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4.5.2 Dissolved reactive phosphorus (DRP)

The concentrations of DRP in the stream at the Top Site and Bottom Site are shown for the whole monitoring period in Fig. 14. At the Top Site, DRP showed an increase to 1989, followed by a decrease to 1993; it then remained relatively constant, varying by around 70 mg/m^3. Thus, although the long-term trend in DRP did not mirror the upward trend seen for nitrate-N, the marked seasonality precisely followed that of nitrate-N, with lower values at both the Top and Bottom Sites in summer months, indicating that the same seasonal process influences both nutrients. There were considerable reductions in concentration of both DRP and nitrate-N at the Bottom Site in the summers during the 1980s (cf. Figs 11 & 14), and moderate reductions between 2003 and 2006.

As explained in section 4.5.1, the concentration (and then mass flow) records have been divided into a number of qualitatively assigned 'Phases' that reflect characteristics of the nutrient record (Figs 14–16 for DRP). The full description of the Phases is provided in the Discussion (section 5.4).

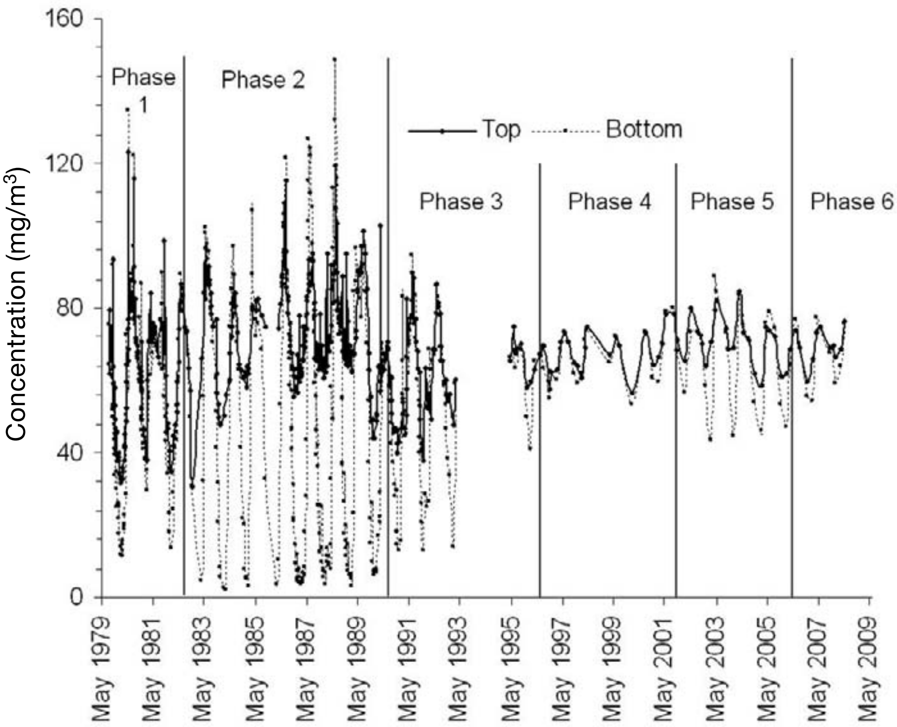


Figure 14. Dissolved reactive phosphorus (DRP) concentrations (mg/m^3) at the Top and Bottom Sites, Whangamata Stream, 1979–2008. Phases 1–6 are described in section 5.4.

Figure 15. Dissolved reactive phosphorus (DRP) concentrations (mg/m^3) at the Top and Bottom Sites, Whangamata Stream, 1995–2008.

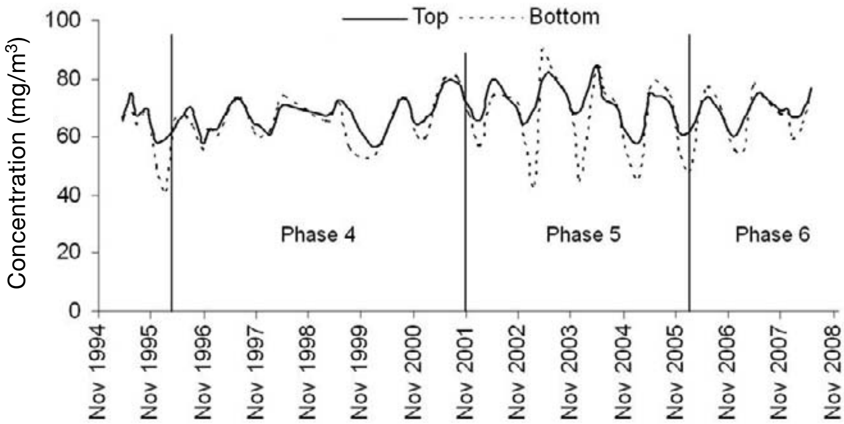
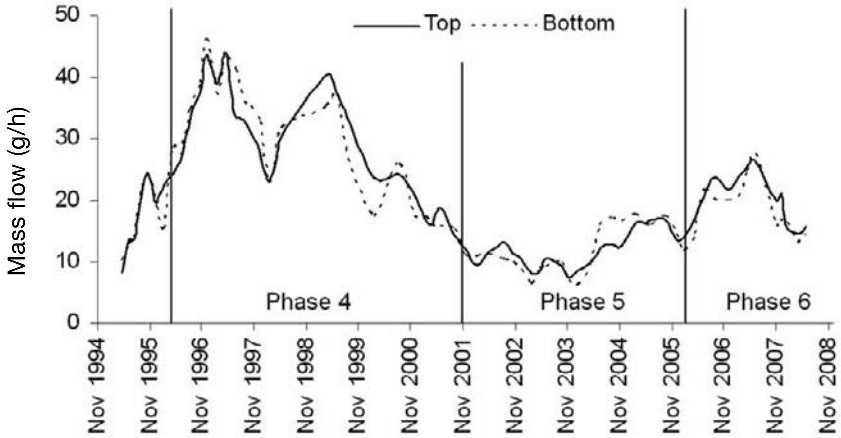


Figure 16. Mass flows (g/h) of dissolved reactive phosphorus (DRP) at the Top and Bottom Sites, Whangamata Stream, 1995–2008.



4.5.3 Ammonium-N

In the spring waters, ammonium-N concentrations have remained low (< 10 mg/m^3) throughout the 30-year period (Appendix 1). In the stream waters, ammonium-N has shown a seasonal periodicity, with summer concentrations at both the Top and Bottom Sites generally in the range of 6–10 mg/m^3, while winter concentrations have been in the range of 13–25 mg/m^3. The Bottom Site generally had slightly higher ammonium-N concentrations than the Top Site, and ammonium-N was generally at a maximum in spring (September–October), when it regularly exceeded 20 mg/m^3 (Appendix 1). The reasons for this are not clear, but may be related to large populations of spawning trout in the stream at that time.

4.5.4 Dissolved organic nutrients

Dissolved organic phosphorus was extremely low throughout the monitoring period, generally ranging between 1 mg/m^3 and 8 mg/m^3, although occasional samples were slightly higher than this (e.g. June 2005—11.5 mg/m^3 at Top Site and 14 mg/m^3 at Bottom Site) (Appendix 1). There was no clear seasonal pattern or difference between the Top and Bottom Sites in the concentration of dissolved organic phosphorus.

Dissolved organic nitrogen levels likewise showed no clear seasonality or differences between the two sites. Values over the period 1998–2008 ranged from 385 mg/m^3 (March 1999) down to < 10 mg/m^3 (in November and April 2008), with the majority of values being < 100 mg/m^3.

4.5.5 Particulate and total nitrogen and phosphorus

Particulate nitrogen and particulate phosphorus were collected in the latter stages of this study, with the sampling initiated in October 2003 (Appendix 1). Total nitrogen and total phosphorus can be calculated by adding total dissolved nitrogen or phosphorus to particulate nitrogen or phosphorus. Particulate nitrogen and phosphorus showed a seasonal cycle, with highest values in the winter (June–September), and in general followed the patterns of TSS (Figs 7 & 8). The concentration of particulate nitrogen ranged from 15 mg/m^3 to 294 mg/m^3, while particulate phosphorus ranged from a summer-time low of 1.1 mg/m^3 to 36.3 mg/m^3 in winter.

Total nitrogen and total phosphorus similarly showed a pattern of highest values in the winter months, with total nitrogen ranging between 609 mg/m^3 and 1732 mg/m^3, and total phosphorus ranging between 5.2 mg/m^3 and 123 mg/m^3 (Appendix 1).

4.6 NUTRIENT REMOVAL

Nutrient removal from the stream water was calculated from the mass flow of nutrient that disappeared from the stream between the Top and Bottom Sites each year during the period of maximum nutrient stripping. Reduced sampling frequency in more recent years resulted in only two or three sampling runs being undertaken in the summer months, so calculations of summer nutrient uptake were not continued. The totals from 1986 to 1998 are shown in Table 3. Nitrate-N removal from stream waters was maximal in the 1980s (see e.g. Fig. 11), ranging from 413 kg N/year to 787 kg N/year when stream discharges were low (section 4.2). Nitrate removal from stream waters (attenuation) decreased to negligible amounts towards the end of the 1990s. The pattern of mass removal of dissolved reactive phosphorus from stream waters closely followed that of nitrate, with maximum removal of 72 kg/year in the summer of 1987/88. Removal then declined into the 1990s, with removal rates being negligible from 1996.

An illustration of mass balance losses and gains to the stream was carried out from a large dataset collected between 1979 and 1981 during Phase 1 (CH-W, unpubl. data). The summary data from a sampling run in each of four seasons

(Table 4) showed an uptake of total nitrogen from stream water in summer and autumn (almost all as nitrate-N), with a high uptake rate of 2.49 kg N/day in summer. In contrast, there was a net export of total nitrogen during winter and spring, mostly as particulate nitrogen, with export rates of 2.19 kg N/day (Table 4), suggesting an approximate balance between uptake of dissolved nutrients in summer and export in particulate form in winter.

Nutrient removal was also calculated from the nutrient attenuation coefficient (Equation 1—section 3.2) for mid-summer periods in the six Phases. The average for each Phase was as follows: Phase 1 = 0.30; Phase 2 = 1.50; Phase 3 = 0.55; Phase 4 = 0.03; Phase 5 = 0.10; Phase 6 = 0.05. These data demonstrate a 50-fold variation in mid-summer nutrient uptake (range 0.03–1.5/m) through the different Phases over the 30-year period.

TABLE 3. MASS REMOVAL OF NITRATE-N AND DISSOLVED REACTIVE PHOSPHORUS (DRP) IN WHANGAMATA STREAM BETWEEN THE TOP AND BOTTOM SITES.

'negl' = negligible, '–' = no calculation.

YEAR	MASS REMOVED (kg/YEAR) NITRATE-N	DRP
1986/87	475	47
1987/88	787	72
1988/89	558	48
1989/90	413	34
1990/91	239	15
1991/92	234	22
1992/93	124	11
1993/94	–	–
1994/95	–	–
1995/96	73	6
1996/97	negl	negl
1997/98	negl	negl

TABLE 4. TOTAL NITROGEN FLUX AT THE TOP SITE, WHANGAMATA STREAM, ON ONE SAMPLING DATE IN EACH SEASON DURING PHASE 1.

