areas, and those five combined to provide a resultant post-development catchment hydrograph. Not surprisingly, the resultant post-development hydrograph with detention exceeds the predevelopment condition for volume (as expected) but also for the peak rate of discharge which goes against the intent of implementing the programme to begin with. In short, flooding may worsen downstream. A programme cannot be based only on structural detention facilities. It must be supported by various approaches which can complement detention to prevent aggravating an existing catchment condition.

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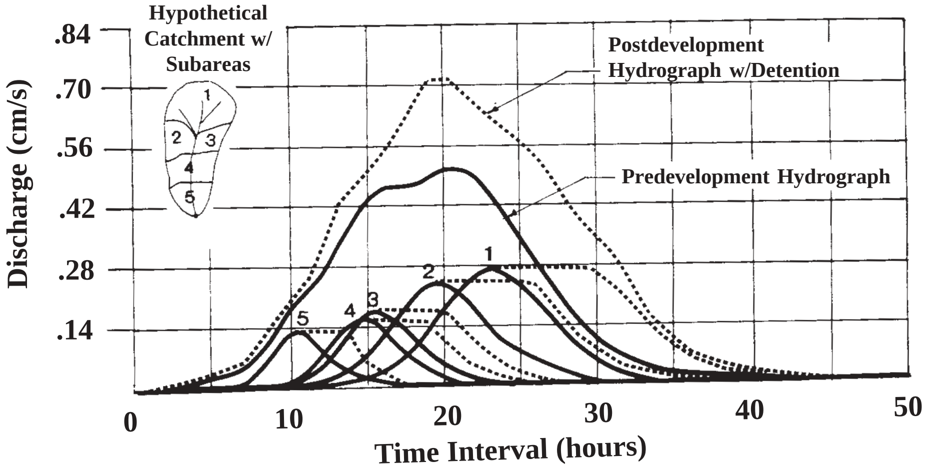
Figure 2-7
Possible Flooding Impacts Depending on Site Locations Within a Catchment



Urbanisation of catchments can result in major flooding and sedimentation problems.

Urbanisation of catchments can result in major flooding and sedimentation problems. The more important stormwater quantity effects of urbanisation which have been generated in the Auckland Region include the following:

- Complete reticulation of a catchment when urbanised will almost double the mean annual flood return period
- A fully urbanised catchment, completely reticulated and with approximately 50% impervious cover will increase the peak discharge of a two year storm by approximately four times
- Large floods of low frequency, such as 50 to 100 year events, show a relatively lesser effect from urbanisation, their peak flows increasing about 2.5 times.
- The number of bank overflows increases, perhaps doubling where the catchment is 20% storm reticulated and 20% impervious.
- Floods rise to a higher peak more quickly than under previous rural conditions and also runoff more rapidly.
- Natural baseflow may decrease as a result of reduced groundwater infiltration
- Where channel materials are erodible, the stream channel will tend to enlarge as part of the process of larger and more frequent floods.

Stormwater Quality

Contaminant Types

Urban stormwater carries with it a wide variety of contaminants from multiple sources. Representing the majority of recognised classes of water contaminants, these originate not only from land activities in the catchment but also from atmospheric deposition. Moreover, surface and groundwaters can exchange. Streams flowing during times with no rain are an indication of the surface groundwater interaction.

Contaminants commonly found in urban stormwater that can harm receiving waters and the specific measures that express them are listed in Table 2-3. Contaminants other than solids and pathogens are associated with being in a solid or in a dissolved state. In urban runoff most contaminants are associated with solids or soil or other natural particulates. This condition differs among the specific contaminants. For example, depending on overall chemical conditions, each metal differs in solubility. For instance, lead (Pb) is relatively insoluble and will generally be seen in a particulate form, while zinc (Zn) may be found in either a particulate or solution form. The nutrients phosphorus (P) and nitrogen (N) typically differ substantially in that phosphorus can be found either in particulate or soluble form while nitrogen is generally found in soluble form only.

