RESEARCH REPORT

Nature's Revenue Streams: Assessment of Stormwater Treatment via Engineered Ecology™ Treatment Systems and Stream Restoration

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Nature's Revenue Streams

Assessment of Stormwater Treatment via Engineered Ecology™ Treatment Systems and Stream Restoration

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RESEARCH HIGHLIGHT

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Assessment of Ecologically Engineered Stormwater Management

INTRODUCTION

This study, funded through the FCM Green Municipal Funds with additional financial support from CMHC, evaluated how five engineered wetland installations and stream restoration projects affected stormwater quality. Projects varied in age and size, but all were built to reduce the negative effects of stormwater on local streams, and all were designed and constructed by the same company within the District of Saanich, B.C., as tributaries of the Colquitz River.

The following projects were studied:

- *Willowbrook subdivison*, where wetlands were constructed to capture stormwater from an in-fill residential development, and Swan Creek, a ditched channel, was restored to a functioning creek.
- *Glanford Station*, where a small wetland was installed to capture stormwater from a subivision before draining into Swan Creek, just downstream from the Willowbrook installation.
- *Baxter Pond*, where a dry detention pond was rehabilitated into a wetland and now accommodates stormwater from a new subdivision, a portion of highway, and a nearby school.
- *Blenkinsop Creek*, where approximately 650 m of ditched channel was rehabilitated into a stream to create natural habitat, attenuate flood flows, and reduce soil erosion and nutrient input from a neighbouring farm.
- *Leeds Creek*, where a stream channel and shallow pond complex were reconstructed to alleviate flooding of a nearby subdivision.

METHODOLOGY

Owing to the isolation of the study sites and budget limitations, this study relied on grab samples instead of the more common well samples and continuous monitoring used in similar investigations. Where possible, samples were taken upstream and downstream of each receiving or reconstructed stream section, as well as at the inlet and outlet of wetland installations.

Samples were collected over 14 months, and during storm events when possible. On-site water analyses using a handheld multi-meter were conducted monthly between October 2006 and July 2007, and again in December 2007. Laboratory water samples for chemistry, bacteriology and metal analyses were also collected monthly, except in summer when water levels were too low. Sediment samples were collected three times: fall 2006, spring 2007, and fall 2007.

Test parameters included:

- *On-site water analyses*: dissolved oxygen, conductance, pH, temperature.
- *Water chemistry analyses*: alkalinity, ammonia, biochemical oxygen demand (May only), chloride, colour, conductivity (at 25° C), hardness, total Kjeldahl nitrogen (TKN), nitrate, nitrite, ortho-phosphate (ortho-P), pH, phenols (May only), total extractable, hydrocarbons, total dissolved solids (TDS), total suspended solids (TSS).

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- *Water Bacteriology analyses*: fecal coliforms, Enterococci
- *Water and sediment metal analyses*: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, gold, iron, lanthanum, lead, magnesium, manganese, mercury, molybdenum, nickel, phosphorus, potassium, scandium, selenium, silicon, silver, sodium, strontium, tin, titanium, tungsten, vanadium, zinc.

Precipitation data was collected from University of Victoria meteorological stations near each site. Both a field and laboratory quality assurance program was implemented to ensure that the data collected were as accurate and precise as possible.

Water and sediment data collected were compared to the Canadian Water Quality Guidelines for the Protection of Aquatic Life, and bacteriological results were measured against the Guidelines for Canadian Recreational Water Quality. Mean influent and effluent values were compared with those listed in the International Stormwater Best Management Practices Database (BMP database)[1], which contains searchable information on more than 200 stormwater studies.

RESULTS

Precipitation

Total precipitation during the sampling period was normal, but was characterized by long dry periods interspersed by large rain and snow events.

Willowbrook Subdivision

Stream data were complicated by additional water inputs along the stream length, and so the analysis focused only on water quality upstream and downstream, and at the inlet and outlet of the main wetland.

<u>Test results:</u>

- *Nutrients*: On average, the wetland removed 17% total nitrogen (ammonia, nitrate, nitrite and Total Kjeldahl Nitrogen). However, between inlet and outlet, ortho-P concentrations increased by 1,103%.
- *Total dissolved solids*: The wetland had an average removal efficiency of 32.7% for TDS and 21.7% for chloride (discounting October's anomalous increase).
- *Suspended solids*: While historically the wetland appears to have been very effective at removing sediment (large accumulations were observed), increased levels of TSS and turbidity in the outflow indicate that stormwater is now mobilizing accumulated sediment and discharging it into the creek.
- *Temperature*: Temperatures dropped 2.7°C on average before entering Swan Creek.
- *Metals* : Arsenic, copper, lead, mercury, sodium, tin and zinc were all lower at the outlet than at the inlet in the fall of 2006. With the onset of winter rains, metal values at the outlet began to exceed those at the inlet, except in the case of sodium, suggesting mobilization from wetland sediments.
- *Sediment Chemistry*: Sediments at the outlet had lower concentrations of all key metals (arsenic, cadmium, chromium, copper, lead, mercury, sodium and zinc) on all three sampling dates with a few exceptions. In October 2006, arsenic and mercury were slightly higher at the outlet than the inlet, and in March 2007, cadmium, lead, sodium and zinc were all higher at the inlet than the outlet, suggesting that sediments might have migrated from the inlet area during higher rainfall.
- *Bacteriology*: The maximum number of fecal coliforms recorded at the inlet was 2,600 CFU/100 mL, and no Enterococci were detected.

[1] The BMP database is sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE) / Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and the U.S. Environmental Protection Agency (EPA), and is available at (www.bmpdatadase.org).

Compliance:

- *Water*: The pond's copper levels were about ten times the guidelines, and while outlet waters were in compliance with lead, inlet waters were not. Allowable zinc levels were exceeded twice at the inlet.
- *Sediment*: Chromium, copper and zinc guidelines were exceeded at the inlet and outlet on all sample dates. Lead levels also exceeded on two occasions, and mercury once, in both locations.
- *Bacteriology*: In compliance.

Summary: The Willowbrook wetland effectively removed heat, nitrogen, TDS and chloride, but exported ortho-P. The wetland generally acted as a sink for metals during low flow summer periods, and exported metals during rainy winter months. Observations of accumulated sediment suggest that the wetland could be made more effective if it were more regularly maintained.

Glanford Wetland:

Analyses focused on the inlet and outlet of this small wetland which is downstream of the Willowbrook system.

Test results:

- *Nutrients*: Total nitrogen was reduced by 38.6%, and a small amount of ortho-P was exported.
- *Total dissolved solids*: Chloride concentration, TDS, and specific conductance decreased on average, but only slightly.

Figure 1 View of wetland between Willowbrook and Glanford 2003

- *Total suspended solids*: Average TSS and turbidity removal rates were 28% and 42.7%, respectively.
- *Temperature*: Temperature decreased from inlet to outlet by 1° C on average, likely owing to plant evapotranspiration.
- *Metals*: Arsenic, chromium, lead, mercury, tin and zinc were all lower at the outlet than at the inlet, with few exceptions. Average reduction of sodium and zinc was 4.1 % and 24.9%, respectively.
- *Sediment Chemistry*: Sediment samples were inconsistent, although wetland sediments at the outlet were lower on average in arsenic, iron, mercury, sodium, lead and tin.
- *Bacteriology*: Fecal coliforms reached 1,200 CFU/100 mL at the inlet on June 11, 2007, at which time there were 144 CFU/100mL Enterococcus.

Compliance:

- *Water*: Copper levels in all locations were ten times the allowable guideline, and lead levels were also exceeded at the inlet. Zinc levels were higher than allowable on isolated occasions at both the inlet and outlet.
- *Sediment*: Glanford exceeded chromium, copper and zinc guidelines on all sample dates, and lead and arsenic levels on two occasions, at both the inlet and outlet. Mercury was exceeded twice at the inlet.
- *Bacteriology*: In compliance.

Summary: The Glanford wetland was effective at removing heat, TSS, metals, and both nitrogen and ortho-P, but did little to remove dissolved materials, likely because of its small size and short residence time. Still, its TDS and metals removal rate was significantly higher than Willowbrook's, a much larger wetland, which was probably because Glanford was recently dredged. Outlet sediments generally had a lower metals concentrations at the inlet, however results were inconsistent, possibly because some sediment was disturbed when the pond was cleaned out.

Baxter Pond

Test Results:

- *Nutrients*: Baxter Pond's total nitrogen removal efficiency varied throughout the year, but was 40.8% on average, and ortho-P was generally exported.
- *Total dissolved solids*: Other than on two occasions, TDS and conductivity decreased through the pond. Chloride and sodium concentrations spiked in December and January from road salt.
- *Total suspended solids*: Baxter Pond was very effective at removing large, heavier particles following winter snowstorms, but finer material did not readily settle out. As a consequence, outlet TSS values were higher than those at the inlet on seven out of ten occasions.
- *Temperature*: Temperature declined by an average of 2.1°C.
- *Metals*: Because of the pond's proximity to the highway, there were large spikes of chromium, sodium, and zinc, as well as a smaller peak of mercury after snow melt. The pond was effective at reducing sodium and, to a lesser extent, mercury and zinc. Between the inlet and the middle of the pond, levels of cadmium, chromium, mercury, lead and zinc declined, but increased again at the outlet, most likely because of Gabo Creek backflowing into the wetland during low flows.
- *Sediment chemistry*: Again, metal concentrations generally reduced from the inlet to the middle of pond, but then sharply increased at the outlet.
- *Bacteriological*: Both fecal coliforms and Enterococci in Baxter Pond were very low, considering the population of ducks living on the pond.

Compliance:

- *Water*: Outlet waters exceeded guidelines for arsenic on one occasion. Chromium levels were exceeded in all samples in January 2007, and at the outlet in March, but were not detectable otherwise. Baxter Pond exceeded copper guidelines on all measurable occasions.
- *Sediment*: Outlet sediments exceeded arsenic guidelines on two occasions, mercury on one occasion, and cadmium, lead and zinc on all three sample dates. At the inlet, Cadmium was also exceeded once, lead twice, and zinc always. Zinc was also exceeded mid-pond on one date. Six of the nine samples exceeded levels for chromium, and all but one exceeded for copper.
- *Bacteriology*: In compliance.

Summary: Baxter Pond is an important thermal buffer for Gabo creek and is also effective at removing dissolved substances, large suspended sediments, and nitrogen, but was an exporter of ortho-P. Water in the middle of the pond had lower metals concentrations than the inlet, but these values rose again at the outlet suggesting backwatering, resuspension of sediment, or both. While the pond may be effective at initially trapping finer sediments, waterfowl in the pond may stir it up so that it washes downstream into Gabo Creek. They do not, however, seem to be adding to the fecal coliform burden in the water, which is surprising given their large number.

Blenkinsop Creek

The analysis for Blenkinsop Creek was complicated by multiple inputs, some seasonal, some from Cumberland Creek backwash and others from Galeys' field drain. For this reason, data analysis focused on the water quality differences between the most upstream site at the outlet of Blenkinsop Lake, and the midpoint of Galeys' field, which is approximately 250 m downstream.

Test results:

- *Nutrients*: Blenkinsop Creek removed both nitrogen and ortho-P.
- *Total dissolved solids*: Specific conductance and TDS were largely unchanged along the length of the channel, although two high readings of both parameters were taken on two separate occasions, which resulted in an average increase.
- *Suspended solids*: The channel reduced TSS more than 50% of the time, however, high value readings (likely caused by resuspension of sediment during sampling) resulted in a TSS average increase of 119%.
- *Metals*: During low flows, zinc (the only heavy metal routinely present in the pond) was measured at higher concentrations upstream than downstream, while during higher flows, the opposite was true. On average, arsenic and chromium levels increased at the outlet, while copper, mercury and zinc decreased.
- *Sediment chemistry*: Concentrations of every heavy metal measured declined significantly except chromium, which was slightly higher downstream than upstream on one occasion. The effective removal of arsenic was 44.7%, cadmium 83.4%, chromium 19.8%, copper 39.9%, lead 90%, mercury 58.3% and zinc 64.7%.
- *Bacteriology*: Both fecal coliform and Enterococci were lower downstream than up on every date except one. Enterococcus values never exceeded 12 CFU.

Compliance:

- *Water*: Guidelines were exceeded once for arsenic, once for chromium, and four times for both copper and Mercury.
- *Sediments*: Upstream, arsenic levels were exceeded once, and cadmium, chromium and mercury levels twice. Cadmium was just over the limit downstream on one occasion as well. Copper exceeded in all samples upstream and downstream except one.

Summary: Because of its slow flow, Blenkinsop Creek acted as a long pond, and was very effective at removing nutrients. Increased sinuosity of the restored channel increased the residence time of water, which encouraged particle settlement and hence pollution removal. Other than zinc and arsenic, the creek had very low metal concentrations, and the markedly lower metals concentrations in downstream sediments suggests that Blenkinsop Lake is the source of most metals in the creek, not the neighbouring fields. The creek also had extremely low dissolved oxygen values, likely due to the anoxic conditions of Blenkinsop Lake, and so cannot support fish at present.

Leeds

Results:

- *Nutrients*: On all but one sampling date, the lower reach of the creek had significantly less nitrogen than the inlet culvert; discounting one anomalous reading, average removal rates were 45.2%. The stream also removed phosphorus on all dates except for two, which were high flow periods when residence time may not have been long enough for the stream to assimilate the nutrients.
- *Suspended solids*: Leeds Creek flows quickly most of the year, and does not allow many particulates to settle, so dissolved solids increased on most sampling dates. The creek did strip some chloride, however.

- *Temperature*: Water temperature was reduced an average of 2.12°C from inlet to outlet.
- *Metals*: Because suspended materials did not settle out, neither did metals, and no reduction in metals was noted.
- *Sediment chemistry*: In the fall, the concentrations of all key metals (except lead) were higher downstream than upstream. In winter and spring, however, this trend was reversed, likely because of a spring flush of sediment, and downstream concentrations of arsenic, chromium, copper, lead and zinc were lower than those measured upstream.
- *Bacteriology*: The fecal coliform counts at the culvert inlet were high, reaching a peak value on February 6, 2007 of 50800 CFU/100 mL and 1.1 CFU of Enterococcus.

<u>Compliance:</u>

- *Water*: Upstream water exceeded the arsenic guideline once. Water from both sites exceeded criterion for copper on eight occasions, chromium on three, lead on nine, and mercury on five. Zinc levels were exceeded once at the inlet and seven times at the outlet.
- *Sediments*: Arsenic, cadmium and lead guidelines were each exceeded once at the outlet. Lead was also exceeded at the inlet twice. Chromium and zinc levels were close or above guidelines at all sites on all sampling dates, except on October 2006 at the inlet. Copper levels were consistently exceeded in all samples. Mercury was high at the outlet twice, and exceeded guidelines at the inlet once.
- *Bacteriology*: In compliance.

<u>Summary</u>: Leeds creek was very effective at removing heat, nitrogen and ortho-P from the stormwater, except during high flow events. However, the creek flows too quickly to effectively remove metals and all but the heaviest suspended sediments.

Comparison to Conventional Stormwater Best Management Practices

To compare study site results with those in the BMP database, median inflow and outflow values were calculated using only those samples that were detectable. This gave a rough estimate only, and so comparisons serve only to assess Saanich wetland performances and to determine whether they should be maintained differently, or if they should be replaced by more traditional stormwater treatment processes.

<u>Findings:</u>

- *Cadmium*: The median outflow cadmium concentration in Baxter Pond (the only project with enough cadmium data for comparison), was approximately half the lowest database outflow value, and so the pond appears to perform as well as any other BMP in this respect.
- *Copper*: Willowbrook and Glanford wetland copper removals were comparable to those of detention pond and biofilter BMPs. Baxter, Blenkinsop and Leeds were not effective at removing copper.
- *Chromium*: Chromium was not commonly present in Saanich stormwater, except in Leeds Creek, which flows too fast to effectively remove this constituent.
- *Lead*: Blenkinsop did not have enough measured lead values for comparison. Willowbrook and Glanford both exported lead, although the effluent vales were still well within the range of waters treated by biofilters, hydrodynamic systems and wetlands, and were well below effluent values for detention ponds.
- *Zinc*: Both Baxter Pond and Blenkinsop Creek were as effective at reducing zinc as any other BMP, except a wet pond. Glanford and Willowbrook were net zinc exporters.
- *Total Suspended Solids*: Glanford's TSS effluent quality superceded all the BMPs, while Blenkinsop was easily within the range of a detention pond and biofilter system. Baxter Pond and Leeds Creek did not remove TSS, and Willowbrook exported TSS.

- *Ortho-P*: Only Blenkinsop Creek was effective at removing ortho-P; the other installations studied were net exporters. A similar trend is recorded in the BMP database, where wet ponds have little effect in total phosphorous, and biofilters are net exporters.
- *Nitrate*: Overall nitrate reduction was significant at every site except Blenkinsop, whose data is skewed by the exclusion of non-detectable values, but which removed 20% nitrate on average. Willowbrook is most similar to a wet pond, while Glanford and Baxter are comparable to a detention pond and biofilter.
- *TKN and Total Nitrogen*: Willowbrook and Baxter were net exporters of TKN but reduced total nitrogen and nitrate at a rate comparable to a wet pond or wetland basin. Blenkinsop removed TKN and Total N at rates comparable with a wet pond, while Glanford superceded all the BMPs at removing TKN, and was comparable to a wetland basin in its ability to remove Total N.

CONCLUSIONS

- The Saanich treatment systems, even small ones like Glanford, effectively treat stormwater pollutants, and their performance is comparable with Best Management Practices recorded in the International Stormwater BMP database.
- The Willowbrook and Baxter Pond wetlands need maintenance. Sediment should be routinely cleaned out to prevent the export of suspended solids and associated metals.
- The Willowbrook and Glanford wetlands, Leeds Creek and Baxter Pond all significantly reduced effluent temperatures, which is a key factor is protecting Blenkinsop and Swan Creeks and the salmon habitat of the Colquitz River.
- All sites, at different times, did not meet the criteria outlined in the Canadian Water Quality Guidelines for Protection of Aquatic Life for heavy metals.
- Streams can be made more effective by improving their functional condition. The increased sinuosity and retention time in Blenkinsop Creek near Galeys' farm also make it effective at trapping sediment and removing metals and nutrients.
- Unlike engineered wet ponds, the systems studied provide wildlife habitat, views, carbon sequestration, thermal regulation, and also act as a buffer for neighbouring streams.

IMPLICATIONS FOR HOUSING INDUSTRY

Ecological solutions can be as or more effective than traditional best management practices for managing and treating stormwater, and should be considered for inclusion in new and existing developments. Given the added aesthetics of such installations, they may also add perceived value to developments.

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LE POINT EN RECHERCHE

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Évaluation de la gestion écologique des eaux de ruissellement

INTRODUCTION

La présente étude, financée par le Fonds municipal vert de la FCM avec le soutien financier supplémentaire de la SCHL, a évalué les effets qu'ont eus cinq projets d'installations écologiques de terres humides et de restauration de cours d'eau sur la qualité des eaux pluviales. Ces projets d'envergure et de date variés ont tous été réalisés par la même société – dans le district de Saanich en Colombie-Britannique – dans un seul et unique but : réduire les effets négatifs des eaux pluviales sur les cours d'eau locaux affluents de la rivière Colquitz.

Les aménagements ont fait l'objet d'étude :

- Le *lotissement de Willowbrook*, où des terres humides ont été construites pour recueillir les eaux pluviales provenant d'un ensemble résidentiel réalisé sur terrain intercalaire, et Swan Creek, un chenal de drainage artificiel, a été restauré et transformé en un ruisseau fonctionnel.
- *Glanford Station*, où une petite étendue de terres humides a été installée pour recueillir les eaux pluviales d'un lotissement avant qu'elles ne soient rejetées dans Swan Creek, juste en aval de l'installation de Willowbrook.
- *Baxter Pond*, où un bassin d'orage à sec a été restauré et transformé en terres humides pouvant maintenant recueillir des eaux pluviales d'un nouveau lotissement, d'un tronçon de route et d'une école située à proximité.
- *Blenkinsop Creek*, où environ 650 m de chenal de drainage artificiel ont été restaurés et transformés en cours d'eau pour créer un habitat naturel, atténuer les débits de crue et réduire l'érosion du sol et l'apport en éléments nutritifs provenant d'une ferme voisine.
- *Leeds Creek*, où un ensemble comprenant un chenal de cours d'eau et un bassin peu profond a été reconstruit pour atténuer les effets des inondations dans un lotissement environnant.

L'utilisation d'un sixième site, le parc de la technologie de l'île de Vancouver (PTIV), a également été envisagée pour cette étude. Toutefois, les sites du PTIV étaient si souvent à sec qu'aucun ensemble de données comparatives n'a pu être obtenu au moment de la préparation du rapport, et le PTIV a dû être omis de l'analyse.

MÉTHODE

Les sites à l'étude étant isolés et les budgets restreints, l'étude s'est fondée sur des échantillons instantanés plutôt que sur les méthodes d'échantillonnage de puits et de surveillance en continu plus couramment utilisées dans des études semblables. Dans la mesure du possible, des échantillons ont été prélevés en amont et en aval de chaque portion du cours d'eau récepteur ou reconstruit ainsi qu'à la prise d'eau et à la sortie d'eau des installations de terres humides.

Des échantillons ont été prélevés pendant plus de 14 mois et, autant que possible, pendant des orages. Des analyses d'eau sur le terrain effectuées à l'aide d'un multimètre portatif ont été menées chaque mois entre octobre 2006 et juillet 2007, et de nouveau en décembre 2007. Chaque mois, sauf pendant la période estivale lorsque les niveaux d'eau étaient trop bas, des échantillons d'eau de laboratoire ont également été prélevés pour analyser les propriétés chimiques et bactériologiques et déceler la présence de métaux. Des échantillons de sédiments ont été prélevés à trois reprises : à l'automne 2006, au printemps 2007 et à l'automne 2007.

Les paramètres d'essai comprenaient notamment les suivants :

- *Analyses d'eau sur le terrain* : oxygène dissous, conductance, pH, température.
- *Analyse des propriétés chimiques de l'eau* : alcalinité, ammoniac, demande biochimique d'oxygène (en mai seulement), chlorure, couleur, conductivité (à 25°C), dureté, azote total Kjeldahl (ATK), nitrate, nitrite, orthophosphate, pH, phénols (en mai seulement), total récupérable, hydrocarbures, matières dissoutes totales (MDT), total des solides en suspension (TSS).
- *Analyses bactériologiques de l'eau* : coliformes fécaux, entérocoques.
- Analyses de métaux dans l'eau et des sédiments : aluminium, antimoine, arsenic, baryum, béryllium, bore, cadmium, calcium, chrome, cobalt, cuivre, or, fer, lanthane, plomb, magnésium, manganèse, mercure, molybdène, nickel, phosphore, potassium, scandium, sélénium, silicium, argent, sodium, strontium, étain, titane, tungstène, vanadium, zinc.

Des données hyétométriques ont été recueillies dans les stations météorologiques de l'Université de Victoria situées à proximité de chaque site. Un programme d'assurance qualité à la fois sur le terrain et en laboratoire a été mis en œuvre pour veiller à ce que les données recueillies soient aussi exactes et précises que possible.

Les données recueillies sur l'eau et les sédiments ont été comparées aux *Recommandations pour la qualité des eaux au Canada en vue de la protection de la vie aquatique*, et les résultats bactériologiques ont été comparés aux *Recommandations au sujet de la qualité des eaux utilisées à des fins récréatives au Canada*. Les valeurs moyennes prélevées à l'affluent et à l'effluent ont été comparées aux valeurs de l'International Stormwater Best Management Practices Database[1] (base de données des meilleures pratiques de gestion [MPG]), qui contient des données consultables provenant de plus de 200 études sur les eaux pluviales.

RÉSULTATS

Précipitations

Les précipitations totales pendant la période d'échantillonnage étaient normales, mais caractérisées par de longues périodes sèches parsemées d'événements de pluie et de neige.

Subdivision Willowbrook

L'analyse des données a été rendue plus complexe en raison des apports d'eau supplémentaires le long du cours d'eau. Par conséquent, l'analyse s'est concentrée uniquement sur la qualité de l'eau en amont et en aval ainsi qu'à la prise d'eau et à la sortie d'eau des principales zones humides.

Résultats d'analyse :

- *Éléments nutritifs* : En moyenne, les terres humides ont éliminé 17 % d'azote total (ammoniac, nitrate, nitrite et azote total Kjeldahl). Toutefois, entre la prise d'eau et la sortie d'eau, les concentrations d'orthophosphate ont augmenté de 1 103 %.
- *Matières dissoutes totales* : Les terres humides ont eu une efficacité d'élimination moyenne de 32,7 % pour les MDT et de 21,7 % pour le chlorure (sans tenir compte de l'augmentation anormale d'octobre).
- *Solides en suspension* : Bien qu'historiquement, les terres humides semblent avoir été très efficaces pour éliminer les sédiments (de larges accumulations ont été observées), des niveaux accrus de TSS et de turbidité dans le courant de débordement indiquent que les eaux pluviales mobilisent maintenant des sédiments accumulés et les rejettent dans le ruisseau.
- *Température* : Avant l'entrée dans Swan Creek, les températures ont chuté en moyenne de 2,7 °C.
- *Métaux* : À l'automne 2006, les niveaux d'arsenic, de cuivre, de plomb, de mercure, de sodium, d'étain et de zinc prélevés à la sortie d'eau étaient tous inférieurs à

[1] La base de données des MPG est parrainée par la Water Environment Research Foundation (WERF), l'American Society of Civil Engineers (ASCE), l'Environmental and Water Resources Institute (EWRI), l'American Public Works Association (APWA), l'Administration fédérale des autoroutes des États-Unis (FHWA) et l'Environmental Protection Agency (EPA) des États-Unis, et peut être consultée à l'adresse suivante : www.bmpdatadase.org.

ceux prélevés à la prise d'eau. À l'arrivée des pluies hivernales, les valeurs des métaux à la sortie d'eau ont commencé à dépasser celles de la prise d'eau, sauf dans le cas du sodium, ce qui permet de croire à une mobilisation des sédiments des terres humides.

- *Composition chimique des sédiments* : À quelques exceptions près, les sédiments prélevés à la sortie d'eau contenaient des concentrations plus faibles de métaux clés (arsenic, cadmium, chrome, cuivre, plomb, mercure, sodium et zinc) aux trois dates d'échantillonnage. En octobre 2006, les niveaux d'arsenic et de mercure étaient légèrement plus élevés à la sortie d'eau qu'à la prise d'eau. En mars 2007, les niveaux de cadmium, de plomb, de sodium et de zinc étaient tous plus élevés à la prise d'eau qu'à la sortie d'eau, ce qui permet de croire que les sédiments avaient migré depuis la prise d'eau pendant les pluies plus abondantes.
- *Bactériologie* : Le nombre maximal de coliformes fécaux enregistrés à la prise d'eau a été de 2 600 UFC/100 ml et aucun entérocoque n'a été détecté.

Conformité :

- *Eau* : Les niveaux de cuivre de l'étang étaient environ dix fois plus élevés que les niveaux recommandés. De plus, alors qu'à la sortie d'eau, les eaux étaient conformes aux niveaux de plomb, elles ne l'étaient pas à la prise d'eau. Les niveaux de zinc permis ont été dépassés deux fois à la prise d'eau.

Figure 1 Vue de terres humides entre Willowbrook et Glanford en 2003

- Sédiments : Les niveaux recommandés de chrome, de cuivre et de zinc ont été dépassés à la prise d'eau et à la sortie d'eau à toutes les dates d'échantillonnage. Les niveaux de plomb ont également été dépassés à deux reprises, et le niveau de mercure à une occasion, aux deux endroits.
- Bactériologie : Conforme.

Sommaire : Les terres humides de Willowbrook se sont révélées efficaces pour éliminer la chaleur, l'azote, les MDT et le chlorure, mais ont exporté l'orthophosphate. Les terres humides ont généralement servi de puits pour les métaux pendant les périodes estivales d'étiage et ont exporté des métaux pendant les mois d'hiver pluvieux. Selon les observations de sédiments accumulés, les terres humides pourraient être plus efficaces si elles étaient entretenues plus régulièrement.

Station Glanford

Les analyses se sont concentrées sur la prise d'eau et la sortie d'eau de cette petite étendue de terres humides qui se situe en aval du système Willowbrook.

Résultats d'analyse :

- *Éléments nutritifs* : L'azote total a été réduit de 38,6 %, et une petite quantité d'orthophosphate a été exportée.
- *Matières dissoutes totales* : En moyenne, la concentration de chlorure et de MDT ainsi que la conductance spécifique ont diminué, mais seulement légèrement.
- *Total des solides en suspension* : Les taux d'élimination moyens de TSS et de turbidité étaient de 28 % et de 42,7 % respectivement.
- *Température* : La température a diminué de 1°C en moyenne entre la prise d'eau et la sortie d'eau, probablement en raison de l'évapotranspiration des plantes.
- *Métaux* : À quelques exceptions près, les niveaux d'arsenic, de chrome, de plomb, de mercure, d'étain et de zinc à la sortie d'eau étaient tous inférieurs à ceux de la prise d'eau. La réduction moyenne de sodium et de zinc était de 4,1 % et de 24,9 % respectivement.
- *Composition chimique des sédiments* : Les échantillons de sédiment étaient divergents, mais les sédiments de terres humides à la sortie d'eau avaient en moyenne des niveaux inférieurs d'arsenic, de fer, de mercure, de sodium, de plomb et d'étain.

- *Bactériologie* : Les coliformes fécaux ont atteint 1 200 UFC/100 ml à la prise d'eau le 11 juin 2007. À cette même date, il y avait 144 UFC/100 ml d'entérocoques.

Conformité :

- *Eau* : À tous les endroits, les niveaux de cuivre étaient dix fois plus élevés que les niveaux permis, et les niveaux de plomb ont également été dépassés à la prise d'eau. Les niveaux de zinc ont été supérieurs aux niveaux permis à de rares occasions, tant à la prise d'eau qu'à la sortie d'eau.
- *Sédiments* : Glanford a dépassé les niveaux recommandés de chrome, de cuivre et de zinc à toutes les dates d'échantillonnage et a dépassé les niveaux de plomb et d'arsenic à deux reprises, tant à la prise d'eau qu'à la sortie d'eau. Le niveau de mercure a été dépassé deux fois à la prise d'eau.
- *Bactériologie* : Conforme.

Sommaire : Les terres humides de Glanford ont été efficaces pour éliminer de la chaleur, le TSS, les métaux ainsi que l'azote et l'orthophosphate, mais ont peu fait pour éliminer les matières dissoutes, probablement en raison de leur petite étendue et du court temps de séjour. Tout de même, leur taux d'élimination de MDT et de métaux a été considérablement plus élevé que celui de Willowbrook, une étendue de terres humides beaucoup plus vaste, probablement parce que la station Glanford a récemment été draguée. De façon générale, les sédiments de la sortie d'eau avaient de plus faibles concentrations de métaux qu'à la prise d'eau. Cependant, les résultats étaient divergents, possiblement parce que certains sédiments ont été déplacés lorsque l'étang a été nettoyé.

Baxter Pond

Résultats d'analyse :

- *Éléments nutritifs* : L'efficacité d'élimination de l'azote total de Baxter Pond a varié toute l'année, mais a été de 40,8 % en moyenne. De façon générale, de l'orthophosphate a été exporté.
- *Matières dissoutes totales* : Sauf en deux occasions, les MDT et la conductivité ont diminué dans l'ensemble de l'étang. Les concentrations en chlorure et en sodium ont connu un pic en décembre et en janvier en raison de l'épandage de sels de voirie.
- *Total des solides en suspension* : Baxter Pond a éliminé de façon très efficace les grosses particules plus lourdes après les tempêtes de neige hivernales, mais les particules plus fines ne se sont pas déposées aisément au fond de l'eau. Par conséquent, les valeurs de TSS à la sortie d'eau étaient supérieures à celles de la prise d'eau sept fois sur dix.
- *Température* : La température a diminué en moyenne de 2,1 °C.
- *Métaux* : Étant donné que l'étang se trouve à proximité de la route, il y a eu de fortes augmentations de chrome, de sodium et de zinc ainsi qu'un pic de mercure moins important après la fonte des neiges. L'étang s'est avéré efficace pour réduire le sodium et, dans une moindre mesure, le mercure et le zinc. Entre la prise d'eau et le milieu de l'étang, les niveaux de cadmium, de chrome, de mercure, de plomb et de zinc ont diminué. Toutefois, ils ont augmenté de nouveau à la sortie d'eau, sans doute en raison du refoulement d'eau de Gabo Creek dans les terres humides pendant les périodes d'étiage.
- *Composition chimique des sédiments* : Là encore, les concentrations en métaux ont généralement diminué entre la prise d'eau et le milieu de l'étang, mais ont brusquement augmenté à la sortie d'eau.
- *Bactériologie* : Les niveaux de coliformes fécaux et d'entérocoques dans le Baxter Pond étaient tous deux très bas si l'on tient compte de la population de canards vivant dans l'étang.

Conformité :

- *Eau* : Les eaux à la sortie d'eau ont dépassé les niveaux recommandés d'arsenic à une occasion. Les niveaux de chrome ont été dépassés dans tous les échantillons prélevés en janvier 2007 ainsi qu'à la sortie d'eau en mars; sinon, ils n'étaient pas décelables. Tous les échantillons de Baxter Pond ont dépassé les niveaux recommandés de cuivre.
- *Sédiments* : Les sédiments à la sortie d'eau ont dépassé les niveaux recommandés d'arsenic à deux reprises, de mercure à une occasion, et de cadmium, de plomb et de zinc aux trois dates d'échantillonnage. À la prise d'eau, le niveau de cadmium a également été dépassé une fois, le niveau de plomb deux fois, et le niveau de zinc chaque fois qu'il a été mesuré. Le zinc a également été dépassé au milieu de l'étang à une occasion. Six des neuf échantillons ont dépassé les niveaux de chrome, et tous les échantillons ont dépassé le niveau de cuivre.
- *Bactériologie* : Conforme.

Sommaire : Baxter Pond est un important tampon thermique pour Gabo Creek et est également efficace pour éliminer les substances dissoutes, les gros sédiments en suspension et l'azote. Il s'est toutefois avéré un exportateur d'orthophosphate. Au milieu de l'étang, les concentrations en métaux étaient inférieures à celles de la prise d'eau, mais ces valeurs ont augmenté de nouveau à la sortie d'eau, ce qui permet de conclure à des remous, la remise en suspension de sédiments ou les deux. L'étang peut être efficace pour piéger des sédiments plus fins au départ, mais les sédiments peuvent ensuite être remués par la sauvagine dans l'étang et être rejetés en aval dans Gabo Creek. Toutefois, la sauvagine ne semble pas ajouter au fardeau de coliformes fécaux dans l'eau, ce qui est surprenant si l'on tient compte de la densité élevée de sa population.

Blenkinsop Creek

L'analyse de Blenkinsop Creek a été rendue plus complexe en raison de nombreux apports en eau, certains saisonniers, certains provenant du contre-courant de Cumberland Creek et d'autres du drain du champ Galeys. Pour cette raison, l'analyse des données s'est concentrée sur les écarts de qualité de l'eau entre le site le plus en amont à la sortie d'eau de Blenkinsop Lake et le milieu du champ Galeys, qui se trouve à environ 250 m en aval.

Résultats d'analyse :

- *Éléments nutritifs* : Blenkinsop Creek a éliminé à la fois l'azote et l'orthophosphate.
- *Matières dissoutes totales* : Les niveaux de conductance spécifique et de MDT sont restés essentiellement les mêmes le long du chenal, bien que deux lectures élevées des deux paramètres aient été prises à deux occasions distinctes, ce qui a entraîné une augmentation de la moyenne.
- *Solides en suspension* : Le chenal a réduit le TSS plus d'une fois sur deux. Toutefois, des lectures élevées (probablement causées par la remise en suspension des sédiments pendant l'échantillonnage) ont entraîné une hausse de la moyenne du TSS de 119 %.
- *Métaux* : Pendant les périodes d'étiage, du zinc (le seul métal lourd présent dans l'étang) a été mesuré en concentrations plus élevées en amont qu'en aval, alors qu'en périodes de crue, l'inverse s'est produit. En moyenne, les niveaux d'arsenic et de chrome ont augmenté à la sortie d'eau, alors que les niveaux de cuivre, de mercure et de zinc ont diminué.
- *Composition chimique des sédiments* : Les concentrations mesurées de tous les métaux lourds ont diminué considérablement, à l'exception du chrome, qui a été légèrement plus élevé en aval qu'en amont à une occasion. L'arsenic a été éliminé avec efficacité à 44,7 %, le cadmium à 83,4 %, le chrome à 19,8 %, le cuivre à 39,9 %, le plomb à 90 %, le mercure à 58,3 % et le zinc à 64,7 %.
- *Bactériologie* : Les quantités de coliformes fécaux et d'entérocoques étaient plus basses en aval qu'en amont à chaque échantillonnage à l'exception d'un seul. Les valeurs d'entérocoques n'ont jamais dépassé 12 UFC.

Conformité :

- *Eau* : Les niveaux recommandés ont été dépassés une fois pour l'arsenic, une fois pour le chrome et quatre fois pour le cuivre et le mercure.
- *Sédiments* : En amont, les niveaux d'arsenic ont été dépassés une fois, et ceux de cadmium, de chrome et de mercure, deux fois. De plus, à une occasion, le cadmium mesuré a tout juste dépassé la limite en aval. Le niveau de cuivre a été dépassé dans tous les échantillons prélevés en aval et en amont, sauf à une occasion.

Sommaire : Étant donné son faible débit, Blenkinsop Creek a agi comme un long bassin et s'est avéré très efficace pour éliminer les nutriments. La sinuosité accrue du chenal restauré a augmenté le temps de séjour de l'eau, ce qui a favorisé le dépôt de particules et, par le fait même, l'élimination des agents polluants. À part le zinc et l'arsenic, le ruisseau avait des concentrations de métaux très faibles. En outre, les concentrations de métaux nettement plus faibles dans les sédiments en aval donnent à entendre que Blenkinsop Lake, plutôt que les champs environnants, est la source de la plupart des métaux présents dans le ruisseau. Le ruisseau avait également des valeurs d'oxygène dissous extrêmement basses, probablement en raison de l'état anoxique de Blenkinsop Lake, ce qui explique pourquoi il ne peut entretenir de populations de poissons pour le moment.

Leeds

Résultats :

- *Éléments nutritifs* : À toutes les dates d'échantillonnage sauf une, le tronçon inférieur du ruisseau avait un niveau d'azote considérablement moins élevé qu'au ponceau d'entrée. À l'exception d'une lecture anormale, le taux d'élimination moyen était de 45,2 %. Le cours d'eau a également éliminé le phosphore à tous les échantillonnages sauf deux, qui ont eu lieu pendant des périodes de crue où le temps de séjour n'a peut-être pas été assez long pour permettre au cours d'eau d'assimiler les éléments nutritifs.
- *Solides en suspension* : Le débit rapide de Leeds Creek pendant la majeure partie de l'année empêche le dépôt de nombreuses particules, ce qui explique que les solides dissous ont augmenté lors de la plupart des dates d'échantillonnage. Le ruisseau a tout de même éliminé une partie du chlorure.
- *Température* : La température de l'eau a été réduite en moyenne de 2,12 °C de la prise d'eau à la sortie d'eau.
- *Métaux* : Étant donné que les matières en suspension ne se sont pas déposées, les métaux ne se sont pas déposés non plus, et aucune réduction des métaux n'a été notée.
- *Composition chimique des sédiments* : À l'automne, les concentrations de tous les métaux clés (sauf le plomb) étaient plus élevées en aval qu'en amont. À l'hiver et au printemps, cependant, cette tendance a été inversée – probablement en raison de l'afflux printanier de sédiments – et les concentrations d'arsenic, de chrome, de cuivre, de plomb et de zinc en aval étaient inférieures à celles mesurées en amont.
- *Bactériologie* : Le nombre de coliformes fécaux à l'entrée du ponceau était élevé et a atteint un sommet le 6 février 2008 avec une valeur de 50 800 UFC/100 ml et 1,1 UFC d'entérocoques.

Conformité :

- *Eau* : L'eau en amont a dépassé les niveaux recommandés d'arsenic une fois. L'eau des deux sites a dépassé les critères de cuivre à huit reprises, de chrome à trois reprises, de plomb à neuf reprises et de mercure à cinq reprises. Les niveaux de zinc ont été dépassés une fois à la prise d'eau et sept fois à la sortie d'eau.
- *Sédiments* : Les niveaux recommandés d'arsenic, de cadmium et de plomb ont chacun été dépassés une fois à la sortie d'eau. Le niveau de plomb a également été dépassé deux fois à la prise d'eau. Les niveaux de chrome et de zinc étaient près ou au-dessus des recommandations dans tous les sites et lors de tous les échantillonnages, sauf en octobre 2006 à la prise d'eau. Les niveaux de cuivre ont été dépassés de façon constante dans tous les échantillons. Le mercure était élevé à la sortie d'eau à deux reprises et a dépassé les niveaux recommandés une fois à la prise d'eau.
- *Bactériologie* : Conforme.

Sommaire : Leeds Creek a éliminé de manière très efficace la chaleur, l'azote et l'orthophosphate des eaux pluviales, sauf durant les périodes de crue. Toutefois, le ruisseau a un débit trop rapide pour éliminer efficacement les métaux et tous les sédiments en suspension, sauf les plus lourds.

Comparaison avec les meilleures pratiques de gestion traditionnelles des eaux pluviales

Pour comparer les résultats de cette étude avec ceux de la base de données des MPG, les valeurs médianes obtenues aux prises d'eau et aux sorties d'eau ont été calculées uniquement d'après les échantillons qui étaient décelables. Cela n'a donné lieu qu'à une estimation très approximative. Par conséquent, ces comparaisons servent uniquement à évaluer les performances des terres humides de Saanich et à déterminer si elles devraient être entretenues différemment ou remplacées par des traitements des eaux pluviales plus traditionnels.

Résultats :

- *Cadmium* : La concentration médiane en cadmium à la sortie d'eau de Baxter Pond (le seul projet comportant assez de données sur le cadmium pour permettre d'effectuer une comparaison) correspondait à environ la moitié de la valeur de la sortie d'eau la plus basse de la base de données. Ainsi, il semble que l'étang ait une aussi bonne performance que n'importe quelle autre MPG à cet égard.
- *Cuivre* : L'élimination du cuivre dans les terres humides de Willowbrook et de Glanford était comparable à celle des MPG de bassins d'orage et de biofiltres. Baxter, Blenkinsop et Leeds n'ont pas éliminé efficacement le cuivre.
- *Chrome* : En général, le chrome n'était pas présent dans les eaux pluviales de Saanich, sauf dans Leeds Creek, dont le débit est trop rapide pour éliminer efficacement ce constituant.
- *Plomb* : À Blenkinsop, le nombre de valeurs de plomb mesurées n'a pas été suffisant pour permettre d'établir une comparaison. Willowbrook et Glanford ont tous deux exporté du plomb, mais les valeurs de l'effluent se situaient dans les mêmes paramètres que des eaux traitées par des biofiltres, des systèmes hydrodynamiques et des terres humides, et bien en deçà des valeurs d'effluent des bassins d'orage.
- *Zinc* : Baxter Pond et Blenkinsop Creek ont tous deux été aussi efficaces pour réduire le zinc que toute autre MPG, à l'exception du bassin de retenue. Glanford et Willowbrook, pour leur part, ont été des exportateurs nets de zinc.
- *Total des solides en suspension* : La qualité d'effluent de Glanford en matière de TSS a dépassé toutes les MPG. Blenkinsop s'est situé aisément dans les paramètres d'un bassin d'orage et d'un système de biofiltre. Baxter Pond et Leeds Creek n'ont pas éliminé le TSS, et Willowbrook a exporté le TSS.
- *Orthophosphate* : Seul Blenkinsop Creek a éliminé avec efficacité l'orthophosphate. Les autres sites étudiés ont été de nets exportateurs. Une tendance similaire est consignée dans la base de données des MPG; les bassins de retenue ont peu d'effet sur le phosphore total, et les biofiltres sont des exportateurs nets.
- *Nitrate* : En général, la réduction de nitrate a été importante dans tous les sites sauf Blenkinsop, dont les données ont été faussées par l'exclusion des valeurs non décelables, mais qui a éliminé 20 % de nitrate en moyenne. Willowbrook est très semblable à un bassin de retenue, alors que Glanford et Baxter se comparent à un bassin d'orage et à un biofiltre.
- *ATK et azote total* : Willowbrook et Baxter ont été des exportateurs nets de TKN, mais ont réduit l'azote total et le nitrate à un niveau comparable à celui d'un bassin de retenue ou d'un bassin de terres humides. Blenkinsop a éliminé l'ATK et l'azote total à des taux comparables à ceux d'un bassin de retenue, alors que Glanford a dépassé toutes les données des MPG en matière d'élimination de l'ATK, et sa capacité à éliminer l'azote total a été comparable à celle d'un bassin de terres humides.