The amount of uptake (loss from stream water between Top Site and Bottom Site) or export (gain to stream water between Top Site and Bottom Site) is also presented.

SEASON	DATE	TOTAL NITROGEN (kg N/DAY)	UPTAKE (–) OR EXPORT (+) (kg N/DAY)	COMMENTS
Spring	24 Oct 1979	7.63	+0.76	Export as particulate nitrogen
Summer	4 Feb 1980	5.64	–2.49	Uptake as nitrate-N
Autumn	7 May 1980	7.68	–0.70	Uptake as nitrate-N
Winter	30 July 1980	10.52	+2.19	Export as particulate nitrogen

5. Discussion

5.1 VEGETATION TRENDS

After 32 years, the vegetation along the riparian strip of the Whangamata Stream is still in a dynamic successional stage, with new species arriving and some existing species disappearing from the stream margins. The flora, if left, will presumably revert to a manuka/kanuka (*Leptospermum scoparium*/*Kunzea ericoides*) scrubland, similar to that which characterised the area before pastoral development (Ward 1956). Many individuals of the species that are currently in the retired area of the stream have been introduced through assisted plantings (Appendix 2). As succession proceeds, there will be a continual exchange of species invading and species disappearing. Many of the invaders that move into the area have not succeeded in establishing themselves. A total of 54 species that had been recorded at some time in previous vegetation surveys were not found in 2008 (Table 1). The average species turnover (lost species/total species) for the survey times since 1982 has been 7.2%. Some of the groups of 'lost species' are discussed in Howard-Williams & Pickmere (1999, 2005).

A total of 189 vascular plant species were recorded for the study area in 2008. If the lost species are added to this species list, the total vascular plant species pool that has been present in the riparian area over the last 32 years exceeds 240. Overall, the vascular plant biodiversity in the riparian strip increased at a rate of 5.7 species per year or 6.6% per year between 1976 and 2008, with the most rapid rises in the first decade.

With increasing maturity of the riparian strip, the number of native species rose steadily to 2003. Most of the increase occurred between 1982 and 1986, when 36 new species established in the area. Between 1986 and 2003, a further 23 native species were added, but since 2003 the number of native species has remained static, with 70 native species recorded in 2003 and 71 in 2008. Native plants now only represent 38% of the total flora, a decline from 42% in 2003. The reason for this reduction in native plant succession may be related to increasing growth of woody species (native and adventive) and the resulting shading of the habitats for the relatively few native herbaceous species able to colonise this area.

Recent vegetation changes in the riparian strip have been dominated by changes in exotic species. Tree lucerne (*Chamaecytisus palmensis*), which was abundant as a result of assisted plantings up to 2003, has now almost disappeared. Tasmanian blackwood (*Acacia melanoxylon*) and Scotch broom (*Cytisus scoparius*) are aggressively colonising the grassed areas alongside the middle reaches of Whangamata Stream, as noted by Beadel (1998) and Howard-Williams & Pickmere (2005). There is little in the way of regeneration of native species within the middle reaches. Of recent concern is that *Prunus serotina* seedlings and saplings are now abundant in the Right Hand Spring tributary in Section A (Fig. 1). In less than 15 years, this species has come to dominate both understorey and edge habitats. Although this species is not well established in the Taupo District, the likely attractiveness of its fruit to mobile bird species such as kererū

(New Zealand pigeon, *Hemiphaga novaeseelandiae*) and tūi (*Prosthemadera novaeseelandiae*) provides the potential for this plant to become a serious woody weed. Three weed species have recently established along the edges of the lower section of Whangamata Stream: *Vinca major*, *Crocosmia* × *crocosmiifolia*, and *Agapanthus praecox*. These weeds are likely to have spread from neighbouring gardens as a result of the increased urbanisation in the area or to have been dumped on the site with garden refuse.

In 2007 and 2008, the removal of in-stream vegetation in autumn continued, with selective chemical control of musk (*Mimulus guttatus*) to allow access for spawning rainbow trout. Clearing of willows (*Salix* spp.) and woody debris was also carried out upstream of Whangamata Road in 2006 (Cudby 2006) both to aid spawning migrations of trout and to enhance establishment of native vegetation. For instance, a stream channel-clearing programme was needed in May 2002 (Hart 2002) to remove musk and watercress from regions of the stream where such in-stream plant growth was not inhibited by stream bank shading. At this time, spawning trout were barely able to remain below the water in transit between deeper lies. This was a long-term continuation, in a more restricted area, of the considerable channel clearing programmes that were needed in the 1980s (Anon. 1985; DOC 1994; Howard-Williams & Pickmere 1999). Subsequent similar channel clearing has continued at intervals to 2008 (Fig. 17) and will need to continue (see section 6.1).

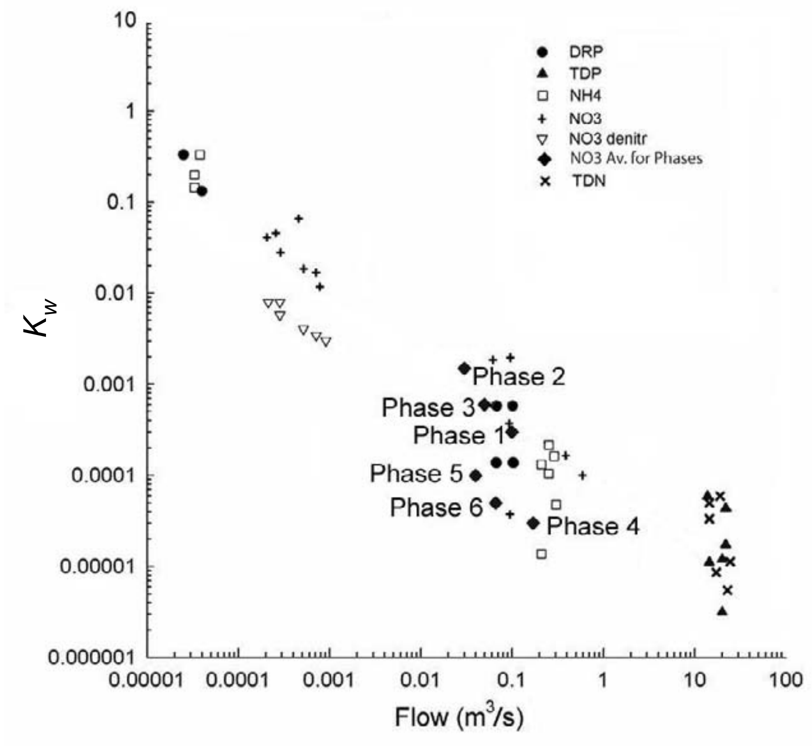


Figure 17. Variation in the nutrient attenuation coefficient (*Kw*) with stream flow in New Zealand streams (modified from Rutherford et al. 1987). Overlayed on the figure are the attenuation coefficients for nitrate-N (from Eq. 1) in the Whangamata Stream for the six phases in the 32-year restoration period: Phase 1—1979–1982; Phase 2—1983–1990; Phase 3—1990–1996; Phase 4—1996–2001; Phase 5—2001–2006; Phase 6—2006–2008 (cf. Fig. 11). NO3 denitr = nitrate-N removed by denitrification.

5.2 STREAM FLOW TRENDS

Inter-decadal fluctuations in discharge rates for the Whangamata Stream (Fig. 6) are not yet understood, but most of the variability in the stream is due to variability in flows from the Left Hand Tributary. The spring waters feeding the Whangamata catchment are old (Vant & Smith 2002), with only 10% being younger than 35 years (Hadfield et al. 2001), and the area is subject to frequent tectonic movements. Thus, a clear explanation of the periodicity of the spring discharges (and hence stream discharge) will be difficult to unravel and may be a function of changes to the levels of groundwater reservoirs and/or an alteration by local tectonics to the geomorphology of the springs. It is noteworthy in this context that plantation forest (particularly *Eucalyptus* spp.) has replaced pasture in some of the upper reaches of the catchment. This could in the future also influence the catchment water budget. Plantation forest has been shown to reduce flows leaving catchments (Duncan 1992).

Of continuing concern is the apparent loss of water between the Top and Bottom Sites, which was noted first in 2002. From the earliest regular measurements in the 1970s to 1998, the Bottom Site consistently had a slightly higher discharge (6.1% higher) than the Top Site (Howard-Williams & Pickmere 1999). However, from 1998, flows at the Bottom Site were lower than at the Top Site on increasingly frequent sampling occasions, until November 2007 to June 2008, when flows were continuously lower by, on average, 0.011 m^3/s. The reason for this water loss over the 2-km reach is not clear. It could be a result of increased evapotranspiration with changing vegetation, but this is unlikely to explain the observed trend in the winter months. Alternatively, water may be being lost to groundwater because of increased groundwater extraction or it could be a result of direct extraction from the stream channel. Given the influence of low discharges on the uptake of nutrients in the stream (section 4.6) and the need for adequate water for rainbow trout spawning runs, it would be prudent to investigate this downstream loss in more detail. The first check might be on surface water takes in the lower reaches in the summer months. In the longer term, if this continues to be an issue, a surface-groundwater balance analysis for the study section of the stream may be necessary.

5.3 CATCHMENT MODIFICATIONS

Changes to the land use in the catchment between the Top and Bottom Sites have accelerated in the last decade, with the development of life-style blocks in the upper catchment and the new 'Holy Oaks' urban subdivision on the true right bank at the bottom end of the catchment (Fig. 1), which has developed rapidly (although many sections are still available).

The Kowhai Ridge subdivision, which is alongside the riparian zone on the true right bank opposite the Top Site, was ready for building in 2006 but has not progressed since then. Kowhai Ridge is therefore unlikely to have had an impact on the Whangamata Stream to date. There was a further development on the true left bank adjacent to the Top Site and opposite Kowhai Ridge subdivision in 2006–2007, where the land was re-sculptured to form a golf driving range and associated residential development. This included removal of top soil, modification of the existing topography and soil replacement. No further development occurred during 2008. The re-sculptured area adjacent to the stream riparian zone has some formed roading but has mainly reverted to long grass. Golf courses require the addition of fertiliser to maintain fairways and greens, so careful nutrient budgeting will be needed to minimise nutrients entering the Whangamata Stream.

To date, there has been no marked deterioration in water quality (as measured by nutrient or sediment concentrations) at the Bottom Site as a result of land use change adjacent to the study reach of the stream.

5.4 NUTRIENT ATTENUATION PROCESSES

Spring groundwater ages mean that current concentrations of nutrients in the Whangamata Stream mostly reflect land use changes to pastoral farming that took place 30–50 years ago. Conversely, changes to land use over the last two decades that have resulted in nutrient enrichment of groundwater may take 30 years or more to show up in the springs and hence the streams that flow into Lake Taupo (Taupomoana). The trend of increasing nitrate-N shown in Fig. 9 may therefore continue for some time to come. It is unclear what the impacts of the urban subdivisions will be on nutrients entering the stream.