Besides these contaminants, other water quality characteristics affect the behaviour and fate of materials in water. These characteristics include:

- Temperature
- pH - an expression of the relative hydrogen ion concentration
- Dissolved oxygen
- Alkalinity - the capacity of a solution to neutralise acid
- Hardness - an expression of the relative concentration of divalent cations, principally calcium and magnesium
- Conductivity - a measure of a water's ability to conduct an electrical current as a result of its total content of dissolved substances (often expressed as salinity in estuarine and marine waters or total dissolved solids (TDS))

These characteristics affect pollutant behaviour in several ways. Metals generally become more soluble as pH drops below neutral and hence become more available to harm organisms (often referred to as bioavailability). In addition, pH also affects the toxicity of some metals and ammonia. Depleted dissolved oxygen can also make some metals more soluble. Anaerobic conditions in the bottom of lakes release phosphorus from sediments, as iron changes from the ferric to the ferrous form. Elements creating hardness work against the toxicity of many heavy metals. Water quality analyses take this relationship into account by varying the allowable level as a function of hardness.

Table 2-3
Urban Contaminants

Category	Specific Measures
Solids	Settleable solids (SS) Total suspended solids (TSS) Turbidity (Turb)
Oxygen demanding substances	Biochemical oxygen demand (BOD) Chemical oxygen demand (COD)
Phosphorus	Total phosphorus (TP) Soluble reactive phosphorus (SRP) Biologically available phosphorus (BAP)
Nitrogen	Total nitrogen (TN) Total Kjeldahl nitrogen (TKN) (ammonia + organic) Ammonia-nitrogen (NH_3)
Metals	Copper (Cu), lead (Pb), zinc (Zn), Cadmium (Cd), arsenic (As), nickel (Ni), chromium (Cr), mercury (Hg), selenium (Se), Silver (Ag)
Micro-organisms	Fecal coliform bacteria (FC) Enterococci bacteria (Ent), Viruses
Petroleum hydrocarbons	Oil and grease (O+G) Total petroleum hydrocarbons (TPH)
Synthetic organics	Polynuclear aromatic hydrocarbons (PNAs) Phthalates Pesticides Polychlorobiphenols (PCBs) Solvents etc..........

<u>Contaminant Sources</u>

Now that types of pollutants have been discussed, it is important to recognise their sources. Knowing where contaminants come from can assist in developing a strategy to reduce their impact on receiving systems. Stormwater practices and approaches do not equally address contaminants and recognising the various land uses that exist in a catchment will assist in evaluating the range of pollutants that can be expected and thus the approach that needs to be taken to reduce their impact. Table 2-4 lists typical sources of contaminants.

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Table 2-4
Urban Runoff Contaminant Sources

Contaminant Source	solids	nutrients	pathogens	oxygen demanding	metals	oils	synthetic organics
Soil Erosion	X	X		X	X		
Cleared land	X	X		X			
Fertilisers		X					
Human waste	X	X	X	X			
Animal waste	X	X	X	X			
Vehicle fuels/fluids	X			X	X	X	
Fuel combustion	X				X	X	X
Vehicle wear	X			X	X		
Industrial/household chemicals	X	X		X	X	X	X
Industrial processes	X	X		X	X	X	X
Paints/preservatives					X	X	
Pesticides				X	X		

When considering water quality in the Auckland Region there are a number of statements that can be made.

Stormwater's impact on the aquatic environment is due to two factors: a large increase in the volume of water that runs off impervious urban surfaces compared with more absorbent vegetated landuses, and the greatly accelerated rate of runoff; and contamination of stormwater with a wide range of substances.

- Stormwater's impact on the aquatic environment is due to two factors: a large increase in the volume of water that runs off impervious urban surfaces compared with more absorbent vegetated landuses, and the greatly accelerated rate of runoff; and contamination of stormwater with a wide range of substances.
- Contaminants are collected by runoff from a variety of diffuse and point sources within a wide catchment area, but are often concentrated by the piped collection system at outfalls into aquatic receiving environments.
- The contaminants of most concern are suspended solids, a range of heavy metals, organochlorines, polynuclear aromatic hydrocarbons and human pathogens. Sources are widespread throughout the urban catchment and are classified as diffuse, or nonpoint sources.
- Many sources of stormwater contamination are difficult to control because of their diffuse distribution catchment-wide.
- Point sources of stormwater contaminants may be increased in industrial areas through yard and equipment washing and accidental or deliberate discharge of products and wastes from industrial processes which allow contaminants to enter the stormwater system.
- A large proportion of most contaminants is bound to particulate matter in the stormwater. A high proportion of these suspended solids pass through the drainage channels and eventually reach the marine receiving environment. In the marine receiving environment, suspended solids settle and are incorporated into marine sediments.
- Other settling processes also occur when contaminants move from freshwater to estuarine or saline waters.
- Settling occurs least along open coasts and harbour entrances as a result of wave action and littoral drift and most occurs in upper estuaries where flow velocities are reduced. The headwaters of most estuaries are poorly flushed because much of the water draining on the ebb tide returns on the following flood tide. In contrast, open coastal regions are well flushed by tides and contaminants can be remobilised into the water column by wave, current and tidal action and are widely dispersed.
- Upper estuaries are therefore regarded as highly sensitive to stormwater contamination, because they act as retention zones where suspended solids are deposited, and where contaminants continually accumulate. There is a higher rate of build-

up of contaminants near stormwater outfalls. Concentrations then decrease with increasing distance from individual stormwater outfalls.