CONCLUSIONS

- Les systèmes de traitement de Saanich, même ceux de petite taille comme celui de Glanford, traitent efficacement les agents polluants des eaux pluviales, et leur rendement se compare aux Pratiques exemplaires de gestion consignées dans l'International Stormwater Best Management Practices Database.
- Les terres humides de Willowbrook et de Baxter Pond ont besoin d'entretien. Les sédiments devraient être nettoyés régulièrement pour éviter l'exportation de solides en suspension et de métaux connexes.
- Les terres humides de Willowbrook et de Glanford ainsi que de Leeds Creek et de Baxter Pond ont tous réduit considérablement les températures de l'effluent, ce qui est un facteur clé pour protéger Blenkinsop et Swan Creek de même que l'habitat du saumon de Colquitz River.

- Tous les sites, à différentes périodes, ont dérogé aux critères établis dans les Recommandations pour la qualité des eaux au Canada en vue de la protection de la vie aquatique en ce qui a trait aux métaux lourds.
- Les cours d'eau peuvent être plus efficaces si on améliore leur état fonctionnel. La sinuosité et le temps de séjour accrus dans Blenkinsop Creek près de la ferme Galeys ont également contribué à piéger efficacement les sédiments et à éliminer les métaux et les éléments nutritifs.
- Contrairement aux bassins de retenue artificiels, les systèmes étudiés fournissent un habitat faunique, des panoramas, la séquestration de carbone, la régulation thermique et agissent en outre comme tampon pour les cours d'eau avoisinants.

CONSÉQUENCES POUR LE SECTEUR DE L'HABITATION

Les solutions écologiques peuvent s'avérer tout aussi efficaces ou encore plus efficaces que les meilleures pratiques de gestion traditionnelles pour gérer et traiter les eaux pluviales, et leur intégration à de nouveaux aménagements résidentiels et à des aménagements résidentiels existants devrait être envisagée. Étant donné l'attrait de telles installations, celles-ci pourraient même rehausser la valeur reconnue aux ensembles résidentiels.

Directeur de projet à la SCHL : Cate Soroczan

Consultants pour le projet de recherche : Aqua-Tex Scientific Consulting Ltd.

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Executive Summary

A stormwater quality monitoring program, sponsored by the Canada Mortgage and Housing Corporation (CMHC) and the Federation of Canadian Municipalities (FCM), was undertaken by Aqua-Tex at five wetland treatment sites and two stream restoration sites in Saanich to assess their treatment performance relative to more conventional stormwater treatment systems. Water and sediment samples were taken 10 times over the 14-month period from October 2006 to December 2007.

Findings

1. The Saanich treatment systems are effective at treating stormwater pollutants and their performance is comparable with the Best Management Practices recorded in the International Stormwater Best Management Practice (BMP) database.
2. The Willowbrook and Baxter Pond wetlands demonstrate that they require maintenance to remove accumulated sediment and prevent export of suspended solids and associated metals.
3. The Glanford wetland performed very well, especially given its small size.
4. Willowbrook, Glanford, Leeds Creek and Baxter Pond all significantly reduced the temperature of their effluent waters prior to the discharge into their respective receiving streams. This is a key factor is protecting Blenkinsop and Swan Creeks and the salmon habitat of the Colquitz River.
5. All sites, at different times, did not meet the criteria outlined in the Canadian Guidelines for Aquatic Life for heavy metals.
6. This study has demonstrated that streams can be made more effective by improving their functional condition (through restoration). The increased sinuosity and retention time in Blenkinsop Creek near Galeys' farm make it effective at trapping sediment and removing metals and nutrients.
7. Unlike engineered wet ponds, the systems in Saanich provide a community amenity in the form of wildlife habitat, views, carbon sequestration in the riparian areas, thermal regulation including shade for neighbouring trails and homes, and act as a physical buffer for their neighbouring streams.

Recommendations

1. Where space permits, Saanich should continue to develop "ecologically engineered" wetlands and stream buffers to treat and control the stormwater from adjacent developments.
2. A maintenance plan should be provided with each installation and the maintenance intervals added into Saanich Parks and Engineering's routine schedules; collaboration on management of these systems will be needed.

3. A record of the cost of building and maintaining these systems, as well as notes on how they might be improved in the future, should be systematically recorded in order to assess their economic performance as well as their ecological performance.

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Objective

For several decades, direct discharge to receiving streams or detention basins has been the customary prescription for managing stormwater. Recently, “low impact” or “conservation design” principles use measures, such as vegetated swales and constructed wetlands, to maintain a nearly natural water budget and improve water quality (Braden and Johnston, 2004). In Saanich, these principles have been taken one step further to design stormwater management in association with stream and wetland restoration, with a goal of improving and augmenting aquatic and riparian habitat.

There are many studies documenting the efficacy of engineered stormwater treatment facilities; however, few have examined the ability of naturalized wetlands and streams to treat stormwater pollutants. This study examined four stormwater installations within the District of Saanich as well as two stream restoration projects. Each stormwater site was designed to attenuate storm flow, reduce thermal loading (shock) to the receiving stream and to reduce particulates reaching the stream. Since between 12 and 94% of metals are known to be associated directly with particulate matter (TSS), it was felt that if the particles could be settled out of the runoff, then the installation would accomplish its task of improving stormwater quality (USEPA, 2000). The plants in the wetlands would assist in nutrient uptake and denitrification. Each system had habitat enhancement as a primary goal, therefore wetlands and streams were designed with habitat as a priority over removal of specific pollutants, however it is important to understand the ability of these systems to treat pollutants (thus this study). Our photographic evidence and anecdotal information on bird populations suggests that these sites have high habitat value and contribute to healthy neighbourhood greenspace. This study thus sought to address the outstanding question of the effect of these installations on stormwater quality.

Study Design

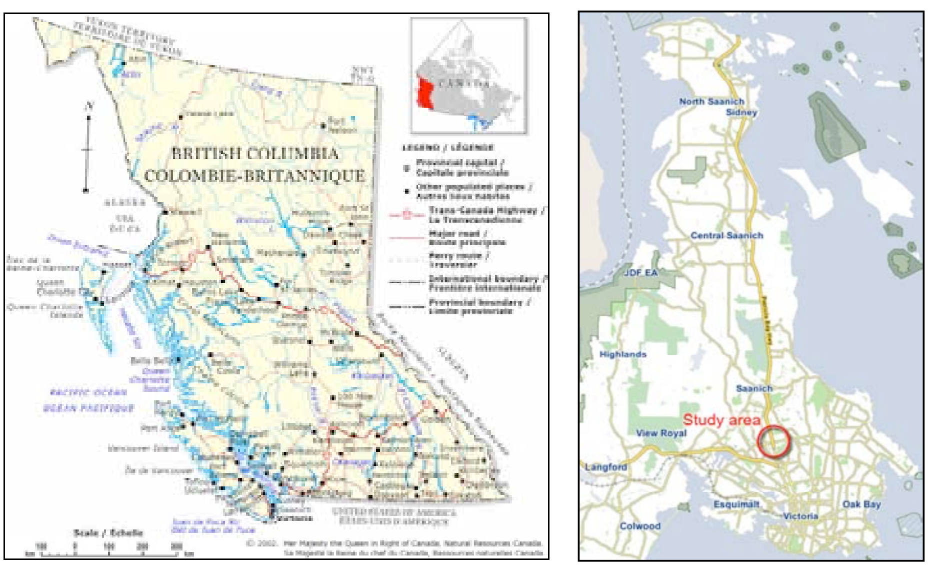
Comprehensive stormwater monitoring studies are normally undertaken by university researchers or institutions with significant equipment and resources. A complete assessment requires detailed water balance measurements and modelling over several years to capture a wide range of storm events and environmental conditions, as well as to provide an adequate number of samples under each of these conditions in order to be statistically significant. *In-situ* pump samplers, piezometers, v-notch weirs and rain gauges all require careful monitoring to prevent vandalism and ensure long-term operation. Given the locations of our study sites (unattended residential areas) and the limitation of the budget, this study used grab samples, over a range of storm events, to estimate the pollutant removal efficiency of each installation.

In order to compare effectiveness and performance between sites, water column chemistry/metals analyses, sediment chemistry/metals analyses and bacterial analyses were undertaken. The sites chosen were: Willowbrook subdivision, Vancouver Island Technology Park (VITP), Baxter Pond, Blenkinsop Creek, and Leeds Creek. These projects varied in age and size, but all were designed to reduce the negative effects of stormwater on local streams, all were designed and constructed by the same company, all are within the District of Saanich and all are tributaries of the Colquitz River. The sites can be divided into two groups: wetland installations that treat stormwater “off-line” before discharge into a receiving water (Willowbrook, Baxter Pond and VITP) and “in-line” stream enhancement projects (Leeds, Blenkinsop Cr.) where ditches were restored back to functional creeks with the appropriate instream vegetation, floodplain, channel morphology and complexity. In the case of the off-line wetland installations, sample locations were selected on each receiving stream upstream and downstream of the stormwater installation, and at the inlet and outlet of each installation. In the case of Leeds and Blenkinsop Creek, sample locations were selected upstream and downstream of the restored stream reach and samples of stormwater discharge into the streams were taken to assess inputs and subsequent fate and transport of the pollutants. A brief description and associated reasoning for the selection of each site is listed below.

Fortunately, precipitation data were available from five school-based meteorological stations, run by the University of Victoria, adjacent to each site. Both a field and laboratory quality assurance program was implemented to ensure that the data collected were as accurate and precise as possible (see Appendix A). Data quality objectives were set and repeat photographs and field notes were taken to document the seasonal changes at each site (Appendix B). Samples were analyzed for a suite of nutrients and metals, with a focus on those that directly affected plant production and those that were known to be associated with road runoff and aquatic toxicity. Temperature measurements were taken to assess thermal loading and dissolved oxygen measurements in each stream provided one measure of habitat suitability for fish.

Study Sites

All of the study sites are tributaries of the Colquitz River. This stream is an urban salmon-bearing system and flows from its headwaters at Elk Lake near Saanich’s northern boundary, twenty-one kilometers south through the community to its outlet in Portage Inlet (Figure 1 and Figure 2).



(Source: Natural Resources Canada; CRD Natural Areas Atlas)

Figure 1. Location of the study area.

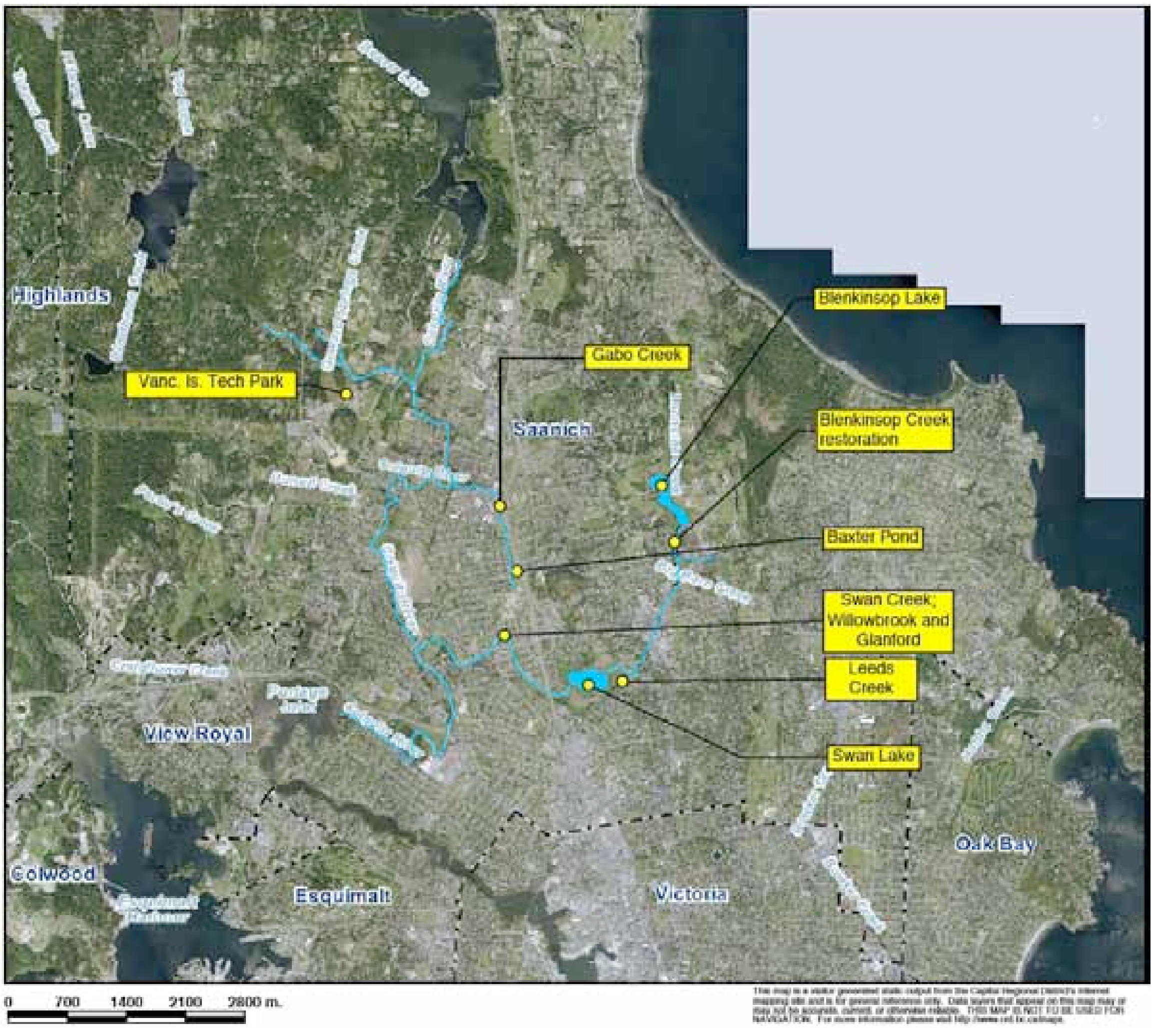


Figure 2. Colquitz watershed showing study site locations.

Willowbrook

The most complex site was Willowbrook subdivision, an in-fill residential development on former agricultural land (Figure 3). A cow pasture, surrounded by development on three sides, with a major arterial road on the fourth side, was redeveloped to accommodate 35 homes. A part of this development, Swan Creek, which had previously been ditched and relocated along one edge of the pasture, was reconstructed complete with a small floodplain and in-stream channel complexity to improve aquatic habitat (Figure 4 - Figure 6). Wetlands were developed along the east side of the stream to attenuate stormwater from the development and to capture pollutants before they reached Swan Creek. A second linear wetland was constructed to the north of the development, along a sewer right-of-way, to provide treatment for stormwater coming from a neighbouring development as well as a portion of the Willowbrook development.

Figure 3. Agricultural field at 650 McKenzie Avenue, prior to the development of the Willowbrook subdivision and wetland complex.

Figure 4. The Willowbrook subdivision and wetland complex six years after construction.

Figure 5. Swan Creek in the first winter following construction. The realigned channel and new pond are at the left, the old channel (ditch) remains on the right.

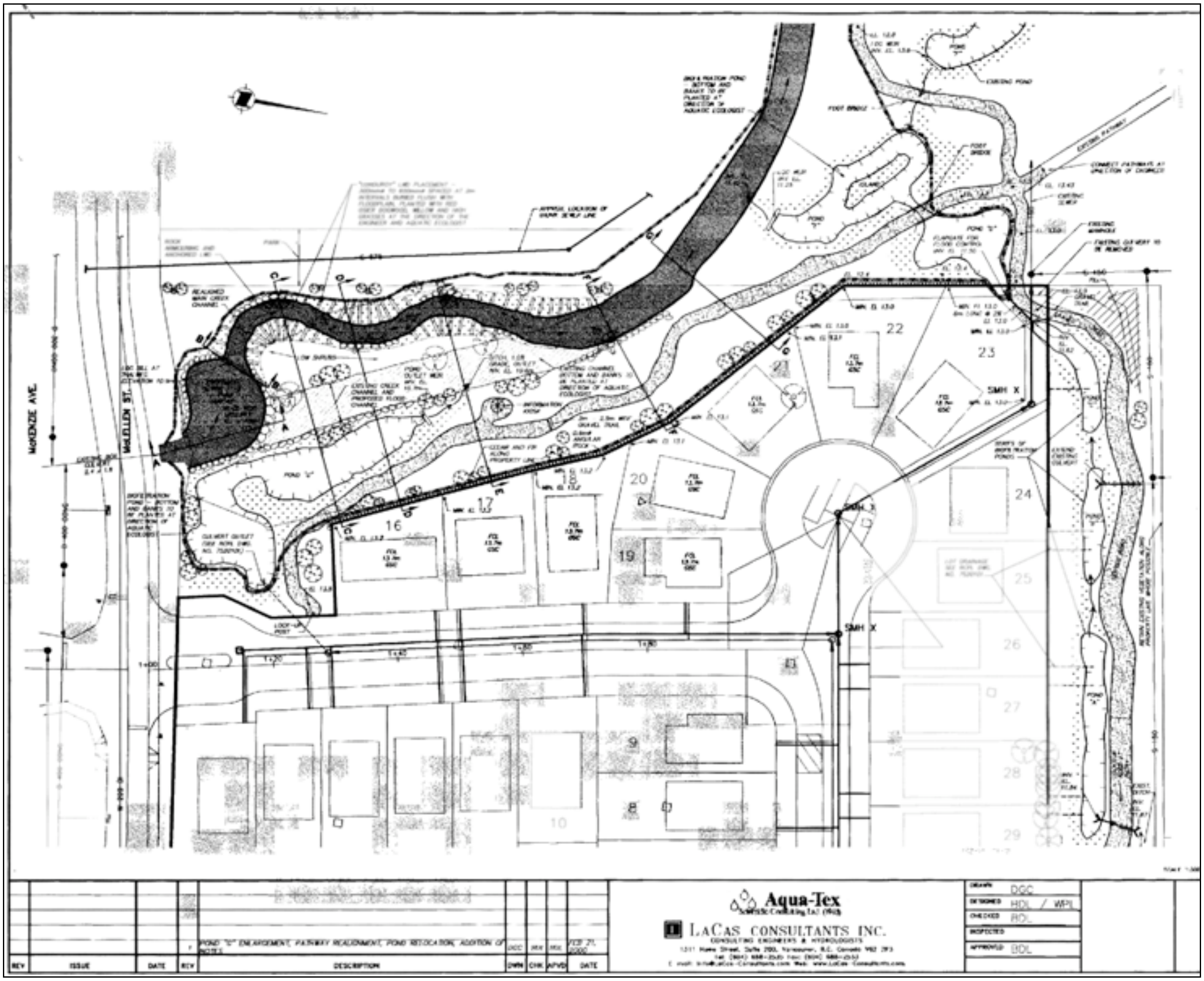


Figure 6. Willowbrook plans showing rebuilt stream channel and intended fate of stormwater flows.

Glanford Station

To the northwest of the Willowbrook site, and as part of the same wetland complex, a small settling pond (forebay) and wetland was built in association with the Glanford Station development. This small wetland drains into Swan Creek just downstream of where the flow from the Willowbrook development enters Swan Creek. It was therefore assessed as part of the Willowbrook complex.

Sample sites were located upstream of the Willowbrook subdivision (W9) at the inlet to the main wetland (W7) and the outlet of the main wetland (W6) in Swan Creek below the main wetland outlet (W8), at the inlet to the chain of wetlands (W5), at the outlet of the linear wetland (W4), at the inlet to Glanford pond (W3) at the outlet from Glanford pond (W2) and in Swan Creek downstream of the wetlands (W1) (Figure 7).

Figure 7. Willowbrook and Glanford Station sample sites. Swan Creek flows from the south to the north and then curves west and southwest toward the Colquitz River.

Baxter Pond

In the early 1990's, Baxter Pond was developed as a dry detention pond to take runoff from the adjacent Pat Bay Highway. This design was not particularly effective because the plants would die off each year when the pond dried out (Figure 8). In 2001 Baxter Pond was redesigned as a wetland pond, with open water in the deepest portions, to treat stormwater from the newly developing Rogers Farm Subdivision on the slopes above the pond and to provide wetland habitat. The area where Baxter Pond was located was previously a wetland that had been filled in as part of the construction of the Pat Bay Highway and this project sought to restore a portion of that habitat. This wetland complex also receives stormwater run-off directly from the Pat Bay Highway and Pacific Christian School. Baxter Pond discharges into Gabo Creek which is a tributary of the Colquitz River.

Figure 8. Dry detention pond prior to reconstruction as Baxter Pond.

Figure 9. Baxter Pond May 2006.

Sample sites were located upstream of Baxter Pond on Gabo Creek (G5), at the inlet to Baxter Pond (G4), mid-way along Baxter Pond (G3), at the outlet of the pond (G2), and downstream of the pond on Gabo Creek (G1). Partway through the study an additional stormwater outlet was located (previously dry) which drained the Hawkes Avenue area (G1a) (Figure 10).

Figure 10. Baxter Pond sample locations. Stormwater flows into Baxter Pond from the right and then north through the pond into Gabo Creek which also flows north.

Blenkinsop Creek

Blenkinsop Creek drains out of Blenkinsop Lake which receives agricultural and urban runoff from the Blenkinsop Valley. The lake used to extend almost a kilometer further south than it presently does. In the early 1900's a channel was blasted to drain the lake and create land for a subdivision. This process was interrupted by the First World War, and the land was turned into farmland to take advantage of the rich soils laid down in the lake. "Blenkinsop Creek" was thus connected to Cumberland Brook and what is now known as "Big Barn Creek," both of which have also been ditched as a result of farming practices over time (Figure 11 top). Blenkinsop Creek flows south almost two and a half kilometers into Swan Lake.

The intent of the Blenkinsop Creek restoration project was to rebuild approximately 650m of Blenkinsop Creek into a stream (Figure 11 middle and bottom), recreate aquatic habitat and bird habitat, attenuate flood flows and reduce the soil erosion and nutrient input from a neighbouring farm. Because these lands were once a lake bed, the soils are very rich in organics and nutrients, which contributes to eutrophication in Swan Lake.

Figure 11. Blenkinsop ditch (top) and Galeys' field (middle) prior to the realignment and restoration of Blenkinsop Creek. (Bottom) the realignment during construction.

Unlike the other sites in this study, limited historical sampling data were available for Blenkinsop Creek. Sites in this study followed the old locations as closely as possible, given the realignment of the channel. Sites were located near the outlet of Blenkinsop Lake, downstream of the weir and upstream of Galeys' field (B6a), midway along Galeys' field (B5a), at the south end of the field, upstream of the confluence with Cumberland Brook (B4), at the discharge of the tile drain from Galeys' field (B3a) and downstream on Blenkinsop Creek at Cumberland Dam (B4) (Figure 12).

Figure 12. Blenkinsop Creek sample locations. Blenkinsop Creek flows south from Blenkinsop Lake toward Swan Lake. Cumberland Brook flows from east to west, into Blenkinsop Creek.

Leeds Creek

Leeds Creek is within the Swan Lake Christmas Hill Nature Sanctuary. It is a tributary to Blenkinsop Creek, which, in turn, flows into Swan Lake, out into Swan Creek and into the Colquitz River. Formerly a wetland and small creek, the area had been ditched and drained for farming and was maintained as a field for many decades. Saanich obtained the farm as part of the nature sanctuary in the 1978 (Edmonds, 2002). Surrounding development resulted in stormwater runoff entering the former field via a culvert. Once the field was no longer cultivated, the reed canary grass took over and effectively plugged the culvert outlet, resulting in flooding of the neighbouring subdivision. The proposed solution was to dig a ditch across the field, to allow the runoff to enter Blenkinsop Creek unimpeded. At the suggestion of Aqua-Tex, a stream channel and shallow pond complex were reconstructed instead, and the idea of a ditch was abandoned. Construction of this creek included structuring the channel so that the water could access the entire site as a flood plain, thus filtering and treating it prior to discharge into Blenkinsop Creek.

Sample sites were located at inlet to Leeds Creek (L3) (a culvert), approximately 100 m downstream on Leeds Creek, upstream of the confluence with Blenkinsop Creek (L1) and on Blenkinsop Creek upstream of its confluence with Leeds Creek (L2) (Figure 13). During the course of sampling, another storm outlet was located downstream of site L1 and was designated L1a.

Figure 13. Leeds Creek sample site locations. Leeds Creek begins in a culvert at the lower right and flows northwest toward Blenkinsop Creek which is flowing south and then east towards Swan Lake.

Vancouver Island Technology Park (VITP)

The present Vancouver Island Technology Park was formerly the Glendale Lodge Hospital. In 2000, the building was redeveloped, and stormwater ponds and channels were created on two sides of the property in order to provide maximum detention and infiltration, and capture runoff from adjacent parking areas at Camosun College and Layritz Park. A permeable grass/gravel pave parking lot was installed to replace the existing asphalt parking lot and a reservoir and infiltration system with overflow drains was installed beneath it.

The VITP site drains into Goward Springs Creek which then flows into Quick’s Bottom and the Colquitz River. The three stormwater wetland ponds were designed to serve both the existing impermeable areas and future development on site. Thus, they were oversized to accommodate future site development.

The pond on the west side of the building was designed to take groundwater and stormwater from future development. Water enters from a neighbouring field at site V5a and flows out of the pond at V5b (Figure 14). It then flows through a small channel into a large manhole which aggregates drainage from the main parking lot to the southeast of the building (grass pave) from the road along the front (south east) of the building as well as some drainage from Layritz Park and Camosun College (east). From the manhole, water is carried in a large (~1000mm) concrete culvert to Goward Springs Creek (V4b). Two additional wetlands were constructed on the northeast side of the building with the upper pond (V3) designed to cascade into the lower pond (V2) before entering Goward Springs Creek. Drainage from the access road along the front of the building and the main (grass pave) parking lot overflow collect in a swale along Markham Road (V6) so a sampling location was established there (Figure 15). Finally a sampling location was established on Goward Springs Creek just upstream of the confluence with the drainage from Layritz Park (V1).

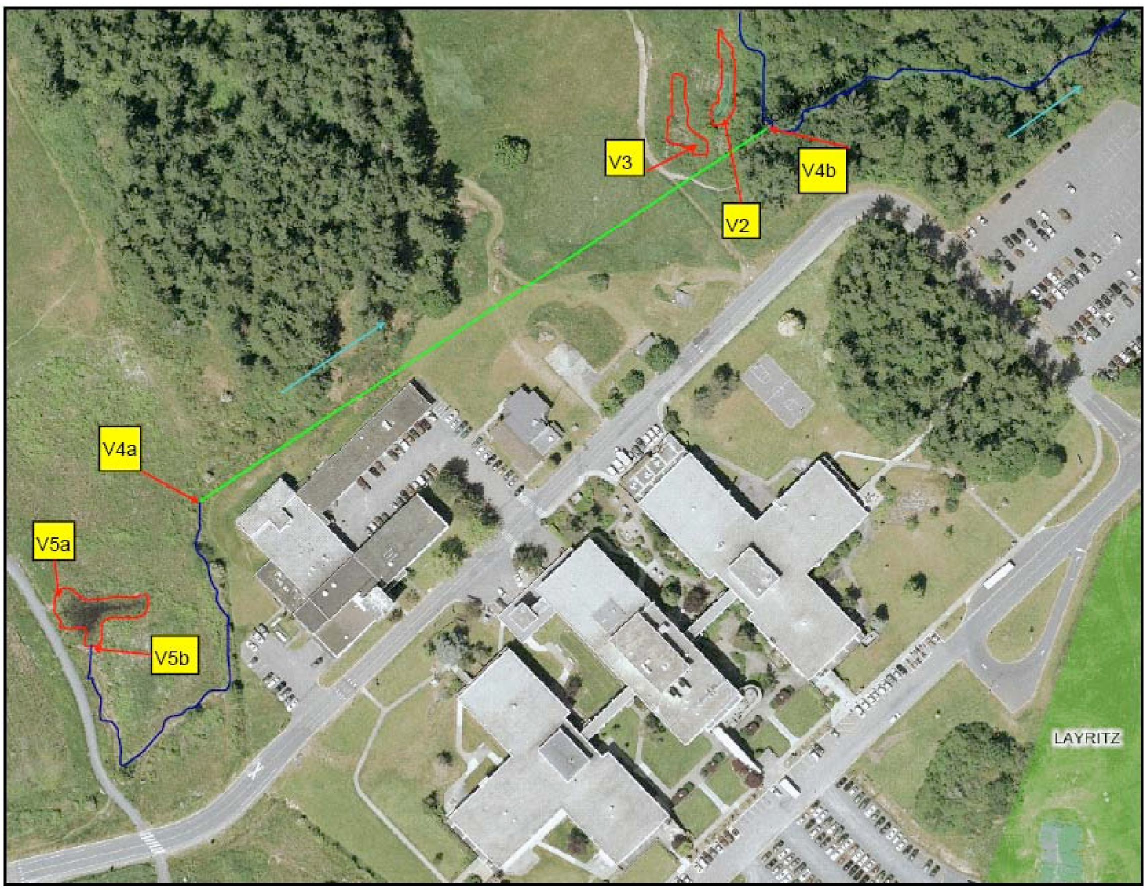


Figure 14. VITP sample site locations. Water generally flows southeast to northwest (L to R), with Goward Springs Creek flowing generally east into Quick's Bottom.

Figure 15. VITP sample sites at outlet of culvert draining the access road and on Goward Springs Creek.

Sampling Program

Samples were taken over the course of 14 months to assess the performance of the stormwater installations throughout the full range of seasons. Whenever possible, samples were taken during storm events; however 2007 was a very unpredictable year and fall 2007 was very dry. If a storm event had not been captured in the previous four weeks, samples were taken to represent the ambient conditions and complete the sampling record. Water chemistry and bacteriology samples were taken approximately monthly during the fall, winter and spring months, and were not sampled during the summer months due to the low water levels. Sediment chemistry samples were taken at the start of the program (fall 2006), in the spring of 2007 following the end of the winter storms, and again in the fall of 2007 at the end of the sampling program.

Water samples were taken ten times: Oct. 14/06, Nov. 3, Dec. 3, Jan. 11/07, Feb. 6, Mar. 9, Apr. 10, May 7, June 11, July 20 and Dec 17/07. Dissolved oxygen, specific conductance and pH were monitored at each site with a hand held multi-meter on a monthly basis, including over the summer.

The parameters measured were:

Alkalinity, Ammonia, BOD (May only), Chloride, Dissolved oxygen, Nitrate, Nitrite, Ortho-P, pH, Specific conductance, Total Ddissolved Solids (TDS), Total Extractable Hydrocarbons (TEH) at selected sites, Total Kjeldahl Nitrogen (TKN), Total colour, Total Suspended Solids (TSS), and Turbidity. We also measured phenols in May.

In addition, water samples were analysed regularly for metals and sediments were analysed three times (fall 2006, spring 2006 and fall 2007). The metals included were:
Aluminum, Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Chromium, Cobalt, Copper, Gold, Iron, Lanthanum, Lead, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Phosphorus, Potassium, Scandium, Selenium, Silicon, Silver, Sodium, Strontium, Tin, Titanium, Tungsten, Vanadium, Zinc.

The data are graphed on a parameter basis and the dates and parameters at which sites exceeded the guidelines for aquatic life are noted.

Methods

Sample Collection and Laboratory Analysis

Details of the sampling and analysis methods can be found in Appendix A.

Results

Precipitation

Total precipitation in 2006/2007 sampling year was normal (Table 1) however the sampling period was characterized by long periods with very little precipitation with intermittent large rain and snow events. Average annual precipitation (1971-2000 normals) for Greater Victoria ranges between 607.6 mm at Gonzales Heights to 883.3 mm at the Victoria International Airport with an average of 698.6 mm recorded at the Phyllis Street station on Ten Mile Point.

Table 1. Total Annual precipitation (mm) at the five meteorological stations used in this study.

	Rogers	McKenzie	Lakehill	Northridge	Swan Lake
2006	754.4	n/a	732	690.8	665.5
2007	695.8	691.7	665.3	762.3	611.5

As demonstrated in the plot below, precipitation trends were very close but actual precipitation was variable between the sampling sites, for a given storm event. Northridge Elementary School (nearest to VITP) consistently received more precipitation than the other sites during major rain events.

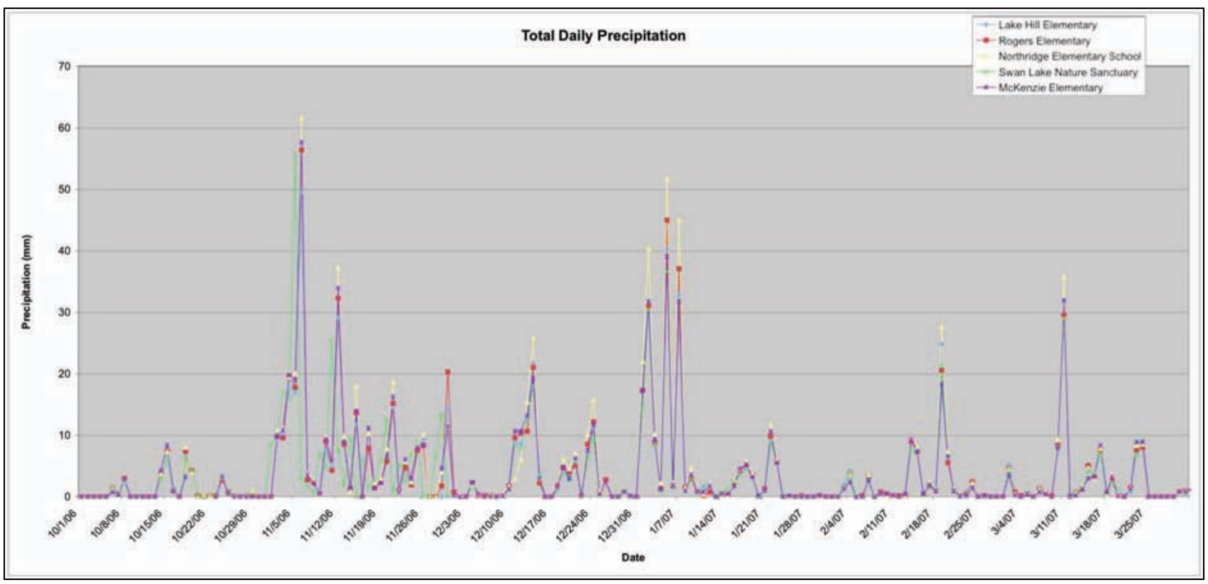


Figure 16. Total daily precipitation across all five monitoring stations from October 2006 to March 31, 2007.

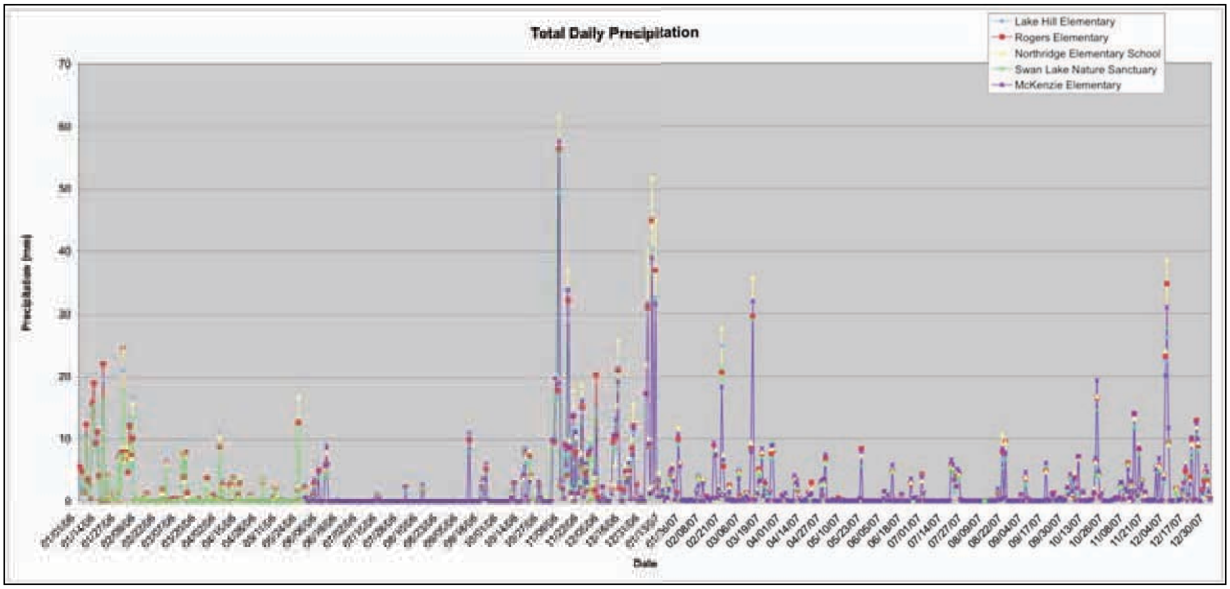


Figure 17. Total daily precipitation across all five monitoring stations from January 1, 2006 to December 31, 2007.

Willowbrook and Glanford Station

McKenzie Elementary School (4005 Raymond Rd N) is less than 500 m from the Willowbrook Subdivision. Total daily precipitation is shown in Figure 18.

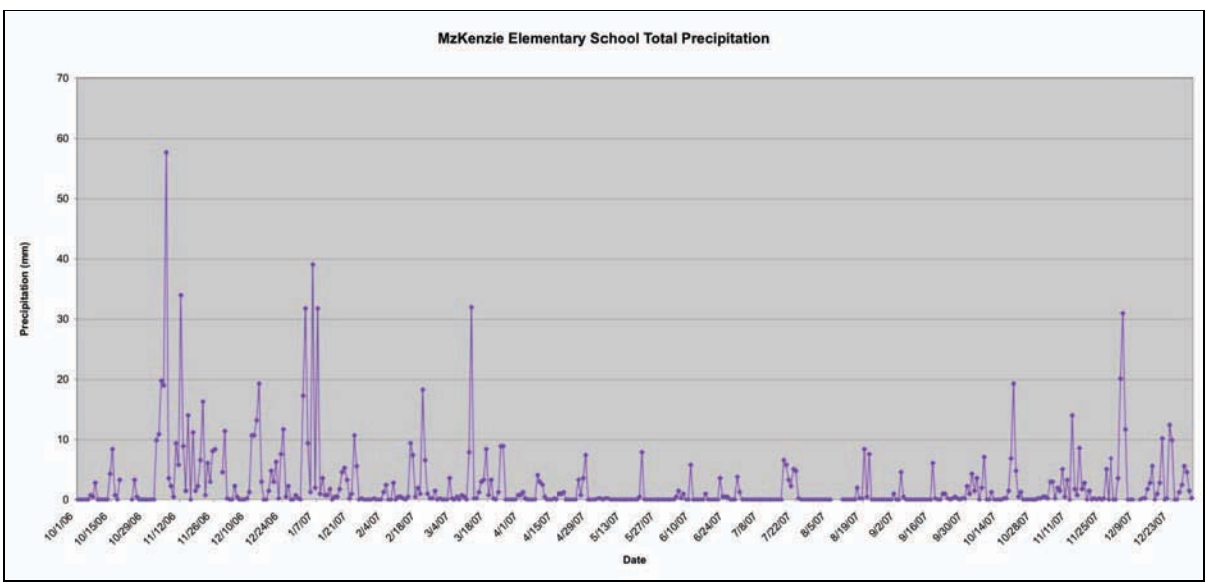


Figure 18. Total daily precipitation at McKenzie Elementary School near Willowbrook and Glanford Station subdivisions.

Baxter Pond

Rogers School (76 Rogers Ave) is immediately adjacent to the Rodgers Farm subdivision and less than 300 m from Baxter Pond. Total daily precipitation is shown in Figure 19 below.

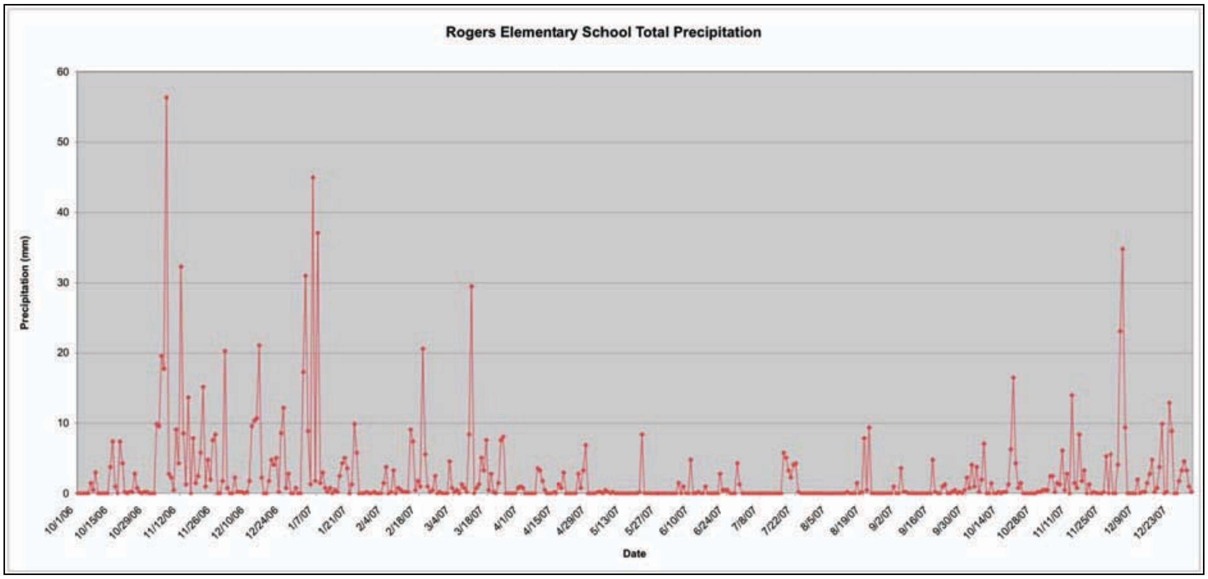


Figure 19. Total daily precipitation at Rogers School neighbouring Baxter Pond.

Blenkinsop Creek

Lakehill Elementary School (1031 Lucas Ave) is approximately 450 m west of Blenkinsop Creek. Total daily precipitation is shown in Figure 20.

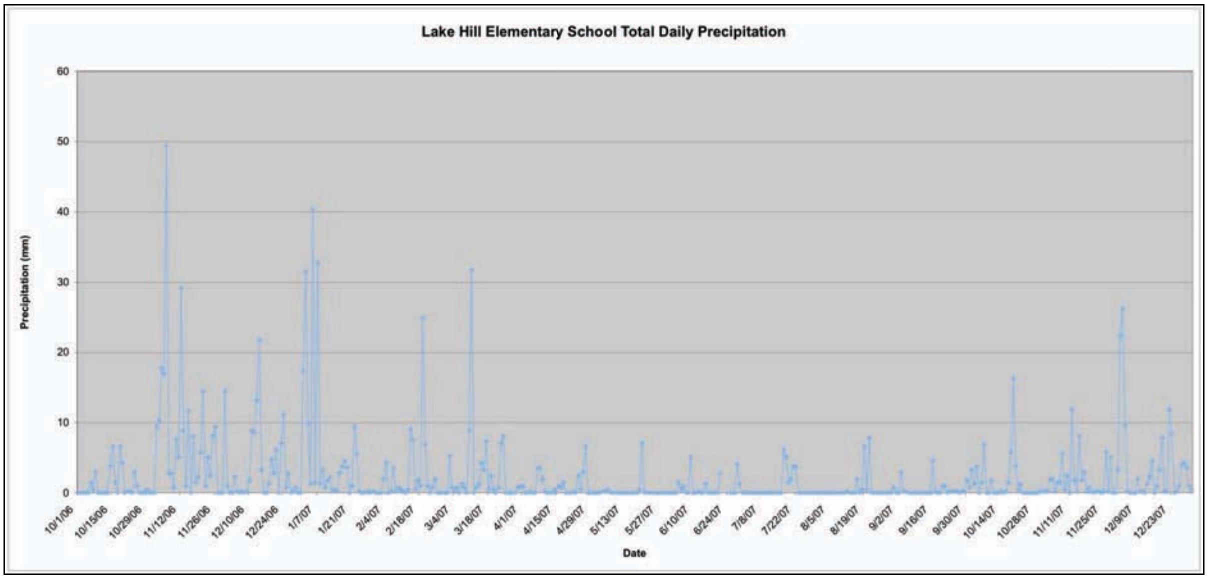


Figure 20. Total daily precipitation at Lakehill Elementary near Blenkinsop Creek.

Leeds Creek

The closest meteorological station to Leeds Creek is at the Swan Lake Nature Sanctuary is approximately 750 m from the culvert inlet to Leeds Creek. Daily total precipitation is shown below in Figure 21.