Attention is currently being given to methods to mitigate the increasing diffuse-source nutrients that are entering streams in many parts of New Zealand. One such mitigation method is retirement of stream edges from stock to promote the development of riparian vegetation (MfE 2001), which in some cases assists in attenuating stream nutrients by reducing nutrient input to streams. Riparian protection also protects in-stream vegetation and assists in attenuating nutrients once they have reached the stream channel through direct uptake by in-stream vegetation. However, the success of this mitigation method has been shown to be highly variable, with results ranging from no apparent attenuation in large rivers to a high attenuation capability in small streams and wetlands (Howard-Williams 1985; Rutherford et al. 1987; Downes et al. 1997).

Nutrient attenuation along a stream reach is measured as flux (kg/h) at the top of the reach minus flux at the bottom. Because the differences in flow rates between the Top and Bottom Sites in the Whangamata Stream are small (Fig. 6), nutrient concentrations can be taken as surrogates for nutrient flux when flux was not calculated. A high degree of variability in nutrient flux was recorded in the stream over the 32-year study period. Maximum nutrient attenuation (flux at Top Site minus flux at Bottom Site) occurred in the 1980s (Figs 11 & 14; Table 3), when stream flow was reduced, there was little if any over-hanging vegetation to shade the stream channel (except at the Top Site), and very dense beds of watercress and musk occupied the channel almost from top to bottom (Howard-Williams & Pickmere 1999, 2005). In the 1990s, flow rates increased and so did the extent of vegetation overhanging the stream channel, particularly in the upper reaches of the channel. Between 2001 and 2004, when flow rates were low, some musk and watercress beds were able to colonise the more open areas of the lower stream channel, resulting again in increased attenuation of nutrients from the stream water at that time (Figs 11 & 14); however, the areas of stream channel colonised by these plants were considerably less than those in the mid-1980s. From 2005 to 2008, there were increased flow rates (Fig. 6), which again corresponded with a period when differences in concentrations between the Top and Bottom Sites were minimal (Figs 12 & 15).

Streams with riparian vegetation can be conveniently separated into two types, which differ in their nutrient attenuation processes (Downes et al. 1997). In Type 1 streams, dissolved inorganic nutrients are removed when surface and subsurface water flows through riparian vegetation before reaching the stream channel. In Type 2 streams, in-stream vegetation can remove nutrients from waters within the stream channel itself. The Whangamata Stream is a Type 2 stream, as the principal source of nutrients and water is from the two springs, and there is little if any lateral flow across the riparian strips, even during rain events. Nutrients are therefore processed in the stream channel. The 32-year dataset for the Whangamata Stream, showing changing patterns of vegetation, water flow and nutrient flux, provides valuable insights into the controls on nutrient processing in a Type 2 stream.

The Whangamata Stream dataset provides an opportunity to evaluate how stream nutrient attenuation processes change with changing vegetation. The time series data for nitrate-N and DRP from 1996 to 2008 can be conveniently divided into six contrasting periods or phases, as shown for the whole period in Figs 11 & 14. These can in turn be related to changing vegetation and flows (cf. Fig. 6):

- **Phase 1** 1979–1982: Characterised by a 30–50% reduction in nitrate-N concentrations (Fig. 11) and a 10–60% reduction in DRP (Fig. 14) for 1–2 months in summer. Flow rates during this time were c. 0.08–0.1 m^3/s. The in-stream vegetation consisted of watercress beds and floating sweetgrass (*Glyceria fluitans*), mostly in the lower sections of the stream (Vincent & Downes 1980), and areas of submerged vegetation (*Myriophyllum* spp.). Nutrient absorption by the in-stream vegetation was shown to be the primary mechanism for both nitrate-N and DRP removal from the stream waters (Vincent & Downes 1980; Howard-Williams et al. 1982).
- **Phase 2** 1983–1990: A period of large-scale summer reduction in nutrient concentration in the stream. Over this period, nitrate-N and DRP were reduced to concentrations below 10 mg/m^3 and 5 mg/m^3, respectively, at the bottom end of the stream. The period of time over which nutrients were continuously depleted to such low concentrations increased from 2–3 months in 1983–1984 to 4–5 months in 1986–1989 (Figs 11 & 14). Flow rates during this phase were lower than during Phase 1, at c. 0.025–0.05 m^3/s. The in-stream vegetation was characterised by dense watercress, followed by watercress and musk beds along almost the entire 2-km length of stream channel during summer and autumn (Howard-Williams et al. 1982, 1986). During this time, the submerged vegetation disappeared. Watercress and musk densely colonised the stream channel in the high light conditions, with floating stems that produced dense root masses hanging into the water. This was the period of maximum nutrient uptake.
- **Phase 3** 1991–1996: This was a period of markedly declining nutrient uptake from the stream water. By 1992–1993, the upstream nutrient concentrations were reduced by only 50–60% at the Bottom Site and for only 2 months. Flow rates were higher than in Phase 2, at c. 0.05–0.06 m^3/s. The in-stream

vegetation changes were characterised by the gradual shading out of the stream channel vegetation (watercress and musk) by tall emergents such as flax, toetoe and other tall species that over-shadowed the stream channel.

- **Phase 4** 1996–2001: A period of higher concentrations of nutrients at the Top Site. While seasonal changes in concentrations were recorded, there was almost no detected nutrient uptake between the Top and Bottom Sites. Flow rates were high during this phase and increased markedly from 0.06 m^3/s to c. 0.2 m^3/s up to 1998; they then decreased to 0.1 m^3/s by 2001. The in-stream vegetation had declined even further as a result of the continued development of herbaceous and woody growth that shaded the stream channel. This coincided with little or no nutrient uptake.
- **Phase 5** 2001–2006: Nutrient concentrations during this phase were lower than in Phase 4, and increased to 2007. Concentrations at the Bottom Site were between 10% and 40% of those recorded at the Top Site in mid-summer. Flow rates were also lower than in Phase 4. Flows decreased to 0.03 m^3/s by 2004 and then increased to 0.07 m^3/s by 2006 (Fig. 6). The general pattern of increased overhanging emergents and woody vegetation remained the same as in Phase 4, but flow rates were reduced. It is possible that the reduced flow rates allowed for proportionately higher nutrient uptake by tall emergent species such as flax and *Carex*. Musk development in the lower stream reaches at this time also allowed for some nutrient uptake.
- **Phase 6** 2006–2008: Nitrate-N concentrations were the highest recorded over the whole period (c. 1500 mg/m^3), and the differences between the Top and Bottom Sites at mid-summer were less than 10%. Concentrations of DRP were c. 60–70 mg/m^3, similar to those of the preceding 20 years, and again the differences between the Top and Bottom Sites were less than 10%. Flows during this period were higher than in Phase 5, initially up to 0.09 m^3/s and later decreasing to 0.05 m^3/s. Further increases in overhanging and woody vegetation characterised the vegetation in Phase 6, with very little in-stream vegetation apparent. However, musk was still present in the lower reaches. Musk control was required to open the channel to trout spawning in late summer.

The key to understanding in-stream attenuation processes is the concept of nutrient spiralling (Newbold et al. 1981; Howard-Williams 1985). Rutherford et al. (1987) discussed attenuation processes in New Zealand streams in a nutrient spiralling framework, where the downstream concentration (*Cz*) can be estimated from the first-order relationship:

$$Cz = Co.\mathrm{e}^{-Kw.z} \qquad \text{Equation 2}$$

where *Kw* was obtained from Equation 1 (section 3.2).

Kw is a direct measure of the downstream uptake rate of a given nutrient. Nutrient attenuation rates between streams or between reaches or times in a stream are made by comparing this coefficient. *Kw* will depend on stream size, stream vegetation, metabolic rates of stream organisms and discharge (Howard-Williams 1985; Rutherford et al. 1987; Hearne & Howard-Williams 1988).

A quantitative summary of nutrient uptake over Phases 1–6 is seen from the relationship of the attenuation coefficient (*Kw*) against stream flow (Fig. 17), which provides an overview of New Zealand stream attenuation rates (Rutherford et al. 1987). The *Kw* values for the six phases in the Whangamata Stream (see section 4.6) have been plotted over the original New Zealand stream data from Rutherford et al. (1987). The attenuation coefficient increased significantly from Phase 1 to Phase 2, coincident with a drop in flow. Attenuation then decreased in Phase 3 and decreased further with increasing flow into Phase 4. A relatively low flow rate during Phase 5 was, however, not followed by a high attenuation coefficient because of increased woody vegetation and lack of in-stream vegetation in 2005 relative to that in the stream in Phase 2. Consequently, the position of a stream or stream reach at a point in time on Fig. 17 depended on a combination of stream flow, and in-stream and riparian vegetation type.

In any discussion of the long-term efficiency of streams to attenuate nutrients, it is important to consider the long-term fate of the nutrients. Dissolved inorganic forms of nitrogen and phosphorus are biologically reactive and, through nutrient processing, are converted to relatively inactive particulate and dissolved organic forms. For instance, nitrate is taken up and converted to particulate nitrogen in live and dead plant tissue, and is often exported as dissolved organic nitrogen by excretion and decomposition, and as particulate nitrogen in detritus.

An analysis of the flux of total dissolved nitrogen in 1982–1983 during Phase 2 showed that over the year there was a large retention of total dissolved nitrogen (which mostly comprised nitrate-N) within the stream from August to April, and a small export from the stream and hence into Lake Taupo (Taupomoana) from May to July (Howard-Williams et al. 1986). The question is what happens to the retained nitrogen? Retained nitrogen can enter one of three pathways: storage in the system, denitrification, or export as particulate and dissolved organic nitrogen. Denitrification rates of the stream bank sediments were shown to be between 1.2 mg N m^{-2} day^{-1} and 83.5 mg N m^{-2} day^{-1}, with a calculated total denitrification rate for the stream of 0.2 kg N/day (Howard-Williams & Downes 1984). This was c. 10% of the maximum summer nutrient uptake rate into the stream-bank vegetation at that time (cf. Table 4). Denitrification will occur throughout the year, so on an annual basis denitrification will be more than 10% (possibly c. 20%) of the nutrient uptake by the stream-bank plants. This is a permanent nitrogen sink. There was considerable export of particulate nitrogen from decomposing vegetation in winter and detritus was a contributor to the increased TSS loads at the Bottom Site in the winter months (Figs 7 & 8). The 1979–1981 data from this stream shown in Table 4 indicated that winter export of particulate organic nitrogen almost balanced the summer uptake of dissolved inorganic nitrogen. A full seasonal analysis of fluxes of the different components is needed to quantify this precisely and to show the loss by denitrification.

The Type 2 stream nutrient processing described here can be summarised as:

- Active dissolved inorganic nutrients were taken up from the stream water into in-stream vegetation during summer, but there was a decline in uptake in autumn.
- The inorganic nutrients were transformed into organic forms (particulate and dissolved).
- In the case of nitrogen, the year-round permanent sink provided by denitrification transformed inorganic nitrogen (directly or via decomposition of the vegetation) into gaseous N_2O and N_2. The transformation rate was estimated at between 10% and 20% of the nitrogen uptake into the vegetation

during Phase 2 (it may be a higher proportion in other Phases when the vegetation uptake was not as great).

- During winter, there was a net export of nutrient from the stream in particulate form at a rate similar to the summer uptake rate.
- Although nutrient uptake began again in spring, the export processes still dominated and there was a small net export from the stream in particulate form.