- Stormwater in New Zealand has similar concentrations and types of contaminants to those found in other developed countries.
- In urban streams, acute and chronic toxicity water quality criteria for the protection of sensitive biological species are regularly exceeded for heavy metal contaminates. Organic contaminant levels in stormwater may sometimes exceed the relevant chronic water quality criteria but the New Zealand information base is sparse. Further downstream where urban streams discharge into larger water bodies, water quality criteria are predicted to be rarely exceeded because of dilution and settling of particulates, which carry most of the contaminants.
- The impacts of urban development on small Auckland streams have been severe. Many of these impacts have been caused by modifications to channel and riparian areas, as well as by the hydrological changes accompanying urbanisation.
- In sheltered coastal sediments there is a clear link between urban stormwater contamination and build-up of contaminants. There is strong evidence that this build-up is detrimental to animals that live in the sediment and which provide the basis of the estuarine ecosystem. Sediment contaminant concentrations in some of urban Auckland's estuaries and harbours exceed North American sediment quality criteria, and there is evidence for stormwater impacts on aquatic animals in Auckland through chronic toxic effects.
- In streams and near stormwater outfalls, many contaminants regularly exceed sediment quality criteria for the protection of sediment-dwelling animals. Many of the retention zones of Auckland estuaries with significantly urbanised catchments exceed the criteria for the major contaminants lead, zinc, and organochlorines.
- If contaminants continue to be generated at present day rates, the rate of sediment contamination will accelerate with urban expansion, and the extent of the affected areas will increase.

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Stream Morphology

The physical appearance and function of a stream's boundaries, generally called the stream morphology, is a product of the magnitude of stream flow and erosional debris produced by a catchment. The individual stream characteristics are further modified by the influence of channel materials, catchment slope, and other features of catchment morphology. As the catchment area increases so do the requirements of the stream to convey water and sediment.

Bankfull discharge

A common term used in stream morphology is "bankfull" flow. This is a term that is used to denote channel capacity. When bankfull flow is exceeded, floodplain flow initiates. Stream dimensions, patterns, and bed features are a function of channel width measures at bankfull stage. The bankfull stage corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels. It is this discharge in concert with the range of flows that make up an annual hydrograph which govern the shape and size of the channel. Bankfull discharge is associated with a momentary maximum flow which, on the average, has a recurrence interval of 1.5 years as determined using a flood frequency analysis. Although great erosion and enlargement of steep, incised channels may occur during extreme flood events, it is the modest flow regimes which often transports the greatest quantity of sediment material over time, due to the higher frequency of occurrence for such events.

<u>Stream channel dimensions</u>

Stream width is a function of streamflow occurrence and magnitude, size and type of transported sediment, and the bed and bank materials of the channel. Channel widths generally increase downstream as the square root of the discharge. Channel width can be modified by the following influences:

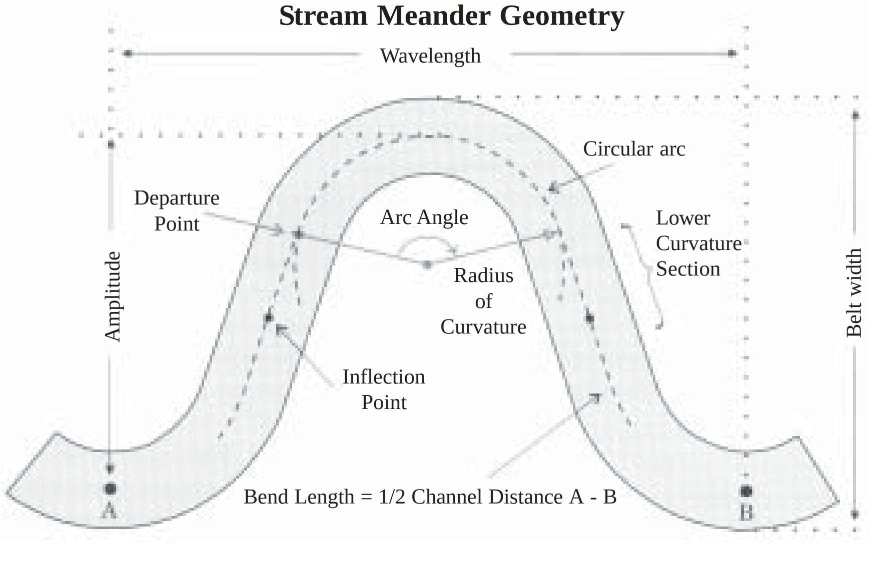
- Direct channel disturbance such as channelisation
- Changes in riparian vegetation that may alter boundary resistance and increase channel erosion potential
- Changes in streamflow regime due to catchment changes such as increased impervious surfaces or increased sediment delivery resulting from construction