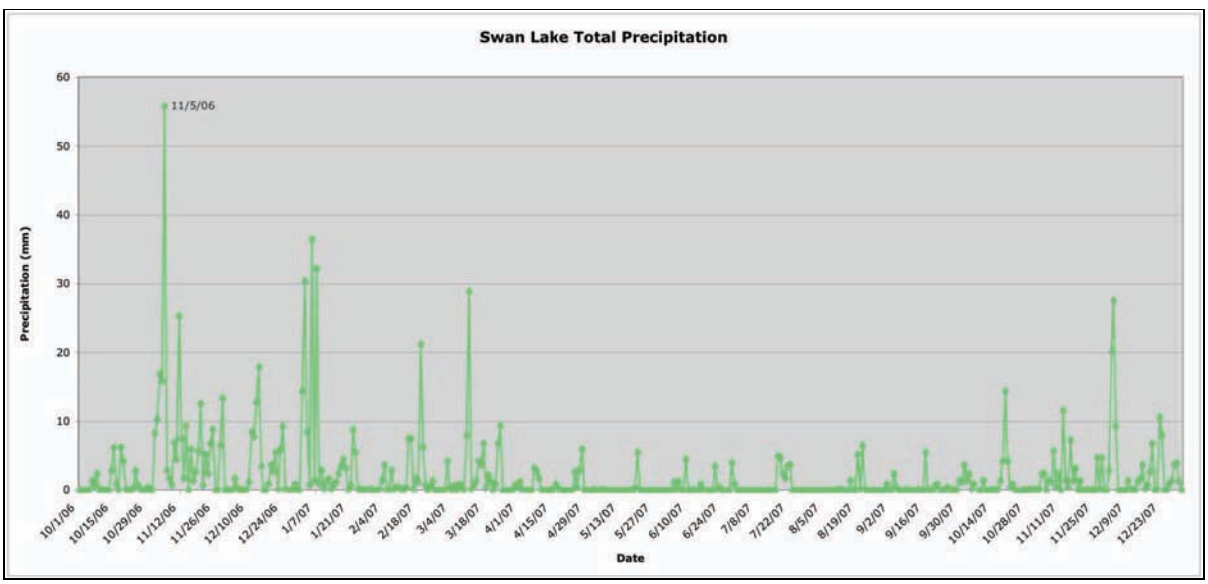


Figure 21. Total daily precipitation at Swan Lake Nature Sanctuary Oct 2006-Dec 2007.

Vancouver Island Technology Park

The closest meteorological station to VITP is approximately 1.6 km away at Northridge Elementary School (4190 Carey Rd.). Though not ideal, this station provides a reasonable approximation of precipitation. Total daily precipitation is shown below in Figure 22.

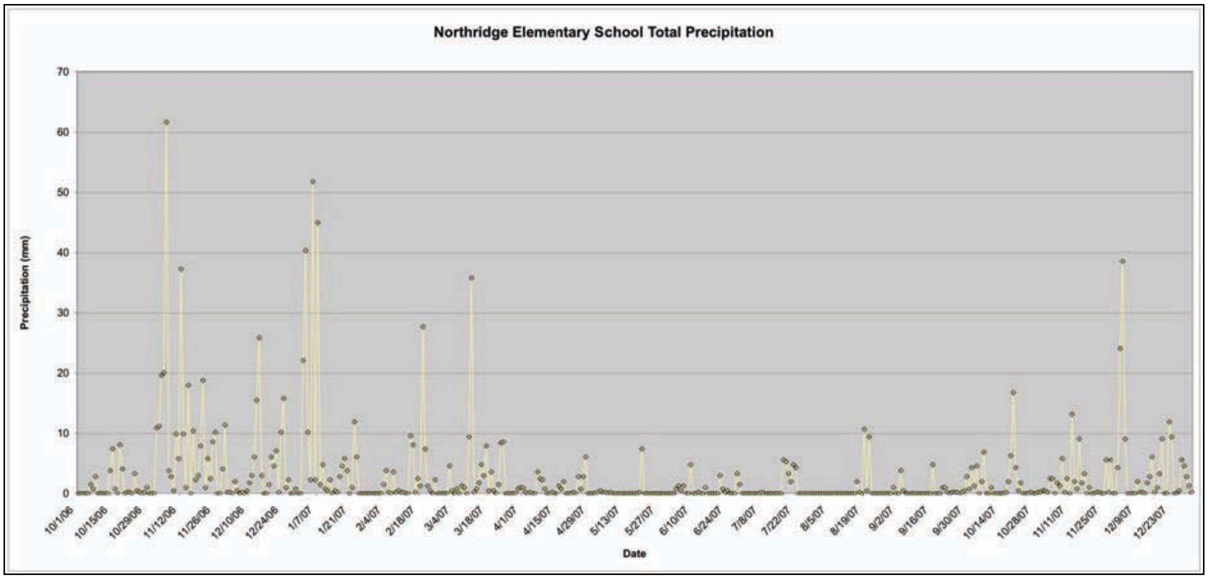


Figure 22. Total daily precipitation at Northridge Elementary School.

Water Chemistry

Nutrients

The water quality in urban streams is most significantly altered by two things: the input of excess nutrients which leads to excess plant and algal growth and subsequent oxygen depletion as the plants and algae die off, and the input of toxic substances, often in the form of metals. The two major nutrients that most affect plant growth are nitrogen and phosphorus. Stormwater treatment is intended to reduce nutrient and toxin input to the receiving streams.

“Wetlands reduce nutrients by encouraging sedimentation (Karr and Schlosser, 1978; Johnston *et al*., 1984), sorbing nutrients to sediments (see Khalid *et al*., 1977), taking up nutrients in plant biomass (Lee *et al*., 1975) and enhancing denitrification (Lowrance et al., 1984)”. Wetlands vary in their ability to take up nutrients and in the forms of nutrients that they take up. For example, in many wetlands the retention of particulate phosphorus is much greater that the retention of ortho-P (Uusi-Kamppa *et al*., 1997). Waterlogged sediments are known to release P into overlying waters (Mortimer, 1941); it is then more likely to be exported from the wetland. “Nitrogen on the other hand, may be removed from the wetland completely via denitrification, which occurs under anaerobic conditions (Jordan *et al*., 1993)” (Fisher and Acreman, 2004).

Nitrogen

The relationship between the various forms of nitrogen is complex and constantly shifting depending upon temperature and oxygen concentration both in the water and sediments. Nitrification is the process by which ammonia is oxidized to form nitrite, which, in turn is oxidized to form nitrate.

$$NH_3 + O_2 \rightarrow NO_2- + 3H+ + 2e-$$
$$NO_2- + H_2O \rightarrow NO_3- + 2H+ + 2e-$$

Denitrification requires a source of organic matter and is the process by which bacteria convert nitrate, under anaerobic conditions, back to nitrogen gas, which is then lost to the atmosphere. This is one of the major pathways that can be harnessed to strip nitrogen out of polluted water.

$$1.25\ CH_2O + NO_3 + H^+ — 0.5N_2 + 1.5CO_2 + 1.75H_20$$

Algae use nitrate and ortho-phosphate directly, together with carbon dioxide and water, to form biomass and oxygen. When the biomass decomposes, it consumes oxygen and releases nitrate and phosphate. Therefore, when algae in the streams and wetlands are actively photosynthesizing, they can be expected to take up nitrate and phosphate. In the fall, when the algae die off, they release the nutrients back into the water. In wetlands or lakes, where large amounts of biomass accumulate over many seasons, the decomposing material continues to export nutrients. Natural wetlands are well known to be net exporters of nutrients, especially phosphorus, once they reach a certain age (Nichols, 1983; Richards, 1985).

Bacteria

Both Fecal coliforms and *Enterococci* were analysed as part of this study. Fecal coliforms indicate potential pollution from human sewage, domestic animals (dogs, cats), farm animals, and wildlife including waterfowl. *Enterococci* are a specific strain of fecal bacteria and the ones most likely to cause illness in humans or pets. For this reason, the standard for marine recreational water quality is less than 350 colony forming units of *Enterococci* (CFU) per 1000 mL of water (geometric mean of 5 samples within 30 days). This is particularly important on southern Vancouver Island, since few people recreate in urban streams, but many people recreate on the ocean beaches where the streams (and stormwater) are discharged. *Escherichia coli* (*E. coli*) often, but not always, make up a large portion of the group known as “fecal coliforms”. The limit for *E. coli* is 2000 *E. coli*/L (200 CFU/100 mL) (geometric mean of 5 samples within 30 days) (Minister of Supply and Services Canada, 1992). When *E. coli*. make up more than 90% of the fecal coliforms, the test for fecal coliforms may be substituted. In this study, fecal coliforms are used as a surrogate for *E.coli* as it is the more conservative measure of pollution.

Willowbrook and Glanford

Data analysis focused on six of the nine sites at Willowbrook. Upon reviewing the data it quickly became evident that the linear wetland data (site W5, the catch basin at W5 and site W4) were complicated by additional inputs along the length of the wetland and no clear trends could be determined. The data analysis therefore focused on the inlet (W7) and outlet (W6) of the main wetland, the inlet (W3) and outlet (W2) of the Glanford wetland and the difference between the quality of Swan Creek upstream (W9) and downstream (W1) of the Willowbrook subdivision.

Willowbrook Wetland

Nutrients

The main wetland at Willowbrook was effective at removing nitrogen from the water (Figure 23, Table 2). On average, the inflow concentration of total nitrogen (as calculated by summing the ammonia, nitrate, nitrite and Total Kjeldahl Nitrogen) was 1.86 mg/L and the outflow concentration was 1.54 mg/L. Outflow concentrations were higher than inflow values in the fall of 2006, but lower on all other occasions. This wetland was consistently a significant exporter of ortho-phosphate (Figure 24). On average, concentrations leaving the wetland were 239 μg/l or 1103% higher than concentrations entering the wetland. This is likely because the sediments have been allowed to build up in the wetland, and, combined with the accumulation of dead plant material, the wetland plants are now unable to use up all the phosphorus that is entering the water either through new inputs from stormwater or from decomposition processes.

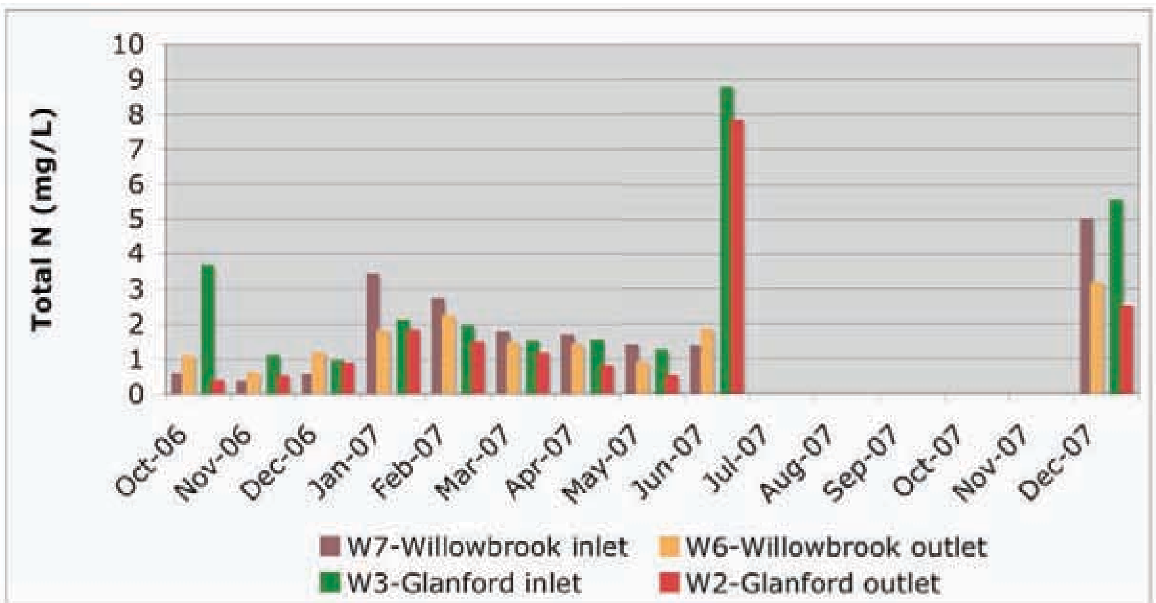


Figure 23. Total nitrogen concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

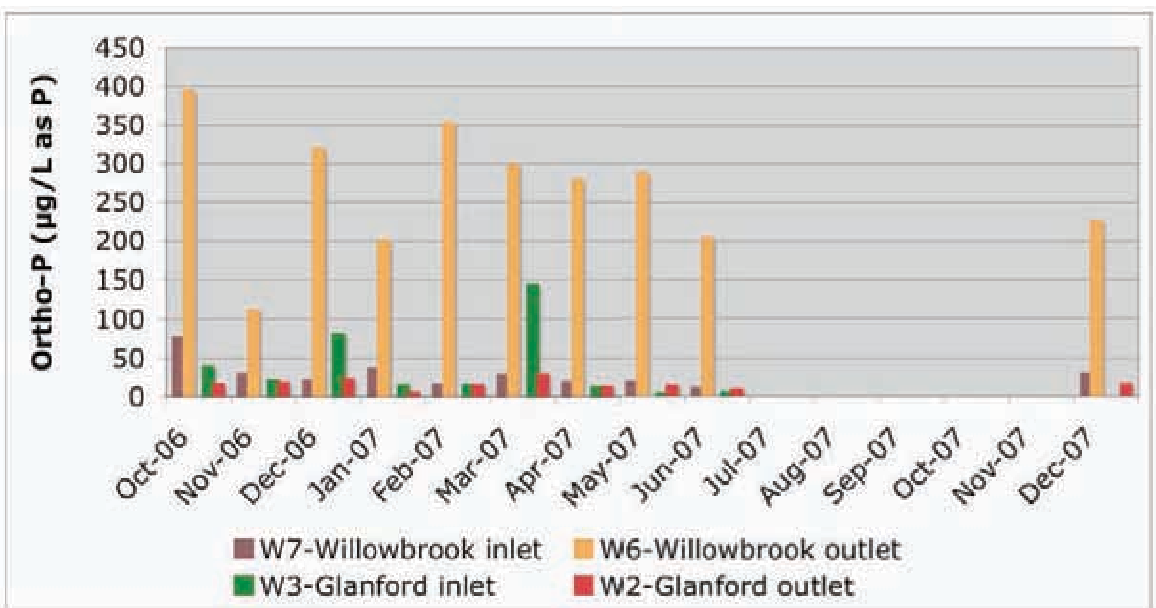


Figure 24. Ortho-P concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

The wetland was effective at reducing the total dissolved solids (TDS) in the water (Figure 25). On average, TDS was reduced by 167 mg/L (average removal efficiency of 32.7%). Chloride was reduced by an average of 9.04 mg/L, representing an average increase of 4.21% (Figure 26). This percentage is highly misleading however, because it was skewed by a single pair of samples in October where the chloride concentration increased from 2.43 to 8.2 mg/L, an increase of 237%. When this value is censored, the average removal is 10.68 mg/L or 21.7%.

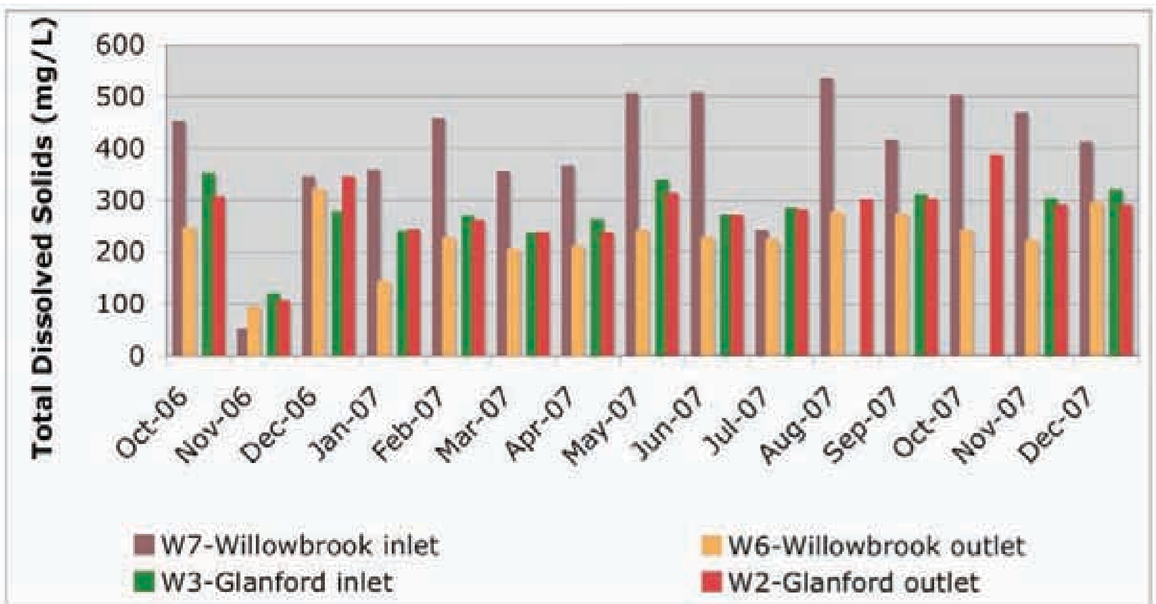


Figure 25. TDS concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

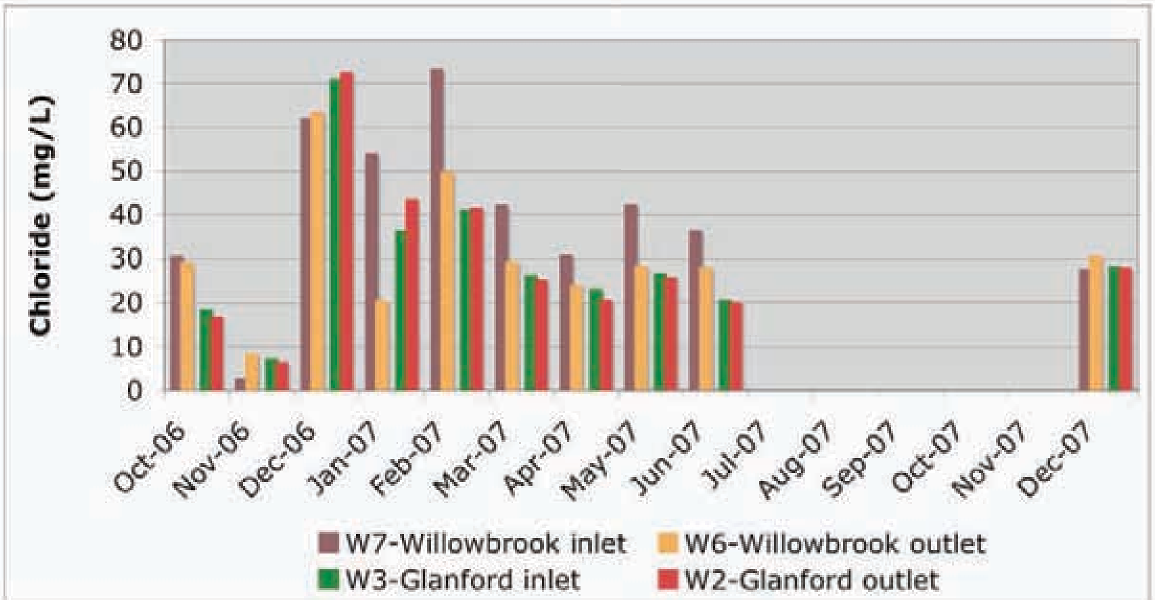


Figure 26. Chloride concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

Suspended Solids

The wetland was less effective at removing suspended solids than anticipated. The average outflow concentration was 16.85 mg/L compared to an inflow concentration of 6.88 mg/L (Figure 27). The extremely high value obtained at site W7 in October 2006, is the result of entrainment of sediment into the water sample, because water levels were so low. Turbidity was also elevated at the outlet compared to the inlet averaging 5.6 NTU higher. There is no question however, that the wetland was very effective at trapping sediments historically, because the flap gate over the inlet structure is nearly buried in sediment (Figure 28). This highlights the need to clean out the accumulated material so that the wetland can resume trapping material. At present, it would appear that the stormwater is mobilizing accumulated sediment from the wetland into the creek.

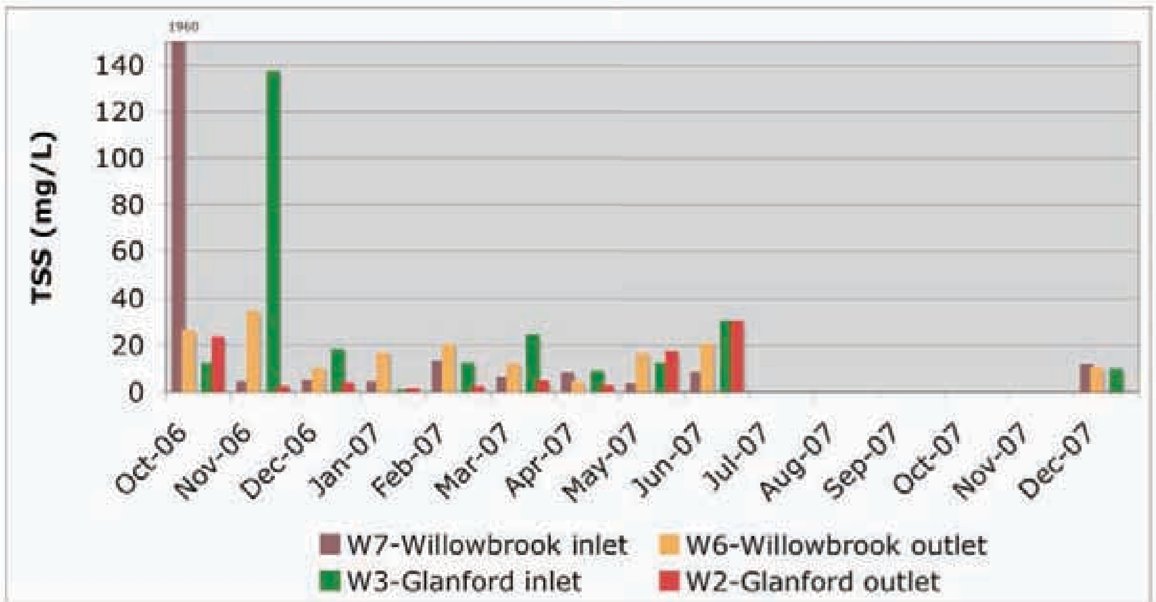


Figure 27. Total suspended solids (TSS) concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

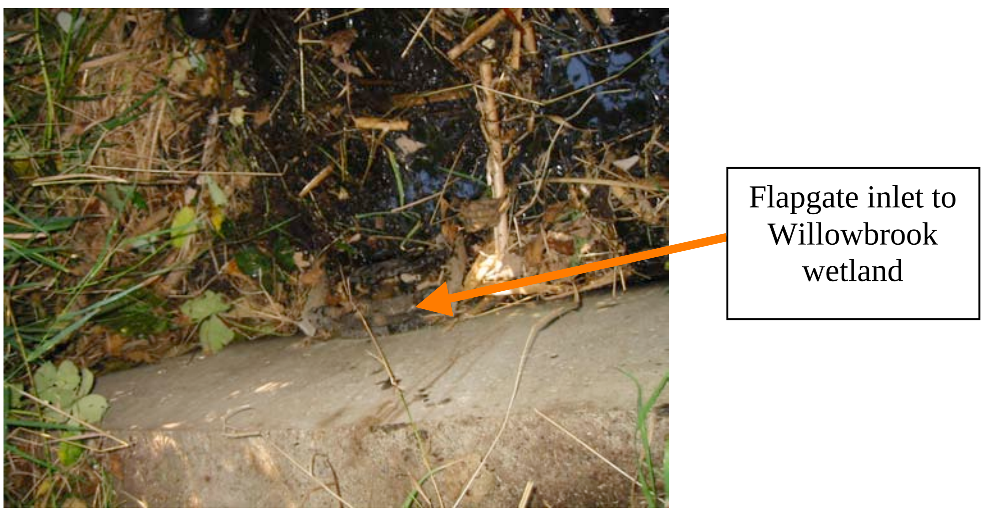


Figure 28. Flapgate inlet to Willowbrook wetland. Note the accumulation of sediment.

Temperature

The wetland is significantly reducing water temperatures of the stormwater before it flows into Swan Creek (Figure 29). On average, temperatures dropped 2.7°C. In July 2007, when the warmest water was entering the creek, the water temperature at the wetland inlet was 19.4°C compared to an outlet temperature of 16.7°C and a receiving stream temperature of 16.3°C. This reduction in temperature is especially important during warm summer months as higher temperatures reduce oxygen concentrations in the water and can be lethal to salmonids. Temperature extremes as high as 22-24 °C and as low as 0 °C are considered life-threatening for salmon species (Walthers and Nener, 1997). For juvenile salmonids in stream environments temperature avoidance may force certain life stages to occupy sub-optimal habitat. Under high temperature extremes, juvenile salmonids become lethargic, unable to defend their territories (McCullough 1999) and more vulnerable to predation (Oliver and Fidler, 2001).

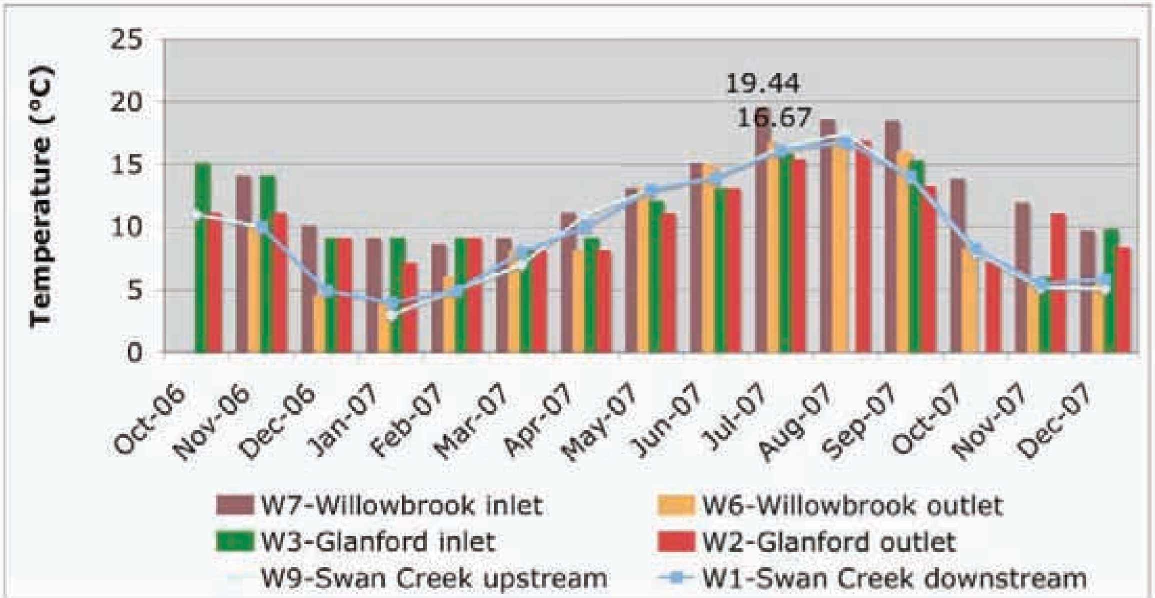


Figure 29. Water temperatures of stormwater entering and exiting the Willowbrook and Glanford wetlands compared to in-stream water temperatures above and below the wetland system.

Table 2. Average difference and average percentage removal (reduction) rates for nutrients, dissolved solids and suspended solids in the water column at the inlet and outlet of the Willowbrook and Glanford wetlands, Baxter Pond, upstream and downstream in Blenkinsop Creek and Leeds Creek. Negative numbers (in red) indicate an increase in concentration. Temperature and pH reflect % reduction, rather than removal.

Parameter	Data	Willowbrook W7-W6	Glanford W3-W2	Swan Creek W9-W1	Baxter G4-G3	Baxter G4-G2	Gabo Creek G5-G1	Leeds L3-L1	Blenkinsop B6a-B5a
(NTU)	Difference (avg)	2.57	6.52	0.57	-4.42	-24.67	-1.56	-19.19	-2.39
(NTU)	% removal (avg)	-136.92	42.77	2.22	-141.91	-1004.20	-117.27	-922.56	-166.01
(TCU)	Difference (avg)	-32.51	9.04	-0.81	-6.59	-1.14	5.22	-5.42	9.62
(TCU)	% removal (avg)	-459.15	22.99	-2.09	-73.57	-21.67	17.53	-309.03	11.83
ALK	Difference (avg)	86.67	-1.50	-7.67	36.50	7.00	72.33	-42.43	-8.00
ALK	% removal (avg)	42.37	-4.63	-7.00	31.41	5.91	34.82	-44.54	-7.48
CaCO3	Difference (avg)	122.55	11.97	-10.10	48.59	27.04	67.17	-54.82	25.10
CaCO3	% removal (avg)	31.92	3.83	-9.73	21.92	14.20	23.51	-71.65	0.91
Celsius	Difference (avg)	2.96	0.75	0.29	1.62	2.10	1.19	2.13	-0.22
Celsius	% removal (avg)	27.53	2.58	2.89	14.19	17.08	9.63	19.52	-1.18
Cl-	Difference (avg)	9.04	-0.19	-0.93	18.16	11.05	-10.60	-2.59	-0.20
Cl-	% removal (avg)	-4.21	1.86	-91.41	24.35	26.49	-29.99	-34.70	-2.78
D.O.	Difference (avg)	1.22	2.78	-1.38	3.68	6.43	1.44	3.35	-0.17
D.O.	% removal (avg)	26.09	35.89	-784.72	37.95	62.75	18.52	10.46	-30.89
E.C.	Difference (avg)	293.67	11.50	-19.67	81.58	52.00	133.42	-31.89	-21.25
E.C.	% removal (avg)	39.75	2.10	-5.32	11.45	4.37	20.96	-7.90	-7.00
NH3-N	Difference (avg)	-82.16	160.89	6.76	-4.92	11.99	160.43	-57.55	223.63
NH3-N	% removal (avg)	-176.18	86.50	-4.46	-31.12	1.91	53.96	-401.28	55.61
NO2-N	Difference (avg)	-7.07	19.82	-2.27	-0.04	1.58	2.71	4.19	3.12
NO2-N	% removal (avg)	-144.52	53.91	-15.59	-35.82	-25.41	16.05	29.57	20.16
NO3-N	Difference (avg)	739.33	343.27	40.05	744.80	812.17	20.18	778.49	-14.89
NO3-N	% removal (avg)	52.44	24.07	-70.48	45.90	52.74	-30.65	59.62	13.95
Ortho-P	Difference (avg)	-239.05	21.25	15.60	-54.81	-73.96	28.20	11.45	186.20
Ortho-P	% removal (avg)	-1103.08	-1.44	3.80	-948.50	-571.81	54.96	-26.23	20.11
pH	Difference (avg)	-0.10	0.09	-0.14	0.24	0.26	0.09	0.45	-0.16
pH	% removal (avg)	-1.40	1.10	-1.87	2.99	3.26	0.98	5.64	-2.18
TDS	Difference (avg)	167.47	7.38	-7.33	49.98	24.71	81.53	-70.65	-78.64
TDS	% removal (avg)	32.74	2.62	-3.27	10.69	4.78	16.43	-81.14	-32.32
TEH	Difference (avg)			-0.01			0.62	0.60	
TEH	% removal (avg)			-0.28			17.66	14.71	0.00
TKN	Difference (avg)	-0.33	0.52	-0.03	0.04	0.03	0.17	-0.05	0.31
TKN	% removal (avg)	-171.74	50.52	-211.05	-83.53	-120.50	5.29	-51.79	16.93
TSS	Difference (avg)	185.35	17.70	5.97	-15.93	-62.02	-2.81	-46.46	-50.93
TSS	% removal (avg)	-175.36	27.84	-76.53	-353.13	-1166.47	-86.39	-2122.43	-118.97

Metals

The Willowbrook wetland generally exported metals during the rainy winter months, and acted as a sink for metals during low flow periods. Extreme low water levels prevented sampling from July-November 2007. Arsenic, copper, lead, mercury, sodium, tin and zinc were all lower at the outlet than at the inlet in the fall of 2006 (Figure 30 to Figure 36). While the wetland continued to take up sodium, with the onset of winter rains, metals values at the outlet began to exceed the inlet. In January and February 2007, lead was not detectable in the water at the inlet, but was present at the outlet. In March 2007, arsenic was present at the outlet, but not at the inlet. This suggests mobilization of metals from the wetland sediments. Cadmium concentrations were too low to confirm a discernable trend at either site. Average removal rates for all metals are presented in Table 3.

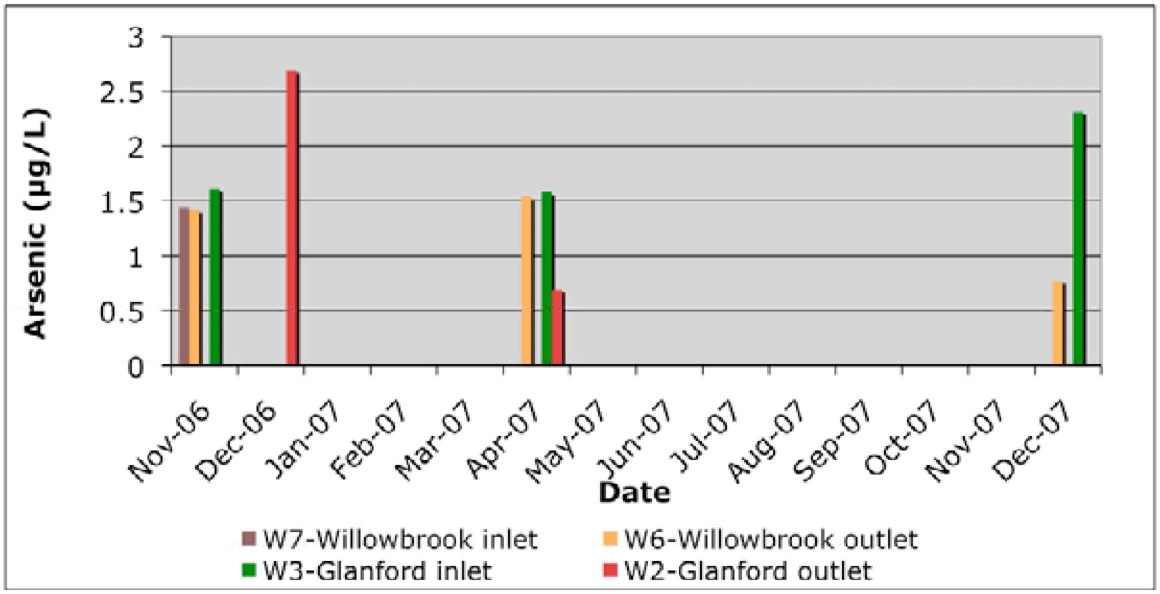


Figure 30. Arsenic concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

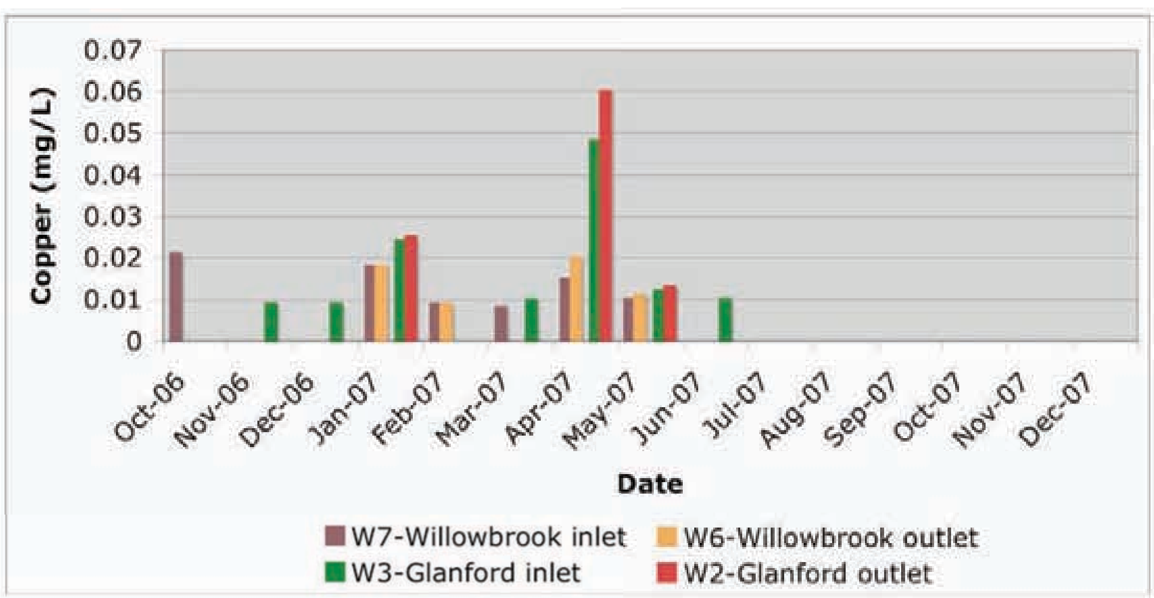


Figure 31. Copper concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

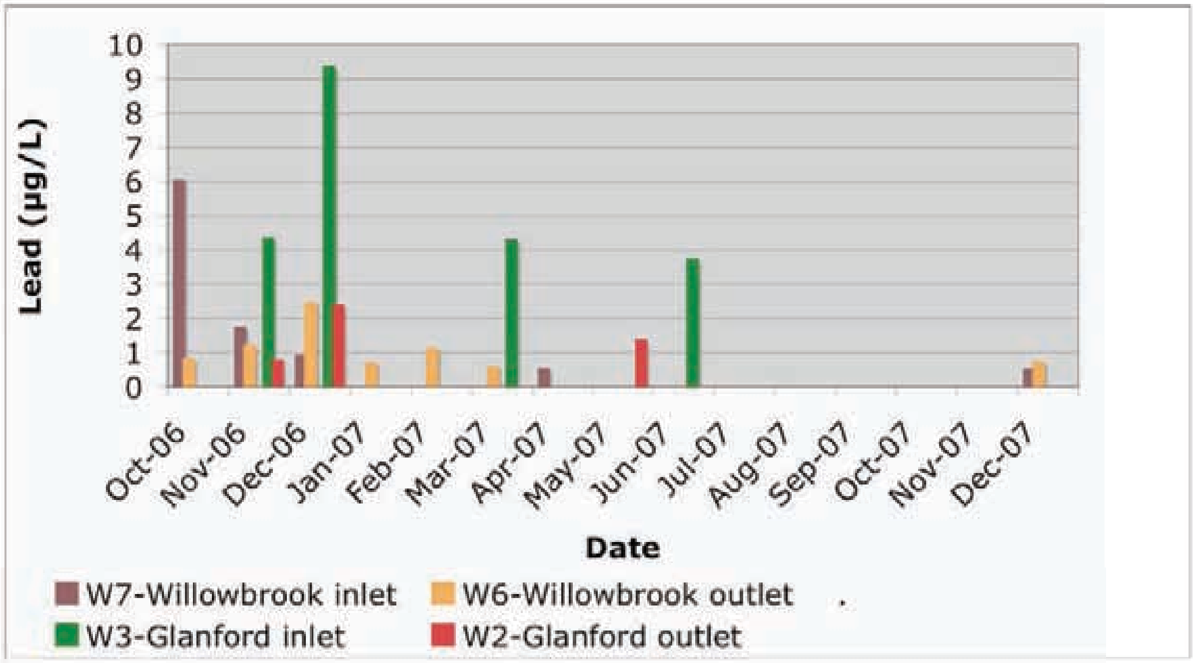


Figure 32. Lead concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

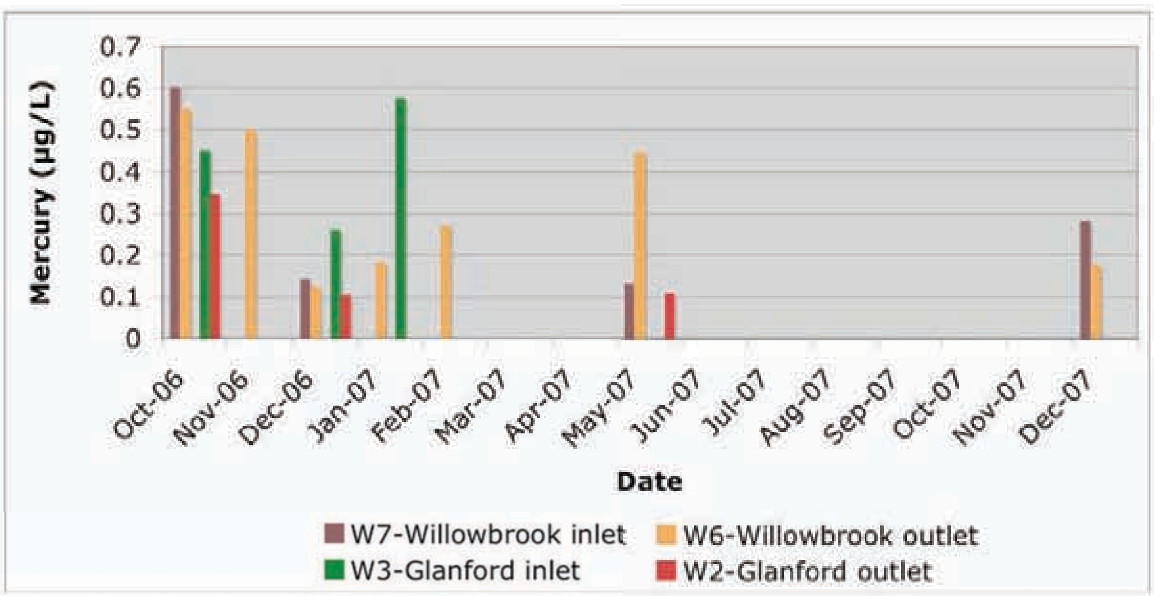


Figure 33. Mercury concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

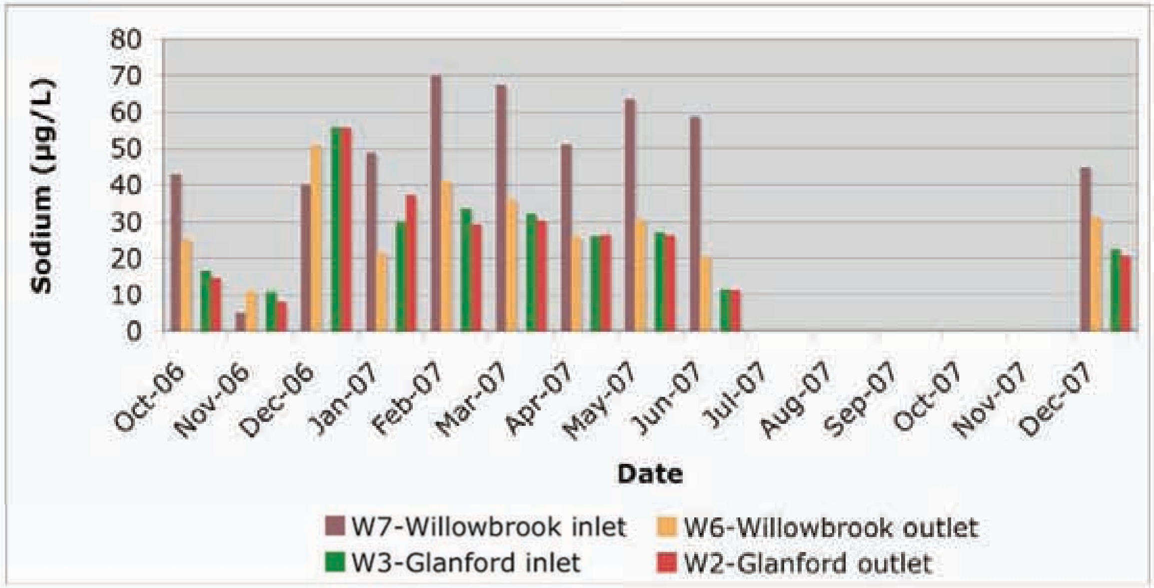


Figure 34. Sodium concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

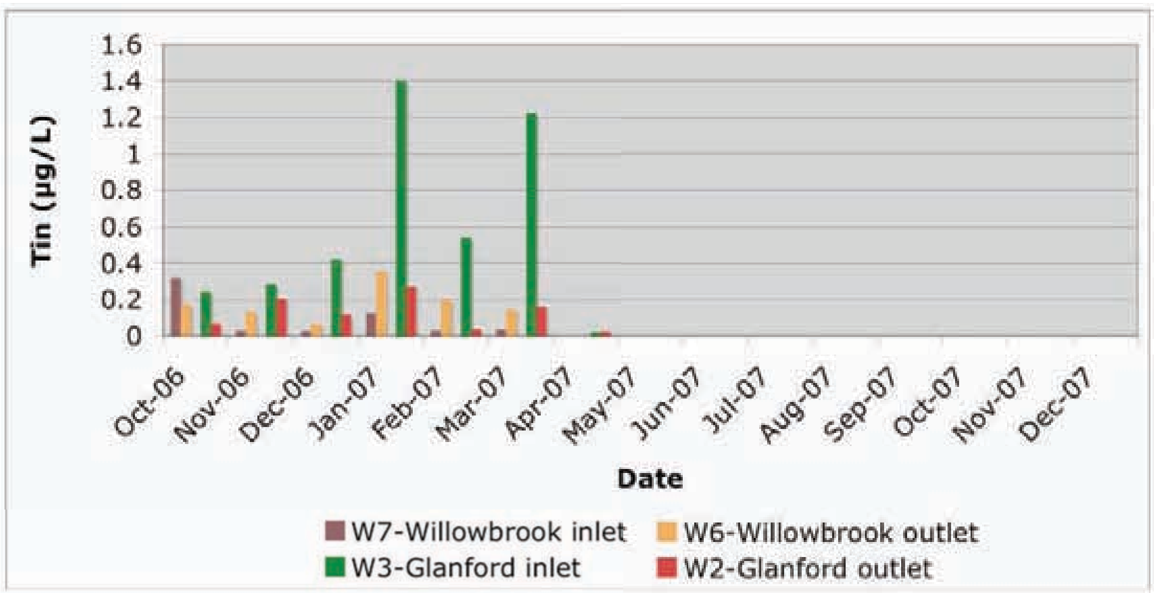


Figure 35. Tin concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

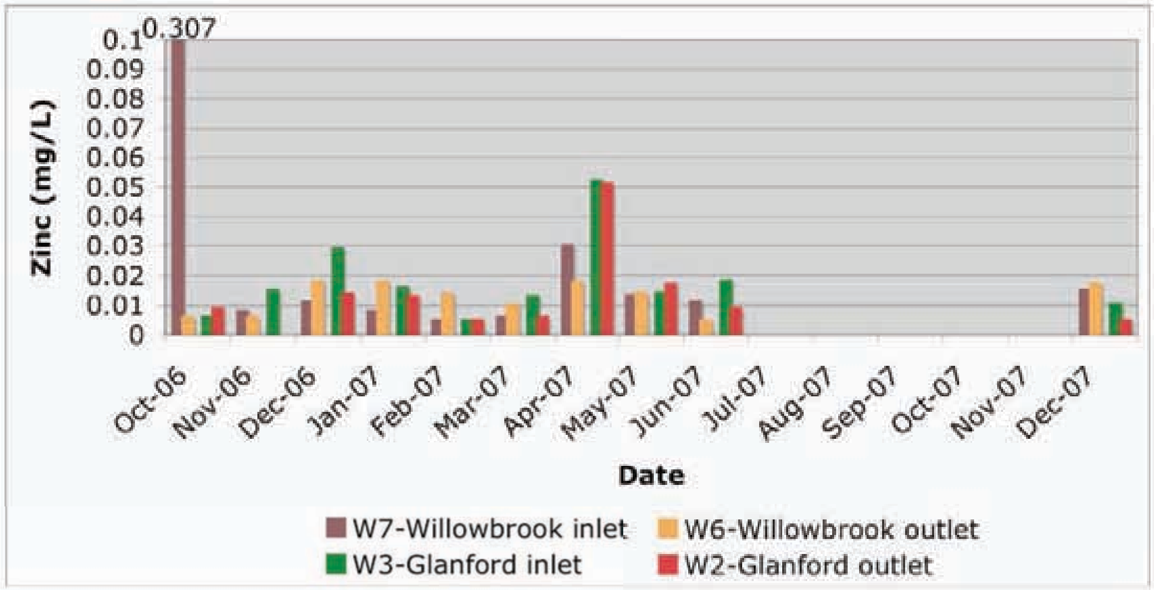


Figure 36. Zinc concentrations in inlet and outlet waters of Willowbrook and Glanford wetlands.