Depending on the downstream system, the transformation of nutrients from inorganic to organic forms may be advantageous in its own right, as the latter are often refractory and may play a small role in subsequent nutrient cycling. If the aim is to remove all forms of nutrients from the system, then in-stream vegetation will need to be removed from the stream channel during and at the end of summer. This would effectively remove the store of nutrients that accumulate during the summer months and prevent subsequent release back into the water in particulate and organic forms following autumn and winter decomposition.

6. Recommendations

Management of riparian strips requires clear objectives. This section provides the authors' suggestions for management options for the Whangamata Stream under the following sub-headings: vegetation management, management for nutrient uptake, flow monitoring, water quality monitoring and publicity.

6.1 VEGETATION MANAGEMENT

- The vegetation in the Whangamata Stream catchment is continuing to change. This 32-year dataset demonstrates change on time scales that are not often recorded. Therefore, we recommend continuation of the 5-year vegetation surveys.
- Following the 2003 survey, concern was expressed about the spread of the invasive weeds Himalayan honeysuckle (*Leycesteria formosa*) and blackberry (*Rubus* sp.) into the riparian protected areas. Evidence from the 2008 survey indicated that these species were still abundant, but Tasmanian blackwood and Scotch broom were aggressively colonising the grassed areas in the middle reaches of Whangamata Stream, as noted by Beadel (1998) and Howard-Williams & Pickmere (2005). Since there is little in the way of regeneration by native species within these areas (Wildland Consultants Ltd 2008), assisted plantings of native species in Sections C, D and E are recommended and would be of long-term value to the stream.
- Three weed species have established along the edges of the lower section of Whangamata Stream: *Vinca major*, *Crocosmia* × *crocosmiifolia* and *Agapanthus praecox*. These weeds are likely to have spread, or been dumped, from neighbouring gardens and their removal is recommended.

- *Prunus serotina* seedlings and saplings are now abundant in the eastern tributary in Section A. In less than 15 years, this species has come to dominate both understorey and edge habitats. This species is not well established in the Taupo District, yet appears to have the potential to become a serious woody weed. Given the likely attractiveness of its fruit to mobile bird species such as kererū and tūi, its removal from the site should be considered (Wildland Consultants Ltd 2008).
- While development of high plant biomass in the stream channel itself may increase nutrient attenuation, it has undesirable consequences for trout spawning. Therefore, the autumn stream channel clearing programme initiated in the 1990s should be continued.

6.2 MANAGEMENT FOR NUTRIENT UPTAKE

Objectives for stream restoration programmes need to be decided on at an early stage. These could include one or more of the following: biodiversity enhancement; landscape and aesthetic enhancement; sediment control; nutrient uptake; Māori traditional freshwater resource (mahinga kai) enhancement; or trout habitat provision.

If nutrient control (attenuation) is a major objective, then a number of conclusions are apparent from the analysis in this paper:

- Optimum management for Type 2 stream nutrient removal processes requires stream sections with sufficient light to support in-stream macrophytes, stream-covering macrophytes such as watercress, or periphyton that can take up nutrients directly from stream water.
- Optimum stream size for Type 2 processes are those with a flow rate of less than 0.5 m^3/s (i.e. that have a Kw of greater than 0.0001/m or > 10% loss of nutrient per km of stream length). If flow rate was the main determinant of Kw (as might be expected from Fig. 17), then a flow of 0.05 m^3/s will result in a potential nutrient loss rate of 0.001/m (at least for the streams illustrated in Fig. 17), which is equivalent to 100% attenuation per km.
- Long-term removal of the attenuated nutrient will require optimising denitrification rates (in the case of nitrogen) and/or harvesting of the in-stream vegetation before decomposition. It is recognised that harvesting may decrease organic matter that could, if retained in the system, enhance denitrification. As most (> 80%) of the retained nutrients at the end of summer in the Whangamata Stream were in the aquatic vegetation, harvesting will provide the largest benefit to nutrient removal. If harvesting is impractical, then nitrogen losses of up to 20% of mass flow could be achieved by denitrification.
- Optimisation of in-stream removal processes (i.e. Type 2 stream processes) for nutrient attenuation requires active management of the riparian vegetation. This should include the maintenance of high light conditions over the stream channel to encourage fast-growing stream-bank plants, and the harvesting these in summer and autumn to remove biomass and minimise the export of particulate nitrogen in winter.

- Stream protection needs to be considered as one of a range of nutrient control methods in a farming catchment.
- If the long-term goal is restoration and recovery to a 'natural state', in-stream nutrient attenuation will decline with time (on the scale of decades) as the vegetation matures and the stream channel becomes shadier.

6.3 FLOW MONITORING

Continuation of flow monitoring at the Top and Bottom Sites is recommended as a basic stream health index, to measure mass flux of nutrients, to assess changes to spring activity, to ensure adequate water is present for trout spawning, and also to monitor catchment activities such as urban development and consented or unconsented abstractions. Therefore, it is recommended that water flow monitoring continue into the future.

6.4 WATER QUALITY MONITORING

Changing land use in the catchment will result in changes to groundwater nutrients, which will first appear at the springs, and to sediments from erosion along the stream channel. The data show that nitrate-N in the Right Hand Spring has doubled since 1984. This may reflect the long-term movement of groundwater. The long residence times in the groundwater mean that it would be prudent to continue to measure the water quality of at least the Right Hand Spring just above the Top Site.

Continuation of nutrient measurements at the Top and Bottom Sites is strongly recommended to maintain this long-term database. This is important for three reasons:

- Spring waters are beginning to show an increase in nitrate that we assume will be reflected in the Top Site samples in the future.
- The vegetation is changing, so attenuation processes between the Top and Bottom Sites will also change.
- Although the developments of the golf course and the Kowhai Ridge subdivision are currently on hold, they will proceed at some stage. Any impacts on the stream are likely to be recorded if the water quality monitoring continues.

6.5 PUBLICITY

With rapidly increasing numbers of people associated with Whangamata Stream, we recommend public presentations and/or posters/signage to alert the local community to this special stream and its history. Publicity should aim to minimise future adverse impacts on the stream as a result of increasing urbanisation and to encourage the formation of a stream care group or other community awareness activities.

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Appendix 1

NUTRIENT CONCENTRATIONS IN WHANGAMATA STREAM, 1995–2008

Duplicate samples were taken from the Top and Bottom Sites on all sampling dates. Left Hand Tributary and Right Hand Spring samples were collected on most, but not all, sampling dates. DRP = dissolved reactive phosphorus; TDP = total dissolved phosphorus, DOP = dissolved organic phosphorus; PP = particulate phosphorus; TP = total phosphorus; NH_4-N = ammonium nitrogen; NO_3-N = nitrate nitrogen; TDN = total dissolved nitrogen; DON = dissolved organic nitrogen; PN = particulate nitrogen; TN = total nitrogen; SS = suspended solids. Data for PP, PN and TP and TN begin on 7 October 2003. ND = not detectable.

DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
3-May-95	Top	66.5	70.2	3.8			2.8	931	1035	101			1.88	0.035	11.2
	Top	33.8	72.5	38.7			6.1	936	1036	94			1.33		
	Bottom	66.0	73.6	7.6			8.3	868	1008	132			7.28	0.043	13.0
	Bottom	66.5	77.1	10.7			7.6	867	995	121			7.06		
	LH Tributary	54.5	57.3	2.8			6.4	750	868	111					
	RH Spring	78.1	76.0	ND			0.5	1053	1106	53					
27-Jun-95	Top	75.9	83.8	8.0			8.3	1064	1180	107			4.61	0.051	10.3
	Top	74.1	82.0	7.8			4.0	1035	1264	225			4.45		
	Bottom	72.2	77.9	5.7			8.5	996	1163	159			8.87	0.052	11.0
	Bottom	64.4	68.4	4.0			11.8	971	1284	301			9.68		
	LH Tributary	63.7	68.7	5.0			10.1	1004	1163	149					
	RH Spring	81.5	88.0	6.5			3.7	1114	1215	97					
31-Jul-95	Top	66.4	72.0	5.6			9.0	1117	1233	107			7.30	0.057	
	Top	68.2	70.3	2.1			8.9	1059	1203	135			10.19		
	Bottom	67.4	69.3	1.8			10.3	1037	1170	122			11.69	0.061	
	Bottom	59.6	68.2	8.5			10.1	1043	1198	145			10.63		
	LH Tributary	55.9	64.2	8.2			12.2	1058	1178	107					
	RH Spring	78.8	81.4	2.6			4.1	1129	1221	88					
19-Oct-95	Top	70.1	70.6	0.5			10.2	1115	1181	57			16.02	0.097	11.5
	Top	69.8	70.0	0.2			9.3	1111	1217	97			14.82		
	Bottom	68.1	68.2	0.1			10.8	1061	1167	96			18.11	0.098	12.2
	Bottom	69.0	69.7	0.7			10.9	1070	1164	82			16.62		
	RH Spring	81.0	82.3	1.3			5.9	1017	1121	99			3.30		
	LH Tributary	64.6	65.5	0.9			11.2	1147	1272	113			20.32		

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DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
19-Dec-95	Top	58.7	61.1	2.4			9.8	1060	1165	95			0.91	0.094	11.3
	Top	58.1	59.5	1.4			6.0	1067	1190	118			1.57		
	Bottom	49.3	51.3	2.0			9.3	932	1033	91			0.58	0.107	13.0
	Bottom	50.4	51.2	0.8			16.4	932	1033	85			0.69		
27-Feb-96	Top	59.0	59.0	ND			14.1	1073	1177	90			0.76	0.105	11.0
	Top	60.3	59.6	ND			7.3	1079	1174	87			1.01		
	Bottom	41.5	43.1	1.5			6.4	878	994	110			0.14		11.0
	Bottom	40.9	42.3	1.4			6.8	884	1002	111			0.13		
23-Apr-96	Top	63.0	63.0	ND			8.0	1206	1337	123			2.26	0.107	10.2
	Top	63.0	64.0	1.0			7.0	1216	1358	135			2.23		
	Bottom	66.0	68.0	2.0			11.0	1189	1384	184			8.86	0.121	11.0
	Bottom	65.0	67.0	2.0			10.0	1192	1410	208			8.30		
	RH Spring	80.0	81.0	1.0			7.0	1103	1274	164			2.03		
	LH Tributary	58.0	59.0	1.0			10.0	1290	1464	164			3.18		
25-Jun-96	Top	67.0	68.0	1.0			12.0	1310	1487	165			25.05	0.113	10.5
	Top	67.0	68.0	1.0			8.0	1312	1475	155			23.71		
	Bottom	67.0	69.0	2.0			14.0	1280	1403	109			38.19	0.114	11.0
	Bottom	67.0	70.0	3.0			13.0	1291	1465	161			40.77		
20-Aug-96	Top	68.7	71.6	2.9			6.3	1307	1350	37			53.9	0.135	
	Top	70.6	72.8	2.2			4.9	1318	1361	38			63.0		
	Bottom	62.0	66.1	4.1			2.3	1271	1310	37			72.8	0.153	
	Bottom	64.8	68.5	3.7			7.7	1281	1361	72			80.4		
5-Nov-96	Top	58.2	62.4	4.2			4.4	1380	1457	73			13.7	0.185	11.3
	Top	57.1	61.8	4.7			2.8	1374	1411	34			15.8		
	Bottom	56.0	65.5	9.5			4.9	1337	1405	63			25.4	0.197	12.1
	Bottom	54.4	64.9	10.5			9.9	1345	1412	57			24.5		
18-Dec-96	Top	61.8	62.9	1.0			6.5	1236	1367	124			2.8	0.195	11.0
	Top	62.8	62.9	0.1			6.5	1236	1354	111			3.0		
	Bottom	62.2	62.6	0.4			6.9	1191	1365	168			14.1	0.206	11.9
	Bottom	62.6	62.6	ND			7.5	1192	1335	136			16.0		
21-Feb-97	Top	63.2	63.4	0.2			7.2	1195	1352	150			4.1	0.172	
	Top	62.7	63.4	0.7			8.4	1191	1363	164			3.3		
	Bottom	60.4	61.4	1.1			6.0	1153	1310	150			5.5	0.172	
	Bottom	59.9	60.8	0.9			6.3	1164	1315	145			4.9		
2-May-97	Top	70.4	70.6	0.3			10.9	1256	1385	117			10.5	0.173	10.2
	Top	70.5	70.6	0.1			9.1	1273	1416	133			10.7		
	Bottom	68.1	68.0	ND			8.7	1231	1372	131			9.6	0.175	10.4
	Bottom	69.0	69.6	0.6			11.6	1224	1378	142			9.1		
	LH Tributary	82.8	82.7	ND			4.0	1016	1165	145			13.5		
	RH Spring	66.2	67.0	0.8			10.9	1346	1505	148			2.6		
30-Jun-97	Top	73.5	74.0	0.4			17.4	1284	1439	137			23.1	0.129	10.0
	Top	73.0	73.7	0.7			15.9	1296	1450	138			22.8		