<u>Stream channel patterns</u>

As catchments are urbanised, widening of streams and changes in channel patterns can be observed. These channel adjustment s are brought on by an acceleration of streambank and bed erosion.

Streams are rarely straight for any substantial distance, rather they tend to follow a sinuous course. Meander geometry is most often expressed as a function of bankfull width. An example of the relationships that exist and the various components of a meander pattern are shown in Figure 2-8. The parameters include bankfull width, meander wavelength, and radius of curvature. Streamflow regimes not only include bankfull channel widths but can also change stream patterns, depending on the magnitude and duration of flows. As an example, as catchments are urbanised, widening of streams and changes in channel patterns can be observed. These channel adjustments are brought on by an acceleration of streambank and bed erosion.

Figure 2-8
Stream Meander Geometry



The patterns of streams are naturally developed to provide for the dissipation of the kinetic energy of moving water and the transport of sediment. The meander geometry and associated riffles and pools adjust in such a way that the work expended on natural processes is minimised. Consequently, straightening stream channels ultimately leads to a state of disequilibrium or instability, often causing entrenchment and changes in morphology and stability. Over the last 150 years, numerous streams have been straightened under the assumption that their functional efficiency would increase. Even today in Auckland, these philosophies and approaches continue to result in abuse of our streams.

The meander patterns that streams exhibit result in maintaining a slope such that the stream neither degrades nor aggrades. When the alignment of the stream is changed by reducing the natural meander, local stream reach slopes are changed and instability results.

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Stream channel profile

Generally, channel gradient decreases in a downstream direction with increases in streamflow. The shape of a longitudinal profile of a first or second order stream at the top of the catchment to the lower part of the catchment is generally concave. Since steep gradient streams are relatively straight, they dissipate energy along the longitudinal profile in relatively close spaced features, normally called riffles and pools. Their spacing is inversely related to slope and proportional to the bankfull width.

Misconceptions/facts

There are so many ways that we abuse our streams and most of them relate to ignorance or personal gain. We need to understand some general principles with respect to our historic approaches.

Misconceptions	Fact
Increasing channel capacity can easily be done by increasing the width of the channel	The width/depth ratio of the bankfull channel increases, decreasing the bankfull shear stress. A change in velocity distribution occurs which then increases sediment deposition and channel aggradation
Straightening the stream thus increasing slope and velocity can increase sediment transport capacity	Straightening the stream channel and increasing the energy changes the velocity distribution and increases the velocity gradient at the banks, as the stream attempts to regain its meander geometry and slope. The end result is increased stream channel erosion
Use levees to prevent overbank flow and eliminate future flooding problems	The same flood stage is now associated with storms of lesser magnitude. In effect, the flood stage was elevated due to bed aggradation, increasing the potential flood hazard

It is important to recognise that streams are dynamic systems where many different variables interact to form the morphology of the stream system. Natural or imposed changes in any of the physical process variables will create a chain reaction of systematic adjustment that is often rapid and certainly significant.

Auckland specific data

Channel widths in the 85% developed Hellyers Creek catchment were up to three times wider than those in adjacent rural catchments. Channel cross-sectional area may increase 2 - 5 times, involving the erosion of 40,000 - 100,000 tonnes of sediment per kilometre along small to medium streams.

The wider channel results in a degraded stream habitat quality because of the lower post-urbanisation stream baseflows. Urban streams typically have lower baseflows as a result of increased runoff from impervious surfaces and reduced soakage into the ground, which would augment stream flow.