Table 3. Average difference and average percentage removal rates for metals in the water column at the inlet and outlet of the Willowbrook and Glanford wetlands, Baxter Pond, upstream and downstream in Blenkinsop Creek and Leeds Creek. Negative numbers indicate an increase in concentration.

		Willowbrook W7-W6	Glanford W3-W2	Swan Creek W9-W1	Baxter G4-G3
Parameter	Data				
Al	Difference (avg) * (mg/L)	0.00	0.13	-0.02	-0.04
	% removal (avg) * (mg/L)	-35.80	20.31	-6.83	-52.18
As	Difference (avg) * (ug/L)	0.02	1.00	0.69	0.95
	% removal (avg) * (ug/L)	1.39	58.10	10.24	58.38
B	Difference (avg) * (mg/L)	-0.01	0.03	-0.07	0.03
	% removal (avg) * (mg/L)	-2.42	6.72	-17.00	4.49
Ba	Difference (avg) * (mg/L)	0.00	0.01	0.01	-0.03
	% removal (avg) * (mg/L)	-1.22	24.40	1.11	-131.00
Be	Difference (avg) * (mg/L)	0.00	0.00	0.00	
	% removal (avg) * (mg/L)	0.00	21.43	-6.67	
Ca	Difference (avg) * (mg/L)	25.39	2.57	-1.17	11.83
	% removal (avg) * (mg/L)	28.36	3.89	-5.79	20.60
Cd	Difference (avg) * (ug/L)		0.43		0.05
	% removal (avg) * (ug/L)		81.32		26.24
Cr	Difference (avg) * (mg/L)	-0.02	0.01	-0.01	0.00
	% removal (avg) * (mg/L)	-44.12	24.54	-29.63	9.68
Cu	Difference (avg) * (mg/L)	0.00	0.00	-0.01	-0.01
	% removal (avg) * (mg/L)	3.38	4.13	-84.63	-113.08
Fe	Difference (avg) * (mg/L)	-0.26	2.09	0.28	-0.07
	% removal (avg) * (mg/L)	-308.64	74.32	-37.91	-17.45
Hg	Difference (avg) * (ug/L)	-0.03	0.25	0.07	0.11
	% removal (avg) * (ug/L)	-45.32	55.17	24.16	24.06
K	Difference (avg) * (mg/L)	-1.21	0.30	-0.09	-0.55

Parameter	Data	Willowbrook W7-W6	Glanford W3-W2	Swan Creek W9-W1	Baxter G4-G3
	% removal (avg) * (mg/L)	-101.41	4.92	-4.73	-29.32
Mg	Difference (avg) * (mg/L)	14.30	1.34	-1.67	4.63
	% removal (avg) * (mg/L)	34.88	3.59	-89.95	24.42
Mn	Difference (avg) * (mg/L)	-0.20	0.74	0.52	-0.21
	% removal (avg) * (mg/L)	-248.31	75.68	-1.04	-61.00
Na	Difference (avg) * (mg/L)	19.91	0.54	-3.18	19.17
	% removal (avg) * (mg/L)	23.89	4.13	-12.69	29.15
P	Difference (avg) * (mg/L)	-0.32	0.07	0.09	-0.29
	% removal (avg) * (mg/L)	-316.63	32.25	10.23	-351.40
Pb	Difference (avg) * (ug/L)	0.80	4.37	-0.50	1.00
	% removal (avg) * (ug/L)	-18.35	83.00	-64.16	39.25
Se	Difference (avg) * (ug/L)	0.11	4.01		
	% removal (avg) * (ug/L)	5.45	88.94		
Si	Difference (avg) * (mg/L)	1.40	0.99	-1.12	1.96
	% removal (avg) * (mg/L)	10.28	8.64	-588.49	25.22
Sn	Difference (avg) * (mg/L)	-0.08	0.46	0.10	-0.04
	% removal (avg) * (mg/L)	-252.65	59.78	21.96	-25.15
Sr	Difference (avg) * (mg/L)	0.10	0.01	0.00	0.03
	% removal (avg) * (mg/L)	17.90	3.97	-3.56	13.57
Ti	Difference (avg) * (mg/L)	0.02	0.01	0.00	
	% removal (avg) * (mg/L)	71.88	43.62	7.41	
Zn	Difference (avg) * (mg/L)	0.03	0.00	0.00	0.01
	% removal (avg) * (mg/L)	-23.87	24.88	-28.62	38.50

Parameter	Data	Baxter G4-G2	Gabo Creek G5-G1	Leeds L3-L1	Blenkinsop B6a-B5a
Al	Difference (avg) * (mg/L)	-0.20	0.00	-0.86	0.19
	% removal (avg) * (mg/L)	-197.37	-11.53	-365.16	22.70
As	Difference (avg) * (ug/L)	1.76	2.24	-7.00	-0.39
	% removal (avg) * (ug/L)	68.16	76.05	-700.00	-11.08
B	Difference (avg) * (mg/L)	0.04	0.01	0.00	0.03
	% removal (avg) * (mg/L)	2.57	5.37	-6.68	7.18
Ba	Difference (avg) * (mg/L)	0.00	0.01	-0.02	0.01
	% removal (avg) * (mg/L)	-37.43	20.97	-178.88	32.36
Be	Difference (avg) * (mg/L)	0.00	0.00	0.00	0.00
	% removal (avg) * (mg/L)	10.00	20.00	-8.33	16.67
Ca	Difference (avg) * (mg/L)	8.78	12.55	-12.75	8.25
	% removal (avg) * (mg/L)	12.37	14.42	-64.65	1.20
Cd	Difference (avg) * (ug/L)	-0.18	-0.12	-0.18	0.20
	% removal (avg) * (ug/L)	-201.73	-130.99	-180.00	-22.84
Cr	Difference (avg) * (mg/L)	0.00	0.00	0.00	-0.01
	% removal (avg) * (mg/L)	-2.40	8.11	19.44	-8.82
Cu	Difference (avg) * (mg/L)	-0.01	0.00	-0.02	0.00
	% removal (avg) * (mg/L)	-32.07	-87.12	-238.77	25.61
Fe	Difference (avg) * (mg/L)	-0.92	0.45	-6.09	0.59
	% removal (avg) * (mg/L)	-258.99	-24.42	-6398.04	43.90
Hg	Difference (avg) * (ug/L)	0.02	-0.05	-0.13	0.08
	% removal (avg) * (ug/L)	-10.13	-30.82	-37.52	19.07

		Baxter G4-G2	Gabo Creek G5-G1	Leeds L3-L1	Blenkinsop B6a-B5a
Parameter	Data				
K	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	0.53 24.29	0.87 34.62	0.29 21.47	0.86 5.46
Mg	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	6.10 28.29	8.70 35.66	-5.63 -89.74	1.08 -0.19
Mn	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	-0.08 -72.35	0.18 0.08	-0.47 -3776.69	1.63 50.46
Na	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	1.22 4.46	-7.80 -12.39	-3.78 -31.94	0.14 -3.29
P	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	0.01 -15.50	0.06 41.77	-0.34 -250.00	0.36 25.63
Pb	Difference (avg) * (ug/L) % removal (avg) * (ug/L)	4.61 -33.05	11.90 -12.56	2.61 50.17	-0.16 -32.58
Se	Difference (avg) * (ug/L) % removal (avg) * (ug/L)		1.14 69.57		
Si	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	0.70 10.70	0.65 9.24	0.28 -16.12	1.08 17.34
Sn	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	-0.39 -270.99	0.06 -35.30	-1.95 -4125.98	0.15 33.16
Sr	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	0.05 16.45	0.09 24.58	-0.07 -85.74	0.03 -1.25
Ti	Difference (avg) * (mg/L) % removal (avg) * (mg/L)			0.01 43.75	0.01 30.81
V	Difference (avg) % removal (avg)	-0.01 -36.34	0.00 -9.52	0.01 55.00	0.00 14.29
Zn	Difference (avg) * (mg/L) % removal (avg) * (mg/L)	-0.06 -142.02	-0.01 -117.42	-0.06 -630.04	0.01 40.54

Sediment Chemistry

Sediment samples were taken in the fall of 2006 prior to the onset of rain, in the early spring of 2007 and again in the fall of 2007. Samples were analysed for the same metals parameters as the water samples. The sediments at the outlet of the wetland had lower concentrations of all the key metals: arsenic, cadmium, chromium, copper, lead mercury, sodium and zinc on all three sampling dates with a few exceptions. In October 2006, arsenic was slightly higher at the outlet than the inlet (5.67 compared to 5.12µg/g). Mercury was also higher (0.297 compared to 0.295µg/g). In March 2007, cadmium, lead, sodium and zinc were all higher at the inlet than the outlet, suggesting that perhaps sediments had migrated from the inlet area toward the outlet with higher rainfall. In November 2007, all outlet samples were lower for all the key metals than those taken at the inlet. Removal rates are summarized in Table 4.

Table 4. Average difference and average percentage removal rates for metals in the sediments at the inlet and outlet of the Willowbrook and Glanford wetlands, Baxter Pond, upstream and downstream in Blenkinsop Creek and Leeds Creek. Negative numbers (in red) indicate an increase in concentration.

		Willowbrook W7-W6	Glanford W3-W2	Leeds L3-L1	Blenkinsop B6a-B5a	Baxter G4-G2	Baxter G4-G3
parameter	Data						
Ag	Average of Difference(ug/g)		0.30	-1.38	0.73	0.02	0.02
	Average % reduction		76.92	-678.33	52.54	16.10	16.10
Al	Average of Difference(ug/g)	-5866.67	-6790.00	2606.67	4360.00	-6506.67	-6166.67
	Average % reduction	-32.89	-52.74	-1.75	25.56	-43.73	-39.15
As	Average of Difference(ug/g)	0.11	8.96	-3.55	3.20	-7.39	-1.35
	Average % reduction	9.97	13.27	-178.79	44.66	-314.48	-69.41
B	Average of Difference(ug/g)	68.00	19.80	-108.10	203.20	-115.30	-21.00
	Average % reduction	34.69	20.12	-725.50	83.97	-585.28	-106.60
Ba	Average of Difference(ug/g)	-87.90	42.33	-36.17	116.47	-116.03	-63.60
	Average % reduction	-84.98	-10.41	-127.93	48.77	-215.89	-130.14
Be	Average of Difference(ug/g)	-0.03	-0.01	-1.56	3.00	-2.42	-0.75
	Average % reduction	-55.32	-59.52	-735.64	73.37	-1383.55	-374.52
Ca	Average of Difference(ug/g)	4863.33	3116.67	-1503.33	-4300.00	-4526.67	-2260.00
	Average % reduction	34.64	26.47	-26.43	-22.12	-55.77	-63.04
Cd	Average of Difference(ug/g)	0.38	-0.17	-0.92	1.14	-0.48	0.34
	Average % reduction	-2.69	-88.43	-1248.02	83.39	-490.46	48.53
Co	Average of Difference(ug/g)	6.91	-2.67	-0.74	6.54	-3.03	0.82
	Average % reduction	36.64	-19.24	-13.86	35.95	-26.10	6.70
Cr	Average of Difference(ug/g)	17.90	-13.17	9.07	8.03	-17.00	18.27
	Average % reduction	24.67	-29.82	9.71	19.82	-53.97	22.53
Cu	Average of Difference(ug/g)	91.33	-9.63	15.17	31.90	-47.60	41.97
	Average % reduction	49.76	-22.07	-13.16	39.89	-85.12	49.40
Fe	Average of Difference(ug/g)	9366.67	21533.33	-4666.67	4806.67	-22600.00	1133.33
	Average % reduction	27.00	20.83	-48.48	20.41	-93.53	2.14
Hg	Average of Difference(ug/g)	-0.02	0.15	-0.26	0.13	-0.17	-0.05
	Average % reduction	-1.99	54.41	-314.82	58.29	-576.67	-160.00
K	Average of Difference(ug/g)	-222.00	-573.67	-34.67	22.33	-1040.33	-367.33
	Average % reduction	-28.74	-56.17	-56.53	16.52	-249.62	-83.31
La	Average of Difference(ug/g)	-5.71	-2.47	-0.58	1.35	-3.39	-2.70
	Average % reduction	-91.00	-44.97	-41.55	17.19	-122.97	-93.04
Mg	Average of Difference(ug/g)	4386.67	-2410.00	1316.67	-2603.33	-736.67	216.67
	Average % reduction	44.20	-32.70	8.45	-19.57	-7.22	3.36
Mn	Average of Difference(ug/g)	433.33	3976.67	-55.67	3598.67	-3151.00	-376.33
	Average % reduction	29.37	-42.76	-29.97	73.81	-562.02	-78.74
Na	Average of Difference(ug/g)	-528.00	80.00	-349.33	1609.33	-2021.33	-1006.00
	Average % reduction	-28.58	21.64	-272.37	-49.38	-659.66	-1006.40
Ni	Average of Difference(ug/g)	-1.87	-26.70	-1.47	-3.17	-14.70	-8.37
	Average % reduction	-0.66	-87.27	-32.16	0.99	-62.20	-37.02
P	Average of Difference(ug/g)	-507.67	1786.67	-1163.67	1878.00	-2690.67	-78.33
	Average % reduction	-49.18	39.43	-286.13	59.91	-390.00	-11.01
Pb	Average of Difference(ug/g)	5.43	12.17	73.37	18.32	2.60	41.61
	Average % reduction	-10.79	34.88	54.57	89.99	-59.57	50.70
pH	Average of Difference(ug/g)	1.79	0.26	1.18	-0.02	0.69	0.84
	Average % reduction	24.25	3.43	16.98	-0.32	9.87	12.02
Sc	Average of Difference(ug/g)	-2.26	-2.92	0.51	0.49	-3.70	-2.50
	Average % reduction	-54.99	-62.73	-2.68	18.89	-159.43	-113.13
Se	Average of Difference(ug/g)	0.23	0.00	-0.33	0.04	0.00	0.01
	Average % reduction	38.42	-27.27	-889.55	29.83	-7.14	32.07
Si	Average of Difference(ug/g)	-60.10	76.45	-25.35	-283.00	-77.00	87.05
	Average % reduction	-67.15	53.57	-46.54	-102.37	-78.30	56.68
Sn	Average of Difference(ug/g)	141.15	3908.50	-1284.15	26.67	10.43	366.52
	Average % reduction	35.10	11.26	-22.21	1.38	-87.40	-13.96
Sr	Average of Difference(ug/g)	3.57	20.63	-13.50	-15.00	-47.60	-16.23
	Average % reduction	5.37	20.63	-78.48	-10.72	-166.82	-94.75
Ti	Average of Difference(ug/g)	626.67	-8.67	456.33	-421.67	84.67	171.33
	Average % reduction	61.86	-11.48	41.86	-68.82	-7.68	15.33
V	Average of Difference(ug/g)	29.23	-13.50	12.50	-2.07	-28.70	-9.27
	Average % reduction	35.25	-18.96	10.94	0.68	-67.41	-25.58
W	Average of Difference(ug/g)	-1.92	0.47	-0.90	3.80	-2.59	0.89
	Average % reduction	-218.54	-276.96	-202.56	96.23	-309.79	69.97
Zn	Average of Difference(ug/g)	22.00	2.00	-91.10	128.97	-457.33	121.20
	Average % reduction	-24.14	-3.19	-146.58	64.65	-230.60	52.23

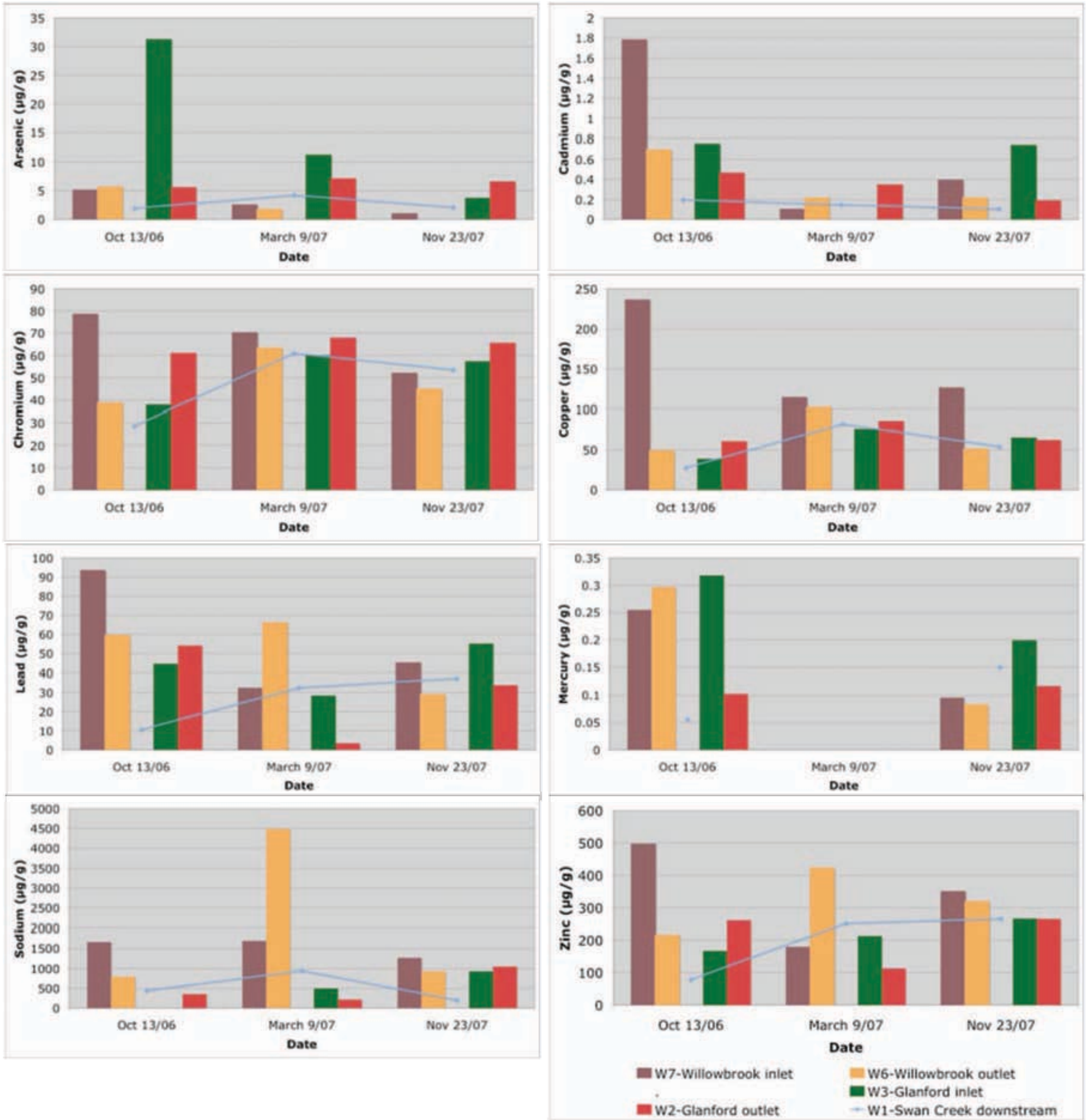


Figure 37. Concentrations of arsenic, cadmium, chromium, copper, lead, mercury, sodium and zinc in the sediments at the inlets and outlets of the Willowbrook and Glanford wetlands.

Glanford Wetland

Nutrients

The Glanford wetland showed the best performance of all the sites tested. It effectively reduced total nitrogen by 1.04 mg/l or 38.6% (Figure 23). Though the wetland was a net exporter of ortho-phosphate, it increased the concentration by an average of only 1.4% or 21.25 µg/L, which is substantially less than the increase seen at the Willowbrook wetland (1103%) (Figure 24).

Dissolved substances were also reduced by the Glanford wetland, though not substantially. On average, TDS decreased by 2.6% and specific conductance decreased by 2.1% (Figure 25). Chloride increased slightly (average 1.9%) suggesting that the wetland made little difference to the concentration of dissolved materials (Figure 26). This is not surprising given its small size and comparatively small surface area of plants on which bacteria and algae can grow and strip nutrients from the water.

Suspended Solids

The Glanford wetland was also effective at removing suspended solids. On average TSS was reduced by 17.7 mg/L or nearly 28% (Figure 27). Except for December 2006 and May 2007 samples, turbidity was consistently lower at the outlet than the inlet, with an average reduction of 42.7%. Saanich has established that this small wetland is effective at trapping sediment as it has been cleaned out in recent years. This maintenance also likely explains why the wetland, despite its small size, is able to effect such a significant improvement in water quality compared to the neighbouring Willowbrook wetland, which is much larger.

Temperature

The average temperature decrease was almost one degree Celsius, likely due to evapotranspiration by the wetland plants, as there is no known source of groundwater to this pond (Figure 29).

Metals

Likely owing to its ability to trap sediments, the Glanford wetland was also effective at reducing metals concentrations. Arsenic, chromium, lead, mercury, tin and zinc were all lower at the outlet than at the inlet with the following few exceptions: in May 2007, lead was below detection limits at the inlet, but detectable at the outlet (1.33 µg/L) as was mercury (0.11 µg/L) (Figure 30 to Figure 36). Sodium was slightly elevated at the outlet in January 2007 and zinc was higher at the outlet than at the inlet in October 2006 and May 2007. Average reduction of sodium was 4.1 % and zinc was reduced by 24.9% (Figure 34 and Figure 36).

Sediment Chemistry

The sediment samples from the Glanford wetland were inconsistent. The October 2006 samples showed that the outlet sediments had lower concentrations of arsenic, cadmium and mercury, but higher concentrations of chromium, copper, lead, sodium and zinc. In March, the outlet had lower concentrations of arsenic, lead and zinc than the inlet. In November 2007, cadmium, copper, lead, mercury and zinc were all lower (Figure 37).

On average the wetland sediments at the outlet were lower in arsenic (13.3%), Iron (20.8%), Mercury (54.1%) sodium (21.6%), lead (34.9%) and tin (11.3%). Details are shown in Table 4.

Bacteriology

Both fecal coliforms and *Enterococci* were comparatively low at Willowbrook and Glanford. The maximum number of fecal coliforms was recorded at the inlet to Willowbrook wetland in October 2006 at 2600 CFU/100 mL. On that date, no *Enterococci* were detected. At the Glanford wetland inlet, fecal coliforms reached 1200 CFU/100 mL on June 11, 2007 and there were 144 CFU/100mL *Enterococcus*. Neither site exceeded the recreational water quality standard of 200 CFU/100 mL for *Enterococcus*.

Baxter

Nutrients

Baxter Pond was generally quite effective at removing nitrogen, but ineffective at removing ortho-phosphorus. Baxter Pond’s total nitrogen removal efficiency ranged between -9% and 84.6%. On average it removed 0.85 mg/L or 40.84% of the total N. Ortho-phosphorus tended to be higher at the outlet than at the inlet, averaging an increase of 73.8 µg/L. If the anomalous value from March 2007 is removed from the data analysis, that value drops to an average increase of only 3.59 µg/L.

Dissolved ions were removed as water transited Baxter Pond. Specific Conductance declined on all sampling dates with the exception of July and October 2007. On average, specific conductance was reduced by 52 µS/cm or 4.4%. These data are confirmed by a parallel trend in TDS, where July and October outlet values exceeded inlet values and, on average, TDS was reduced by an average of 24.7 mg/l or 4.8%.

The chloride signature from road salt is readily apparent in the December 2006 and January 2007 chloride values. Chloride rose from 7.44 mg/L at the inlet in November to 120 mg/L in December 2006 and 204 mg/L in January 2007. This same signature is seen in the sodium analysis, noted below in the metals section.

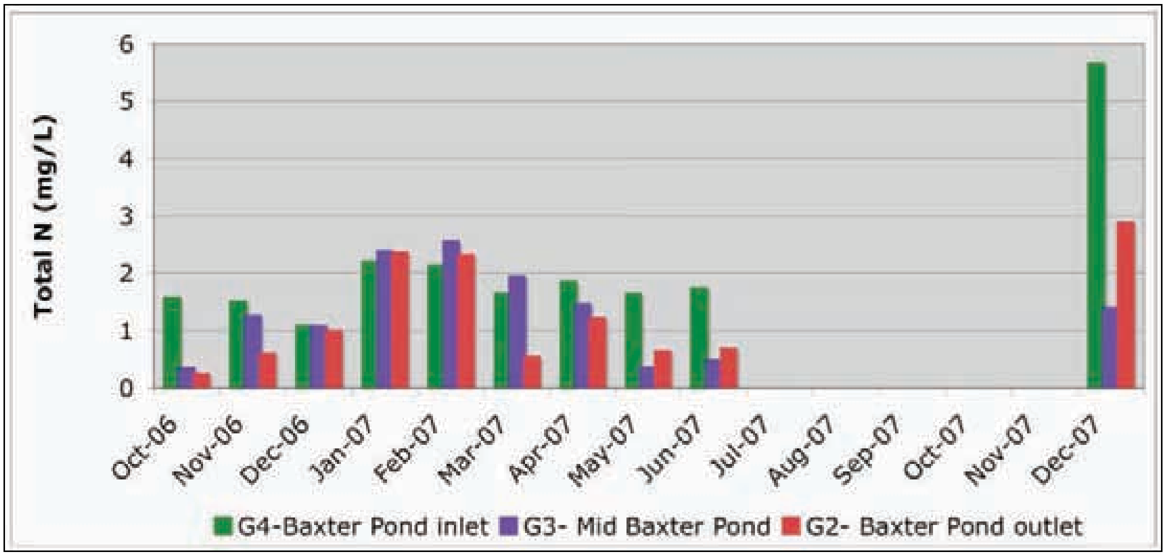


Figure 38. Total nitrogen concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

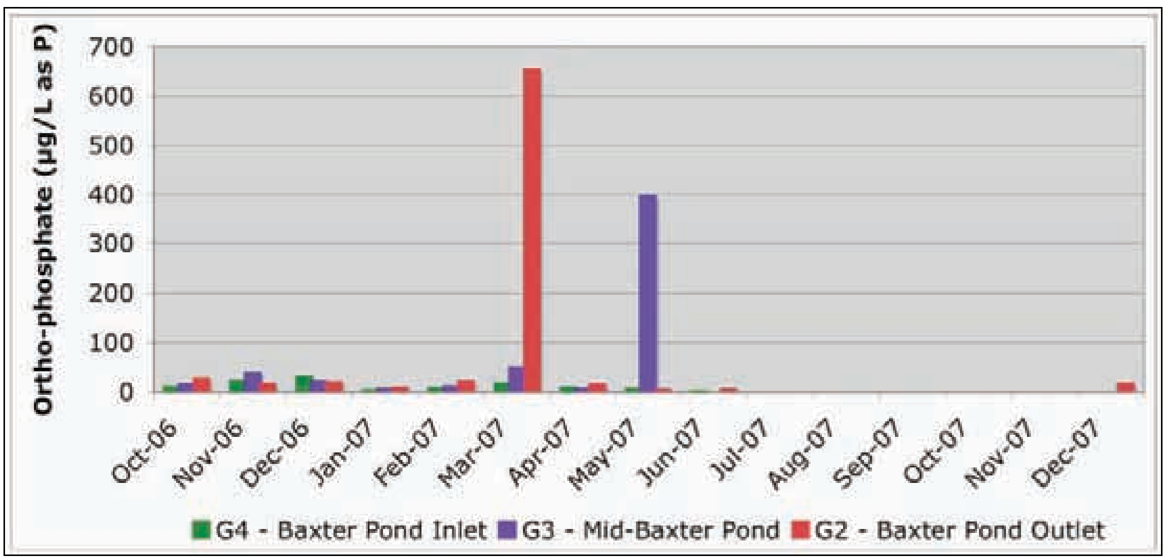


Figure 39. Ortho-phosphate (as P) concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

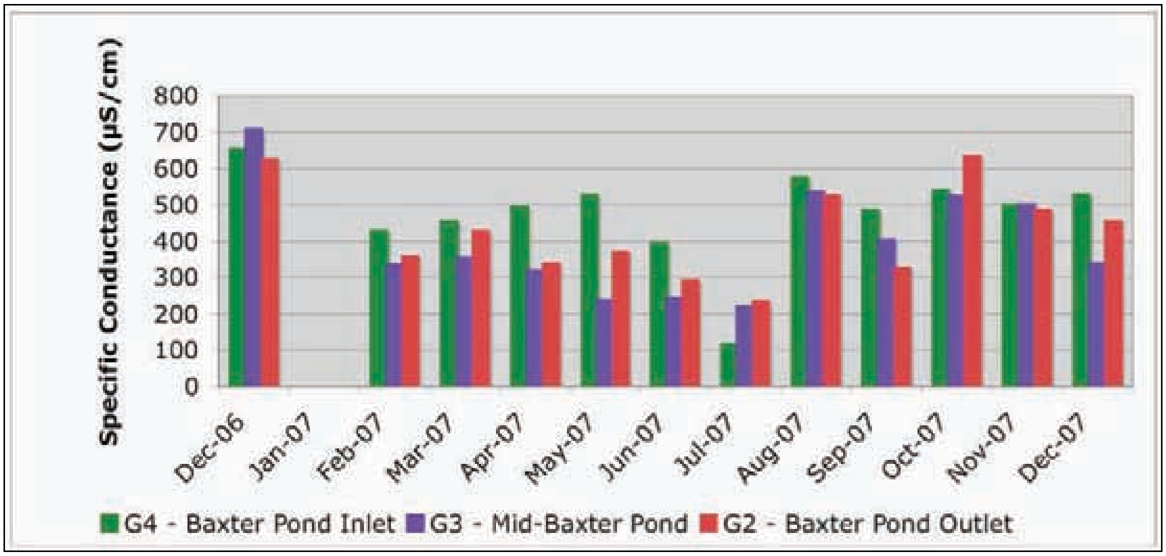


Figure 40. Specific conductance of inlet, mid-pond and outlet waters of Baxter Pond.

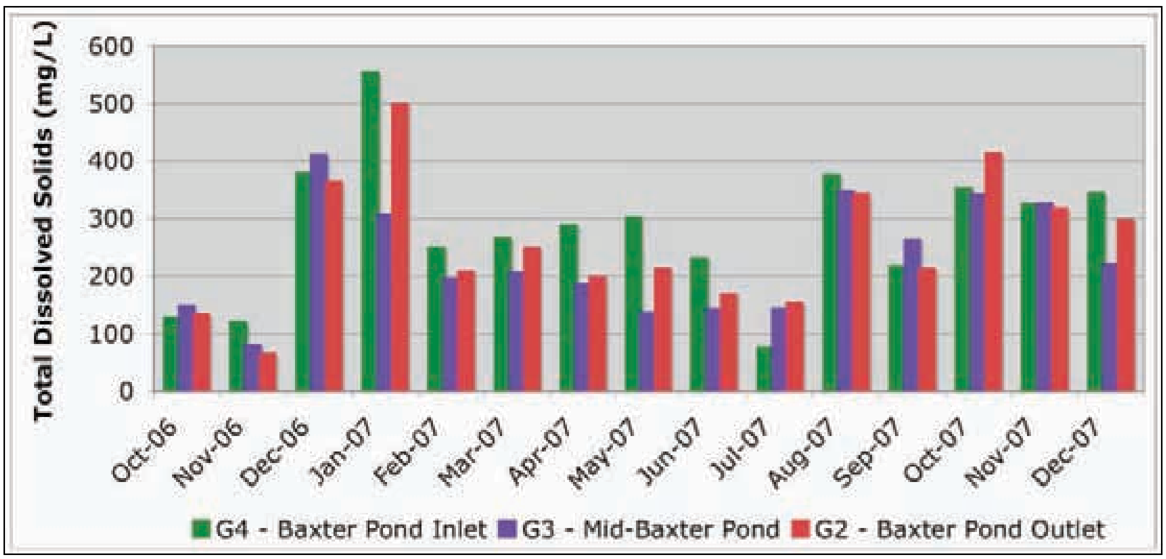


Figure 41. Total dissolved solids (TDS) concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

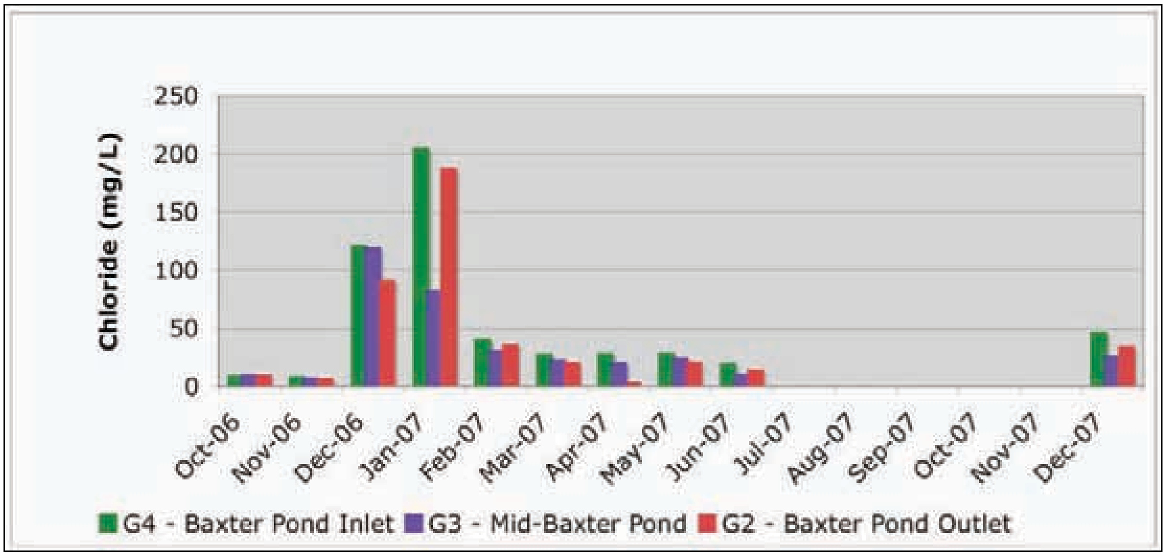


Figure 42. Chloride concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

Suspended Solids

Baxter Pond was very effective at removing large, heavier particles, as seen below in Figure 43 following a winter snow storm. Sand from the Pat Bay Highway and neighbouring streets was washed into the pond and trapped. The finer, more easily suspended material did not readily settle out and the outlet values were higher than the inlet values on seven out of ten occasions. Two large turbidity events in February and March resulted in an overall TSS removal rate of -1166% and an overall turbidity removal rate of 1004%. With respect to suspended material, Baxter Pond is somewhat problematic for analysis as there are ducks and at least one Great Blue Heron that frequent the pond and stir up the sediments as they feed. The pond’s ability to trap particulates from road runoff is not well described by the data, however it is apparent upon visual inspection.

Figure 43. Sediment deposited in Baxter Pond just beyond the stormwater inlet. Material was washed off the Pat Bay Highway following a winter snowstorm.

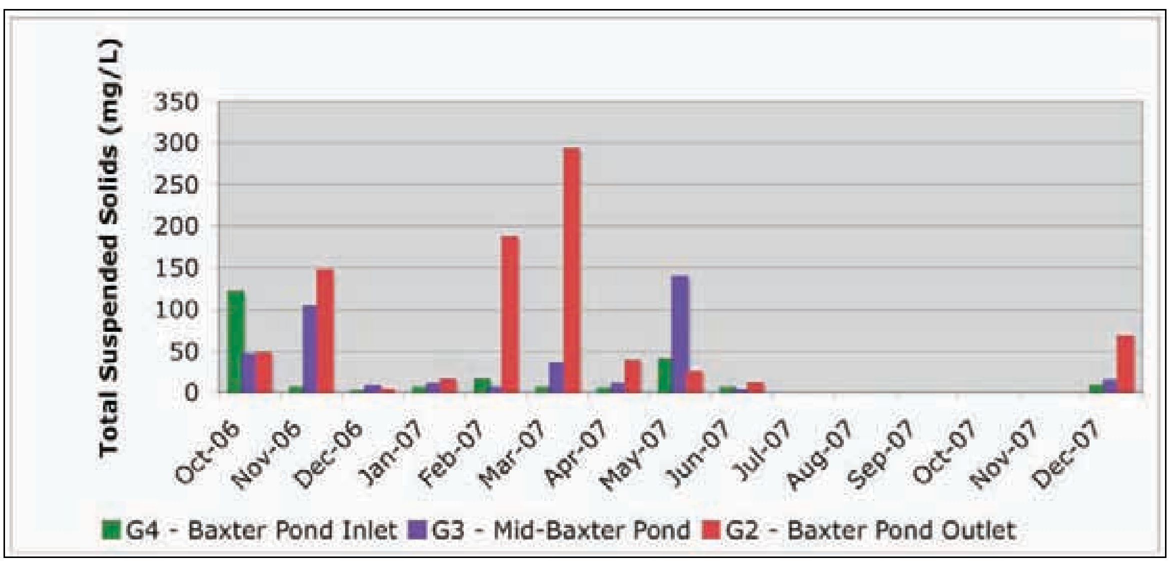


Figure 44. TSS concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

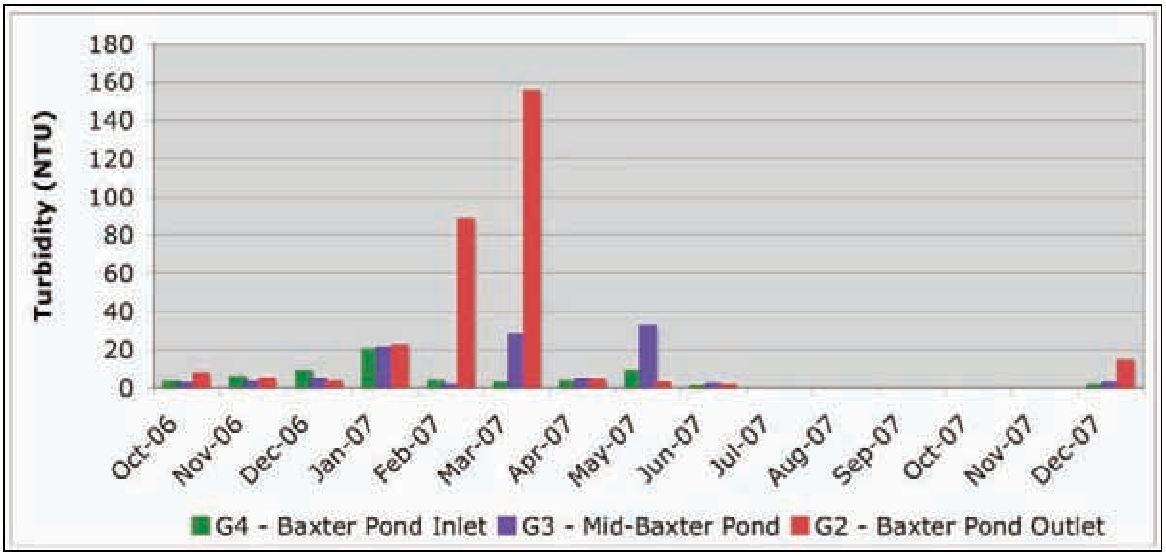


Figure 45. Turbidity concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

Temperature

Temperature between the inlet and outlet declined by an average of 2.1°C and was lower at the outlet than the inlet on every occasion except May 2007. The temperature of the outlet water was also lower than that of Gabo Creek throughout most of the year, especially in the late fall. The effect of this cool water is particularly evident from October to December 2007 where the comparison of Gabo Creek temperature upstream of Baxter Pond and downstream of Baxter Pond shows a difference of almost 7°C. The effect is likely exaggerated due to low water levels in the creek and a constant base flow from the wetland. That period was particularly dry, and Baxter Pond was therefore likely a significant source of water for Gabo Creek during that period.

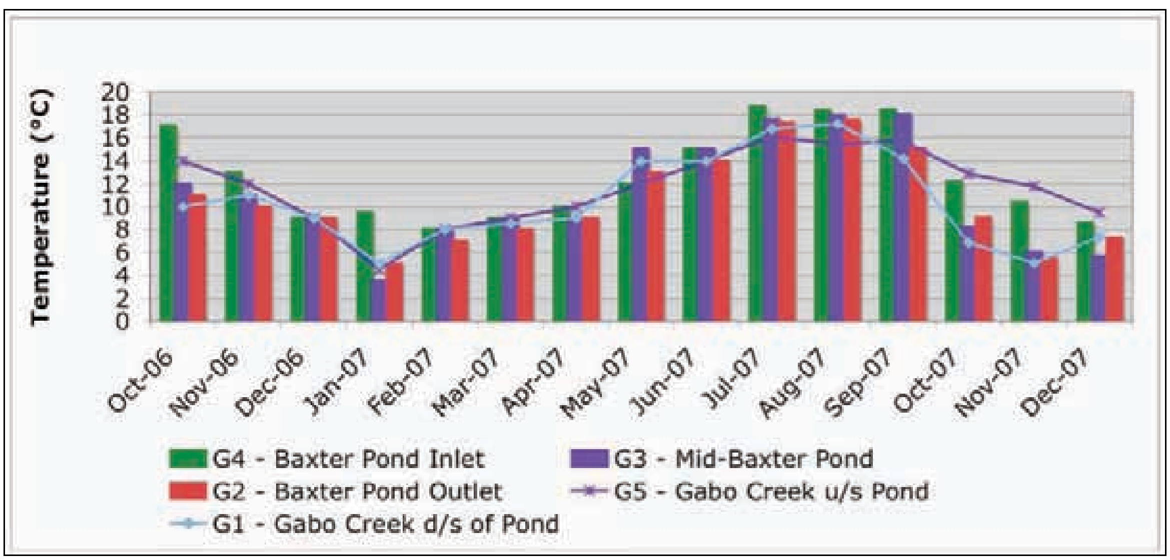


Figure 46. Temperature of water at the inlet, mid-pond and outlet of Baxter Pond as well as in Gabo Creek upstream and downstream of Baxter Pond.

Metals

Given its proximity to the Pat Bay Highway, the metals concentrations in Baxter Pond were surprising. In general, concentrations of most metals were of the same magnitude as those in the Willowbrook wetland. When the snow melted in January of 2007 however, there were large spikes of chromium (Figure 48), sodium (due to road salt) (Figure 52), and zinc (Figure 53) and a smaller peak of mercury (Figure 51). These peaks were higher at the outlet than the inlet, suggesting that the initial flush was already partially through the pond before the samples were taken. The pond was effective at reducing sodium and to a lesser extent at reducing mercury and zinc. Between the inlet and the middle of the pond, cadmium declined by an average of 26.2%, chromium declined by 9.7%, mercury by 24.1%, lead by 39.35% and zinc by 38.5%. When looking at the differences between the inlet and outlet however, those removal rates drop significantly to: cadmium -201.7%, chromium -2.4%, mercury -10.3%, lead -33.1% and zinc to 142.0%. Since the outlet elevation of Baxter Pond is very close to the elevation of the creek, there appears to be a backwater effect - Gabo Creek flows into Baxter Pond via its outlet when there is not enough water moving through Baxter Pond to prevent the creek from entering it. The effects of Gabo Creek may be more strongly evident in the metals analysis because the polluted sediments to which most of the metals are bound become resuspended.