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DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
	Bottom	73.6	73.7	0.1			14.2	1281	1414	119			23.9	0.158	9.7
	Bottom	72.6	73.7	1.2			14.2	1277	1430	139			23.3		
25-Aug-97	Top	70.2	72.8	2.6			20.9	1308	1390	61				0.13	10.3
	Top	70.9	72.6	1.7			21.2	1330	1419	68			45.17		
	Bottom	69.9	71.7	1.8			24.0	1273	1373	76			38.48	0.142	10.2
	Bottom	71.3	72.6	1.3			19.5	1294	1371	58			35.92		
	RH Spring	78.8	80.4	1.6			6.9	1094	1142	41			4.24		
	LH Tributary	66.6	68.1	1.5			30.9	1355	1451	65			37.29		
21-Oct-97	Top	65.4	66.4	1.0			15.6	1254	1323	53			10.22	0.133	10.6
	Top	64.8	65.9	1.1			13.4	1243	1339	83			14.99		
	Bottom	62.4	66.2	3.8			19.2	1140	1234	75			25.55	0.159*	10.9
	Bottom	61.3	66.1	4.8			13.2	1179	1207	15			23.61		
12-Dec-97	Top	63.7	69.2	5.5			10.8	1203	1249	35			3.71	0.123	12.1
	Top	63.7	66.1	2.4			10.9	1208	1259	40			2.70		
	Bottom	60.0	61.8	1.8			9.4	1125	1167	33			2.24	0.154	12.8
	Bottom	58.6	61.9	3.3			58.6	1143	1180	ND			2.26		
16-Feb-98	Top	61.1	63.8	2.7			9.9	1148	1223	65			1.36	0.105	
	Top	60.8	60.9	0.1			6.3	1167	1220	47					
	Bottom	61.6	62.7	1.1			7.0	1133	1180	40			7.76	0.104	
	Bottom	62.5	62.9	0.4			7.7	1136	1167	23			8.33		
17-Apr-98	Top	67.0	71.0	4.0			11.0	1272	1241	ND			5.76	0.108	10.6
	Top	71.0	73.0	2.0			10.7	1271	1273	ND			5.52		
	Bottom	69.0	72.0	3.0			11.3	1241	1219	ND			12.75	0.105	10.8
	Bottom	73.0	73.0	ND			10.4	1251	1193	ND			11.67		
20-May-98	Top	74.5	75.2	0.7			15.2	1276	1304	ND			13.99	0.12	10.0
	Top	74.9	77.1	2.2			14.5	1219	1406	173			14.92		
	Bottom	74.5	75.7	1.2			15.2	1214	1207	ND			17.17	0.119	10.0
	Bottom	73.5	76.1	2.6			15.8	1188	1156	ND			18.89		
	LH Tributary	70.2	72.3	2.1			20.2	1298	1336	18			18.12		
	RH Spring	88.3	88.5	0.2			6.2	1106	1078	ND			3.98		
29-Mar-99	Top	66.6	66.8	0.2			9.6	1002	1397	385			2.86	0.166	12.7
	Top	67.7	67.7	ND			7.0	1002	1347	338			2.88		
	Bottom	63.8	66.3	2.5			9.5	975	1292	308			11.95	0.151	12.6
	Bottom	65.7	66.0	0.3			7.7	975	1295	312			10.24		
8-Jun-99	Top	72.4	74.1	1.7			17.2	1055	1394	322			13.1	0.144	10.7
	Top	72.3	72.3	ND			13.8	1055	1380	311			12.95		
	Bottom	71.8	72.6	0.8			12.8	1028	1370	329			17.04	0.144	10.6
	Bottom	72.4	73.0	0.6			13.4	1041	1376	322			16.83		
10-Aug-99	Top	70.1	71.7	1.6			12.1	1402	1449	35			19.81	0.138	10.0
	Top	68.6	70.8	2.2			11.8	1400	1438	26			21.66		
	Bottom	68.6	70.7	2.1			14.0	1383	1412	15			26.18	0.14	10.1
	Bottom	70.1	71.1	1.0			12.8	1383	1431	35			28.83		

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DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
	LH Tributary	65.6	67.7	2.1			15.1	1491	1533	27			31.63		
	RH Spring	80.6	82.3	1.7			7.3	1179	1203	17			1.345		
22-Feb-00	Top	56.7	59.6	2.9			6.8	1213	1242	22			2.17	0.116	11.6
	Top	56.7	57.2	0.5			7.8	1112	1152	32			2.23		
	Bottom	53.7	55.3	1.6			8.6	1121	1152	22			10.58	0.09	12.4
	Bottom	53.7	55.5	1.8			8.8	1112	1162	41			11.13		
17-Aug-00	Top	73	77	4.0			21	1270	1350	59			17.56	0.092	10.2
	Top	73	78	5.0			20	1300	1390	70			17.36		
	Bottom	73	79	6.0			20	1250	1350	80			20.99	0.098	10.2
	Bottom	74	81	7.0			22	1240	1370	108			20.35		
	LH Tributary	68	73	5.0			25	1360	1510	125			18.65		
	RH Spring	80	87	7.0			9	1120	1200	71			6.24		
27-Nov-00	Top	65	71	6.0			15	1120	1200	65			3.18	0.091	11.6
	Top	64	70	6.0			15	1120	1200	65			3.59		
	Bottom	61	68	7.0			12	1040	1110	58			6.65	0.08	12.4
	Bottom	61	69	8.0			12	1030	1110	68			6.36		
	LH Tributary	61	68	7.0			22	1160	1260	78			4.33		
	RH Spring	70	77	7.0			5	1050	1090	35			2.52		
13-Feb-01	Top	66	75	9.0			11	1120	1220	89			0.97	0.072	13.0
	Top	67	71	4.0			10	1120	1210	80			1.25		
	Bottom	60	67	7.0			10	1000	1130	120			3.2	0.082	12.4
	Bottom	59	65	6.0			10	1010	1140	120			3.24		
	LH Tributary	61	68	7.0			14	1160	1270	96			1.31	0.038	
	RH Spring	73	76	3.0			7	1110	1160	43			0.89	0.034	
5-Apr-01	Top	69	74	5.0			8	1150	1200	42			4.91	0.063	11.0
	Top	71	78	7.0			8	1140	1230	82			8.23		
	Bottom	70	77	7.0			10	1050	1130	70			5.6		11.2
	Bottom	70	76	6.0			10	1060	1110	40			3.19		
	LH Tributary	62	70	8.0			8	1140	1220	72			17.37		
	RH Spring	77	80	3.0			5	1100	1160	55			11.66		
5-Jun-01	Top	78.0	77.0	ND			10.0	1180	1330	140			8.67	0.067	9.4
	Top	79.0	79.0	ND			10.0	1270	1310	30			8.4		
	Bottom	80.0	84.0	4.0			14.0	1230	1260	16			14.24	0.056	8.5
	Bottom	78.0	79.0	1.0			12.0	1230	1300	58			14.77		
	LH Tributary	72.0	77.0	5.0			23.0	1340	1410	47			10.6		
	RH Spring	88.0	90.0	2.0			6.0	1230	1250	14			2.97		
17-Sep-01	Top	77.0	75.0	ND			20.0	1260					23.98	0.051	11.2
	Top	80.0	77.0	ND			21.0	1240					18.81		
	Bottom	80.0	80.0	ND			28.0	1250					35.11	0.055	11.8
	Bottom	80.0	80.0	ND			28.0	1300					33.1		
	LH Tributary	73.0	74.0	1.0			34.0	1380					32.5		
	RH Spring	81.0	80.0	ND			8.0	1380					11.62		

Continued on next page

DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
27-Nov-01	Top	71.0	71.0	ND			12.0	1270					3.93	0.048	11.3
	Top	71.0	70.0	ND			12.0	1270					3.97		
	Bottom	68.0	70.0	ND			13.0	1200					5.68	0.044	12.1
	Bottom	68.0	70.0	2.0			12.0	1200					5.24		
	LH Tributary	64.0	65.0	1.0			18.0	1230					5.86		
	RH Spring	74.0	74.0	ND			8.0	986					4.55		
22-Feb-02	Top	65	67.0	2.0			6	943	1000	51			0.78	0.04	11.5
	Top	66	69.0	3.0			6	943	992	43			0.77		
	Bottom	56	62.0	6.0			6	749	821	66			0.68	0.046	12.4
	Bottom	57	62.0	5.0			8	756	838	74			0.76		
	LH Tributary	50	54.0	4.0			7	719	816	90			0.45		
	RH Spring	74	73.0	ND			5	1070	1090	15			0.79		
9-May-02	Top	80	82.0	2.0			8	1030	1100	62			3.14	0.041	10.8
	Top	80	82.0	2.0			8	1050	1070	12			3.04		
	Bottom	73	75.0	2.0			27	998	1080	55			196.6*	0.039	11.0
	Bottom	74	79.0	5.0			25	1020	1110	65			191.1*		
	LH Tributary	69	71.0	2.0			11	863	916	42			1.21		
	RH Spring	84	84.0	ND			7	1140	1160	13			3.59		
2-Sep-02	Top	73.0	74.0	1.0			4.0	1080	1120	36			5.52	0.05	10.5
	Top	73.0	74.0	1.0			8.0	1070	1140	62			6.07		
	Bottom	74.0	76.0	2.0			16.0	1030	1120	74			12.95	0.039	9.8
	Bottom	73.0	78.0	5.0			15.0	1040	1110	55			12.68		
	LH Tributary	59.0	62.0	3.0			7.0	989	1070	74			11.94	0.017	9.5
	RH Spring	81.0	83.0	2.0			7.0	1140	1180	33			4.0	0.033	11.2
22-Oct-02	Top	70.0	71.0	1.0			8.0	964	1050	78			3.21	0.045	11.8
	Top	70.0	73.0	3.0			8.0	962	1020	50			3.71		
	Bottom	72.0	79.0	7.0			22.0	916	1010	72			15.83	0.04	13.7
	Bottom	72.0	76.0	4.0			22.0	915	1020	83			15.62		
	LH Tributary	57.0	61.0	4.0			10.0	769	849	70			8.13		12.1
	RH Spring	76.0	79.0	3.0			7.0	1060	1100	33			3.57		11.7
19-Dec-02	Top	64.0	70.0	6.0			9.0	895	1000	96			1.91	0.046	12.0
	Top	64.0	68.0	4.0			10.0	895	1010	105			2.4		
	Bottom	58.0	66.0	8.0			10.0	782	892	100			3.1	0.039	14.0
	Bottom	59.0	67.0	8.0			10.0	764	876	102			3.07		
	LH Tributary	49.0	59.0	10.0			20.0	641	970	309			0.84		
	RH Spring	72.0	78.0	6.0			7.0	1020	1150	123			3.65		
6-Mar-03	Top	71.0	74.0	3.0			5.0	964	978	9			0.91	0.031	11.4
	Top	70.0	75.0	5.0			3.0	961	971	7			0.91		
	Bottom	44.0	44.0	ND			5.0	696	745	44			0.24	0.025	11.9
	Bottom	43.0	44.0	1.0			1.0	680	729	48			0.21		
	LH Tributary	56.0	56.0	ND			ND	567	616	49			0.36		
	RH Spring	72.0	72.0	ND			3.0	1060	1080	17			1.19		