Riparian vegetation, in particular has benefits for bank stabilisation as well as instream water quality improvement because of shading and cover. In addition, contaminants are filtered during storms where there is out-of-bank flow. Surveys on a 10 kilometre stretch of the Ngongataha Stream in Whenuapai showed substantial reduction in stream bank erosion between 1977 (pre-riparian retirement) and 1989 (post riparian retirement), 23 percent of the streambank was found to be actively eroding, compared with 30 percent in 1977.

Direct interference with channels during stream works can produce significant sediment yields of up to five times average stream sediment loads. This, together with the inevitable long term destruction of natural stream habitat, indicates that such works should be avoided wherever possible.

Stream Ecology

As water in streams only moves in one direction (down hill) there is a constant loss of organisms and materials to the sea, the stream community is totally dependent on materials entering the system from mostly terrestrial ecosystems, typically as particulate matter (leaves, organic and inorganic matter). As a result, different streams and reaches of streams have different aquatic communities. Upland fast-flowing streams with stony beds differ in community structure from slow-flowing lowland rivers with muddy bottoms. Looking at what lives in a stream in an undisturbed forested condition and relating that to what commonly exists in a stream that is impacted by urban development can provide a barometer of what we can expect if development was to occur in a traditional manner. A discussion of ecological issues also can provide guidance of what site resources are important to maintain if aquatic ecosystem protection is a goal.

Looking at what lives in a stream in an undisturbed forest condition and relating that to what commonly exists in a stream that is impacted by urban development can provide a barometer of what we can expect if development was to occur in a traditional manner.

The dynamic nature of wet-weather flow regimes and water quality make it difficult to assess the impact of urbanisation and stormwater on aquatic ecosystems. Physical habitat and biological measures reflect aquatic ecosystem conditions over months and years and thus integrate these variable conditions into a more easily understood set of measures. Physical habitat is a principal element of ecological analysis. Without the proper channel and riparian characteristics (floodplain, shade, stable channel, riffles, pools, etc.) improvements in hydrology and water quality will demonstrate little change in ecosystem function or value. Most importantly, the aquatic community (plants, invertebrates, fish) provides a direct measure of ecosystem quality and sustainability.

Physical habitat

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. Bare soil stream banks also result from deliberate removal of vegetation and are a common feature of urban streams.

The loss of stable riparian vegetation is further accelerated by the direct removal of trees and shrubs as part of urban development. The resulting stream ecosystem is in a constant state of instability with little opportunity to become stable and more complex.

Ecosystem function and quality increases with increased complexity, and the more complex the habitat, the more complex the ecosystem functions. Forests are more complex ecosystems than pastures.

Ecosystem function and quality increases with increased complexity, and the more complex the habitat, the more complex the ecosystem functions.

Impacts of Urbanisation on Stream Habitats	
accelerated bank erosion	
accelerated bank undercutting	
increased siltation	Stable habitats
elimination of meanders	rocks
channel widening	woody debris
reduced depth	aquatic plants
reduced baseflow	vegetated banks
increased flood flows	
loss of shading	
loss of pools	
increased water temperature	

Plant Community

Plants in the Auckland Region can be considered in two broad categories: periphyton and macrophytes. The following is a general discussion of both.

Periphyton

Periphyton and animals attach to hard surfaces (rocks, stream bottom) that are submerged in standing or running water. It appears as very slick, nearly invisible coverings on rocks in fast-flowing streams or long, weaving strands of algae or bacteria and fungi that completely cover the bottom in a slow flow stream.

The faster running headwater streams support growth of blue-green and filamentous green algae. Hard rocky substrates provide a firm footing for these species. In nutrient rich environments, periphyton growth can reach nuisance levels but this is not common in the Auckland Region. Downstream, the slower running, siltier nature of the streams (as a result of flatter slopes) does not support good periphyton growth except where macrophytes are abundant, for they provide a suitable substrate for attachment near the surface.

Macrophytes

The higher plants in aquatic environments are usually rooted and mostly of the submerged or floating type. They occupy either the edges of lakes or the slow-moving or stagnant reaches of rivers. Emergent types dominate marshy, wetland areas. Most rooted macrophytes are not able to withstand excessive currents and an adequate substrate is needed for their rooting and adequate light must be present.

Macrophytes act as a physical surface for periphyton and insects and thus can have positive benefit to the ecosystem. They are also involved in the life history of fish, supplying surfaces for egg incubation and protection of young.