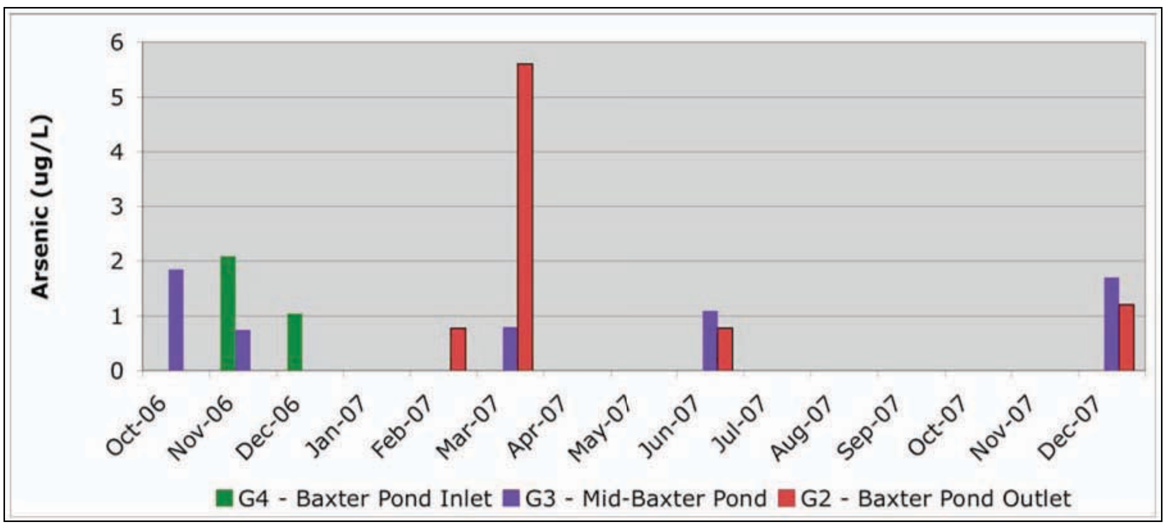


Figure 47. Arsenic concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

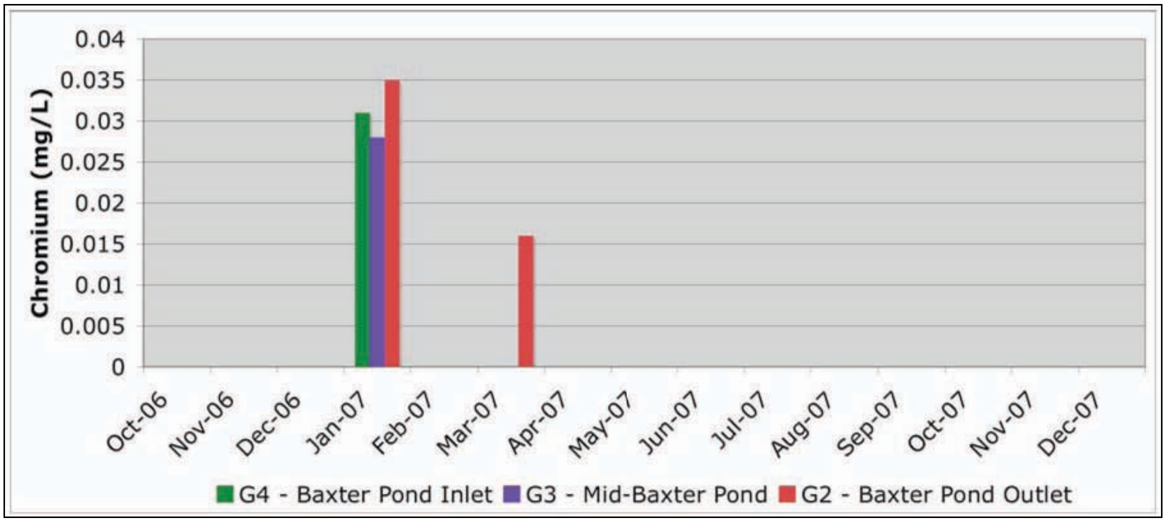


Figure 48. Chromium concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

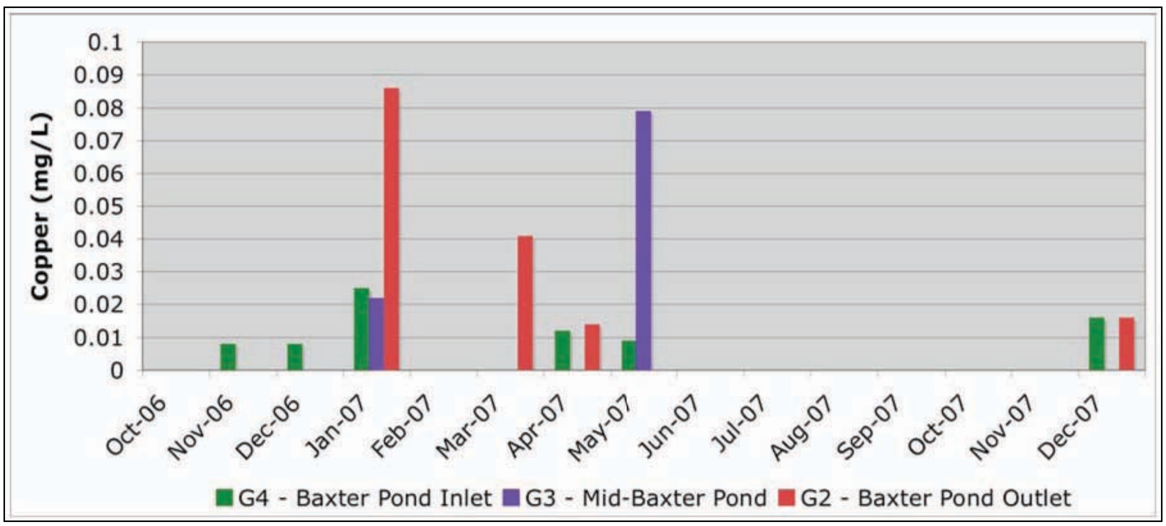


Figure 49. Copper concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

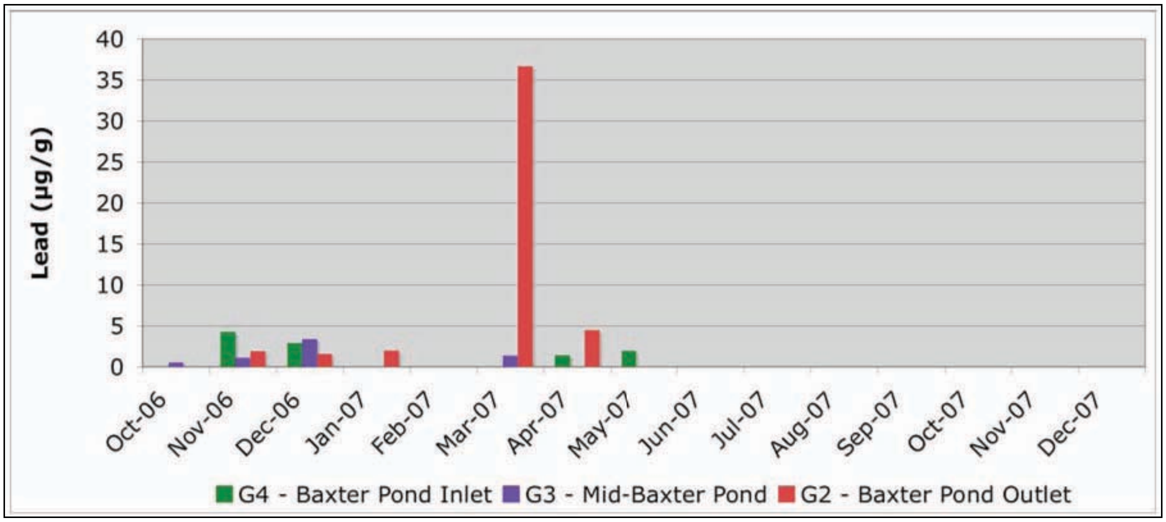


Figure 50. Lead concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

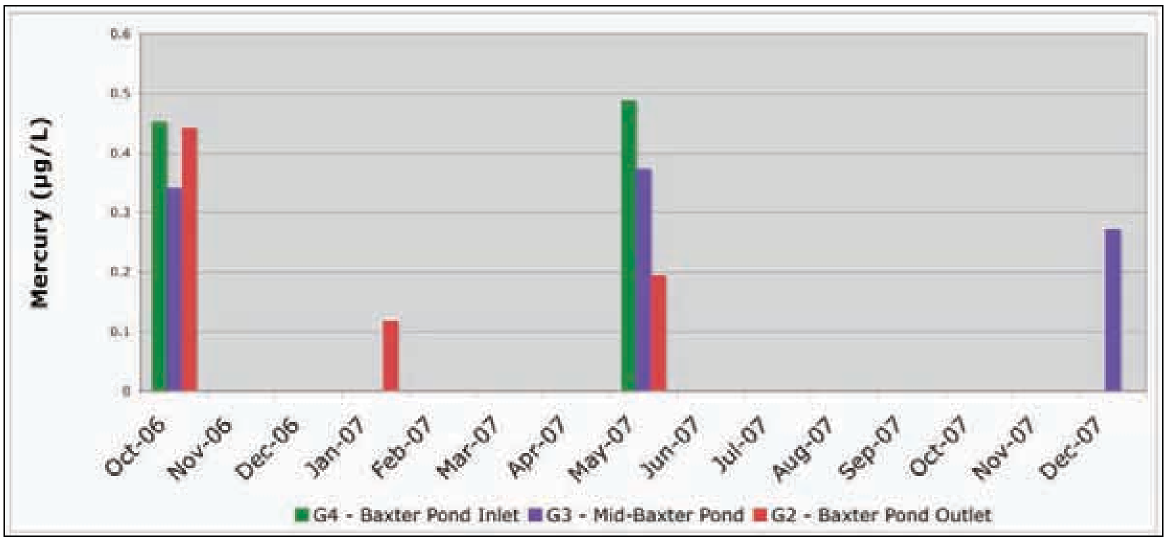


Figure 51. Mercury concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

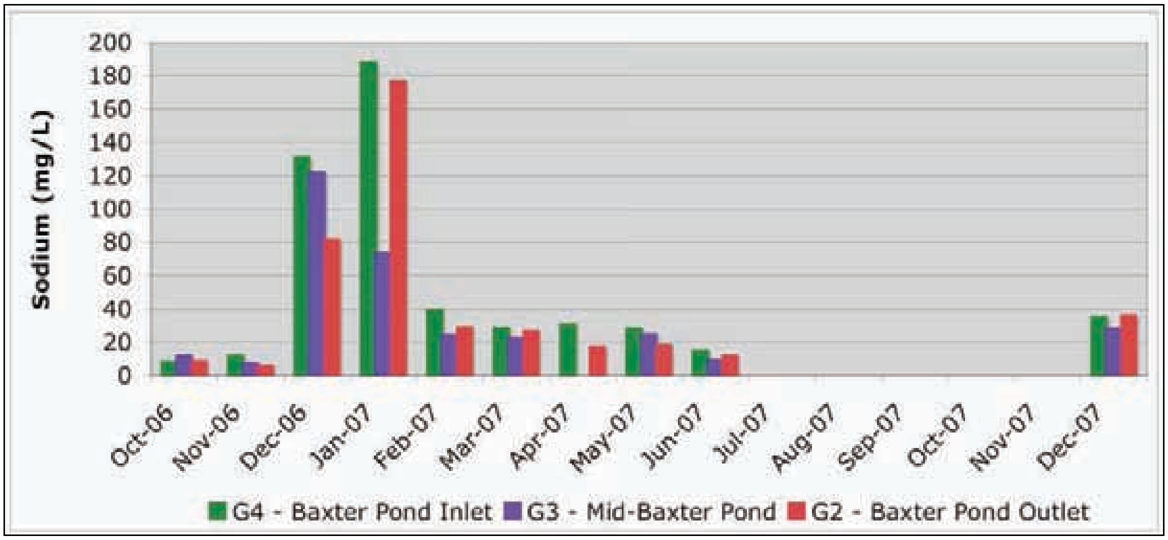


Figure 52. Sodium concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

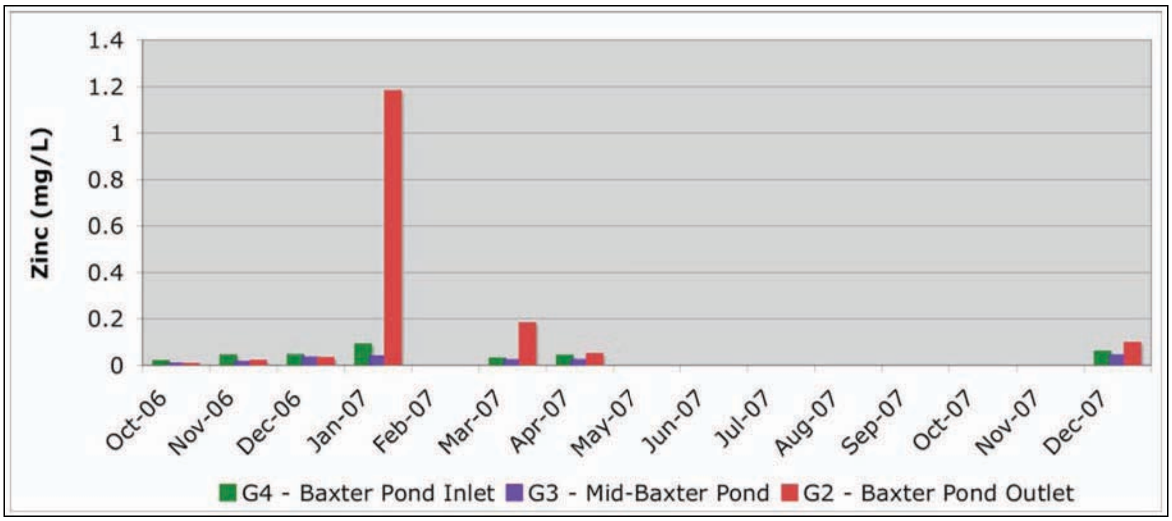


Figure 53. Zinc concentrations in inlet, mid-pond and outlet waters of Baxter Pond.

Sediment Chemistry

As with the water chemistry, metals concentration in the sediments were highly variable. There is generally a reduction in concentration from the inlet (G4) to the middle of the pond (G3) but then a sharp increase at the outlet (G2). For example, cadmium, chromium, copper and lead all decline in October and March between the inlet and middle of the pond, but concentrations increase between the middle of the pond and the outlet. This appears to be due to the backwater effect of Gabo Creek.

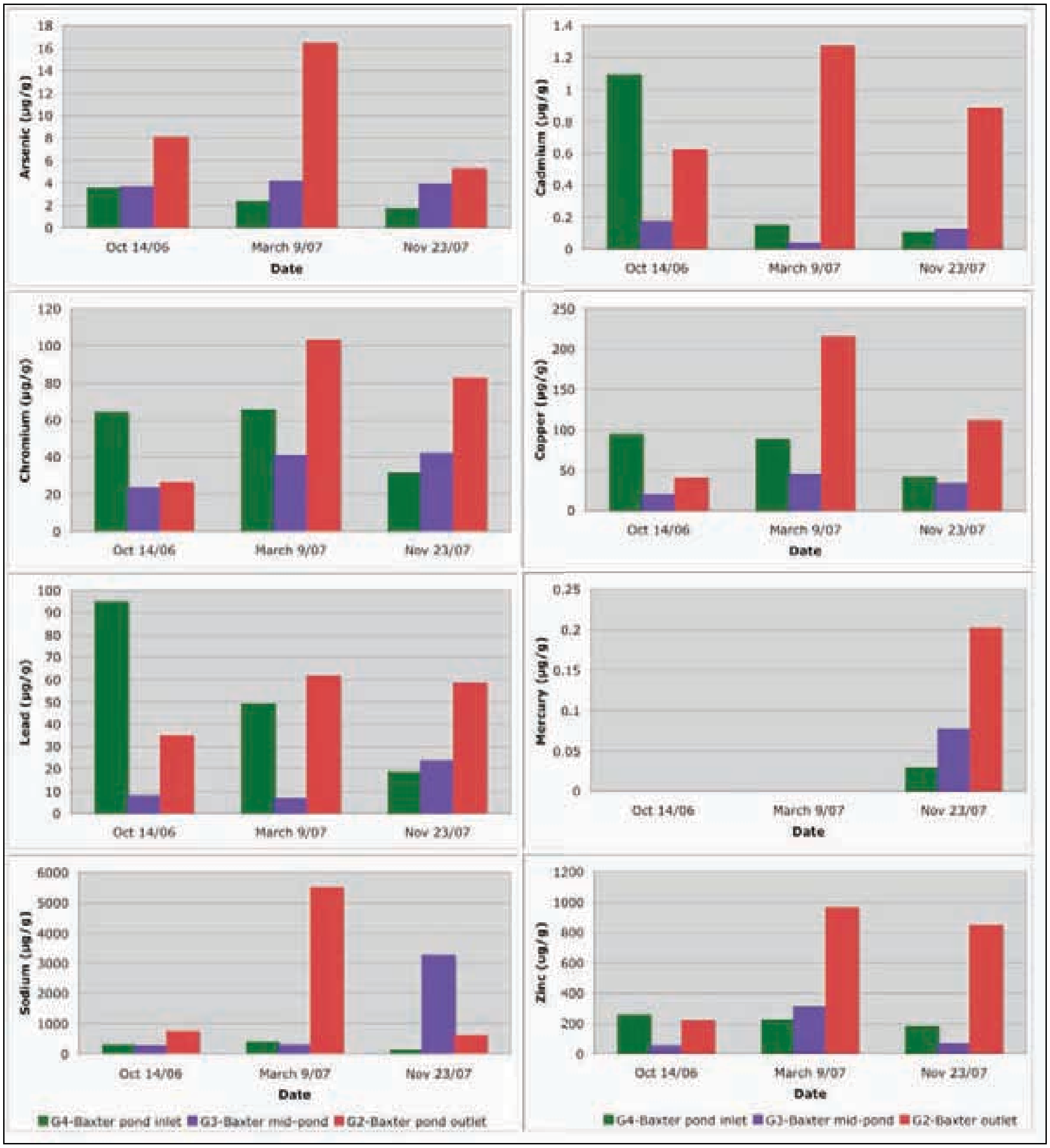


Figure 54. Concentrations of arsenic, cadmium, chromium, copper, lead, mercury, sodium and zinc in the sediments at the inlet, mid-pond and outlet of Baxter Pond.

Coliforms

Both fecal coliforms and *Enterococci* in Baxter Pond were very low, especially given the population of ducks that lives on the pond. Fecal coliforms were generally less than 100 CFU (Figure 55).

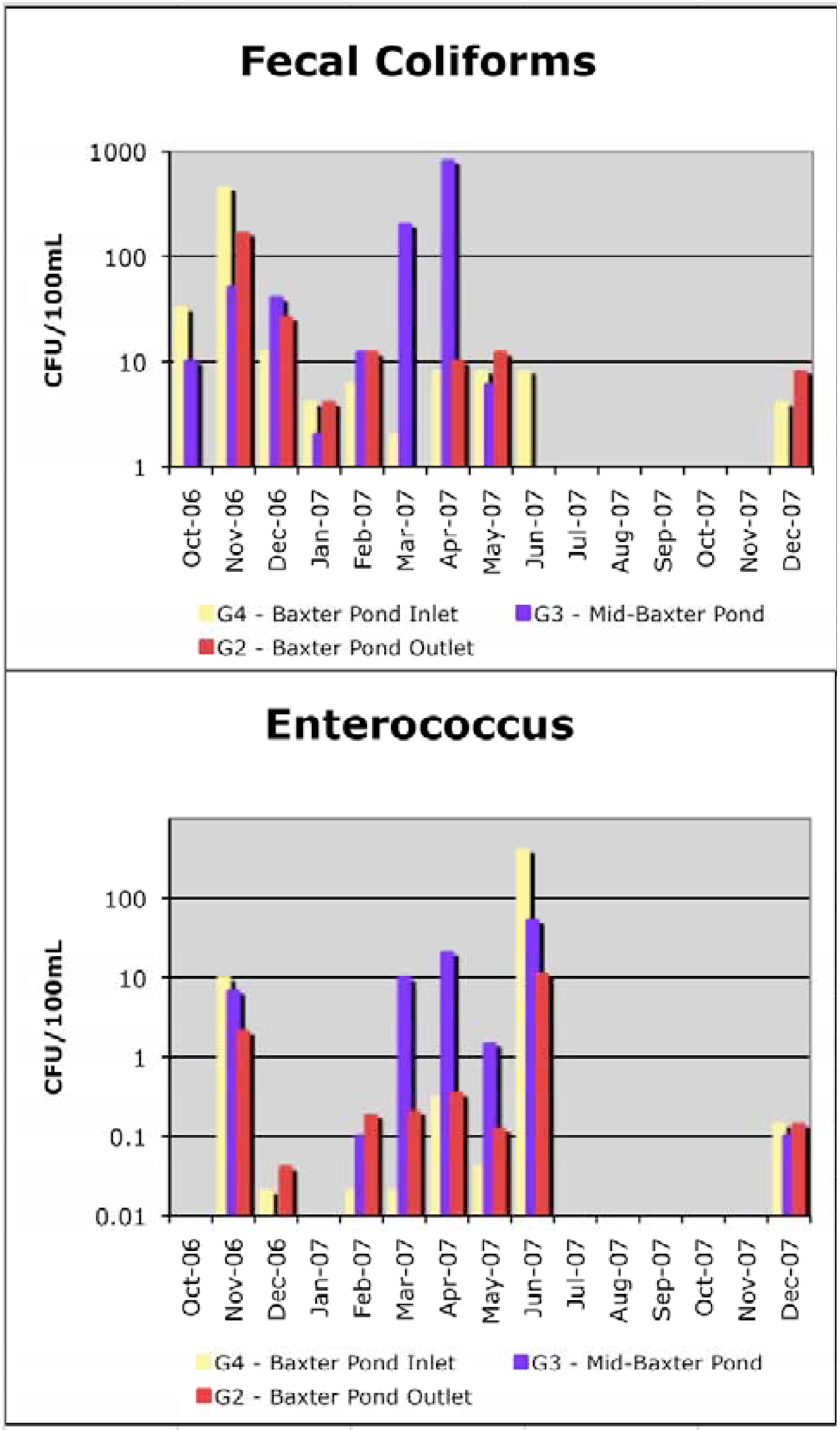


Figure 55. Fecal coliform and Enterococcus counts in the waters at the inlet, mid-pond and outlet of Baxter Pond.

Blenkinsop

The analysis for Blenkinsop Creek was complicated by multiple inputs, some of them seasonal and the backwater effects of a) Cumberland Creek into Blenkinsop Creek, and b) Galeys' field drain mixing with water at the B4 sample site which, during low flows when the drain was not in use, was intended to capture the maximum amount of "treatment" as it was the greatest distance from the input of Blenkinsop lake, before the confluence with Cumberland Brook

Given the difficulty in partitioning out the effects, data analysis focused on the water quality differences between the most upstream site, B6a, at the outlet of Blenkinsop Lake downstream of the weir, and the mid point of Galeys' field (B5a) approximately 250 m downstream.

Nutrients

Blenkinsop Creek was very effective at removing nutrients. The channel removed between -1.2% and 38.9% of the total nitrogen with an average removal efficiency of 18.8% (Figure 56). On average, the ammonia was reduced by over 55.6%, the nitrate by 20.2% and the nitrite by 13.9%. The ortho-phosphorus was reduced by an average of 186.2 µg/L or 20.1% (Figure 57). As demonstrated by these data, Blenkinsop Creek is very slow flowing for most of the year and acts as a long pond.

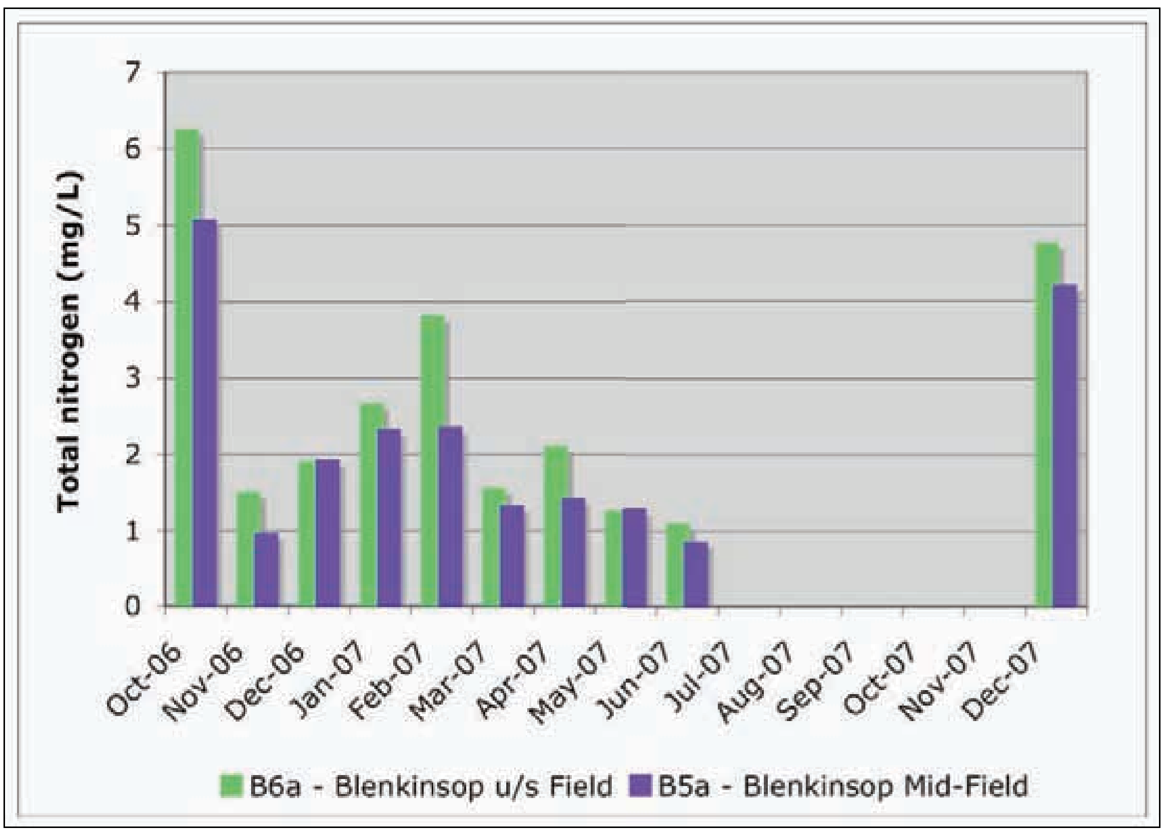


Figure 56. Total nitrogen concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

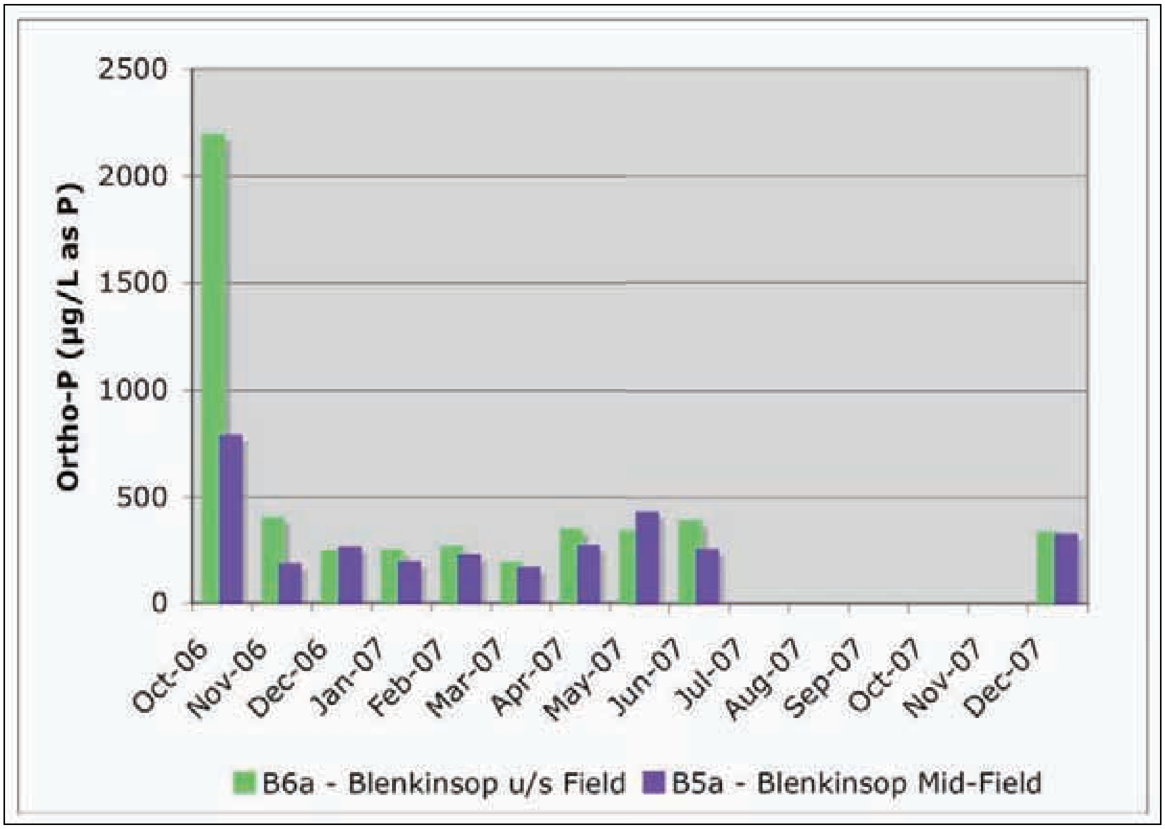


Figure 57. Ortho-P concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

Specific Conductance and TDS were largely unchanged along the length of the channel. On average TDS increased by 7.0% and specific conductance increased by 32.3% largely due to a high TDS value in November 2006 and a high specific conductance value in Dec 2007.

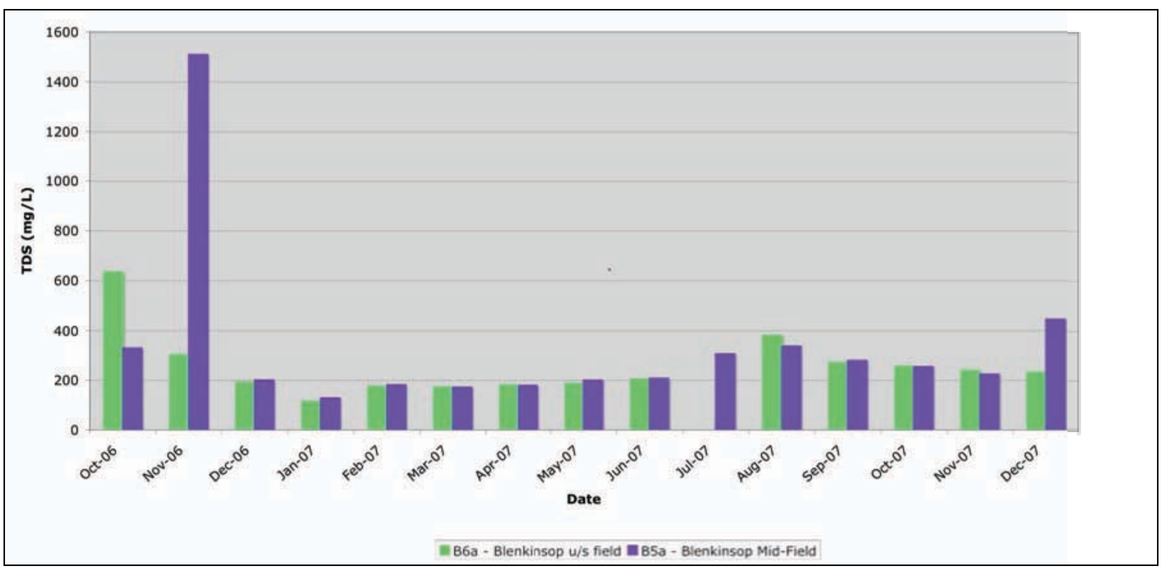


Figure 58. Total dissolved solids (TDS) concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

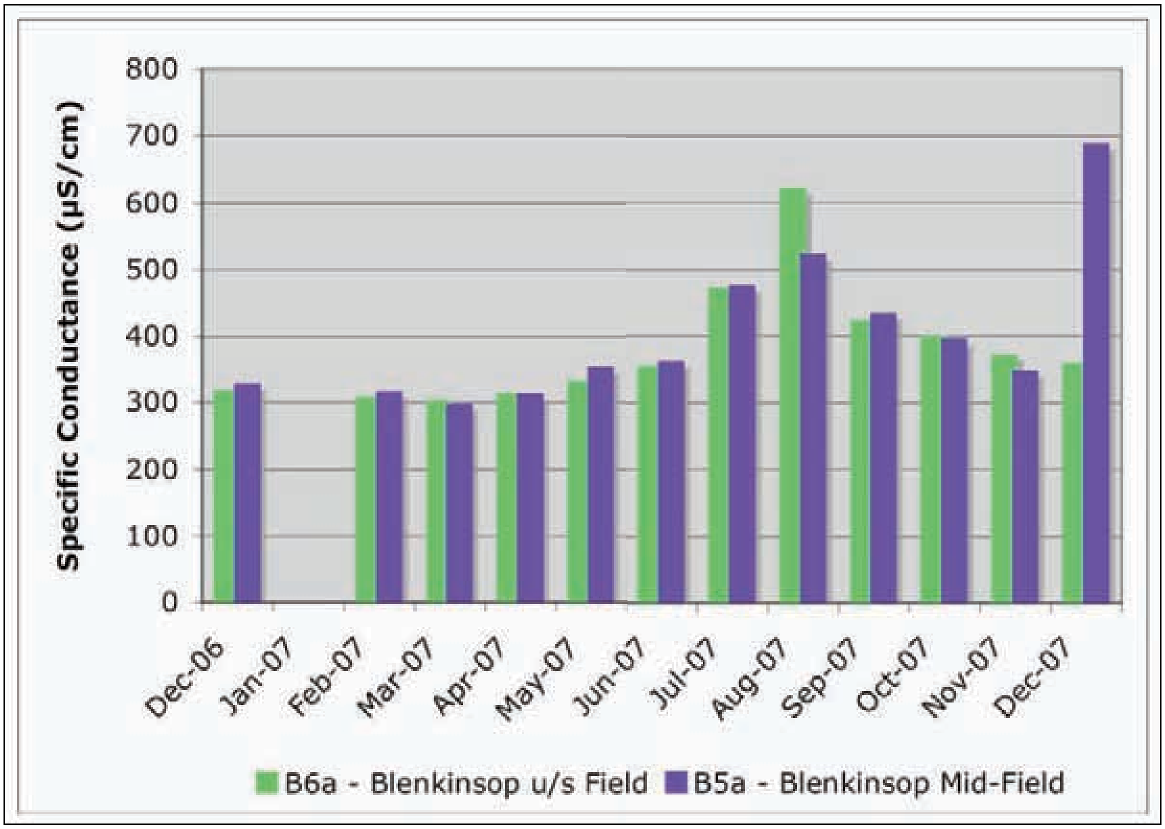


Figure 59. Specific conductance (µS/cm) in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

Suspended Solids

Results were variable, but the channel reduced TSS more than 50% of the time. There was an unexplained increase in TSS in both October and November 2006 at site B5a, possibly due to sampling error. The vegetation enclosed the stream here and it is easy to dislodge fine sediment from the surface of the vegetation when accessing the stream channel and contaminate the sample. On average the TSS increased 119% (inclusive of the high values).

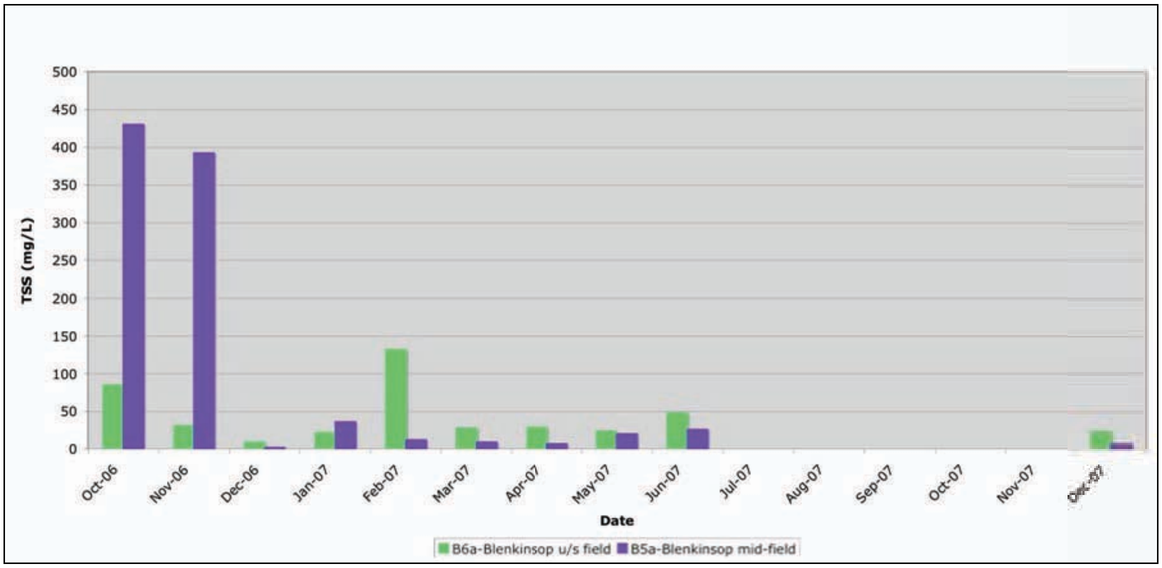


Figure 60. Total suspended solids (TSS) concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

Temperature and Dissolved Oxygen

Temperature in Blenkinsop Creek is high as a result of Blenkinsop Lake immediately upstream. Values in mid-summer are above 15°C even though little runoff from hot surfaces such as roads reaches these upper reaches of the creek or lake. On average, the creek warmed slightly (1.2°C) between the outlet of the lake and the mid-way along Galeys' field. Oxygen values are very low, ranging between 0.07 mg/L and 11.8 mg/L at the lake outlet and between 0.21 mg/L and 10.8 mg/L at site B5a. This is due to the eutrophic conditions in Blenkinsop Lake where the decomposition of the biomass strips oxygen from the water, and due to the fact that the reconstructed creek channel has very little gradient and therefore no opportunity for physical aeration.

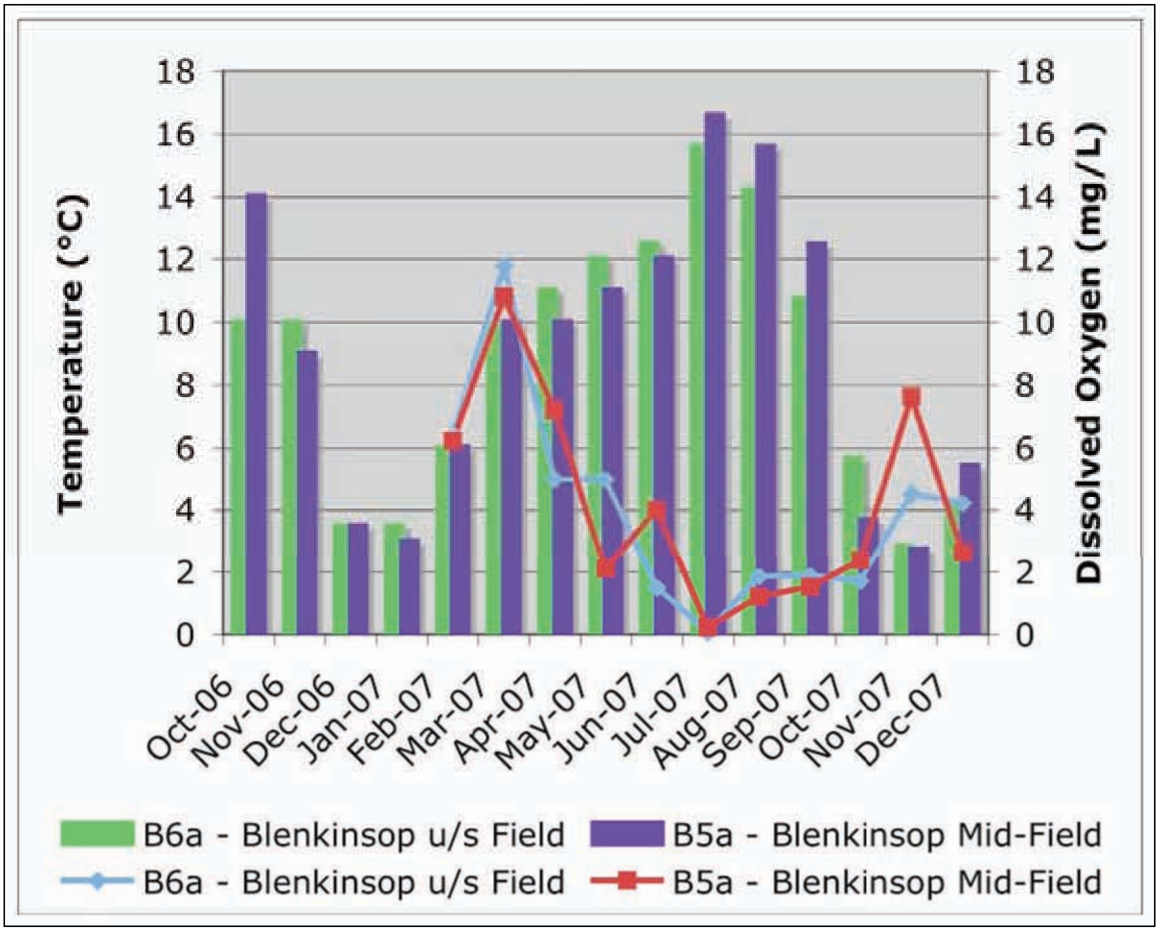


Figure 61. Temperature and dissolved oxygen concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field.

Metals

Most metals were routinely below detection limits in Blenkinsop Creek. Zinc was the only heavy metal that was routinely present. Zinc concentrations at site B5a appeared to follow a seasonal trend and were highest during high flows. During low flows, zinc concentrations were higher at the upstream site (B6a) and declined substantially at site B5a. During higher flows the downstream site had a higher concentration than the upstream site. Between site B6a and B5a, arsenic increased an average of 11.1%, chromium increase an average of 8.8% (n=1), copper decreased 25.6%, mercury decreased 19.1% and zinc decreased 40.5%. As noted earlier, the average reduction in zinc is misleading as the average change was a decrease of only 0.0067 mg/L (6.7 µg/L).