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Appendix 1—continued

DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
1-May-03	Top	79.0	84.0	5.0			2.0	1010	1060	48			1.12	0.03	10.9
	Top	80.0	84.0	4.0			3.0	1010	1060	47			1.11		
	Bottom	89.0	97.0	8.0			6.0	974	1050	70			0.93	0.031	10.4
	Bottom	89.0	98.0	9.0			6.0	974	1050	70			0.85		
	LH Tributary	67.0	74.0	7.0			4.0	663	722	55			0.37		
	RH Spring	80.0	86.0	6.0			1.0	1090	1120	29			1.18		
10-Jun-03	Top	82	86	4.0			10	1020	1070	40			5.39	0.036	10.5
	Top	82	86	4.0			10	1020	1060	30			4.42		
	Bottom	85	90	5.0			18	962	1040	60			12.38	0.031	10.0
	Bottom	84	91	7.0			16	958	1040	66			13.87		
	LH Tributary	71	75	4.0			11	648	733	74			3.67		
	RH Spring	86	90	4.0			9	1120	1150	21			3.68		
7-Oct-03	Top	75	79	4.0	7.0	86	12	1040	1080	28	53.75	1134	6.35	0.035	11.8
	Top	74	80	6.0	7.2	87	14	1040	1090	36	52.6	1143	5.77		
	Bottom	72	82	10.0	18.1	100	27	997	1100	76	125.5	1226	13.69	0.037	10.9
	Bottom	74	81	7.0	17.8	99	28	1000	1110	82	127	1237	13.46		
	LH Tributary	66	72	6.0	9.7	82	16	736	834	82	63.1	897	5.92		
	RH Spring	79	84	5.0	6.1	90	11	1150	1200	39	46.8	1247	5.84		
18-Nov-03	Top	69	74	5.0	4.1	78	6	980	1010	24	35	1045	3.00	0.03	12.0
	Top	68	74	6.0	4.1	78	4	981	1020	35	37.4	1057	3.58		
	Bottom	68	74	6.0	18.7	93	17	915	970	38	153	1123	12.61	0.029	13.9
	Bottom	69	75	6.0	20.1	95	17	917	935	1	156.5	1092	13.78		
	LH Tributary	64	71	7.0	11.1	82	5	668	713	40	87.4	800	8.18		
	RH Spring	67	75	8.0	3.6	79	7	1040	1080	33	25.6	1106	3.96		
22-Jan-04	Top	69.0	71.0	2.0	2.5	73	5.0	946	994	43	25.7	1020	1.83	0.034	12.1
	Top	69.0	72.0	3.0	2.1	74	3.0	944	993	46	17.9	1011	1.56		
	Bottom	44.0	49.0	5.0	2.7	52	8.0	642	719	69	15.8	735	1.06	0.024	14.4
	Bottom	45.0	48.0	3.0	2.6	51	7.0	642	720	71	16.4	736	1.22		
	LH Tributary	62.0	64.0	2.0	3.6	68	8.0	605	648	35	24.3	672	1.85		
	RH Spring	71.0	71.0	ND	1.7	73	5.0	1030	1100	65	14.8	1115	1.32		
29-Apr-04	Top	85.0	94.0	9.0	2.4	96	4.0	998	1040	38	20.4	1060	1.34	0.033	11.2
	Top	84.0	93.0	9.0	2.3	95	3.0	993	1030	34	24.2	1054	1.34		
	Bottom	83.0	94.0	11.0	5.4	99	7.0	809	900	84	38.45	938	2.91	0.032	11.8
	Bottom	84.0	96.0	12.0	5.5	101	7.0	807	892	78	40	932	2.67		
	LH Tributary	62.0	71.0	9.0	4.0	75	6.0	499	580	75	29.0	609	1.37		
	RH Spring	89.0	95.0	6.0	5.8	101	3.0	1110	1150	37	38.9	1189	0.62		
22-Jun-04	Top	74.0	78.0	4.0	7.7	86	11.0	1060	1210	139	57.5	1267	6.01	0.046	10.3
	Top	73.0	79.0	6.0	7.5	86	12.0	1070	1210	128	57.2	1267	5.86		
	Bottom	76.0	83.0	7.0	14.5	97	17.0	964	1150	169	95.8	1246	9.08	0.06	9.3
	Bottom	75.0	84.0	9.0	14	98	15.0	970	1140	155	91.05	1231	9.17		
	LH Tributary	54.0	61.0	7.0	9.9	71	17.0	965	1200	218	68.3	1268	5.92		
	RH Spring	87.0	91.0	4.0	4.3	95	6.0	1140	1220	74	39.8	1260	4.13		

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DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
9-Sep-04	Top	71.0	78.0	7.0	9.3	87	13.0	1120	1180	47	68.1	1248	8.29		10.6
	Top	71.0	76.0	5.0	10.6	87	10.0	1130	1170	30	66.1	1236	8.92		
	Bottom	71.0	78.0	7.0	21.6	100	22.0	1100	1250	128	145	1395	16.32		10.8
	Bottom	72.0	76.0	4.0	23.7	100	21.0	1090	1240	129	162	1402	17.28		
	LH Tributary	59.0	65.0	6.0	19.8	85	13.0	1110	1250	127	123.5	1374	7.65		
	RH Spring	81.0	86.0	5.0	3.4	89	11.0	1130	1180	39	30.9	1211	1.61		
25-Nov-04	Top	62.0	64.0	2.0	8.7	73	7.0	1070	1090	13	69.9	1160	9.94	0.056	12.1
	Top	62.0	65.0	3.0	6.9	72	7.0	1070	1090	13	48.9	1139	9.21		
	Bottom	54.0	58.0	4.0	5.2	63	7.0	955	985	23	37.1	1022	3.63	0.074	11.7
	Bottom	54.0	58.0	4.0	5.3	63	7.0	950	989	32	37.2	1026	3.33		
	LH Tributary	54.0	58.0	4.0	11.2	69	14.0	1080	1140	46	81.1	1221	13.97		
	RH Spring	73.0	74.0	1.0	1.8	76	6.0	1070	1070	ND	16	1086	1.79		
3-Mar-05	Top	55.0	68.0	13.0	1.4	69	4.0	1170	1230	56	11.5	1242	0.77	0.077	11.3
	Top	62.0	68.0	6.0	1.6	70	5.0	1170	1220	45	15	1235	0.68		
	Bottom	44.0	58.0	14.0	2.9	61	4.0	985	1050	61	22.6	1073	1.53	0.084	12.3
	Bottom	48.0	57.0	9.0	3.1	60	4.0	984	1070	82	24.9	1095	1.41		
	LH Tributary	54.0	62.0	8.0	1.8	64	5.0	1210	1300	85	17.1	1317	1.14		
	RH Spring	67.0	79.0	12.0	1.1	80	3.0	1100	1140	37	13.7	1154	0.84		
10-May-05	Top	75.0	77.0	2.0	6.4	83	5.0	1320	1370	45	48.8	1419	4.65	0.06	9.5
	Top	75.0	78.0	3.0	6.5	85	5.0	1320	1380	55	50.4	1430	4.50		
	Bottom	76.0	81.0	5.0	11.2	92	10.0	1270	1310	30	94.8	1405	9.32	0.059	8.2
	Bottom	76.0	80.0	4.0	11.5	92	10.0	1280	1320	30	95	1415	9.02		
	LH Tributary	67.0	70.0	3.0	8.7	79	5.0	1430	1460	25	68.2	1528	4.96		
	RH Spring	84.0	87.0	3.0	2.6	90	5.0	1190	1200	5	28	1228	2.42		
23-Jun-05	Top	72.0	84.0	12.0	19.5	104	10.0	1320	1380	50	146	1526	13.10	0.063	9.8
	Top	76.0	87.0	11.0	20.8	108	10.0	1320	1370	40	158	1528	14.54		
	Bottom	80.0	88.0	8.0	32.5	121	17.0	1280	1350	53	264	1614	23.36	0.06	9.8
	Bottom	78.0	92.0	14.0	30.7	123	18.0	1270	1360	72	241	1601	23.50		
	LH Tributary	68.0	77.0	9.0	34.2	111	13.0	1420	1470	37	170	1640	22.11		
	RH Spring	88.0	94.0	6.0	4.2	98	6.0	1200	1220	14	35.8	1256	5.10		
21-Sep-05	Top	71.0	77.0	6.0	16.2	93	16.0	1290	1380	74	143	1523	19.64	0.065	9.7
	Top	73.0	80.0	7.0	17.1	97	17.0	1290	1360	53	136	1496	19.23		
	Bottom	74.0	80.0	6.0	33.9	114	28.0	1260	1380	92	261	1641	36.18	0.067	9.2
	Bottom	75.0	80.0	5.0	36.3	116	27.0	1260	1350	63	294	1644	33.19		
	LH Tributary	67.0	74.0	7.0	28.7	103	22.0	1390	1480	68	230	1710	25.54	0.043	
	RH Spring	84.0	86.0	2.0	6.2	92	12.0	1170	1220	38	49.3	1269	11.33		
7-Dec-05	Top	61.0	66.0	5.0	2.3	68	6.0	1120	1200	74	24.7	1225	1.84	0.062	11.7
	Top	62.0	68.0	6.0	2.5	71	7.0	1120	1190	63	28.2	1218	2.12		
	Bottom	53.0	59.0	6.0	4.9	64	6.0	968	1120	146	44.1	1164	3.45	0.066	13.4
	Bottom	54.0	59.0	5.0	5.6	65	7.0	969	1040	64	43.2	1083	3.07		
	LH Tributary	54.0	60.0	6.0	3.3	63	7.0	1140	1220	73	30	1250	2.30		
	RH Spring	71.0	76.0	5.0	1.6	78	5.0	1100	1160	55	22.9	1183	1.95		