However, if too dense, aquatic vegetation can lead to excessive siltation and extreme pH and dissolved oxygen variations. In that same regard, unshaded streams having high nutrient loadings can become infested with aquatic weeds. These weeds can reduce habitat values and impact adversely on water quality if they expand too rapidly and use available oxygen in the water.

Benthic Macroinvertebrates

Macroinvertebrates include grazers, shredders, collectors/browsers, piercers, suckers, and filter feeders on detritus, and predators. They process and utilise the energy entering streams from either organic materials built up by the stream systems instream primary production such as leaves, needles and bark from forestlands and organic wastes from human or animal sources. Macroinvertebrates can be lumped into feeding types, such as large particle detritivores (shredders), small particle detritivores (collectors), grazers (periphyton scrapers), and predators. A diverse community of macroinvertebrates is important in processing organic matter. The efficiency with which that process proceeds depends upon the diversity of the community.

The presence of a diverse macroinvertebrate community indicates consistently good water quality and a stable stream structure (available habitat)

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. As indicators of stream health in relevant conditions, macroinvertebrates are extremely valuable.

In a recurring theme, headwater streams, or first and second order streams, have the greatest diversity in benthic fauna, particularly where riparian vegetation exists. Mayfly and caddisfly nymphs and alderfly larvae are typical sensitive species inhabiting these cleaner stream bottoms. Lower pastoral subcatchments are where sediments tend to be deposited and the often turbid nature of the water limits periphyton (algae, bacteria, fungi) and macrophyte growth, and therefore food for macroinvertebrates. Silt deposits are also inhospitable to the more sensitive macroinvertebrates. Those found in pastoral streams are shrimps, snails, damselflies, and dragonfly nymphs, water boatmen, and pondskaters among others. Degraded streams tend to have mainly snails, flatworms, and mosquito larvae. Table 2-5 lists macroinvertebrates in relation to their tolerance to both water quality and habitat conditions.

Table 2-5
Macroinvertebrates and Water Quality Tolerance

Species Only Tolerant of High Water Quality	
Spiny gilled mayfly nymphs	Coloburiscus sp.
Double gilled mayfly nymphs	Zephlebia sp.
Caddisfly nymphs	Triplectides obsoleta
	Hydrophyche colonica
	Hydropsyche obsoleta
	Paroxyn ethira hendersoni
Alderfly larvae	Archichauliodes diversus
F.W. mussel	Hydriedela menziesi
Species Tolerant of a Range of Water Qualities	
Snail	Potamopyrgus antipodum
Damselfly nymphs	Xanthocnemis zealandica
	Austrolestes colensonis

Dragonfly nymphs	Uropetala carovei
Sandfly larvae	Austrosimulium sp.
Snail	Lymnaea tomentosa
F.W. shrimp	Paratya curvirostrus
Planarian	Dugesia sp.
Pond skater	Microvelia sp.
Water boatman	Sigara sp.
Backswimmer	Perisyas assimilis

Species Tolerant of Poor Water Quality

Midge (bloodworms)	Chironomus zealandicus
Mosquito larvae	Culex pervigilans
Hoverfly larvae	Tubifera tenax
Tubifex worms	Tubifex tubifex
Sewage fungus	Sphaerotilus sp. and others

Fresh Water Fish Species

Fish are another barometer of health that the average individual can easily relate to and understand. Absence or presence of fish may provide a picture of the overall health of a stream. A discussion of fish found in the Region and their tolerance of various water quality and habitat conditions will provide an awareness of what we can expect in a given stream with a given level of urban development.

Fish are another barometer of health that the average individual can easily relate to and understand. Absence or presence of fish may provide a picture of the overall health of a stream.

Banded Kokopu - Galaxias fasciatus

Once more common but somewhat rarer now, this galaxiid is found potentially in streams of good water quality with extensive overhead riparian vegetation, which provide overhead terrestrial invertebrate input, although they are relatively adaptable as a species. The eggs are laid among instream debris and the fry hatch during floods to be swept downstream to the sea. After approximately 6 months at sea, the juveniles then form part of the whitebait migration, returning upstream during the spring. They are most often found in small 1st order, stable streams that have rocky-boulder beds with small cascades interspersed with small pools. The presence of riparian forest cover is very important. In addition, they have one of the lowest lethal temperature tolerances of any native fish species.