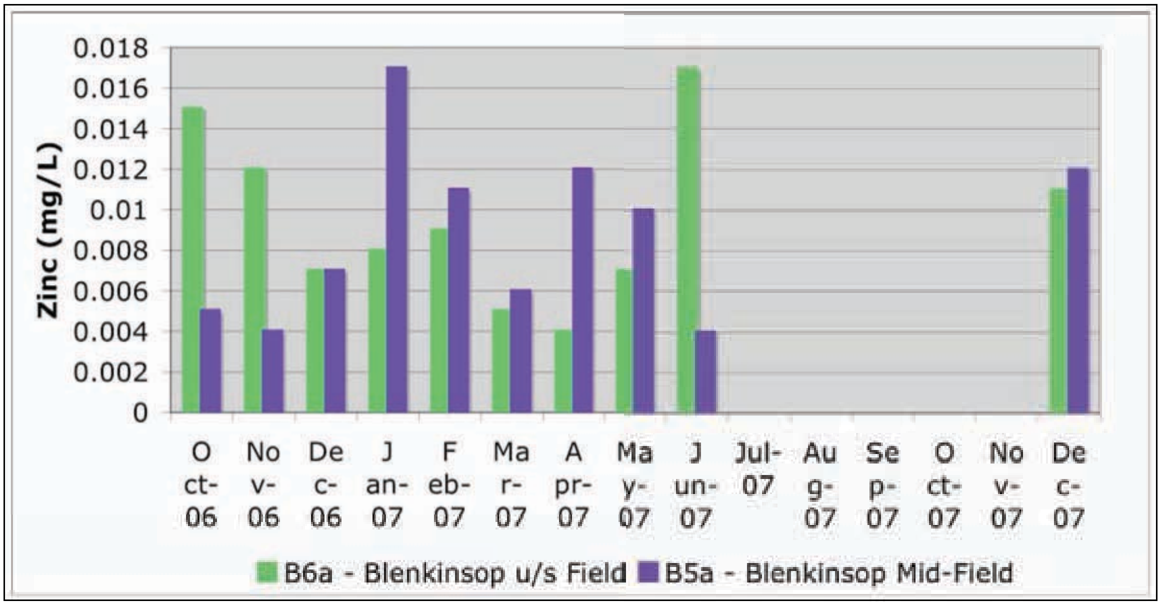


Figure 62. Total zinc concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

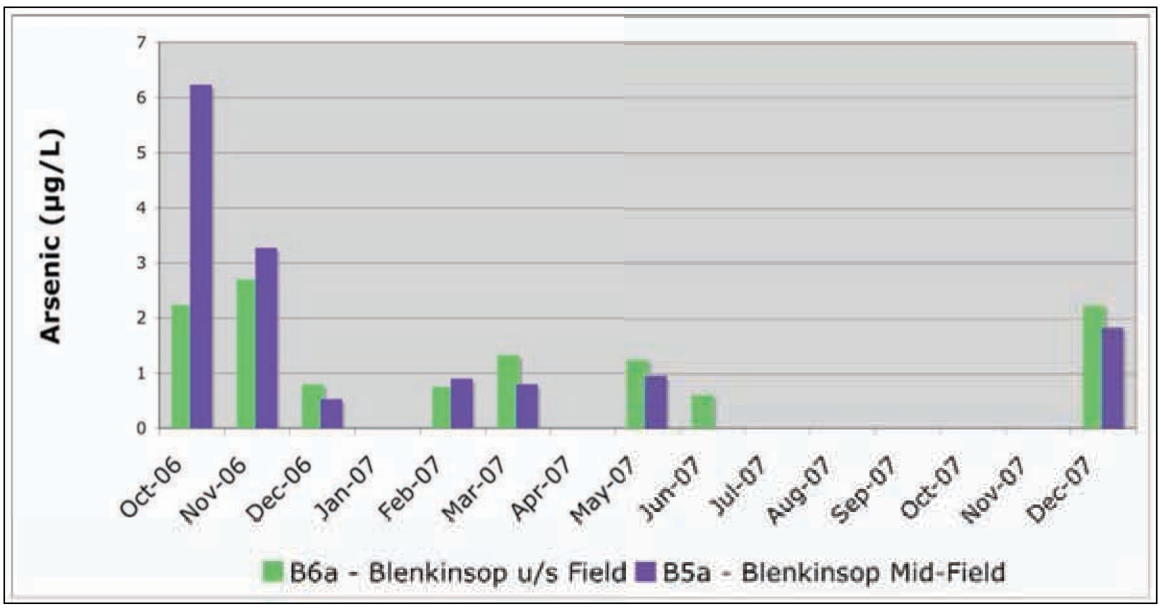


Figure 63. Total arsenic concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

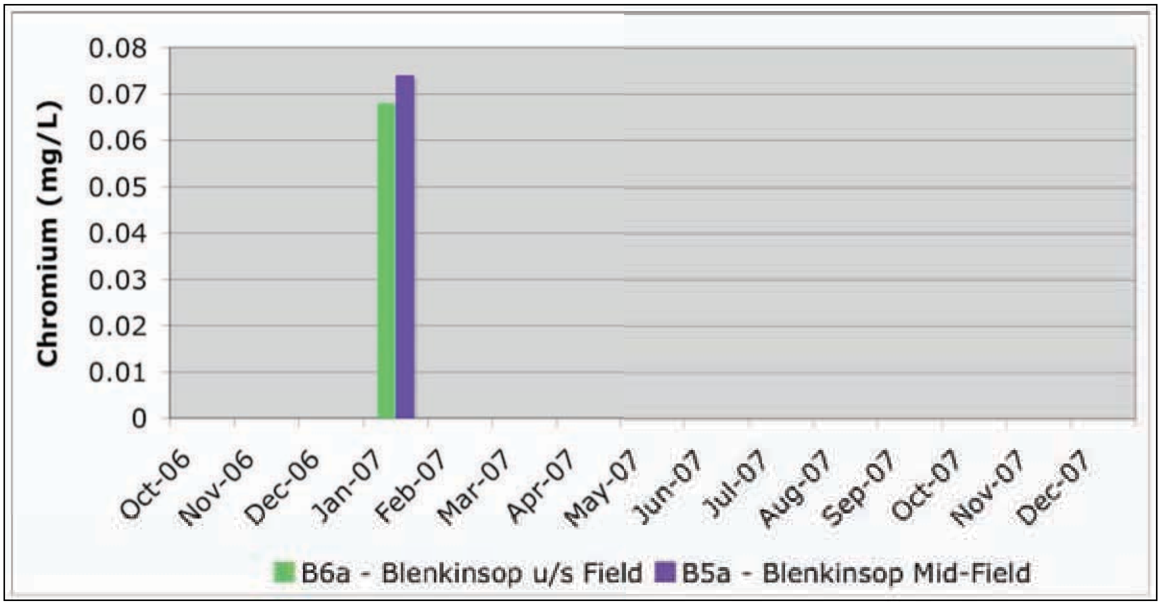


Figure 64. Total chromium concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

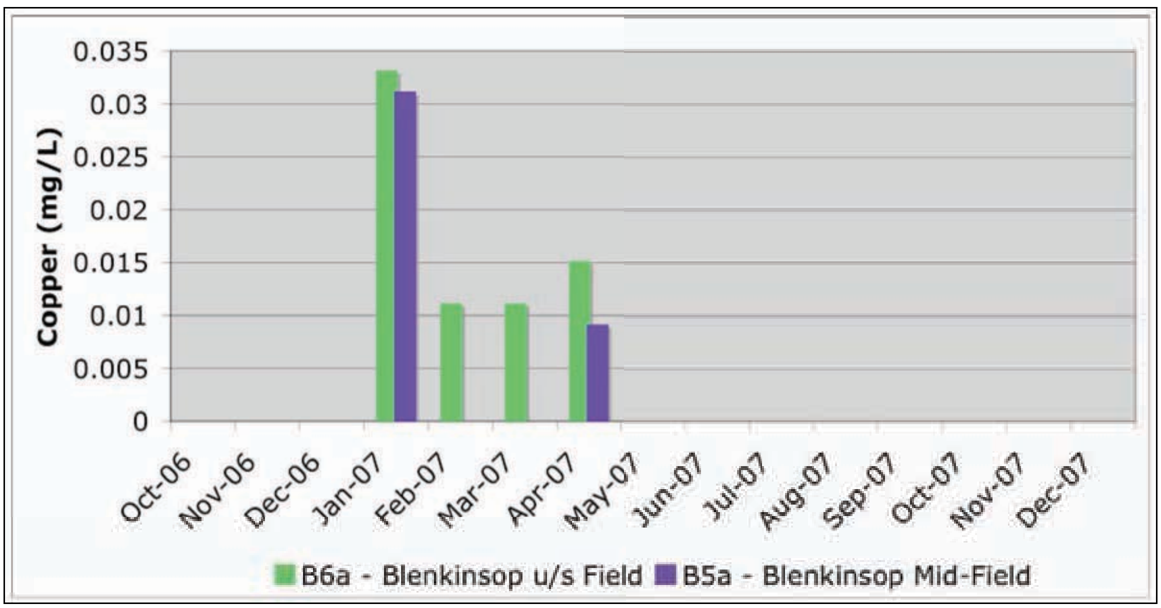


Figure 65. Total copper concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

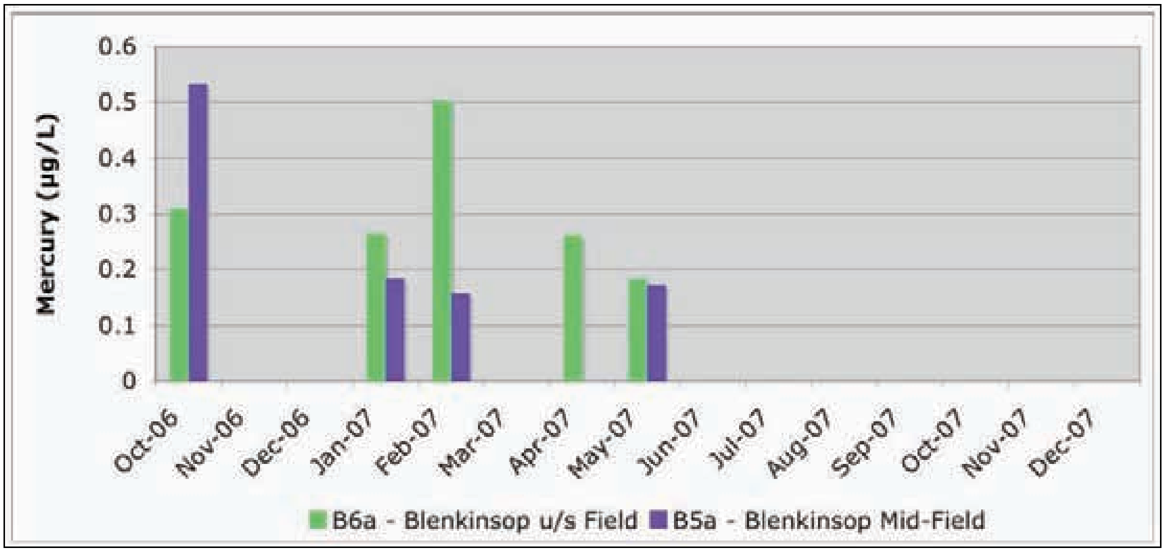


Figure 66. Total mercury concentrations in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

Sediment Chemistry

The difference in metals concentrations between the outlet of Blenkinsop Lake and mid-way along Galeys' field is striking. Every heavy metal tested declined significantly, with one very small exception. Only chromium was slightly higher (3.3 µg/g) at the downstream site than the upstream site on March 9, 2007. The effective removal of arsenic was 44.7%, cadmium 83.4%, chromium 19.8%, copper 39.9%, lead 90%, mercury 58.3% and zinc 64.7%. This suggests that Blenkinsop Lake, and not the neighbouring field, is the source of the heavy metals in Blenkinsop Creek and that the heaviest particulates to which the metals are bound, are settling out significantly before they reach the middle of the channel along Galeys' field. It is important to consider how the change in channel morphology, from a ditch intended to convey water quickly, to a sinuous stream channel intended to slow the water and create complexity, may have increased the water residence time and thus improved the removal of heavy metals from the water column.

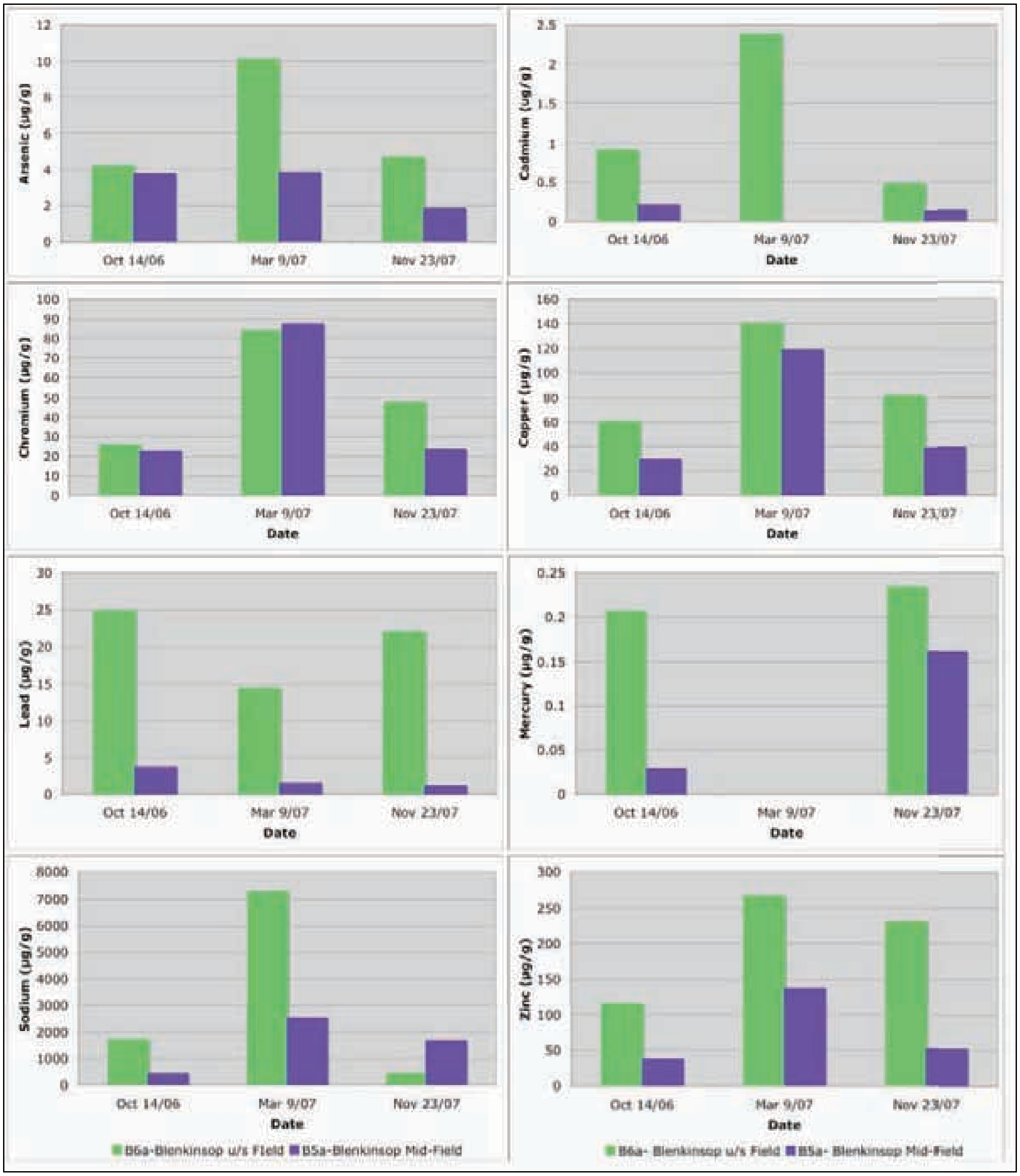


Figure 67. Concentrations of arsenic, cadmium, chromium, copper, lead, mercury, sodium and zinc in the sediments in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

Bacteriology

Both fecal coliform and *Enterococcus* were lower at site B5a than at the upstream site (B6a) on every date except Nov 6, 2006. *Enterococcus* values were exceptionally low and never exceeded 12 CFU at the two most upstream sites.

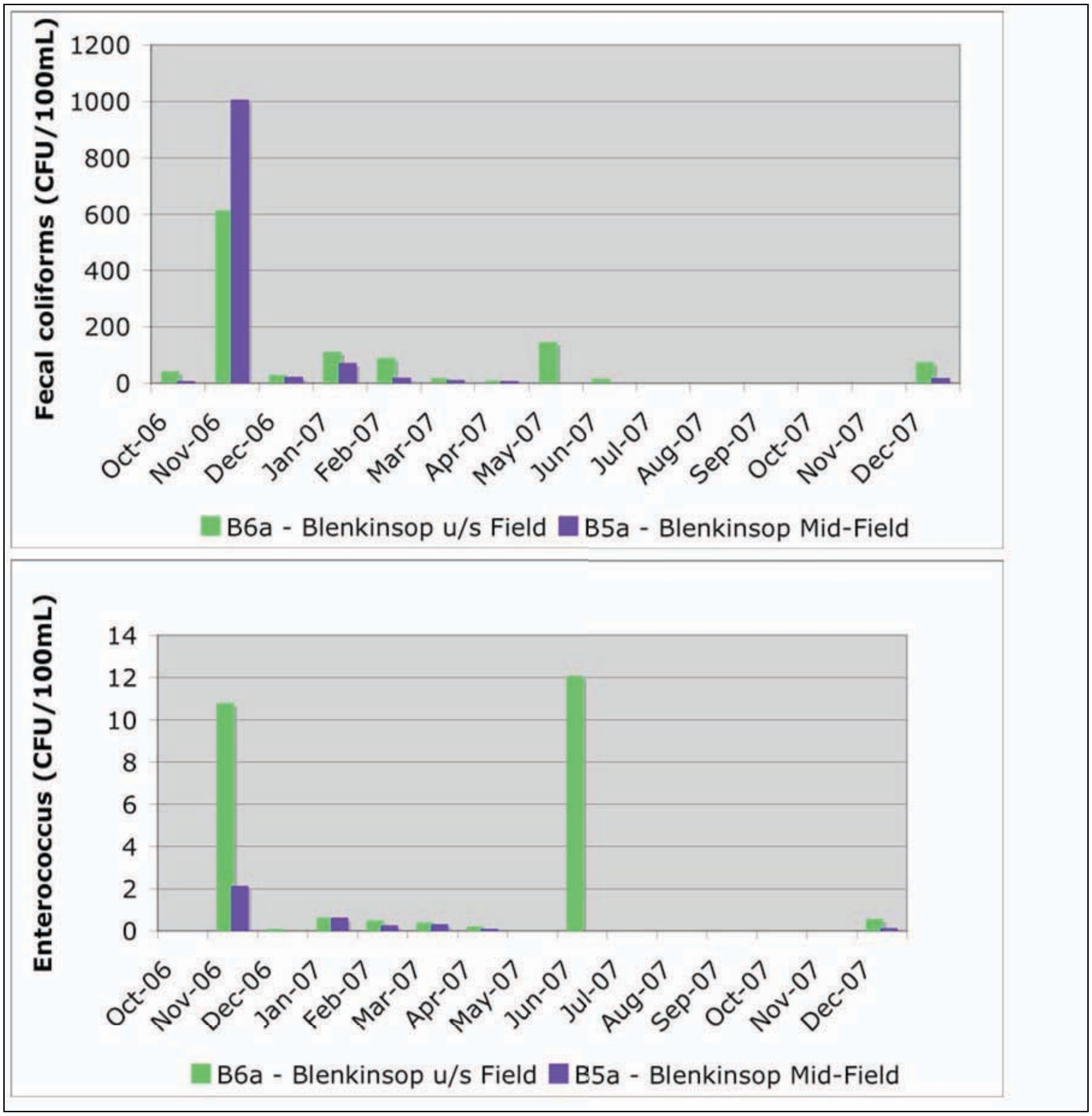


Figure 68. Fecal coliform and Enterococcus counts in Blenkinsop Creek upstream of Galeys' field and mid-way along Galeys' field (restored channel).

Leeds

Nutrients

The restored Leeds Creek channel was very effective at removing nitrogen (Figure 69). On all but one sampling date (Oct 2007) the lower reach of the creek had significantly less nitrogen than the inlet culvert. On average, the total nitrogen was reduced by 0.7 mg/L if the October value is included in the data analysis. When it is excluded, the average removal rises to 1.07 mg/L representing a removal rate of 45.2%. Water levels were very low in October and it was difficult to sample without entraining sediment. This value is thus considered an exception and not a true representation of stream conditions.

The stream also removed phosphorus on all dates except for two high flow periods in February and March 2007. This suggests that when flows are high, the residence time is not long enough for the stream to assimilate the nutrients. The removal rate for ortho-phosphorus averaged 46.7% with the exception of March 9/07 when it was -682%, increasing from 41.8 to 327 µg/L. This value skews the average to -26.2% which is not indicative of the function of the stream during the majority of the year. As can be seen in Figure 70, the phosphorus concentrations in Leeds Creek are substantially lower than those in neighbouring Blenkinsop Creek (see locations in Figure 13 on page 11).

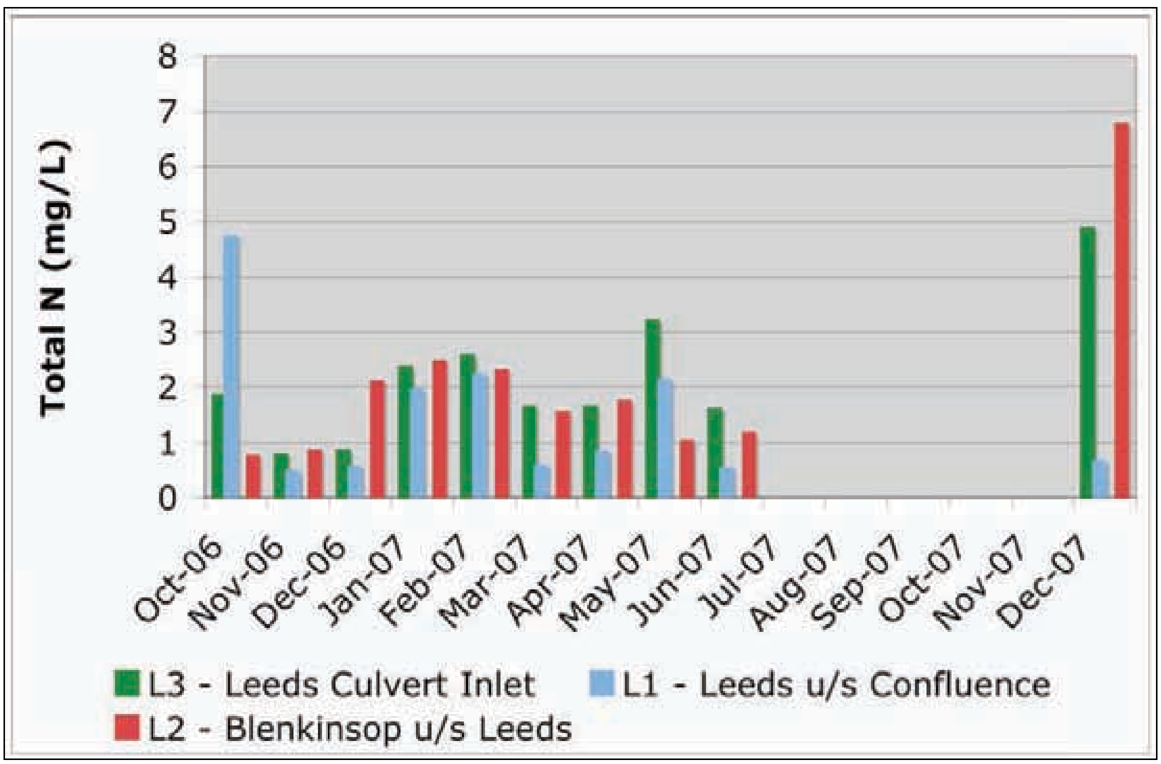


Figure 69. Total nitrogen concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

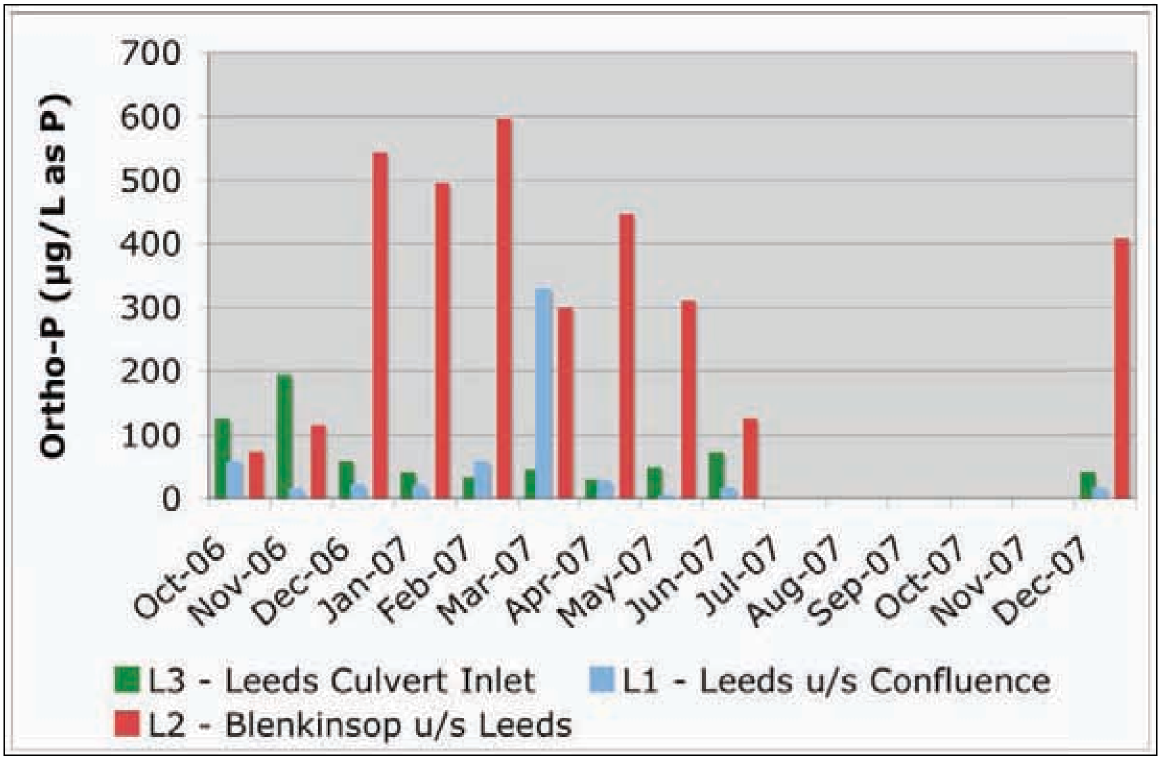


Figure 70. Ortho-P concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Suspended Solids

Because the water in Leeds Creek is flowing most of the year (it is spring-fed via the culvert) the water does not have much opportunity to slow down and allow particulates to settle. As a result it is ineffective at removing suspended materials throughout most of the year. Removal rates averaged -46.5mg/L (-2122.4%) (Figure 71).

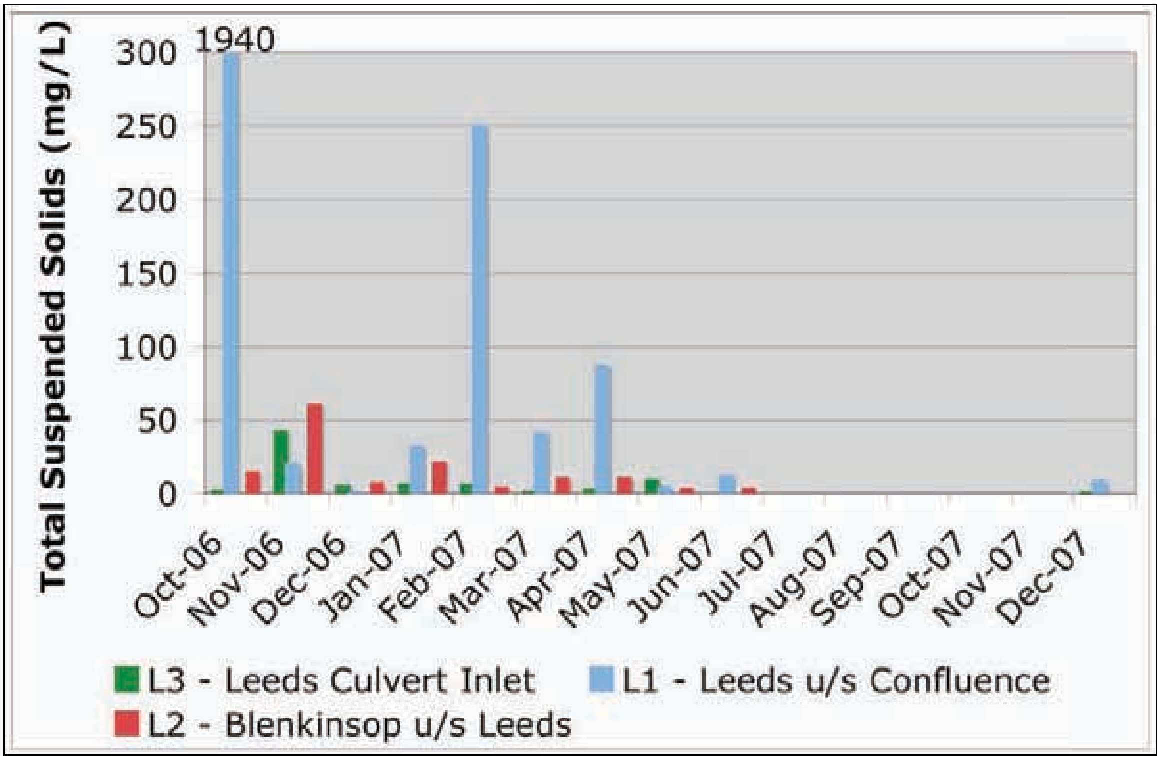


Figure 71. Total Suspended Solids (TSS) concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Dissolved solids also increased on most sampling dates. Removal rates averaged -33.1 mg/L or 70.6%. The creek did strip some chloride from the water (Figure 73) and the effect of winter road salt in the road runoff is evident in the elevated December and January values.

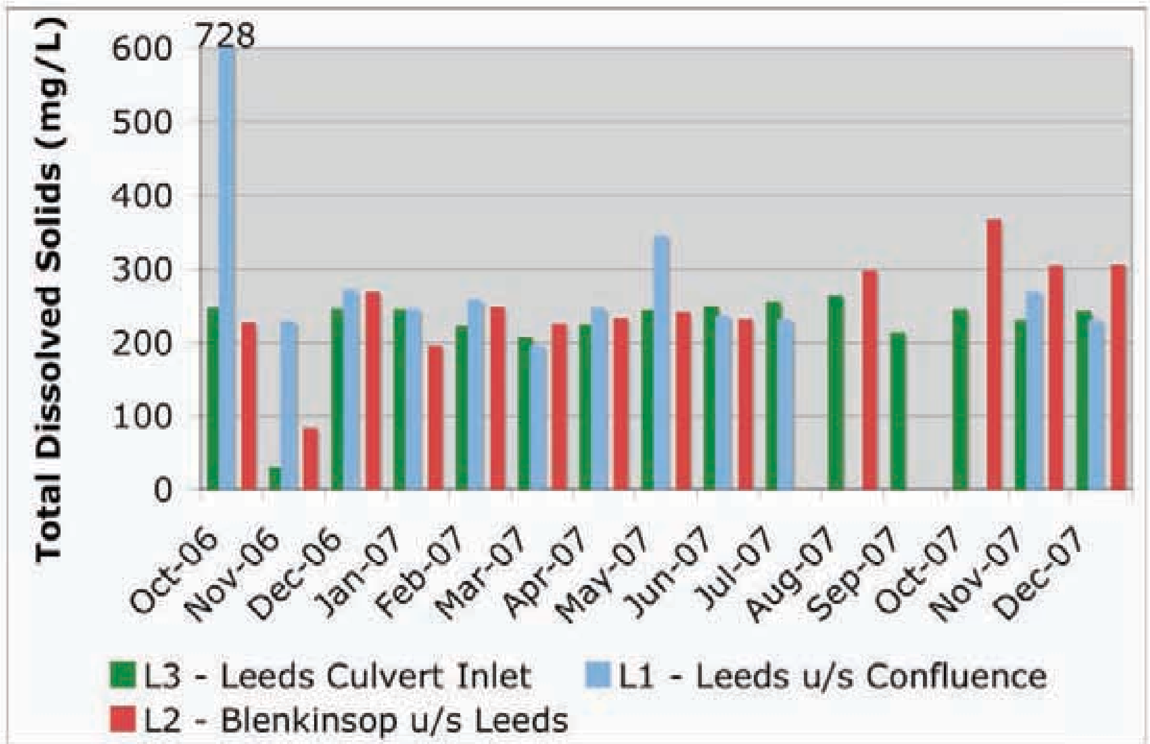


Figure 72. Total Dissolved Solids (TDS) concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

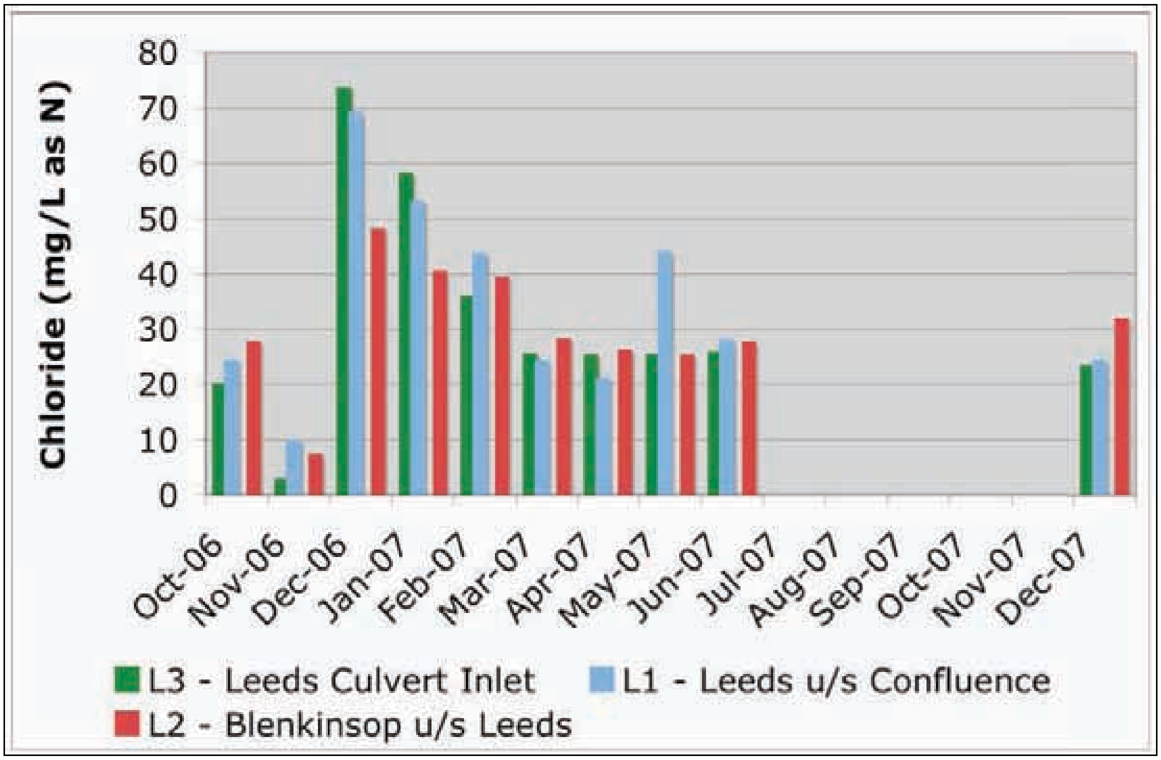


Figure 73. Chloride concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Temperature

The greatest positive effect of Leeds Creek is upon the water temperature. Water upstream of the confluence with Blenkinsop Creek was up to 4.6°C cooler than water at the culvert outlet. The average difference was 2.12°C or 19.5%.

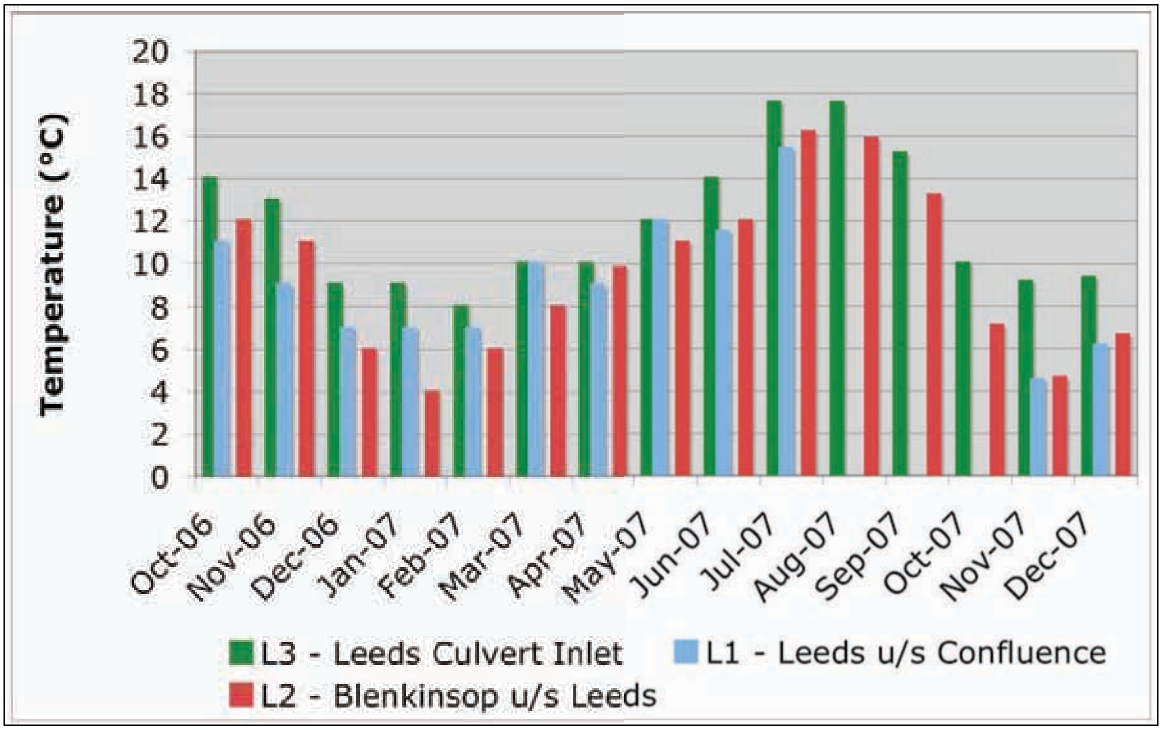


Figure 74. Water temperature in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Metals

Once in the flowing water, the metals largely remained unchanged. As noted above, the flowing creek afforded little opportunity for suspended materials to settle out, and since the metals are largely bound to particulates, the metals did not settle out either. There may have been a small measure of uptake by bacteria and plants, however the detection limits of this analysis were too robust to detect such small differences. The removal rates for the key metals were: arsenic -365%, chromium 19.4%, copper -239%, lead -676%, mercury -36%, sodium -32%, tin -4658% and zinc -630%. Several metals, notably copper and mercury, are elevated at site L1 (Leeds upstream of Blenkinsop). This may be due to the contribution of a small culvert draining the neighbouring cul de sac. The source of these metals is not known. After examining old maps to determine if this was a fill site, and thoroughly searching the neighbourhood, we could find no obvious source of the metals.

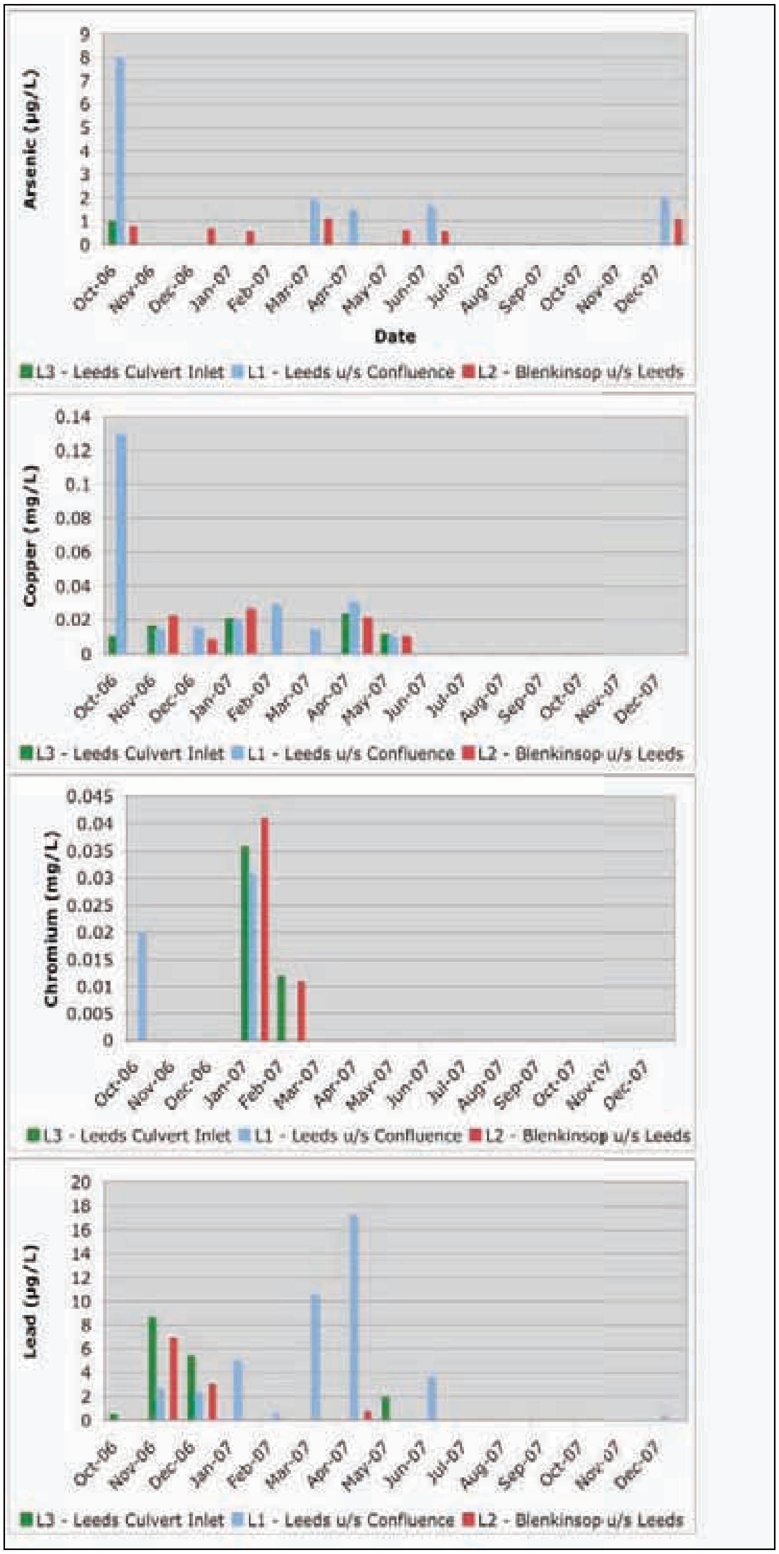


Figure 75. Arsenic, copper, chromium and lead concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

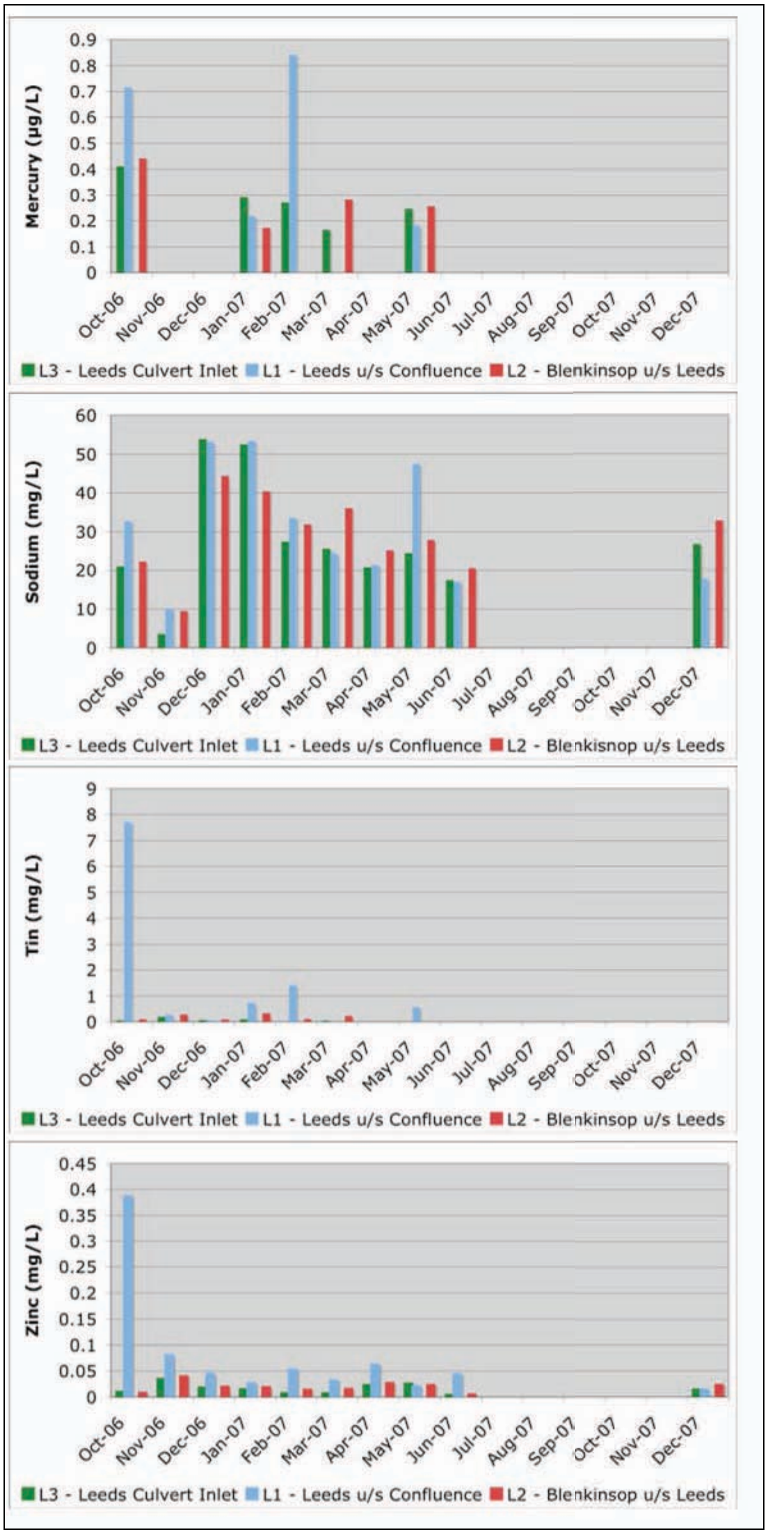


Figure 76. Mercury, sodium, tin and zinc concentrations in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Sediment Chemistry

There appears to be a seasonal trend in the sediment constituents. In October 2006, all the key metals were higher at the downstream end of the channel than at the culvert, with the exception of lead. In both March and December 2007, the values at the downstream end of the channel were lower than at the inlet for arsenic, chromium, copper, lead and zinc (Figure 77). This may be explained by the long very dry summer of 2006 which allowed the cleaner spring water to wash the accumulated sediments downstream. By March 2007 new sediments had been deposited along the length of the stream by the snow melt of January 2007. The removal rates for the key metals were: arsenic -179%, chromium 9.7%, copper -13.2%, lead 54.6%, mercury -314.8%, sodium -272.37%, tin -22.21% and zinc -146.6%.