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DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
9-Feb-06	Top	64.0	65.0	1.0	1.6	67	5.0	1160	1180	15	18.2	1198	0.81	0.063	10.6
	Top	61.0	65.0	4.0	1.4	66	4.0	1160	1180	16	13.7	1194	0.72		
	Bottom	51.0	57.0	6.0	1.8	59	4.0	1000	1040	36	14.5	1055	0.67	0.053	10.8
	Bottom	44.0	57.0	13.0	1.9	59	4.0	999	1020	17	16.1	1036	0.67		
	LH Tributary	54.0	56.0	2.0	3.1	59	6.0	1190	1200	4	24.5	1225	0.54		
	RH Spring	75.0	78.0	3.0	1.2	79	2.0	1130	1130	ND	17.4	1147	0.39		
20-Apr-06	Top	68.0	73.0	5.0	2.3	75	5.0	1250	1290	35	26.6	1317	1.44	0.069	10.3
	Top	69.0	74.0	5.0	2.8	77	6.0	1250	1310	54	27.6	1338	1.46		
	Bottom	64.0	72.0	8.0	2.5	75	6.0	1140	1210	64	20.4	1230	0.95	0.059	9.7
	Bottom	65.0	72.0	7.0	2.4	74	4.0	1140	1220	76	21	1241	0.88		
	LH Tributary	59.0	65.0	6.0	4.7	70	7.0	1320	1390	63	40.9	1431	2.67		
	RH Spring	79.0	84.0	5.0	1.7	86	4.0	1170	1200	26	22.9	1223	1.19		
20-Jun-06	Top	74.0	78.0	4.0	11.8	90	10.0	1330	1330	ND	98.8	1429	10.27	0.077	8.7
	Top	74.0	76.0	2.0	12.4	88	11.0	1330	1410	69	107	1517	9.54		
	Bottom	77.0	79.0	2.0	19.4	98	19.0	1290	1360	51	161	1521	12.56	0.08	8.0
	Bottom	77.0	81.0	4.0	18.8	100	19.0	1290	1330	21	146	1476	13.47		
	LH Tributary	65.0	68.0	3.0	21.2	89	14.0	1410	1470	46	171	1641	15.78		
	RH Spring	86.0	87.0	1.0	2.1	89	5.0	1200	1210	5	32.7	1243	2.43		
5-Sep-06	Top	68	72	4.0	20.3	92	12	1480	1480	ND	150	1630	19.92	0.095	10.6
	Top	69	74	5.0	19.0	93	12	1480	1460	ND	152	1612	18.10		
	Bottom	70	75	5.0	34.9	110	24	1460	1470	ND	262	1732	42.93	0.081	10.3
	Bottom	70	76	6.0	35.3	111	22	1460	1450	ND	263	1713	41.44		
	LH Tributary	63	68	5.0	35.8	104	14	1580	1560	ND	260	1820	43.63		
	RH Spring	80	83	3.0	2.8	86	10	1260	1250	ND	27.4	1277	2.13		
11-Dec-06	Top	60	65	5.0	3.9	69	5	1440	1400	ND	32.0	1432	3.08	0.1	11.4
	Top	60	66	6.0	4.1	70	5	1430	1410	ND	33.8	1444	2.87		
	Bottom	55	61	6.0	10.5	72	7	1340	1360	13	81.2	1441	10.81	0.092	11.8
	Bottom	56	61	5.0	9.3	70	7	1330	1350	13	74.1	1424	9.19		
	LH Tributary	56	61	5.0	5.6	67	5	1540	1550	5	50.6	1601	3.79		
	RH Spring	70	73	3.0	2.1	75	3	1160	1170	7	23.3	1193	2.03		
27-Feb-07	Top	65	64	ND	3.7	68	1	1360	1360	ND	33.0	1393	1.91	0.101	11.0
	Top	67	66	ND	3.9	70	2	1360	1360	ND	29.8	1390	2.08		
	Bottom	54	56	2.0	2.7	59	3	1230	1270	37	19.6	1290	1.65	0.087	11.7
	Bottom	55	56	1.0	3.5	60	4	1240	1290	46	24.3	1314	1.43		
	LH Tributary	60	59	ND	5.3	64	5	1470	1550	75	38.7	1589	3.69		
	RH Spring	77	78	1.0	1.6	80	3	1160	1310	147	11.8	1322	0.72		
1-May-07	Top	74.0	81.0	7.0	12.1	93	11.0	1440	1520	69	102	1622	7.56	0.098	11.1
	Top	72.0	80.0	8.0	12.4	92	10.0	1440	1600	150	104	1704	8.01		
	Bottom	78.0	87.0	9.0	13.1	100	12.0	1370	1460	78	99.8	1560	7.18		11.6
	Bottom	77.0	88.0	11.0	13.9	102	12.0	1380	1450	58	107	1557	7.54		
	LH Tributary	64.0	72.0	8.0	17.3	89	12.0	1540	1610	58	124	1734	12.2		
	RH Spring	91.0	99.0	8.0	2.3	101	4.0	1230	1270	36	32.5	1303	1.37		

Continued on next page

Appendix 1—continued

DATE COLLECTED	SAMPLE	DRP mg/m^3	TDP mg/m^3	DOP mg/m^3	PP mg/m^3	TP mg/m^3	NH_4-N mg/m^3	NO_3-N mg/m^3	TDN mg/m^3	DON mg/m^3	PN mg/m^3	TN mg/m^3	SS g/m^3	FLOW m^3/s	TEMP °C
20-Jun-07	Top	75.0	75.0	ND	14.1	89	12.0	1530	1530	ND	111	1641	11.29	0.098	8.3
	Top	75.0	75.0	ND	18.2	93	12.0	1530	1540	ND	120	1660	10.59		
	Bottom	74.0	76.0	2.0	27.6	104	15.0	1500	1500	ND	199	1699	24.75	0.103	7.2
	Bottom	75.0	78.0	3.0	24.5	103	14.0	1500	1500	ND	174	1674	20.76		
	LH Tributary	67.0	86.0	19.0	24.5	111	14.0	1650	1630	ND	186	1816	17.71		
	RH Spring	87.0	91.0	4.0	3.1	94	5.0	1290	1290	ND	42.1	1332	2.59		
9-Nov-07	Top	69.0	67.0	ND	5.9	73	6.0	1380	1360	ND	43.4	1403	4.88	0.08	10.4
	Top	69.0	67.0	ND	5.2	72	6.0	1370	1350	ND	10.8	1361	4.8		
	Bottom	68.0	68.0	ND	12.8	81	10.0	1300	1320	10	104	1424	13.57	0.063	11.9
	Bottom	67.0	68.0	1.0	13.3	81	8.0	1300	1310	2	100	1410	13.18		
	LH Tributary	62.0	62.0	ND	9.7	72	6.0	1490	1460	ND	64.2	1524	7.33		
	RH Spring	77.0	76.0	ND	2.2	78	3.0	1160	1170	7	25.9	1196	1.39		
20-Dec-07	Top	70.0	71.0	1.0	5.1	76	8.0	1300	1350	42	31.6	1382	3.51	0.085	11.7
	Top	69.0	70.0	1.0	5.5	76	8.0	1300	1360	52	35.5	1396	3.18		
	Bottom	68.0	71.0	3.0	10.5	82	9.0	1200	1390	181	93.5	1484	10.12	0.066	12.5
	Bottom	69.0	70.0	1.0	9.6	80	11.0	1200	1280	69	72.7	1353	8.54		
	LH Tributary	64.0	66.0	2.0	6.2	72	13.0	1380	1430	37	41.6	1472	3.43		
	RH Spring	79.0	77.0	ND	2.5	80	4.0	1170	1180	6	17.7	1198	1.40		
24-Jan-08	Top	67.0	65.0	ND	3.5	69	7.0	1290	1310	13	27.4	1337	1.38	0.066	11.1
	Top	66.0	65.0	ND	3.1	68	6.0	1290	1340	44	23.4	1363	1.35		
	Bottom	59.0	59.0	ND	5.5	65	6.0	1170	1300	124	41.1	1341	5.07	0.069	12.3
	Bottom	59.0	61.0	2.0	6	67	5.0	1170	1200	25	44	1244	4.85		
	LH Tributary	59.0	59.0	ND	5.7	65	6.0	1390	1400	4	38	1438	2.23		
	RH Spring	75.0	70.0	ND	9.3	79	2.0	1170	1180	8	15.5	1196	0.65		
10-Apr-08	Top	68.0	69.0	1.0	3.2	72	5.0	1280	1280	ND	32.6	1313	2.07	0.059	9.9
	Top	69.0	70.0	1.0	3.3	73	4.0	1270	1280	6	33.3	1313	1.96		
	Bottom	64.0	65.0	1.0	5	70	7.0	1170	1170	ND	55.5	1226	3.99	0.053	9.3
	Bottom	64.0	66.0	2.0	4.8	71	7.0	1170	1170	ND	43.4	1213	3.47		
	LH Tributary	58.0	61.0	3.0	1	62	4.0	1360	1360	ND	19.5	1380	6.09		
	RH Spring	78.0	78.0	ND	18.6	97	4.0	1220	1220	ND	156	1376	0.84		
4-Jun-08	Top	75.0	79.0	4.0	6.6	86	5.0	1320	1350	25	57.9	1408	5.29	0.057	9.4
	Top	77.0	79.0	2.0	7.2	86	6.0	1320	1350	24	62.7	1413	6.03		
	Bottom	77.0	80.0	3.0	14.2	94	8.0	1300	1300	ND	115	1415	10.75	0.053	8.8
	Bottom	76.0	81.0	5.0	14.3	95	9.0	1290	1320	21	119	1439	10.44		
	LH Tributary	68.0	70.0	2.0	11.1	81	7.0	1440	1460	13	89.9	1550	7.67		
	RH Spring	84.0	86.0	2.0	2.6	89	4.0	1280	1300	16	30.3	1330	2.32		

* SS Sample taken when hand-weeding for musk (*Mimulus guttatus*) control occurred above the sample point.

Appendix 2

VASCULAR PLANTS OF THE WHANGAMATA STREAM, MARCH 2008

Taken from Wildland Consultants Ltd (2008).

Grid reference: NZMS260 T17 649806.

Key (species superscripts)

1 = New record 1993

2 = New record 1998

3 = New record 2003

4 = New record 2008

5 = Name reviewed in 2008 from 2003 survey

(p) = planted

(pn) = natural and planted

Percentage cover class abundance scale (from Allen 1992):

1 = < 1%

2 = 1–5%

3 = 6–25%

4 = 26–50%

5 = 51–75%

6 = 76–100%

Survey Areas A–G equate to Sections A–G (Fig. 1).