Inanga - Galaxias maculatus

The Inanga, classified as whitebait, is the most well known of the species of Galaxias. Its juvenile is the most important species in the whitebait catch. Inanga prefer a shaded stream without much waterlogged debris, but with sufficient margin cover to hide in during the day. Unlike some galaxiids, the Inanga cannot climb falls, and is prevented from migrating upstream by small blockages. For this reason it is not often found far inland. The Inanga is unique in that spawning takes place in the grasses and rushes of the river banks at high tide after the highest of the spring tides. Hence, the eggs are not covered again by water until the next cycle of spring tides about two weeks later. The tiny larvae are flushed out of the estuary into the sea as the tide falls, to return in the spring as whitebait.

Common Bully - Gobiomorphus cotidianus

The Common Bully is the most widespread and familiar of the bullies. It is found throughout the region. It is found hiding among marginal cover, such as overhanging banks, logs, large rocks, and debris. Spawning occurs in streams in spring and summer and the larvae go downstream to the sea. Later in the summer they migrate into fresh water where they grow to maturity. The Common Bully appears fairly tolerant and resistant to changes in water quality and habitat.

Redfinned Bully - Gobiomorphus huttoni

This species is less common than the Common Bully in the Auckland Region. It is capable of moving upstream many kilometres in streams that are not too swiftly flowing and have no barriers like large falls, dams, and weirs. Its habitat is similar to Banded Kokopu - well shaded generally with good riparian cover and clear running water. It is absent in unstable streams with high sediment loadings and is particularly sensitive to changes in the natural habitat. Hatching is stimulated by floods when the young go down to the sea where their larval life is spent. They then make their way back into fresh water and move upstream towards the rocky adult habitats.

Eels - Anguilla spp

Two species of eels are found in New Zealand. The longfinned eel (Anguilla dieffenbachii) is the eel commonly found in rivers and streams: whereas the shortfinned eel (Anguilla australis) is also found in ponds, wetlands, lakes, and estuaries and is more lowland in distribution. They are tolerant, hardy species and particularly resistent to stresses such as low dissolved oxygen. When young, they feed almost exclusively on insects and other bottom fauna. Larger eels also feed on fish. Adult eels migrate to the sea to breed. Young eels migrate up the streams in large numbers and for considerable distances and are extremely good climbers.

Freshwater crayfish (or koura) - Paranephrops planifrons

Freshwater crayfish are commonly found throughout New Zealand in a variety of habitats ranging from lakes and ponds, streams of all sizes and swamps. They may be found on gravel or muddy substrates. They appear to be more common in forested catchments with good water quality. Crayfish are bottom dwellers and are omnivorous scavengers, feeding on small invertebrates, pieces of organic detritus and plants. They are moderately sensitive to pollution and sediment inputs. They are uncommon in impacted agricultural and urban streams. They were once wide spread in smaller streams around Auckland however, the loss of these low order streams and the removal of riparian vegetation, channelising, etc. has had a large impact on the extent of their distribution and abundance.

Giant Kokopu - Galaxias argenteus

Not much is known about the giant kokopu. It is found in very variable habitats, often in swamps, swampy creeks, forest streams, some lakes, and some gravelly streams but always where there is plenty of cover in the water or along the banks. It is one of the whitebait species. In general it is a sea-migratory species although there is evidence that it can live in a landlocked system.

In many parts of New Zealand the giant kokopu is rare. Undeveloped areas, especially the West Coast may have good populations but in populated and well developed agricultural areas few are found. Its decline can be attributed to loss of cover, decreased stability of the flows, and other habitat related issues. It is restricted to altitudes of less than 80 metres.

Less Common Species

Included here are the Cran's Bully, Torrent Fish, Giant Bully, Smelt Koaro, and Black Mudfish. These are found generally in small numbers in specialist habitat.

Ecological stress factors

The main factors influencing plants and animals in streams are the following:

- Physical habitat
- temperature
- dissolved oxygen
- suspended solids
- stream flow
- nutrients
- light
- contaminants
- instream barriers
- clearance of riparian vegetation

Urbanisation results in impacts related to all of the above items. No one single item is of primary importance. If we are to reduce impacts to aquatic ecosystems, we must develop approaches to address all of the above items. Thus the design approaches listed in Chapter 4 attempt to reduce the impacts associated with each item.