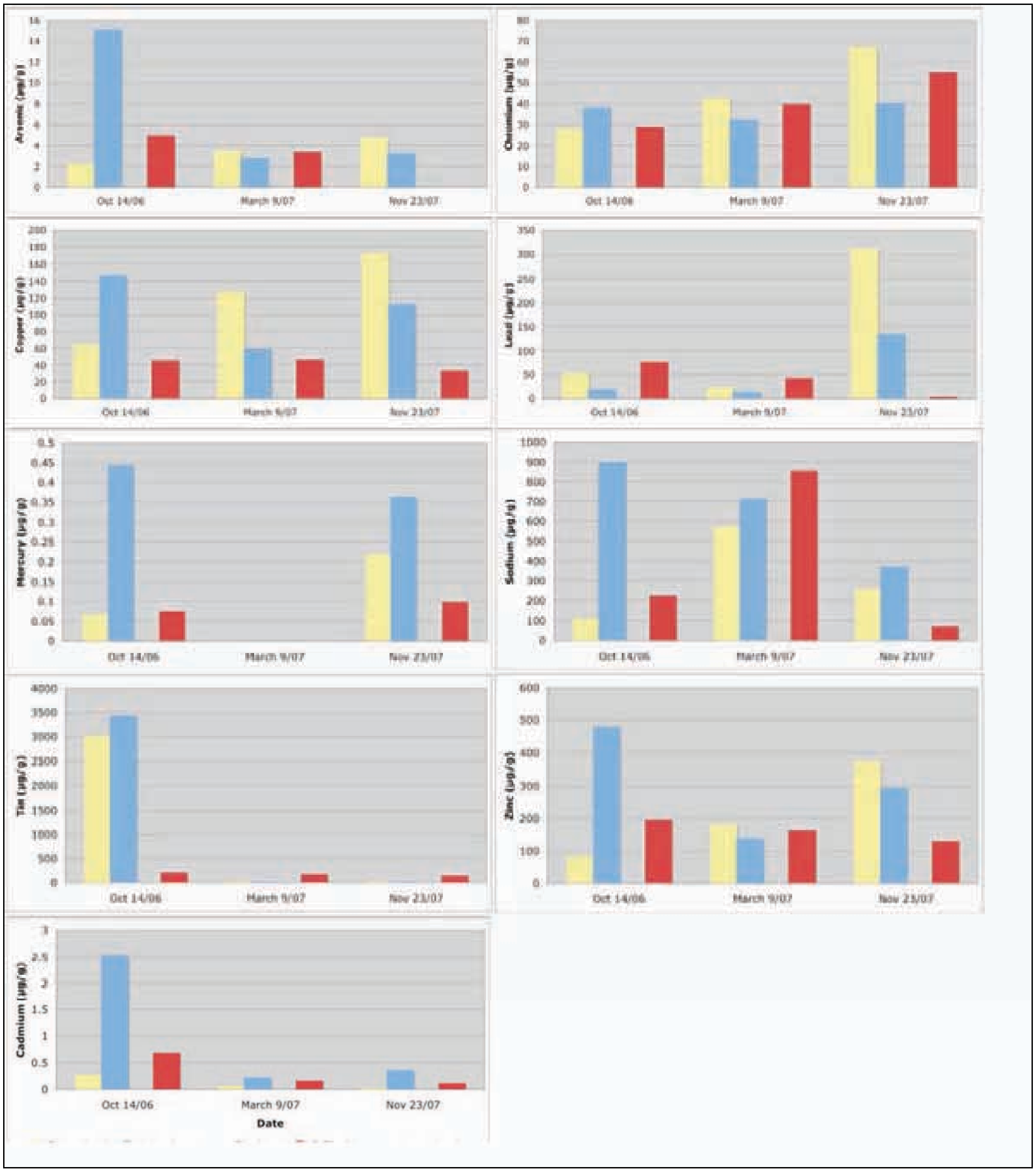
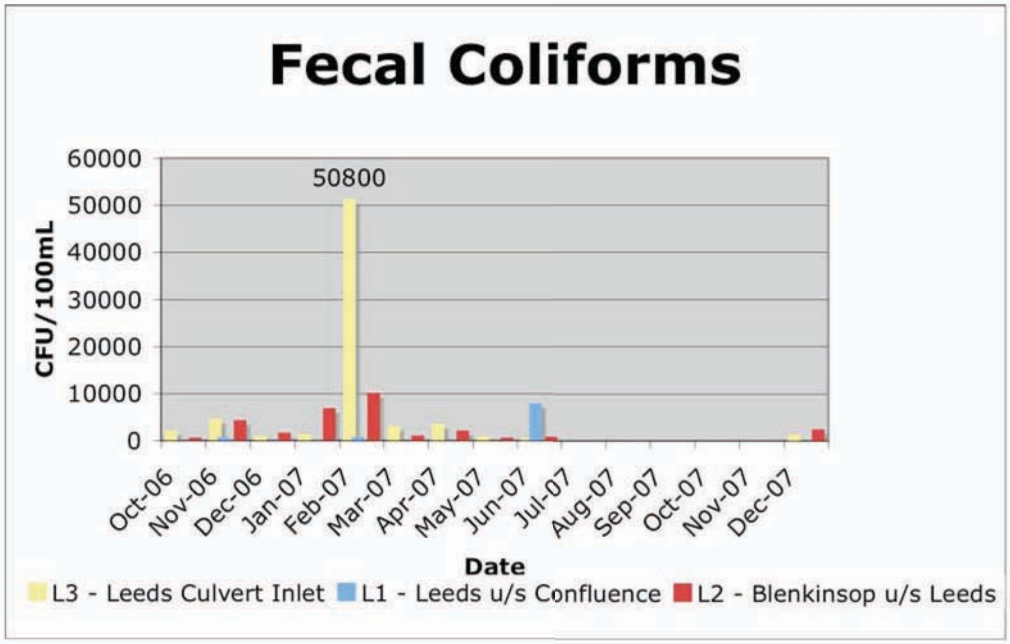


Figure 77. Concentrations of arsenic, chromium, copper, lead, mercury, sodium, tin, zinc and cadmium in the sediments of Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Bacteriology

The fecal coliform counts in Leeds Creek at the culvert inlet were high. The peak value was recorded on February 6, 2007 at 50800 CFU/100 mL. There were only 1.1 CFU of *Enterococcus* in this same sample. There was no noticeable trend between sites.



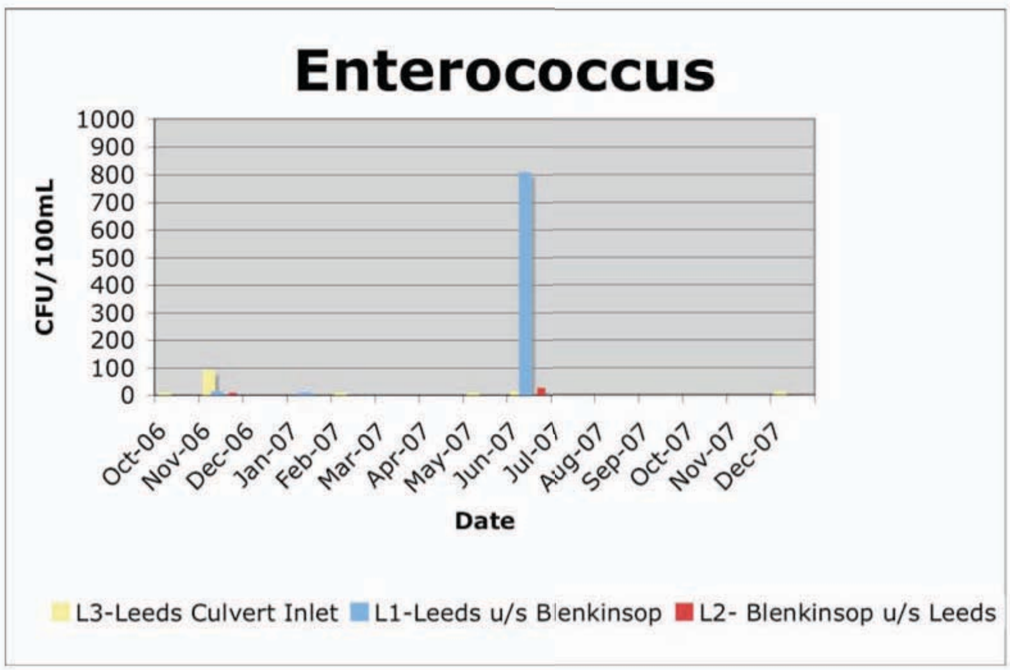


Figure 78. Fecal coliform and *Enterococcus* counts in Leeds Creek at the inlet to the creek, upstream of the confluence with Blenkinsop Creek and in Blenkinsop Creek upstream of the confluence with Leeds Creek.

Vancouver Island Technology Park

During many of the sampling occasions, the VITP sites were dry. This demonstrates the effectiveness of the infiltration BMPs, but does little to provide comparative information. As a result of the lack of water, data collection was suspended and data analysis was not pursued. The raw data that were collected are contained in Appendix D.

Aquatic Life Guidelines

Compliance with Aquatic Life Guidelines

The water and sediment quality for each site was compared to the Canadian Guidelines for Aquatic Life (Table 5, Table 6, and Table 7).

Willowbrook and Glanford:

- met the guidelines for arsenic;
- were in the order of 10 times above the guidelines for copper;
- outlet waters were in compliance for lead, but inlet waters were not;
- both inlet and outlet waters exceeded the guidelines for mercury;
- Willowbrook was consistently in compliance for zinc except for the inlet waters in Oct 06 and April 07. Glanford was in compliance except for April 07 (inlet and outlet both exceeded the guideline).

Sediments

- Willowbrook was incompliance for arsenic, but the Glanford inlet exceeded the guideline on Oct 06 and March 07 and the outlet waters exceeded the guidelines on March 07 and Nov 07. Oct 06 was border line.
- Willowbrook inlet and outlet was exceeded the cadmium guideline in Oct 06. Glanford inlet exceeded it in Oct 06 and Nov 07.
- Both Willowbrook and Glanford exceeded the chromium guidelines at the inlet and outlet on all sample dates.
- Both Willowbrook and Glanford exceeded the copper guidelines at the inlet and outlet on all sample dates.
- Willowbrook exceeded the lead guidelines at the inlet and outlet on Oct 06, at the outlet on March 9/07 and at the inlet on Nov 23/07. Glanford exceeded the guidelines at the inlet and outlet on Oct 06 and Nov 23/07.
- Willowbrook exceeded the guidelines for mercury at the inlet and outlet on Oct 13/06. Glanford exceeded the guidelines at the inlet on Oct 13/06 and Nov 23/07. Outlet sediments were in compliance.
- Both Willowbrook and Glanford exceeded the guidelines for zinc at the inlet and the outlet on all occasions.

Baxter Pond

- Only the outlet of Baxter Pond exceeded the guidelines for arsenic and only on one occasion (Mar 07).
- The inlet, mid point and outlet exceeded the guidelines for chromium on Jan 07 and the outlet exceeded the guidelines in March 07. It was undetectable on all other occasions.
- Baxter Pond exceeded the guidelines for copper on all occasions that it was measurable: inlet (Nov 06, Dec 06, Jan 07, Apr 07, May 07 and Dec 07), mid-pond (Jan 07 and May 07) and outlet (Jan 07, Mar 07, Apr 07 and Dec 07). It was undetectable on all other dates.

- Lead guidelines vary, based on the hardness of the water, between 1 and 7 µg/L. The hardness in Baxter Pond also varied. Lead was detectable in Oct 06 to Jan 07 and Mar to May 07. Values were generally less than 5 µg/L except for the outlet on March 07 when values exceeded 35 µg/L.
- Mercury was detectable four times: Oct 06 and May 07 at all three sites and at the outlet in Jan 07 and at the mid-pond site in Dec 07. It exceeded the guideline whenever detectable.
- Zinc was detectable throughout the fall and spring of 06/07, except for February, and was not detectable again until December. It exceeded the guideline of 30 µg/L six times at the inlet (Nov 06, Dec 06, Jan 07, Mar 07, Apr 07 and Dec 07). At the id-pond it exceeded the guideline four times (Dec06, Jan 07, May 07 and Dec 07). At the out let it exceeded the guideline on Dec 06, Jan 07 and April 07.

Sediments

- Only the sediments at the outlet exceeded the arsenic guidelines (Oct 06 and March 07) with the March value more than twice the acceptable limit.
- Cadmium at the outlet exceeded the guidelines on all three sampling dates with the March value again more than twice the acceptable limit. The inlet sediments in Oct 06 were also almost double the acceptable limit.
- Chromium in the sediments of Baxter Pond was also high, with six of the nine samples exceeding the limit of 37.3 µg/g.
- Copper exceeded the 35.7 µg/g guideline at all sites, on all dates, with the exception of the mid-pond site in Oct 06.
- At the outlet, lead was higher than the acceptable limit on all three sampling dates and inlet water exceeded the criterion in Oct 06 and Mar 07. In Oct 06 the value was almost three times the acceptable limit.
- Mercury was detected only once (Nov 07), and was present at all three sites. Only the outlet exceeded the criterion.
- Zinc was present at all sites on all dates and exceeded the guideline of 123 µg/g at the inlet and outlet on all dates and in the mid-pond in Mar 07.

Blenkinsop Creek

- Zinc was the only heavy metal routinely present in Blenkinsop Creek and levels at both sites were less than half the 0.030 mg/L (30 µg/L) guideline for aquatic life.
- Arsenic exceeded the guideline of 5 µg/L once at the mid-field site in Oct 06.
- Chromium was detected only once and exceeded the limit for aquatic life of 0.0089 mg/L by approximately seven times.
- Copper was detected four times, but exceeded the guideline by between three and ten times the allowable limit.
- Mercury was detected four times and was between seven and twenty times the aquatic criterion of 0.026 µg/L.

Sediments

- Arsenic exceeded the aquatic guideline only once, at the upstream site, on Mar 9/07. It was approximately 1.7 times the limit.

- Cadmium exceeded the guideline twice, both times at the upstream site, on Oct 14/06 and Mar 9/07. The highest values were approximately four times the criterion.
- Chromium was double the acceptable limit at both sites on Mar 07 and was just over the limit at the upstream site in Nov 07.
- Copper exceeded the guideline at both sites on all dates except for Oct 14/06 at the downstream site.
- Lead was present at all sites on all occasions, but did not exceed the aquatic life criterion.
- Mercury marginally exceeded the guideline at the inlet in Oct 06 and Nov 07.
- Zinc was present at all sites on all dates and exceeded the guideline at both sites in Mar 07 and at the inlet in Nov 07.

Leeds

- The upstream site at Leeds exceeded the guideline for arsenic only once, in Oct 06. It was detected on seven other dates, but all were in compliance.
- Copper was detected on eight occasions and exceeded the criterion at all sites.
- Chromium was detected on three sampling dates. It exceeded the criterion on all dates at all sites.
- Lead was detected in the water on eleven dates. With the exception of Oct 06 ad Dec 07, it exceeded the criterion at all sites on all dates
- Mercury was present on five sampling dates. On each date, at each site, it exceeded the criterion of 0.026 µg/L.
- Zinc exceeded the criterion once at the inlet on November 3/06 and seven times at the outlet (Oct 06, Nov 06, Dec 06, Feb 07, Mar 07, Apr 07, and June 07. The highest recorded value was 0.387 µg/L at the outlet in Oct 06.

Sediments

- The arsenic guideline was exceeded once, at the outlet, on Oct 14/06.
- Chromium exceeded or was very close to the guideline at all sites on all sampling dates, except for Oct 06 at the inlet.
- Cadmium exceeded the guideline only once, at the outlet, in Oct 06 when it was four times the acceptable limit.
- Copper was detected at all sites on all dates and consistently exceeded the guidelines.
- Lead exceeded the criterion on two dates at the inlet: Oct 06 and Nov 07. It also exceeded the guideline at the outlet in Nov 07.
- Mercury was high at the outlet in both Oct 06 and Nov 07. It also exceeded the guidelines at the inlet in November. It was not detected in March.
- Zinc was detected at all sites on all dates and consistently exceeded the guideline with the exception of in inlet in Oct 06, when the value was within acceptable limits.

The stormwater installations are effective at reducing metals, primarily by filtering and trapping suspended sediments. Once these sediments are resuspended (*e.g.* washed downstream) the metals can once again be liberated. It is therefore critical that these systems are maintained by removing accumulated sediment and properly disposing of it.

Table 5. Canadian and BC Guidelines for Aquatic Life for nutrients and general water chemistry.

Parameter	unit	Canadian Aquatic Life Criteria	BC Aquatic Life Criteria
Alkalinity	mg/L		
Ammonia - N	ug/L	19 (Unionized)	Varies with temp and pH
Colour (True)	TCU		30-d average shall not exceed background by more than 5 mg/L Pt
Nitrate-N	ug/L	2900 ug/L	200 mg/L
Nitrite-N	ug/L	60	.06 mg/L when chloride is <2 mg/L
pH		6.5 - 9.0	
Total Dissolved Solids	mg/L		25 mg/L when background between 25 and 250; 10% when background is ≥25 and ≤250
Turbidity	NTU		Induced turbidity of 8 NTU when background ≥8 and ≤80; 10% when background is ≥80

Table 6. Canadian and BC Guidelines for Aquatic Life- Metals in water.

Parameter	unit	Aquatic Life Criteria	BC Guidelines
Aluminum	ug/L	6 µg/L at pH <6.5 100 µg/L at pH ≥6.5	dissolved Al = exp(1.209 -2.426 K+ 0.286 K2) [where K = pH] at pH <6.5 100 µg/L at pH ≥6.5
Arsenic	ug/L	5 µg/L	5 µg/L
Boron	ug/L		1.2 µg/L
Cadmium	ug/L	10{0.86[log(hardness)] - 3.2}	
Chromium	ug/L	Trivalent chromium (Cr(III)): 8.9 Hexavalent chromium (Cr(VI)): 1.1	
Cobalt	ug/L		110 µg/L
Copper	ug/L	2 µg/L at [CaCO3] = 0–120 mg/L 3 µg/L at [CaCO3] = 120–180 mg/L 4 µg/L at [CaCO3] >180 mg/L	≤2 µg/L at [CaCO3] = 0–50 mg/L ≤.04 (mean hardness) µg/L at [CaCO3] > 50 mg/L
Iron	ug/L	300 µg/L	
Lead	ug/L	1 µg/L at [CaCO3] = 0–60 mg/L 2 µg/L at [CaCO3] = 60–120 mg/L 4 µg/L at [CaCO3] = 120–180 mg/L 7 µg/L at [CaCO3] = >180 mg/L	3 µg/L total lead at [CaCO3]≤ 8mg/L ≤3.31 µg/L+ $_e$(1.273 ln [mean hardness]-4.704) at [CaCO3]> 8 mg/L
Manganese	mg/L		0.8 mg/L at hardness ≤20 mg/L 1.1 mg/L at hardness ≤1.1 mg/L 1.6 mg/L at hardness ≤100 mg/L 2.2 mg/L at hardness ≤150 mg/L
Mercury	ug/L	0.026 µg/L	0.1 µg/L
Molybdenum	ug/L	73 µg/L	2000 µg/L
Nickel	ug/L	25 µg/L at [CaCO3] = 0–60 mg/L 65 µg/L at [CaCO3] = 60–120 mg/L 110 µg/L at [CaCO3] = 120–180 mg/L 150 µg/L at [CaCO3] = >180 mg/L	
Phosphorus	ug/L	35 - 100 µg/L (eutrophic)	None proposed for streams (total P)
Selenium	ug/L	1.0	2.0 µg/L mean
Silver	ug/L	0.1	0.1 µg/L hardness ≤100 mg/L 3.0 µg/L hardness > 100 mg/L
Zinc	ug/L	30	33 µg/L for water hardness ≤90

Table 7. Canadian Guidelines for Aquatic Life- Metals in sediment.

Parameter	unit	Aquatic Life Guidelines - ISQG: Interim freshwater sediment quality guidelines (ISQGs; dry weight)
Arsenic	ug/g	5.9
Cadmium	ug/g	0.6
Chromium	ug/g	37.3
Copper	ug/g	35.7
Lead	ug/g	35
Mercury	ug/g	0.17
Zinc	ug/g	123

Comparison to Conventional Stormwater BMPs

The International Stormwater Best Management Practices Database, sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE) / Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (EPA), tracks BMP performance (www.bmpdatadase.org). In October 2007, they published an overview of BMP performance by category *(e.g.* detention basin, media filter, wetland basin, etc) and pollutant type (Geosyntec, 2007). This overview-level analysis grouped BMPs into broad categories and acknowledged that these categories may mask distinctive differences in design and performance in subcategories for multiple BMP types. Limitations aside, this database provides a useful comparator for the treatment systems included in this NRS study.

The BMP database does not use percent removal as the comparator value. Instead it uses median influent and effluent concentrations (Event Mean Concentrations). This is for several reasons, but the top three reasons that its authors list are:

"1. Percent removal is primarily a function of influent quality. In almost all cases, higher influent pollutant concentrations into functioning BMPs result in reporting of higher pollutant removals than those with cleaner influent. In other words, use of percent removal may be more reflective of how "dirty" the influent water is than how well the BMP is actually performing. Therefore (and ironically), to maximize percent removal, the catchment upstream should be "dirty" (which does not encourage use of good source controls or a "treatment train" design approach).

2. Significant variations in percent removal may occur for BMPs providing consistently good effluent quality. Stated differently, the variability in percent removal is almost always much broader than the uncertainty of effluent pollutant concentrations. These variations in percent removal have little relationship to the effluent quality achieved.

3. BMPs with high percent removal (e.g., >80% removal of TSS) may have unacceptably high concentrations of pollutants in effluent (e.g., >100 mg/L TSS), which can lead to a false determination that BMPs are performing well or are "acceptable," when in fact, they are not."

Values were extracted from the ISBMP overview study and plotted against the performance of the wetland and stream restoration projects in this NRS study. The results are shown in the figures below.

Comparison to ISBMP database.

For the purposes of comparison, the Saanich data were not censored to remove anomalous values. This is because no details were given by the authors of the International Stormwater BMP database as to how it may have been censored. The median Saanich values are abnormally high however, because there were a great many values that were less than the detection limit. If these samples were left in the database and recorded as "0" for the purposes of calculation, the median value was almost invariably 0 because the number of non-detectable samples was greater than the number of samples for which a real value was recorded. Similarly, if the values were recorded as 1 unit less that the detection limit (*i.e.* a result of <0.02 would result in a value recorded as 0.019) then the median would simply reflect the detection limit. Therefore, samples for which the sample was recorded as below the detection limit were removed from the calculation. The result is a median inflow value and a median outflow value, not necessarily paired for each date (*i.e.* on some dates only the inflow or outflow had a measurable value).

<u>These comparisons should therefore be considered rough estimates</u>- a guideline by which to assess whether the Saanich wetland installations have similar treatment abilities to other BMPs, whether they should be maintained differently, or whether they should be replaced by more traditional stormwater treatment processes.

Metals

Cadmium

Only Baxter Pond had enough data to compare cadmium removal performance of the Saanich installations. Though the Baxter influent value was lower than the median influent values for the BMPs, the median outflow concentration was approximately half of the lowest outflow value for any of the BMPs (media filter) (Figure 79). This indicates that Baxter Pond performs as well as any of the BMPs noted.

Copper

Willowbrook and Glanford wetlands were comparable in performance to the detention pond and biofilter BMPs (Figure 80). Baxter, Blenkinsop and Leeds were not effective at removing copper.

Chromium

Chromium was not commonly present in the stormwater in Saanich. For most sites the incidence was sporadic and therefore there were few data pairs to compare (Figure 81). Leeds Creek, as mentioned earlier, flows quickly and does not allow adequate time for settling. It was therefore ineffective at removing chromium.

Lead

Lead was detected at all sites, but Blenkinsop did not have enough measured values for comparison. Willowbrook and Glanford both exported lead, although the effluent vales were well within the range of waters treated by biofilters, hydrodynamic systems and wet lands and were well-below the effluent values for detention ponds (Figure 82).

Zinc

Both Baxter Pond and Blenkinsop Creek were as effective as reducing zinc as any of the other seven BMPs with the exception of the wet pond whose median effluent quality is slightly superior (Figure 83). Though Glanford removed zinc eight out of ten times, the statistical calculation shows it to be a net exporter when only the median value is considered. Willowbrook tended to export lead, but the median influent and effluent values show no difference.

Particulates and Nutrients

Total Suspended Solids

Both the Glanford wetland and Blenkinsop Creek definitively removed TSS (Figure 84). Glanford's effluent quality superceded all the BMPs and Blenkinsop was easily within the range of the detention pond and biofilter systems. Willowbrook, Baxter and Leeds Creek did no remove TSS and in the case of Willowbrook, exported TSS. The high Baxter Pond effluent values may be accounted for by the backwater effect from Gabo Creek and the physical disturbance of waterfowl.

Total Phosphorus

Total P was not measured in the Saanich study. In lakes, phosphorus is recycled very quickly and thus ortho-P is rarely unbound and bio-available or measurable. In streams, ortho-P can be measured because the supply of P is constantly renewed by sediments washing in from the surrounding watershed. Ortho-P is thus a better measure of the nutrient status of the creek as the results are not clouded by the particulate phosphorus that is included in a Total-P measurement. In terms of removal, only Blenkinsop Creek was effective at removing ortho-P and the others were net exporters (Figure 85). A similar trend is seen in the BMP database where wet ponds have little effect in Total P and biofilters are net exporters.

Nitrate

The Saanich systems were particularly effective at removing nitrate from the stormwater (Figure 86). The overall reduction was significant at every site except Blenkinsop whose data is skewed by the inability to include "non-detectable" values but which removed an average of 20% of the nitrate and had very low effluent values overall. Willowbrook is most similar to a wet pond, while Glanford and Baxter are comparable to the detention pond and biofilter.

TKN and Total Nitrogen

Willowbrook and Baxter were net exporters of TKN but reduced total nitrogen and nitrate, comparable to a wet pond or wetland basin (Figure 87 and Figure 88). Blenkinsop removed TKN and Total N at a level comparable with a wet pond. Glanford removed Total N and TKN and superceded all the BMPS at removing TKN and was most comparable to a wetland basin in its ability to remove Total N.

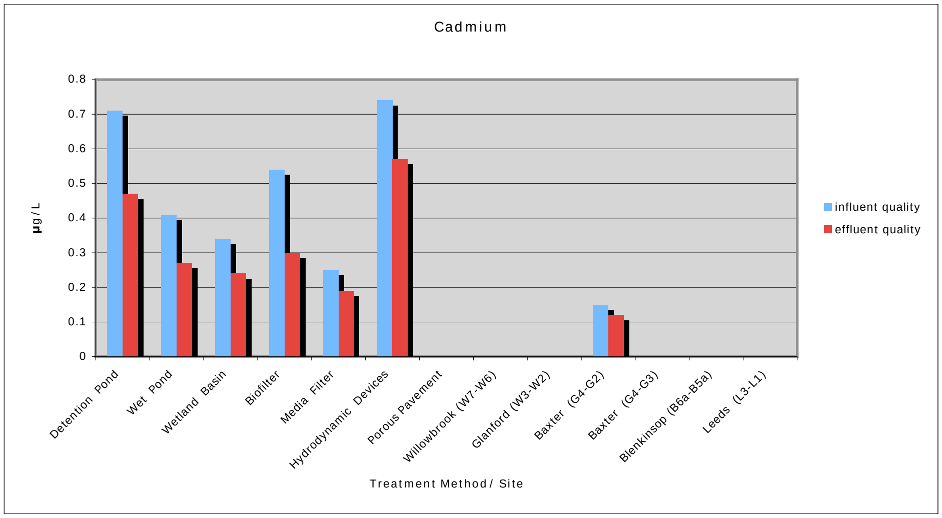


Figure 79. Comparison of median influent and effluent concentration of cadmium in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

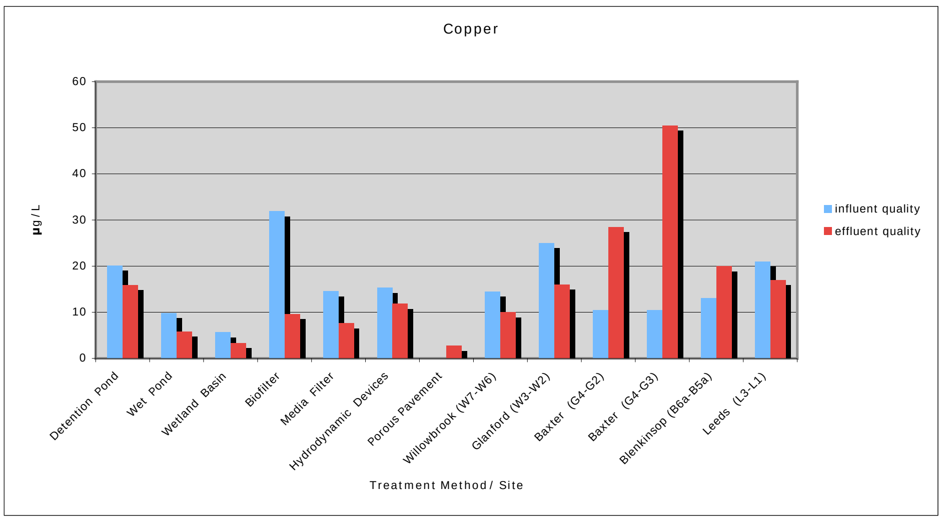


Figure 80. Comparison of median influent and effluent concentration of copper in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

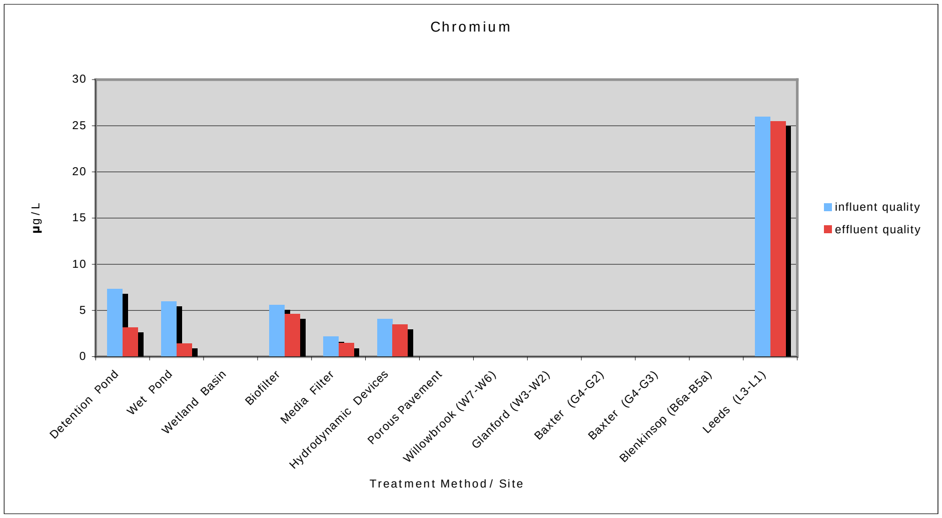


Figure 81. Comparison of median influent and effluent concentration of chromium in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

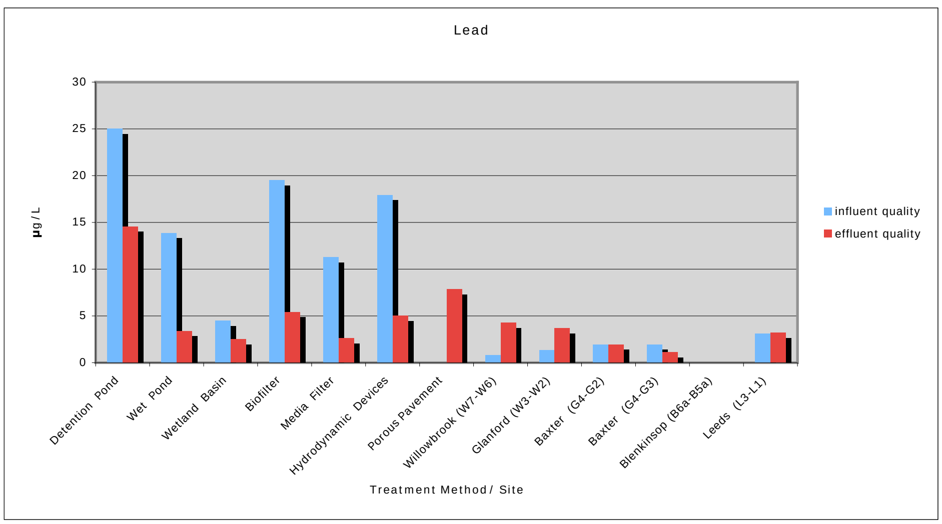


Figure 82. Comparison of median influent and effluent concentration of lead in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

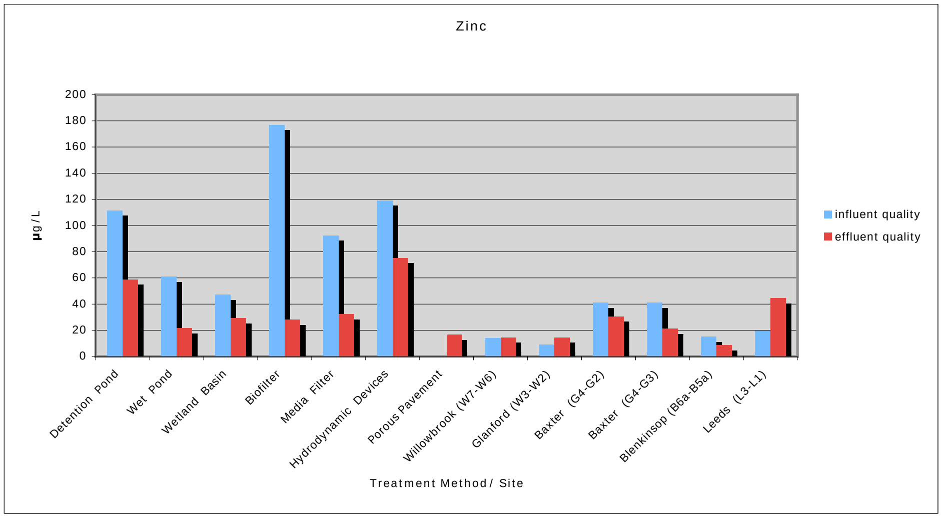


Figure 83. Comparison of median influent and effluent concentration of zinc in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

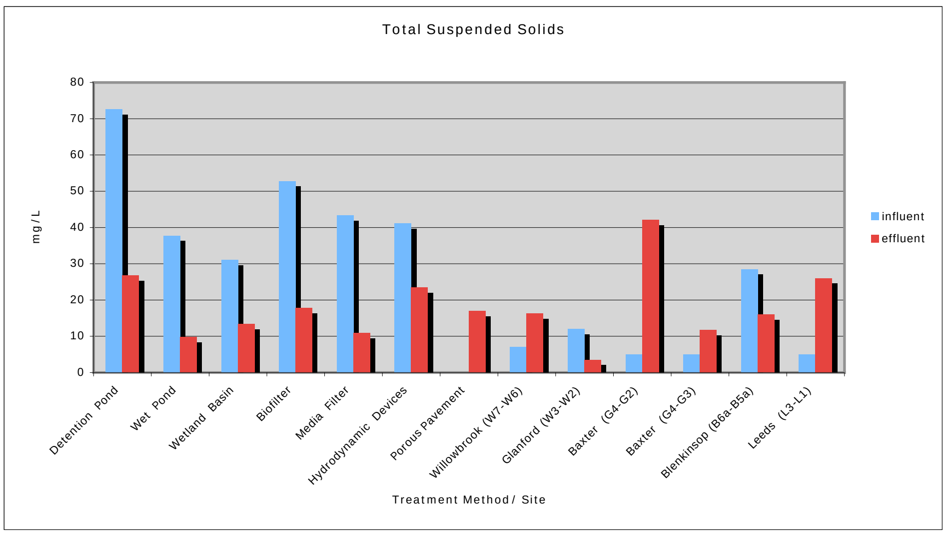


Figure 84. Comparison of median influent and effluent concentration of Total Suspended Solids (TSS) in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

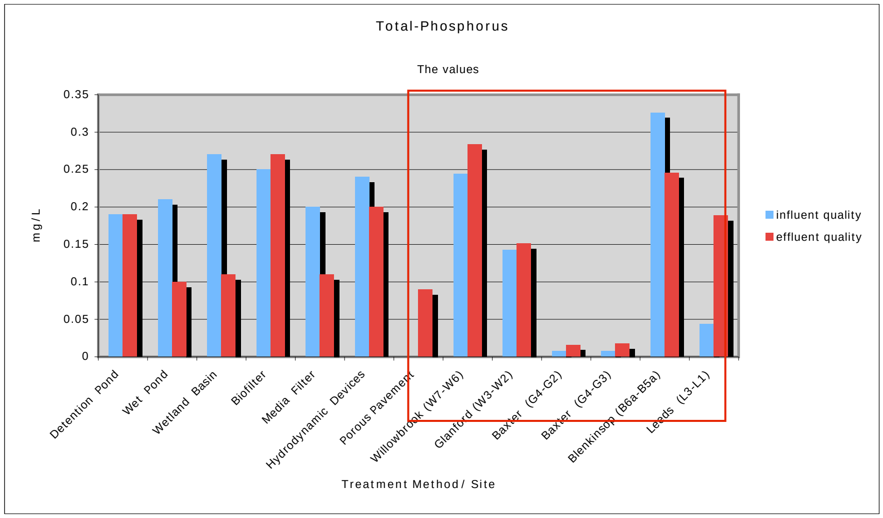


Figure 85. Comparison of median influent and effluent concentration of phosphorus in Saanich stormwater wetlands compared to BMPs in the ISBMP database. Note that the Saanich data (outlined in red box) is ortho-P (Bioavailable P) compared to Total P in the ISBMP database.

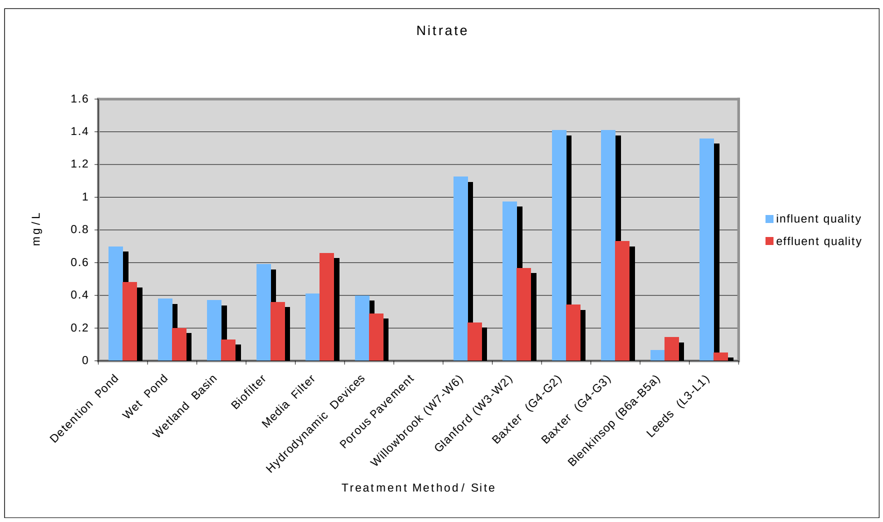


Figure 86. Comparison of median influent and effluent concentration of nitrate in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

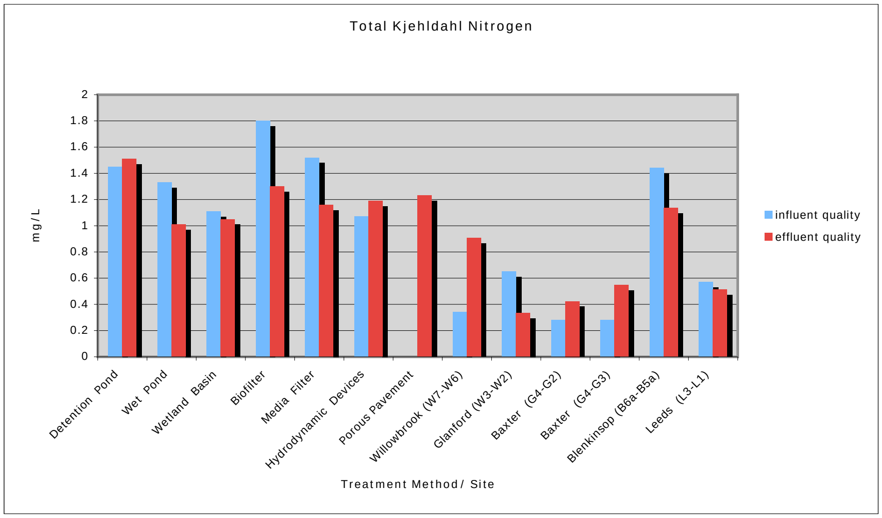


Figure 87. Comparison of median influent and effluent concentration of Total Kjeldahl Nitrogen (TKN) in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

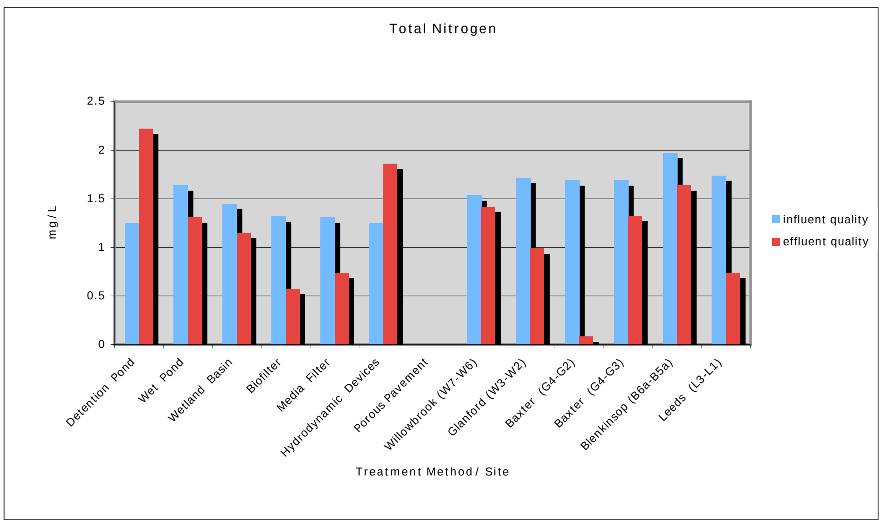


Figure 88. Comparison of median influent and effluent concentration of Total Nitrogen in Saanich stormwater wetlands compared to BMPs in the ISBMP database.

Conclusions

Willowbrook

The Willowbrook wetland:

- effectively removed nitrogen but was an exporter of ortho-phosphorus.
- was effective at reducing TDS and chloride.
- was not effective at removing Total Suspended Solids. It has, however trapped a great volume of material, suggesting that it needs to be cleaned out in order to work effectively.
- reduces water temperatures by an average of 2.7°C before the water enters Swan Creek.
- behaves differently in winter than in summer with respect to metals capture. In winter, the wetland generally exported metals (likely due to the export of sediment as a result of not being maintained) and trapped metals in the summer when water levels were lower and the residence time was longer.
- outlet sediments had lower metals concentrations than those at the inlet, suggesting that the wetland could be made effective at removing metals contamination by regularly maintaining it.

Glanford

The Glanford wetland:

- was effective at removing both nitrogen and ortho-P.
- did little to remove dissolved materials. This is likely due to its small size and short residence time.
- was very effective at removing TSS. It was cleaned out in the summer of 2004, and continues to function well.
- reduces water temperature by approximately one degree. Its value may lie more in detaining warm water as it flows toward Swan Creek, such that its entry into the creek is prolonged and the thermal shock to the creek is smaller.
- was effective at reducing metals concentrations. In particular, zinc was reduced by up to 25%.
- outlet sediments generally had a lower metals concentrations than the inlet, however these results were inconsistent. This may be a function of its sediment chemistry or an artifact of manually disturbing the sediments when the wetland was cleaned out.

The bacteriological quality of the stormwater entering the Willowbrook and Glanford wetlands was generally low compared to typical urban stormwater; however, it did not meet the criterion of less than 200 fecal coliforms / 100 mL for recreational water quality.

Baxter Pond

Baxter Pond:

- was effective at removing nitrogen, but was an exporter of ortho-phosphorus (comparable to Willowbrook and Glanford);

- removed dissolved substances, and showed a decrease in both TDS and specific conductance between the inlet and the outlet;
- has an outlet that is influenced by a backwater effect from Gabo Creek;
- stormwater is contaminated by road salt, and its associated metals;
- is very effective at removing large suspended particles (sand, large silt.). While it may be effective at initially trapping finer sediments, *e.g.* fine silt and clay, the waterfowl in the pond appear to stir it up and allow it to wash downstream into Gabo Creek;
- is effective at reducing the thermal loading in Gabo Creek. It reduced the temperature of the runoff by an average of 2.1°C. Gabo Creek was up to 7°C warmer upstream of Baxter Pond than downstream, suggesting that Baxter Pond is an important thermal buffer for the creek;
- metals analyses were confounded by the backwater effect of Gabo Creek at the outlet. When the inlet and mid-pond metals concentrations are compared, it is evident that the water in the middle of the pond has lower metals concentrations than the inlet; however, values rise again at the outlet suggesting backwatering, resuspension of sediment, or both.
- waterfowl do not appear to be adding to the fecal coliform burden in the water. Values in Baxter Pond were lower than the other wetlands.