VASCULAR PLANTS	COVER CLASS ABUNDANCE SURVEY AREA						
	A	B	C	D	E	F	G
INDIGENOUS							
Gymnosperms							
Dacrycarpus dacrydioides[1]			1(p)	2(p)			1(p)
Monocot. trees and shrubs							
Cordyline australis[pn]	2(p)	2(p)	1(p)	2(p)	1(p)	2(p)	1(p)
Phormium tenax[pn]	3(p)	2(p)	2(p)	3(p)	2(p)	2(p)	3(p)
Dicot. trees and shrubs							
Aristotelia serrata[3]				1			
Brachyglottis repanda var. *repanda*[1]	2	1		1			
Coprosma propinqua subsp. *propinqua*[3]							1(p)
Coprosma propinqua subsp. *propinqua* x *Coprosma robusta*[3]		1				1(p)	1(p)
Coprosma robusta	1	1	1	1		1	1
Coriaria arborea	1	1		1			
Fuchsia excorticata	2						
Gaultheria antipoda[2]		1					
Geniostoma rupestre var. *ligustrifolium*[2]	1			1			
Griselinia littoralis[1]	1(p)						
Hebe stricta[1]	2(p)	2(p)	1(p)	2(p)		1(p)	1(p)
Kunzea ericoides var. *ericoides*[1]	1(p)	1(p)	1(p)		1(p)	2(p)	2(p)
Leptospermum scoparium						1(p)	1(p)
Leucopogon fasciculatus[3]	1						1(p)
Leucopogon fraseri[1]	1	1					
Melicytus ramiflorus subsp. *ramiflorus*[1]	1			1			
Nothofagus fusca[1]	2(p)	1(p)					
Pittosporum colensoi[1]	1(p)	1(p)					1(p)
Pittosporum eugenioides[2]							1(p)
Pittosporum tenuifolium[1]	1(p)	1(p)	2(p)	1(p)		2(p)	1(p)
Plagianthus regius[3]							1(p)
Pseudopanax arboreus[2]	2(p)	1(p)	1(p)	2(p)		1(p)	1(pn)
Schefflera digitata[4]	1						
Sophora tetraptera[1]		1	1				1(p)
Dicot. lianes							
Calystegia sepium[1]	2	1		1		1	1
Muehlenbeckia australis	3	1	1	1		1	1
Ferns							
Asplenium bulbiferum s.s.[3]	1			1			
Asplenium flaccidum subsp. *flaccidum*	1	1	1	1			
Asplenium oblongifolium			1				
Asplenium polyodon[2]	1	1		1			
Blechnum chambersii[3]	1		1*				
Blechnum fluviatile[2]	1	1					
Blechnum novae-zelandiae s.s.	1	1	1	2	1	2	1
Blechnum novae-zelandiae (wetland form; *B. minus* of NZ authors)					1		1
Blechnum penna-marina		1					
Blechnum vulcanicum[4]	1						
Cyathea dealbata[2]	1			1			
Deparia petersenii		1					1
Dicksonia fibrosa[3]	2	1	1	1	1	1	
Dicksonia squarrosa	1	1		2			
Diplazium australe	1						
Histiopteris incisa	2		1	1			
Hypolepis ambigua	1	1	1	1	1		1
Lastreopsis glabella[4]	1						

* Dead plant only.

Continued on next page

VASCULAR PLANTS	COVER CLASS ABUNDANCE SURVEY AREA						
	A	B	C	D	E	F	G
Lastreopsis microsorum[4]		1					
Paesia scaberula	1	1	1	1			
Pellaea rotundifolia		1					
Phymatosorus pustulatus[1]	1	1	1	1			1
Polystichum vestitum	2	1	1	1			
Pteridium esculentum	2	2	2	2		2	1
Pyrrosia eleagnifolia[3]	1			1			
Grasses							
Cortaderia fulvida	1	2	2	2	1	3	3
Deyeuxia avenoides[3]	1						
Microlaena stipoides	1			1			1
Sedges							
Carex secta	2	1	1	1		1	1
Carex virgata							1
Carex sp. (*C. geminata* agg.)[1≠]	2	1		1	2	3	2
Eleocharis acuta							1
Composite herbs							
Euchiton collinus		1					
Senecio glomeratus[4]							1
Dicot. herbs (other than composites)							
Acaena novae-zelandiae	1	1	1				1
Cardamine sp.[4]		1					
Gonocarpus micranthus							1
Haloragis erecta							1
Hydrocotyle moschata[4]		1					
Oxalis exilis[4]					1		
Perlagonum inodorum[4]							1
Pratia angulata[2]				1			1
ADVENTIVE							
Gymnosperms							
Larix sp.[2]	1			3			
Pinus pinaster[3]		1			1		
Pinus radiata[2]		1			1		
Pseudotsuga menziesii[2]		2					
Dicot. trees and shrubs							
Acacia melanoxylon	3	3	4	3			
Acer pseudoplatanus[5] (previously recorded as *Acer* sp.)	1			1			
Betula pendula[2]	1	1			1	1	1
Buddleia davidii[2]							1
Chaemaecytisus palmensis[1]		1	1				1
Cotoneaster franchetti[3]					1		1
Cotoneaster glaucophyllus							1
Cytisus scoparius	2	2	3	2		1	1
Erica lusitanica[1]		1					1
Eucalyptus sp.[5] (previously recorded as *Eucalyptus globulus*)		1		2			
Euonymus europaeus[5]	1						
Ilex aquifolium[4]	1						
Leycesteria formosa[2]	1	1	2	1			
Liquidambar styraciflua[3]	1						
Lupinus arboreus				1		1	1
Malus domestica[2]						1	
Populus sp.[3]					3		

≠ Recorded as *Carex lessoniana* in 1993, 1998 and 2003.

Continued on next page

Appendix 2—continued

VASCULAR PLANTS	COVER CLASS ABUNDANCE SURVEY AREA						
	A	B	C	D	E	F	G
Populus nigra cv. Italica[1]							2
Prunus campanulata	1	1		1			1
Prunus serotina	3	1		1			
Prunus persica[3]						1	
Quercus palustris	2						
Quercus robur[3]	2	2					
Rosa rubiginosa	1	1	1	1	1		1
Rubus sp. (*R. fruticosus* agg.)	4	3		3	1	2	2
Salix cinerea[1]	1			1			
Salix x chrysocoma (previously recorded as *Salix babylonica*)	1					1	
Salix fragilis[1]							1
Sorbus aucuparia subsp. *aucuparia*[3]	1	1				1	
Ferns							
Dryopteris filix-mas[3]	1	1					
Dicot. lianes							
Calystegia sylvatica[4]				1			
Lonicera japonica[3]				1			1
Vinca major[4]							1
Grasses							
Agrostis capillaris	3	2	2	3	2	1	2
Anthoxanthum odoratum		2	2		1	1	2
Bromus hordaceus[4]							1
Bromus willdenowii[2]					1	1	1
Dactylis glomeratus	2	2	2	2	3	3	2
Ehrharta erecta[4]							1
Festuca rubra[4]		1		2			1
Glyceria declinata				1	1		1
Holcus lanatus	2	1	1	2	1	2	2
Lolium perenne				1	1		1
Paspalum dilatatum					1		1
Phleum pratense[1]						1	1
Poa annua	1	1					1
Rytidosperma racemosa (previously recorded as *Rytidosperma racemosa*)		1					1
Schedonorus phoenix[3]		1	1		1	1	1
Sedges							
Carex divulsa[4]					1		
Carex ovalis							1
Rushes							
Juncus acuminatus							1
Juncus articulatus				1	1	2	1
Juncus bufonius		1		1	1	2	1
Juncus effusus	1				1		1
Juncus tenuis						1	1
Monocot herbs (other than orchids, grasses, sedges and rushes)							
Agapanthus praecox[4]						1	
Crocosmia x crocosmiifolia[4]							1
Composite herbs							
Achillea millefolium		1	2	2	2	3	2
Arctium minus subsp. *minus*[4]							1
Bidens frondosa							1
Cirsium arvense				1	1		
Cirsium vulgare	1	1	1	1	1	1	1
Conyza albida		1	1		1		1

Continued on next page

VASCULAR PLANTS	COVER CLASS ABUNDANCE SURVEY AREA						
	A	B	C	D	E	F	G
Crepis capillaris		1	1	1	1		1
Gamochaeta spicata	1						
Hypochoeris radicata	1	1			1	1	1
Lactuca serriola[1]		1	1	1	1	1	1
Lapsana communis[4]							1
Leontodon taraxacoides[3]							1
Mycelis muralis			1	1	1		1
Senecio bipinnatisectus		1	1			1	1
Senecio jacobaea	1	1		1	1	1	1
Sonchus asper[4]						1	
Sonchus oleraceus					1		1
Taraxacum officinale[1]				1	1		1
Dicot. herbs (other than composites)							
Anagallis arvensis							1
Atriplex prostrata[4]							
Callitriche stagnalis				1	1		1
Capsella bursa-partoris[3]					1		1
Cerastium fontanum subsp. *triviale*				1	1		
Cerastium glomeratum[4]		1			1		
Chenopodium pumilio[4]					1		
Duchesnea indica[3]						1	
Epilobium ciliatum		1		1		1	
Galium aparine		1	1	1			1
Galium divaricatum[4]							1
Geranium molle[3]		1		1			
Geranium robertianum[2]		1	1	1			
Hypericum japonicum[4]							1
Lotus pedunculatus	1	1	1	1	1	1	2
Mentha spicata subsp. *spicata*						1	1
Mimulus guttatus	2	1	1	1	1	1	1
Myosotis laxus[4]		1		1	1		1
Myosotis sylvatica[4]					1		1
Plantago lanceolata[1]	1				2	1	1
Polygonum aviculare[4]							1
Polygonum hydropiper	1			1	1	1	1
Polygonum persicaria[4]						1	
Prunella vulgaris				1			
Ranunculus acris[1]				1			1
Ranunculus repens			1	1	1	1	1
Rorippa nasturtium-aquaticum	1	1	1	1	1	1	1
Rumex acetosella[1]		1	1	1	1	1	1
Rumex conglomeratus				1	1		1
Rumex obtusifolius	1		1	1	1	1	1
Sagina procumbens[4]							1
Solanum nigrum[1]				1	1		
Stachys sylvatica[3]			1	1			
Stellaria media				1		1	1
Silene gallica[4]					1		1
Trifolium pratense				1	1	1	1
Trifolium repens					1	1	1
Verbascum virgatum							1
Verbascum thapsus[4]		1			1	1	

What changes can be seen in a retired pasture stream after 30 years of protection?

Whangamata Stream was retired from pastoral agriculture in 1976, with the establishment of riparian strips. The vegetation along the stream is still in a dynamic successional stage, with a 7.2% annual turnover in species and an average increase of 5.2 species per year with the help of conservation plantings. In the source springs, nitrate concentrations have increased by 50% since 1984, but there have only been slight increases in dissolved reactive phosphorus concentrations. In the stream channel, there have been marked changes over time in the concentrations and mass flows of suspended solids and nutrients, related to long-term changes in stream flows and successional changes in stream bank vegetation.

Howard-Williams, C.; Pickmere, S. 2010: Thirty years of stream protection: long-term nutrient and vegetation changes in a retired pasture stream. *Science for Conservation 300.* 49 p.

New Zealand Government