Importance of First and Second Order Streams

When considering aquatic resource protection, it is important to consider the entire catchment and to recognise that all waterways regardless of how small are integral components of the whole. To understand the relative importance of each part it is helpful to classify streams in terms of their "order". Order is based upon smaller streams draining into larger ones. First order streams are catchment headwater streams. They are generally the smallest streams and flow can be perennial or ephemeral. Second order streams are those formed by the junction of two first order streams. A third order stream is formed by the junction of two second order streams, and so forth. A schematic representation of stream order is shown in Figure 2-9.

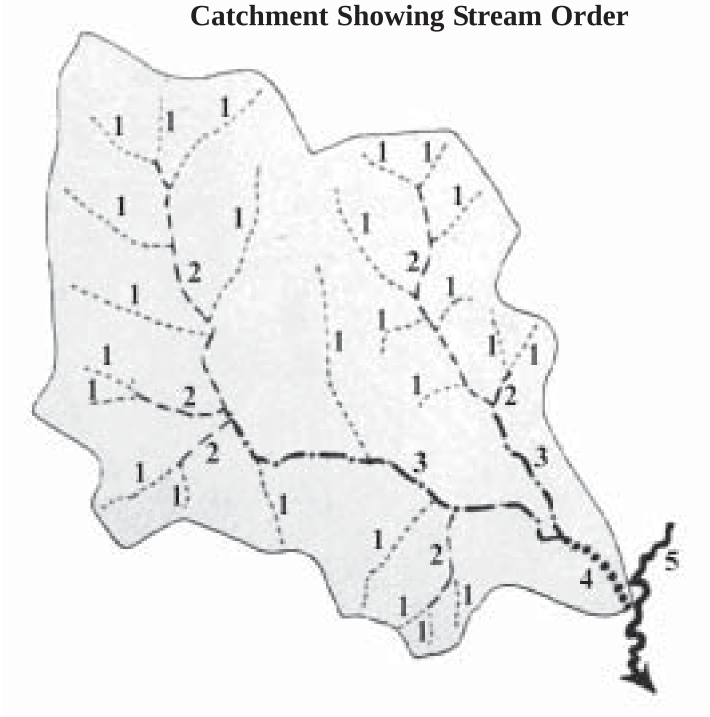
When considering aquatic resource protection, it is important to consider the entire catchment and to recognise that all waterways regardless of how small are integral components of the whole.

The definition of what is a stream is not easily provided. There are a number of definitions which are not necessarily in agreement with one another. The Resource Management Act does not define a stream but does define a river as:

"River" means a continually or intermittently flowing body of fresh water; and includes a stream and modified watercourse; but does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal).

The Proposed Regional Plan: Sediment Control has a definition for watercourse which is the following:

Figure 2-9
Catchment Showing Stream Order



Watercourse means a waterbody which ceases to flow not more than once in a five year period.

Whereas the Regional Plan is somewhat restricted by only considering streams which are essentially perennial flow, the Resource Management Act has a very broad definition. The Regional Plan definition will be revisited in conjunction with reconsideration of the Regional Plan. In this document, the definition of what is a stream will be in line with the RMA definition.

A stream, as discussed here, will be a natural water body of water, which includes a free slfowing area of concentrated flow, an area having stable pools of water, a spring outfall, or a wetland.

To provide further guidance, a stream as discussed here will be a natural body of water, which includes a free flowing area of concentrated flow, an area having stable pools of water, a spring outfall, or a wetland. In the context of a stream, the area of concentrated flow shall have defined banks and bottom. This would not include areas of sheet or shallow concentrated flow such as swales or field flow.

To provide specific information on the Auckland Region regarding streams and their order, including percentage of total length, a review of Auckland streams was done by NIWA (1999), detailed in Table 2-6, and provides the following information.

Table 2-6
Stream Inventory Table

Auckland Region Streams			Number		Length	
Order	Number of Streams	Length (m)	% of total	Cumulative %	% of total	Cumulative %
1	810	1,961,112	60.18	60.18	68.25	68.25
2	365	598,097	27.12	87.30	20.81	89.07
3	108	187,888	8.02	95.32	6.54	95.60
4	56	105,073	4.16	99.48	3.66	99.26
5	7	21,233	0.52	100.00	0.74	100.00
Total	1,346	2,873,403	100.00		100.00	

It is important to recognise that almost 70 percent of Auckland streams, in terms of total length, are first order streams. When combined with second order streams, that total increases to almost 90 percent. If it is our goal is to protect third order or larger streams, that goal cannot be attained if first and second order streams are destroyed by mass earthworks.

It is important to recognise that almost 70% of Auckland streams are first order streams. When combined with second order streams, that total increases to almost 90%.

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