Blenkinsop Creek

Blenkinsop Creek:

- acted as a long "pond". It was very effective at removing nutrients, including both nitrogen and phosphorus. This has a net benefit for the nutrient load in Swan Lake and, ultimately, for the Colquitz River;
- generally reduced suspended sediments, although there were two notable occasions when TSS was higher downstream than upstream, possibly the result of sampling error;
- had extremely low dissolved oxygen values. This is likely due to the anoxic conditions of Blenkinsop Lake. At present, the oxygen concentrations are too low to support fish. Aeration in Blenkinsop Lake may improve this condition in the future; however, until the section of Blenkinsop Creek between Galeys' field and Swan Lake Nature Sanctuary can be remediated, there is little chance that fish could survive downstream. Therefore aeration may be many decades in the future;
- had very low metals concentrations. This is likely because the urban runoff is first trapped by Blenkinsop Lake. This could be determined by sampling the sediments of the lake. Zinc was detectable 10 out of 15 times and arsenic was detectable 7 out of 15 times. Zinc is used in galvanization and arsenic was formerly used in control of fruit pests and to treat fence posts. Both metals would therefore be more common pollutants in agricultural settings;
- Sediments, downstream, had markedly lower metals concentrations than in upper Blenkinsop. This suggests that Blenkinsop Lake is the source of most metals in the creek, not the neighbouring fields;
- increased sinuosity of the restored Blenkinsop channel increased the residence time of water and likely contributed in a positive way to the treatment of pollutants and capture of sediment;

- had unexpectedly low fecal coliforms and Enterococcus, given its agricultural setting. It is evident from these numbers that contamination from animal husbandry is not occurring in upper Blenkinsop Creek. The coliform values were lower than at the more urbanized sites.

Leeds Creek

- was very effective at removing nitrogen from the stormwater. It is also effective at removing ortho-P except during high flow events. The levels of ortho-P were much lower in Leeds Creek than in neighbouring Blenkinsop Creek.
- flows too quickly to be effective at removing all but the heaviest suspended sediments. It was also therefore ineffective at removing metals.
- was very effective at moderating the water temperature. The outlet was up to 4.6°C cooler than the inlet.

Summary and Recommendations

The Saanich treatment systems are effective at treating stormwater pollutants and their performance is comparable with the Best Management Practices recorded in the International Stormwater BMP database. The Willowbrook and Baxter Pond wetlands demonstrate that they require maintenance to remove accumulated sediment and prevent export of TSS and associated metals. With maintenance however, these systems should perform as well as conventional BMPs, as evidenced by the Glanford wetland which did receive maintenance prior to this study and performed very well. Neither the Saanich treatment systems nor the conventional BMPs are highly effective at removing excessive metals; this points to the need for source control, rather than treatment. Limiting the use of pesticides and wood treatment products, marking catchbasins (e.g. with a yellow fish, or “do not dump- flows to stream” signs), and educating businesses and home owners should be combined with dry street sweeping and catch basin maintenance to prevent pollutants from reaching the streams in the first place.

Willowbrook, Glanford, Leeds Creek and Baxter Pond all significantly reduced the temperature of their effluent waters prior to the discharge into their respective receiving streams. This is a key factor is protecting Blenkinsop and Swan Creeks and, by extension, the salmon habitat of the Colquitz River.

This study has also demonstrated that streams can be made more effective by improving their functional condition (physical morphology and health). The increased sinuosity and retention time in Blenkinsop Creek near Galeys’ farm make it effective at trapping sediment and removing metals and nutrients.

Finally, unlike engineered wet ponds, hydrodynamic systems and other similar BMPs, the systems in Saanich provide a community amenity in the form of wildlife habitat, views, carbon sequestration in the riparian areas, thermal regulation including shade for neighbouring trails and homes, and act as a physical buffer for their neighbouring streams.

The value of these services is documented in a separate report entitled "*Nature's Revenue Streams: Five Ecological Value Case Studies*" that is also part of the larger Saanich/CMHC/FCM project.

Where space permits, Saanich should continue to develop "ecologically engineered" wetlands and stream buffers to treat and control the stormwater from adjacent developments. A maintenance plan should be provided with each installation and the maintenance intervals added into Saanich's routine Parks and drainage schedules. Since these systems do not fall neatly into the purview of either engineering or Parks, collaboration on their management will be needed. A record of the cost of building and maintaining these systems, as well as notes on how they might be improved in the future, should be systematically recorded in order to assess their economic performance as well as their ecological performance.

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Appendix A- Sampling Methods and QA/QC

Table of Contents- Appendix A

Sampling Procedures:

1. A new bottle (either 1L or 500mL depending on sample required) still capped, was placed into the water with the neck pointing downstream.
2. The lid was removed underwater.
3. Once the cap was removed, the bottle was turned around, keeping it submerged, until the bottle neck was oriented upstream while ensuring there was little disturbance to the surrounding river/stream bed in order to avoid collecting turbid water thus exaggerating turbidity readings.
4. Bottle was filled at least 75% full.
5. Lid replaced while underwater.
6. Bottle was extracted, dried off and a label attached indicating site identification (site ID), time (using the 24 hour clock), date, company name, and the name(s) of samplers.
7. Top of the lid was labelled with the site ID using a black permanent marker.
8. Using an all-weather field book, the site identification number was documented together with a description of the site, time, date and what sample was acquired while also noting any smells or observations such as algae growth, water level, flow, animals, presence of squatters, or anything that may affect the stream.
9. Photographs were taken upstream and downstream from the site.

For quality analysis and comparison for irregularities, trip blanks, field blanks, and field duplicates were used throughout the sampling regimen.

Calibration and Maintenance of Equipment

Calibration is a process of standardizing a monitoring instrument to ensure that it functions properly in the environment it is subjected to, by ensuring that is will measure a specific range in which the instrument is designed to operate.

A Dissolved Oxygen (DO) meter on loan from MB Labs, was calibrated before and after use recalibrated against an in house DO meter at MB labs to determine any variations. In order to ensure that the DO meter reading was accurate the temperature gauge on the DO meter had to be calibrated as well. These records were maintained.

The YSI mulitprobe was calibrated according to manufacturer's directions and cross-checked against another calibrated DO meter in the lab or with a saturated air standard. Barometric pressure was obtained from Environment Canada and corrected for elevation. The equipment was calibrated prior to sampling via a 3-point pH calibration, a DO % saturation calibration, and a calibration against Conductance standards (141.7 us/cm, 282.9 us/cm, and 1417 us/cm) supplied by an accredited laboratory.

Quality Assurance

Although this program was relatively small or pilot study scale, it was a goal of the study that results maintain a significant level of scientific credibility, with a goal of possible publication in the scientific literature. To this regard a set of six Data Quality Objectives were defined in addition to the lab's in-house DQOs:

1. Sample Completeness: not more than 5% of collected samples should be lost for any reason.
2. Laboratory Completeness: no more than 5% of collected samples should fail to be analyzed.
3. Measurability: For each parameter a substantial majority (i.e., more than 50%) of values should fall above the Limit of Quantitation (LOQ). In addition, for those parameters for which water quality criteria are to be evaluation the MDL should be not greater than 10% of each relevant criterion.
4. Precision: relative mean differences between pairs of laboratory analyses above the Limit of Quantitation (LOQ) should not exceed 25%.
5. Contamination: field blanks should exceed MDL not more than 5% of the occurrences, and also field blanks should not exceed 0.1 of lowest genuine values measured.
6. Homogeneity: relative mean differences between pairs of samples should not exceed 50% for concentrations 10 times MDL, nor exceed 100% for concentrations at or below 10 times MDL.

Results of the QA Program – Completeness

Sampling Completeness

Any missing samples were tabulated with reason. Since this pilot project was slowly adding sites as it developed, early omissions were not truly missed samples, but simply an indication of the developing program. Also several sites could not be located during heavy snow cover. There was no substantial omission of samples.

Analytical Completeness

Analysis was complete except for specific conductance on Oct 06, Nov 06 and Jan 07. Although specific conductance had been requested from MB laboratories, and although they were reminded on several occasions, for unexplained reasons conductivity was not analyzed for a substantial number of collected samples.

Field measurements were complete with the exception of Oct 06 through Jan 07, when a DO meter was not available and any dates for which water levels were too low to use the meter.

Measurability

MB Laboratories supplied estimates of both Method Detection Limits (MDLs) and Limits of Quantitation (LOQs), as tabulated in Table 1. For this study Aqua-Tex used a DQO that for each parameter a substantial majority (i.e., more than 50%) of values should fall above the Limit of Quantitation (LOQ).

Table 1. Method Detection Limits and Limits of Quantitation, MB Laboratories

Matrix: Water -- General					
Parameter	**unit**	**CAEAL**	**Detection Limits**	**LOQ**	**Aquatic Life Criteria**
Alkalinity	mg/L				
Ammonia - N	ug/L		0.5	1.5	19 (Unionized)
Biochemical Oxygen Demand	mg/L				
Chloride	mg/L	yes	0.001	0.005	
Colour	TCU		0.1	0.5	
Conductivity (25C)	uS/cm	yes	0.5	1.5	
Hardness	mg/L		0.01	0.03	
Total Kjeldahl Nitrogen	mg/L	yes	0.005	0.02	
Nitrate-N	ug/L	yes	0.48	1.5	2900
Nitrite-N	ug/L		0.9	9	60
Ortho-Phosphate-P	ug/L		0.1	0.5	
pH	"pH units"	yes	na	na	6.5 - 9.0
Phenols	mg/L				
Total Extractable Hydrocarbons			1	3	
Total Disolved Solids	mg/L		0.1	0.5	
Total Suspended Solids	mg/L	yes	1.2	5	
Turbidity	NTU		0.045	0.45	

Matrix: Water -- Elemental List ***Matrix Dependent***					
Parameter	**unit**	**CAEAL**	**Detection Limits**	**LOQ**	**Aquatic Life Criteria**
Aluminium	ug/L		10	30	6 µg/L at pH <6.5 100 µg/L at pH ≥6.5
Antimony	ug/L		0.1	0.5	
Arsenic	ug/L		0.1	0.5	5
Barium	ug/L		1	3	
Beryllium	ug/L		2	6	
Boron	ug/L		1	3	
Cadmium	ug/L	yes	0.005	0.01	10{0.86[log(hardness)] - 3.2}
Calcium	mg/L		0.001	0.003	
Chromium	ug/L		4	12	Trivalent chromium (Cr(III)): 8.9 Hexavalent chromium (Cr(VI)): 1.1
Cobalt	ug/L		5	15	
Copper	ug/L	yes	2	6	2 µg/L at [CaCO3] = 0–120 mg/L 3 µg/L at [CaCO3] = 120–180 mg/L 4 µg/L at [CaCO3]

					>180 mg/L
Gold	ug/L		4	40	
Iron	ug/L	yes	5	15	300
Lanthanum	ug/L		2	6	
Lead	ug/L	yes	0.1	0.5	1 µg/L at [CaCO3] = 0–60 mg/L 2 µg/L at [CaCO3] = 60–120 mg/L 4 µg/L at [CaCO3] = 120–180 mg/L 7 µg/L at [CaCO3] = >180 mg/L
Magnesium	mg/L		0.001	0.003	
Manganese	ug/L		4	12	
Mercury	ug/L		0.01	0.1	0.026
Molybdenum	ug/L		10	30	0.073
Nickel	ug/L		10	30	25 µg/L at [CaCO3] = 0–60 mg/L 65 µg/L at [CaCO3] = 60–120 mg/L 110 µg/L at [CaCO3] = 120–180 mg/L 150 µg/L at [CaCO3] = >180 mg/L
Phosphorus	ug/L	yes	10	30	35 - 100 (eutrophic)
Potassium	mg/L		0.001	0.003	
Scandium	mg/L		0.001	0.003	
Selenium	ug/L		0.1	0.3	1.0
Silicon	mg/L		0.01	0.03	
Silver	ug/L		0.005	0.015	0.1
Sodium	mg/L	yes	0.01	0.03	
Strontium	ug/L		1	3	
Tin	ug/L		10	30	
Titanium	ug/L		5	15	
Tungsten	ug/L		10	30	
Vanadium	ug/L		10	30	
Zinc	ug/L	yes	0.005	0.015	30

Matrix: Soil/Sediments -- Elemental List	*****Total Extractable Metals*****				

Parameter	unit	CAEAL	Detection Limits	LOQ	Aquatic Life Guidelines - ISQG: Interim freshwater sediment quality guidelines (ISQGs; dry weight)
Aluminium	ug/g		500	2500	
Antimony	ug/g	yes	0.005	0.025	
Arsenic	ug/g	yes	0.005	0.025	5.9
Barium	ug/g		50	250	
Beryllium	ug/g	yes	100	500	
Boron	ug/g		50	250	
Cadmium	ug/g	yes	0.00025	0.00125	0.6
Calcium	ug/g		0.05	0.25	
Chromium	ug/g	yes	200	1000	37.3
Cobalt	ug/g	yes	250	1250	
Copper	ug/g	yes	100	500	35.7
Gold	ug/g		200	1000	
Iron	ug/g		250	1250	
Lanthanum	ug/g		100	500	
Lead	ug/g	yes	0.005	0.025	35
Magnesium	ug/g		0.05	0.25	
Manganese	ug/g		200	1000	
Mercury	ug/g	yes	0.0005	0.0025	0.17
Molybdenum	ug/g		500	2500	
Nickel	ug/g	yes	500	2500	
pH	pH units				
Phosphorus	ug/g		500	2500	
Potassium	ug/g		0.05	0.25	
Scandium	ug/g		0.05	0.25	
Selenium	ug/g		0.0005	0.0025	
Silicon	ug/g				
Silver	ug/g		0.25	1.25	
Sodium	ug/g		0.5	2.5	
Strontium	ug/g		50	250	
Tin	ug/g		500	2500	
Titanium	ug/g		250	1250	
Tungsten	ug/g		500	2500	
Vanadium	ug/g		500	2500	
Zinc	ug/g	yes	0.25	1.25	123

In addition, for those parameters for which water quality criteria are to be evaluated, the MDL should be not greater than 10% of each relevant criterion. For convenience of comparison, the criteria for protection of aquatic life have been added to the right side of the MDL table (Table 1). With regard to the criteria to protect aquatic life in water, the DQO was met for all General parameters.

Precision

For this study Aqua-Tex used a DQO that relative differences between pairs of laboratory analyses above the Limit of Quantitation (LOQ) should not exceed 25%. The great majority of laboratory analyses did meet the specified DQO. Out of 191 lab duplicates above the LOQ, 24 (12.5%) had a relative difference of greater than 25%. When the VITP values were removed, 13 samples remained. Of these only 7 were above the LOQ. Note that no evaluation was performed where either of the duplicates included a value below detection.

Water Chemistry – General- Lab Duplicates

Parameter	Site	Date	%RD	Low Value	LOQ	>LOQ?
TSS	G5	2-Dec-06	34%	12 mg/L	5 mg/	yes
NO3-N	G5	7-May-07	116%	169 µg/L	1.5 µg/L	yes
NO2-N	G5	7-May-07	195%	8.76 µg/L	9 µg/L	no
pH	G5	7-May-07	137%	8.67	N/A	
NO3-N	W8	10-Apr-07	79%	151 µg/L	1.5 µg/L	yes
NO2-N	W8	10-Apr-07	189%	9.9 µg/L	9 µg/L	yes
Ortho-P	W8	10-Apr-07	186%	9.64 µg/L	0.5 µg/L	yes
pH	W8	10-Apr-07	188%	8.48	N/A	
NO3-N	W8	7-May-07	47%	108 µg/L	1.5 µg/L	yes
NO2-N	W8	7-May-07	172%	8.02 µg/L	9 µg/L	no
pH	W8	7-May-07	187%	8.69	N/A	
Chloride	W9	3-Nov-06	164%	1.11 mg/L	0.005 mg/L	yes
TSS	W9	2-Dec-06	40%	2 mg/L	5 mg/L	no

Note: %RD= % Relative Difference
Low value = Lowest of the duplicate analyses
LOQ = Limit of Quantitation

Precision: Elemental Water Chemistry

For Water Chemistry – elemental, only one %RD value exceeded the 25% criterion and it was not for a measurement above the LOQ. Data for VITP is excluded from this summary since they are not presented elsewhere in the report.

Parameter	**Site**	**Date**	**%RD**	**Low Value**	**LOQ**	**>LOQ?**
Zn	W8	9-Mar-07	29	.009 µg/L	0.015 µg/L	no

Note: %RD= % Relative Difference
Low value = Lowest of the duplicate analyses
LOQ = Limit of Quantitation

Precision: Water - Bacteria

For Water – Bacteriology 4 *Enterococcus* pairs of lab duplicates exceeded the 25% criterion but all were less than 1 CFU. For field duplicates. 21 exceeded the 25% criterion, but only 4 exceeded 1 CFU. One Fecal Coliform lab duplicate and 13 out of 32 pairs of field duplicates exceeded the criterion. [Note that no MDL nor LOQ were defined for either parameter by MB Laboratories.]

Precision: Elemental Sediment Chemistry

Eighteen data pairs failed the DQO of a maximum relative difference of 25%; 8 were for analyses well above the LOQ.

Sediment Chemistry - Elemental

Parameter	Site	Date	%RD	Low Value*	LOQ	>LOQ?
Se	W9	13-Oct-06	118%	.122	.0025	yes
Ti	W9	13-Oct-06	28%	548	1250	no
W	L3	14-Oct-06	25%	.348	2500	no
Zn	W9	13-Oct-06	25%	185	1.25	yes
As	W9	23-Nov-07	58%	1.59	.025	no
Ba	W9	23-Nov-07	79%	45	250	no
Cd	W9	23-Nov-07	36%	.385	.00125	yes
Pb	W9	23-Nov-07	33%	34.6	.025	yes
Mg	W9	23-Nov-07	39%	6010	.25	yes
Si	W9	23-Nov-07	49%	79.8	Not given	
Na	W9	23-Nov-07	31%	151	2.5	yes
Sn	W9	23-Nov-07	44%	8.82	2500	no
Ti	W9	23-Nov-07	36%	600	1250	no
W	W9	23-Nov-07	183%	3.41	2500	no
V	W9	23-Nov-07	49%	58.7	2500	no
Cd	G1a	23-Nov-07	26%	.581	.00125	yes
Se	G1a	23-Nov-07	171%	.057	.0025	yes
W	G1a	23-Nov-07	30%	1.03	2500	no

Note:
%RD= % Relative Difference
Low value = Lowest of the duplicate analyses
LOQ = Limit of Quantitation

*all units µg/g

Contamination Check

A number of blank water samples were submitted to ensure samples were not being contaminated during sample collection. Results of the blank analyses are presented in Table 2. Results indicate that low levels of contamination were present on all four occasions that field blanks were submitted. In all instances, the level of contamination was very low and did not normally involve parameters of interest. In terms of meeting the DQO, 90 out of 405 samples showed some contamination, however of these 79 were above the MDL. The DQO for contamination was therefore not met. What is not known is the source of the contamination (e.g. sample bottles, airborne contaminants).

Table 2. Results of Field Blank analysis

Site	Date	Value	Parameter	unit	MDL	>MDL?
L3	7-May-07	6.25	ALK	mg/L	N/A	
W1	7-May-07	6.25	ALK	mg/L	N/A	
L3	7-May-07	0.858	pH		N/A	
B3	6-Feb-07	5.48	pH		N/A	
G3	6-Feb-07	5.69	pH		N/A	
B1	9-Mar-07	5.61	pH		N/A	
B4	9-Mar-07	5.37	pH		N/A	
G1	10-Apr-07	5.62	pH		N/A	
G1	10-Apr-07	5.62	pH		N/A	
L3	7-May-07	5.25	pH		N/A	
W1	7-May-07	5.26	pH		N/A	
B3	6-Feb-07	0.02	EC	CFU/100mL	N/A	
G3	6-Feb-07	0.44	Colour	TCU	.1 TCU	Yes
B3	6-Feb-07	0.197	Colour	TCU	.1 TCU	Yes
B4	9-Mar-07	0.089	Colour	TCU	.1 TCU	Yes
V4a	9-Mar-07	0.089	Colour	TCU	.1 TCU	Yes
G1	10-Apr-07	0.381	Colour	TCU	.1 TCU	Yes
G1	10-Apr-07	0.381	Colour	TCU	.1 TCU	Yes
L3	7-May-07	2.44	Colour	TCU	.1 TCU	Yes
W1	7-May-07	4.31	Colour	TCU	.1 TCU	Yes
G1	10-Apr-07	15.0	Fe	mg/L	5 µg/L	Yes
B3	6-Feb-07	1.23	NO2-N	ug/L	.9 µg/L	Yes
G1	10-Apr-07	0.459	NO2-N	ug/L	.9 µg/L	Yes
G1	10-Apr-07	0.459	NO2-N	ug/L	.9 µg/L	Yes
G3	6-Feb-07	0.35	Ortho-P	ug/L	0.1 µg/L	Yes
B3	6-Feb-07	0.5	TSS	mg/L	1.2 mg/L	Yes
G1	10-Apr-07	0.667	TSS	mg/L	1.2 mg/L	Yes
G1	10-Apr-07	0.667	TSS	mg/L	1.2 mg/L	Yes
G3	6-Feb-07	0.08	Turbidity	NTU	0.045 NTU	Yes
L3	7-May-07	0.09	Turbidity	NTU	0.045 NTU	Yes
B1	9-Mar-07	32	Al	µg/L	10 µg/L	Yes
B4	9-Mar-07	32	Al	µg/L	10 µg/L	Yes
G1	10-Apr-07	92	Al	µg/L	10 µg/L	Yes
L3	7-May-07	108	Al	µg/L	10 µg/L	Yes
W1	7-May-07	120	Al	µg/L	10 µg/L	Yes
G1	10-Apr-07	339.	B	mg/L	1 µg/L	Yes
B3	6-Feb-07	0.037	Ca	mg/L	.001 mg/L	Yes
G3	6-Feb-07	0.055	Ca	mg/L	.001 mg/L	Yes
B1	9-Mar-07	0.04	Ca	mg/L	.001 mg/L	Yes
B4	9-Mar-07	0.032	Ca	mg/L	.001 mg/L	Yes
G1	10-Apr-07	0.166	Ca	mg/L	.001 mg/L	Yes
L3	7-May-07	0.064	Ca	mg/L	.001 mg/L	Yes
W1	7-May-07	0.094	Ca	mg/L	.001 mg/L	Yes
B3	6-Feb-07	0.175	CaC03	mg/L	.01 mg/L	Yes
G3	6-Feb-07	0.205	CaC03	mg/L	.01 mg/L	Yes

B1	9-Mar-07	0.1	CaC03	mg/L	.01 mg/L	Yes
B4	9-Mar-07	0.08	CaC03	mg/L	.01 mg/L	Yes
G1	10-Apr-07	0.53	CaCO3	mg/L	.01 mg/L	Yes
G1	10-Apr-07	0.53	CaCO3	mg/L	.01 mg/L	Yes
L3	7-May-07	0.16	CaCO3	mg/L	.01 mg/L	Yes
W1	7-May-07	0.287	CaCO3	mg/L	.01 mg/L	Yes
G3	6-Feb-07	0.587	Cl-	mg/L	.001 mg/L	Yes
G1	10-Apr-07	8.0	Cu	µg/L	2 µg/L	Yes
G3	6-Feb-07	1.9	E.C.	uS/cm	0.5 µS/cm	Yes
B3	6-Feb-07	2.4	E.C.	uS/cm	0.5 µS/cm	Yes
B4	9-Mar-07	2.3	E.C.	uS/cm	0.5 µS/cm	Yes
V4a	9-Mar-07	2.5	E.C.	uS/cm	0.5 µS/cm	Yes
G1	10-Apr-07	2	E.C.	uS/cm	0.5 µS/cm	Yes
G1	10-Apr-07	2	E.C.	uS/cm	0.5 µS/cm	Yes
L3	7-May-07	3	E.C.	uS/cm	0.5 µS/cm	Yes
W1	7-May-07	3	E.C.	uS/cm	0.5 µS/cm	Yes
G3	6-Feb-07	0.127	K	mg/L	.001 mg/L	Yes
L3	7-May-07	0.056	K	mg/L	.001 mg/L	Yes
W1	7-May-07	0.058	K	mg/L	.001 mg/L	Yes
B3	6-Feb-07	0.31	Na	mg/L	.01 mg/L	Yes
G3	6-Feb-07	2.02	Na	mg/L	.01 mg/L	Yes
G1	10-Apr-07	1.59	Ortho-P	ug/L	0.1 µg/L	Yes
G1	10-Apr-07	1.59	Ortho-P	ug/L	0.1 µg/L	Yes
B3	6-Feb-07	0.092	Si	mg/L	.01 mg/L	Yes
G3	6-Feb-07	0.325	Si	mg/L	.01 mg/L	Yes
B1	9-Mar-07	0.055	Si	mg/L	.01 mg/L	Yes
B4	9-Mar-07	0.062	Si	mg/L	.01 mg/L	Yes
G1	10-Apr-07	0.12	Si	mg/L	.01 mg/L	Yes
L3	7-May-07	0.314	Si	mg/L	.01 mg/L	Yes
W1	7-May-07	0.516	Si	mg/L	.01 mg/L	Yes
G3	6-Feb-07	1.1	TDS	mg/L	0.1 mg/L	Yes
B3	6-Feb-07	1.39	TDS	mg/L	0.1 mg/L	Yes
G1	10-Apr-07	1.16	TDS	mg/L	0.1 mg/L	Yes
G1	10-Apr-07	1.16	TDS	mg/L	0.1 mg/L	Yes
L3	7-May-07	1.14	TDS	mg/L	0.1 mg/L	Yes
W1	7-May-07	1.71	TDS	mg/L	0.1 mg/L	Yes
G1	10-Apr-07	0.76	Turbidity	NTU	0.045 NTU	Yes
G1	10-Apr-07	0.76	Turbidity	NTU	0.045 NTU	Yes
B3	6-Feb-07	2	Zn	mg/L	0.005 µg/L	Yes
G3	6-Feb-07	3	Zn	mg/L	0.005 µg/L	Yes
B1	9-Mar-07	3	Zn	mg/L	0.005 µg/L	Yes
B4	9-Mar-07	3	Zn	mg/L	0.005 µg/L	Yes
G1	10-Apr-07	10	Zn	mg/L	0.005 µg/L	Yes
L3	7-May-07	2	Zn	mg/L	0.005 µg/L	Yes
W1	7-May-07	2	Zn	mg/L	0.005 µg/L	Yes

Homogeneity Evaluation

A small number of duplicate samples were collected order to evaluate heterogeneity of waters and sediments being sampled. Results of duplicate samples are tabulated in below. The DQO employed for the homogeneity evaluation was that relative differences between pairs of samples should not exceed 100% for concentrations above the LOQ,

Homogeneity: General Water Chemistry

With regard to general water chemistry, 10 pairs of analyses out of 276 failed the homogeneity DQO that values above the LOQ should show a % Relative Difference no greater than 100%, and of these 7 pairs of analyses fell above the LOQ.

All other duplicate pairs met the DQO. Note that no evaluation was performed where either of the duplicates included a value below detection.

Water Chemistry - General

Parameter	**Site**	**Date**	**%RD**	**Low Value**	**LOQ**	**>LOQ?**
Ammonia	W1	11-Jan-07	176%	4.73 ug/L	1.5 ug/L	yes
Chloride	W1	3-Nov-06	158%	11.3 mg/L	.005 mg/L	yes
Hardness	W1	3-Nov-06	151%	64.7 mg/L	0.03 mg/L	yes
Specific Conductance	W1	2-Dec-06	168%	465 uS/cm	1.5 uS/cm	yes
TKN	W1	11-Jan-07	163%	0.076 mg/L	0.02 mg/L	yes
TSS	G4	3-Nov-06	149%	5 mg/L	5 mg/L	no
TSS	B1	3-Dec-06	105%	2.5 mg/L	5 mg/L	no
Ammonia	B1	6-Feb-07	200%	0.236 µg/L	1.5 µg/L	no
TSS	B1	7-May-07	164%	18 mg/L	5 mg/L	yes
TSS	G4	7-May-07	150%	40 mg/L	5 mg/L	yes

Note:

%RD= % Relative Difference
Low value = Lowest of the duplicate analyses
LQ = Limit of Quantitation

Homogeneity: Elemental Water Chemistry

With regard to general water chemistry, 8 pairs of analyses out of 391 failed the homogeneity DQO that values above the LOQ should show a % Relative Difference no greater than 100%, and of these all pairs of analyses fell above the LOQ.

All other duplicate pairs met the DQO. Note that no evaluation was performed where either of the duplicates included a value below detection.

Water Chemistry - Elemental

Parameter	**Ste**	**Date**	**%RD**	**Low Value**	**unit**	**LOQ**	**>LOQ?**
K	B1	11-Jan-07	**171%**	.491	mg/L	.003 mg/L	yes
Na	B1	11-Jan-07	**103%**	6.97	mg/L	0.03 mg/L	yes
Al	G4	7-May-07	**139%**	298	µg/L	30	yes
Cu	G4	7-May-07	**127%**	9.0	µg/L	6	yes
Fe	G4	7-May-07	**140%**	1190	µg/L	15	yes
P	G4	7-May-07	**125%**	.084	µg/L	,003	yes
Zn	G4	7-May-07	**124%**	48.0	µg/L	.015	yes
Ba	B1	7-May-07	**113%**	28.0	µg/L	3	yes

Note:
%RD= % Relative Difference
Low value = Lowest of the duplicate analyses
LQ = Limit of Quantitation

Homogeneity: Water-Bacteria

For homogeneity evaluations for bacterial analyses counts of 10 and higher were expected to show a relative difference better than 100%. Out of 30 pairs of analyses evaluated, 15 pairs had a %RD greater than 100% but all were for low concentrations for which the DQO did not apply. Note that even if the estimate for LOQ was lowered to 1 CFU/100mL, the results would be identical.

Water Bacteriology

Parameter	**Site**	**Date**	**%RD**	**Low Value**	**LOQ (est.)**	**>LOQ?**
Fecal Coliforms	B3	6-Feb-07	200%	0 CFU/100mL	10 CFU/100mL	no
Fecal Coliforms	G3	6-Feb-07	200%	0	10 CFU/100mL	no
Fecal Coliforms	W1	9-Mar-07	120%	10	10 CFU/100mL	no
Fecal Coliforms	B1	7-May-07	200%	0	10 CFU/100mL	no
Fecal Coliforms	G4	7-May-07	200%	0	10 CFU/100mL	no
Fecal Coliforms	W1	11-June-07	120%	4	10 CFU/100mL	no
Fecal Coliforms	G4	11-June-07	200%	0	10 CFU/100mL	no

Enterococcus	B1	6-Feb-07	127%	0.04	10 CFU/100mL	no
Enterococcus	G4	6-Feb-07	150%	.02	10 CFU/100mL	no
Enterococcus	G3	6-Feb-07	200%	0	10 CFU/100mL	no
Enterococcus	G4	2-Dec-06	200%	0 CFU/100mL	10 CFU/100mL	no
Enterococcus	B3	6-Feb-07	200%	0 CFU/100mL	10 CFU/100mL	no
Enterococcus	B1	6-Feb-07	127%	0.04 CFU/100mL	10 CFU/100mL	no
Enterococcus	B1	3-Dec-06	120%	0.02 CFU/100mL	10 CFU/100mL	no
Enterococcus	G4	17-Dec-07	150%	0.02 CFU/100mL	10 CFU/100mL	no

Note:

%RD = % Relative Difference
Low value = Lowest of the duplicate analyses
LQ = Limit of Quantitation (Estimated)

Homogeneity: Elemental Sediment Chemistry

The sediment chemistry of the field duplicates was quite variable. Nine out of 238 pairs showed a relative difference of greater than 100% and 40 had a relative difference of more than 50%. On each sample date, 33 different metals were analysed, so a small difference in sediment quality could be reflected as a very large percentage of affected samples. In total duplicates were taken on 2 occasions at each of four sites.

Appendix B1 Photo Record-Willowbrook


Willowbrook Photo 1, 2007-01-11. Stormwater pond west of footbridge.


Willowbrook Photo 2, 2007-01-11. Swan Creek.


Willowbrook Photo 3, 2007-02-06. Stormwater pond west of footbridge.


Willowbrook Photo 4, 2007-02-06. Swan Creek.


Willowbrook Photo 5, 2007-03-09. Stormwater pond south of footbridge.


Willowbrook Photo 6, 2007-03-09. Swan Creek.


Willowbrook Photo 7, 2007-04-10. Stormwater pond west of footbridge.


Willowbrook Photo 8, 2007-04-10. Swan Creek.


Willowbrook Photo 9, 2007-05-07. Stormwater pond south of footbridge.


Willowbrook Photo 10, 2007-05-07. Swan Creek.


Willowbrook Photo 11, 2007-06-11. Stormwater pond west of footbridge.


Willowbrook Photo 12, 2007-07-20. Stormwater pond south of footbridge.


Willowbrook Photo 13, 2007-08-03. Stormwater pond west of footbridge.


Willowbrook Photo 14, 2007-08-03. Swan Creek.


Willowbrook Photo 15, 2007-09-07. Stormwater pond south of footbridge.


Willowbrook Photo 16, 2007-09-07. Swan Creek.


Willowbrook Photo 17, 2007-10-30. Stormwater pond south of footbridge.


Willowbrook Photo 18, 2007-10-30. Swan Creek.


Willowbrook Photo 19, 2007-11-23. Stormwater pond south of footbridge


Willowbrook Photo 20, 2007-11-23. Swan Creek.


Willowbrook Photo 21, 2007-12-17. Stormwater pond south of footbridge


Willowbrook Photo 22, 2007-12-17. Stormwater pond west of footbridge


Willowbrook Photo 23, 2007-12-17. Catchbasin at Trafalgar Crescent.


Willowbrook Photo 24, 2007-12-17. Downstream of catchbasin.

Appendix B2 Photo Record- Baxter Pond

Baxter Pond Photo 1, 2006-11-13. View from the Patricia Bay Highway pedestrian overpass.

Baxter Pond Photo 2, 2006-11-13. Looking down into the pond from the path.

Baxter Pond Photo 3, 2007-01-11. Looking south toward Pacific Christian Highschool.

Baxter Pond Photo 4, 2007-01-11. Facing west from the path to the row of houses on western edge of pond.

Baxter Pond Photo 5, 2007-02-06. Sediment deposition in forebay accumulated from road runoff.

Baxter Pond Photo 6, 2007-02-06. Facing west from path.


Baxter Pond Photo 7, 2007-03-09. Gabo Creek flowing to the west of Baxter Pond.


Baxter Pond Photo 8, 2007-03-09. Facing west from path.


Baxter Pond Photo 9, 2007-04-10. Gabo Creek flowing to the west of Baxter Pond.


Baxter Pond Photo 10, 2007-04-10. Facing west from path.


Baxter Pond Photo 11, 2007-05-07. Gabo Creek flowing to the west of Baxter Pond.


Baxter Pond Photo 12, 2007-05-07. Facing west from path.


Baxter Pond Photo 13, 2007-06-11. Gabo Creek flowing to the west of Baxter Pond.


Baxter Pond Photo 14, 2007-06-11. Facing west from path.


Baxter Pond Photo 15, 2007-07-11. Gabo Creek flowing to the west of Baxter Pond.


Baxter Pond Photo 16, 2007-07-20. Facing west from path.


Baxter Pond Photo 17, 2007-08-03. Facing west from path.


Baxter Pond Photo 18, 2007-09-09. Facing west from path.

Baxter Pond Photo 19, 2007-09-09. Gabo Creek flowing to the west of Baxter Pond.

Baxter Pond Photo 20, 2007-10-30. Facing west from path.

Baxter Pond Photo 21, 2007-11-23. Gabo Creek flowing to the west of Baxter Pond.

Baxter Pond Photo 22, 2007-11-23. Facing west from path.

Baxter Pond Photo 23, 2007-12-17. Gabo Creek flowing to the west of Baxter Pond.

Baxter Pond Photo 24, 2007-12-17. Facing west from path.

Appendix B3 Photo Record- Blenkinsop


Blenkinsop Creek, Photo 1, 2006-10-13. Looking downstream from Blenkinsop Lake.


Blenkinsop Creek, Photo 2, 2006-10-13. Widened channel upstream of pedestrian bridge


Blenkinsop Creek, Photo 3, 2007-01-11. After a large snowfall, agricultural drainage contrasts dramatically with the snow-covered banks.


Blenkinsop Creek Photo 4, 2007-02-06.


Blenkinsop Creek Photo 5, 2007-02-06.


Blenkinsop Creek Photo 6, 2007-03-09.


Blenkinsop Creek, Photo 7, 2007-05-07.


Blenkinsop Creek, Photo 8, 2007-05-07.


Blenkinsop Creek, Photo 9, 2007-06-11.


Blenkinsop Creek, Photo 10, 2007-06-11.


Blenkinsop Creek, Photo 11, 2007-08-03.


Blenkinsop Creek, Photo 12, 2007-08-03.


Blenkinsop Creek, Photo 13, 2007-10-30.


Blenkinsop Creek, Photo 14, 2007-10-30.


Blenkinsop Creek, Photo 15, 2007-11-23.


Blenkinsop Creek, Photo 16, 2007-11-23.


Blenkinsop Creek, Photo 17, 2007-12-17.


Blenkinsop Creek, Photo 18, 2007-12-17.

Appendix B4 Photo Record- Leeds Creek


Leeds Creek Photo 1, 2007-02-06. Looking downstream from the culvert at Leeds Place.


Leeds Creek Photo 2, 2007-03-9. Downstream of culvert at Leeds Place.


Leeds Creek Photo 3, 2007-04-10. Downstream of culvert at Leeds Place.


Leeds Creek Photo 4, 2007-05-07. Boggy area upstream of Leeds Creek and Blenksinop Creek confluence. Note presence of iron bacteria.


Leeds Creek Photo 5, 2007-06-11. Downstream of culvert at Leeds Place.


Leeds Creek Photo 6, 2007-08-03. Downstream of culvert at Leeds Place.

Leeds Creek Photo 7, 2007-10-30. Downstream of culvert at Leeds Place.

Leeds Creek Photo 8, 2007-10-30. Boggy area upstream of Leeds Creek and Blenksinop Creek confluence.

Leeds Creek Photo 9, 2007-11-23. Downstream of culvert at Leeds Place.

Leeds Creek Photo 10, 2007-11-23. Blenkinsop Creek staff gauge upstream of its confluence with Leeds Creek.

Leeds Creek Photo 11, 2007-12-17. Downstream of culvert at Leeds Place.

Leeds Creek Photo 12, 2007-12-17. Blenkinsop Creek staff gauge upstream of its confluence with Leeds Creek.

Appendix B5 Photo Record-
Vancouver Island Technology Park


VITP Photo 1, 2006-10-13. Upper constructed wetland.


VITP Photo 2, 2006-10-13. Viaduct Creek. Note headcut presence on tributary channel to the right.


VITP Photo 3, 2007-01-11. Upper constructed wetland.


VITP Photo 4, 2007-01-11. Viaduct Creek. Note headcut presence on tributary channel to the right.


VITP Photo 5, 2007-02-06. Upper constructed wetland.


VITP Photo 6, 2007-02-06. Viaduct Creek. Note amount of material being supplied by tributary headcut.


VITP Photo 7, 2007-04-10. Upper constructed wetland.


VITP Photo 8, 2007-04-10. Viaduct Creek. Note amount of material being supplied by tributary headcut.


VITP Photo 9, 2007-05-07. Upper constructed wetland.


VITP Photo 10, 2007-05-07. Viaduct Creek.


VITP Photo 11, 2007-06-11. Upper constructed wetland.


VITP Photo 12, 2007-06-11. Viaduct Creek.


VITP Photo 13, 2007-08-03. Upper constructed wetland.


VITP Photo 14, 2007-08-03. Viaduct Creek.


VITP Photo 15, 2007-09-07. Viaduct Creek.


VITP Photo 16, 2007-09-07. Viaduct Creek tributary headcut.


VITP Photo 17, 2007-11-23. Upper constructed wetland.


VITP Photo 18, 2007-11-23. Viaduct Creek.

VITP Photo 19, 2007-12-17. Upper constructed wetland.

VITP Photo 20, 2007-12-17. Viaduct Creek.

VITP Photo 21, 2007-12-17. Upper constructed wetland.

VITP Photo 21, 2007-12-17. Viaduct Creek (looking upstream).

Appendix C- Glossary

Anaerobic – "A life or process that occurs in, or is not destroyed by, the absence of oxygen". [i]

Best Management Practices (BMPs) – "Policies, practices, procedures, or structures implemented to mitigate the adverse environmental effects on surface water quality resulting from development. BMPs are categorized as structural or non-structural"[ii]

Biomass – "All of the living material in a given area; often refers to vegetation"[iii].

Catchment – "The area that drains surface runoff and groundwater supply from precipitation into a watercourse or urban stormwater drainage system"[iv].

Channel Morphology – "The stream morphology of a section of flowing water and associated flood plain"[v].

Complexity – Referring to the roughness of a channel that provides in stream habitat (*i.e.,* large woody debris, boulders, etc).

Conservation Design Principles –Development design principles that maximize the amount of open space on a developable landscape by specifically identifying and preserving primary and conservation areas (*i.e.*, steep slopes, wetlands, etc).

Constructed Wetland – "Engineered or constructed wetland that utilizes natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist, at least partially, in treating an effluent or other water source.[vi]"

Dentrification – "The reduction of nitrates to nitrites, ammonia and free nitrogen in the soil under anaerobic conditions, resulting in loss of nitrogen from ecosystems.[vii]"

Detection Limit – "The lowest concentration of a chemical that can reliably be distinguished from a zero concentration"[viii].

Detention Basin – "Basins whose outlets are designed to detain the stormwater runoff from a water quality "storm" for some minimum duration (e.g., 24 hours) which allow sediment particles and associated pollutants to settle out". Dry detention ponds do not have a permanent pool.[ix]

Effluent – "Wastewater or stormwater--treated or untreated--that flows out of a treatment plant, sewer, stormwater pipe or industrial outfall. Generally refers to wastes discharged into surface waters"[x].

Engineered Stormwater Treatment Facilities – "A treatment facility that requires engineering analysis to determine the hydrology, hydraulics and design of the structure.

Engineered treatment facilities include features such as dry and wet detention basins, engineered water quality swales (bioswales), treatment wetlands, and proprietary systems"[xi].

Event Mean Concentration (EMC) – "The total constituent mass for an event divided by the total flow volume for the event"[xii].

Functional Condition - An aquatic system is considered to be in a functional condition when it is in balance with the landscape (*i.e.*, gradient, hydrology, soils and vegetation) as there is adequate landform present to dissipate high energy flows.

Gradient – "The degree of slope, or steepness of a geographic feature"[xiii].

Impermeable – "The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water."

Infill – Vacant or underutilized land within an existing urban center that is developed.

Inlet – "An opening providing a means of entrance or intake."[xiv]

In Situ – "In its original place; unmoved unexcavated; remaining at the site or in the subsurface."[xv]

Hydrodynamic Systems - Systems that rely on the motion of water to separate pollutants and sediments from a water column (*i.e.*, gravity and vortex separators).

Low Impact Strategies – "Stormwater design strategies that allow for the natural infiltration of rainwater to occur as close as possible to the original area of rainfall" - EPA (2000). Low impact development: A literature review.

Naturalized Wetland – A man-made wetland that is built specifically to mimic natural ecological functions and which, over time, becomes nearly indistinguishable from a natural wetland in its features and attributes. It is self-sustaining..

Photosynthesizing – The process by which plants manufacture "carbohydrates and oxygen from carbon dioxide mediated by chlorophyll in the presence of sunlight"[xvi].

Proper Functioning Condition – a) the assessment method developed jointly by the US Bureau of Land Management, US Forest Service, and Natural Resources Conservation Service which uses attributes of hydrology, vegetation and soils to assess stream health b) a stream is deemed to be in proper functioning condition (PFC) when there is adequate "vegetation, landform or large woody debris present to dissipate energy associated with high water flows, thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood water retention and ground water recharge; develop root masses that stabilize stream banks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and develop the water depth, duration and temperature necessary for fish production, waterfowl breeding and other uses; and support greater biodiversity.[xvii]"

Right-of-way – "An easement to use another's land for passage. A right-of-way is most commonly used for pipelines that cross lands that the operator does not control entirely by lease[xviii]".

Settling Pond – A basin designed to capture and detain stormwater run-off enabling sediment and other suspended materials or particulates to settle out of the water column.

Spring-fed – Referring to a perennial or intermittent stream that receives a base water supply by underground springs.

Statistically Significant – A parameter or statistical result is termed this if there is very low likelihood that the parameter or result had occurred by chance.

Stream Restoration – Physically altering stream channel morphology and/or vegetation, or a change in management activities upstream (or within) in order to return the stream to a natural ecological balance where the stream is in balance with the current landscape setting.

Thermal Loading – An increase in water temperatures due to an external input(s) discharging effluent that is warmer than the receiving environment (*i.e.*, stormwater).

Vegetated Swale – "Broad, shallow channel with a dense stand of vegetation covering the side slopes and bottom. Swales can be natural or manmade, and are designed to trap particulate pollutants (suspended solids and trace metals), promote infiltration, and reduce the flow velocity of storm water runoff"[xix].

Water Balance – "Balance of the water resources of a region, comparing precipitation and inflow with outflow, evaporation, and accumulation"[xx].

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