# Chapter 29

## Infiltration wetland systems

### 29.1 Summary

Combined wetlands and infiltration ponds are cost-effective 'end of pipe' drainage solutions that can be applied for local source control as part of urban development and regeneration plans. The aims of this case study were to assess constraints associated with the planning, design and operation of these ponds, the influence of aquatic plants on infiltration rates and the water treatment potential.

Storm runoff was first stored and treated in a constructed wetland, before it overflowed into parallel infiltration ponds of which one was planted and the other one was unplanted. Three international sustainable urban drainage system (SUDS) design guidelines failed in practice. The presence of macrophytes in one infiltration pond had no significant influence on the drainage properties. The water quality of both ponds was not acceptable for water reuse directly after the system set-up.

Filamentous green algae within the unplanted pond were blooming in spring and summer, creating an aesthetically unpleasing pond surface area. After one year of operation, barley straw and *Carassius auratus* (common goldfish) were introduced successfully to control the growth of algae.

### 29.2 Introduction

#### 29.2.1 Need for SUDS and critical issues

Conventional stormwater systems are designed to dispose off surface runoff as quickly as possible. This results in 'end of pipe' solutions that often involve the provision of large interceptor and relief sewers, huge storage tanks at downstream locations and centralized wastewater treatment facilities. These traditional civil engineering solutions often lead to flooding and environmental pollution during storms (Butler et al., 2000; Galuzzi and Pflaum, 1996; Scholz, 2004).

In contrast, SUDS systems such as combined attenuation pond and infiltration pond systems (Ellis et al., 2002; EPA, 1999) can be applied as cost-effective local 'source control' drainage solutions; e.g., delaying storm runoff and reducing peak flows. It is often possible to divert all storm runoff for infiltration or storage and subsequent water reuse. As runoff from roads is a major contributor to the quantity of surface water requiring disposal, this is particularly a beneficial approach where suitable ground conditions prevail (Butler and Davies, 2000). Furthermore, infiltration of storm runoff can reduce the concentration of diffuse pollutants such as leaves, feces, metals and hydrocarbons, thereby improving the water quality of surface water runoff (Ellis et al., 2002; Scholz, 2003; Scholz, 2004).

Despite the theoretical benefits of SUDS, the technical constraints associated with the design and operation of large features such as ponds have not been explored due to a lack of experimental data. The rainfall, runoff and infiltration relationships for planted infiltration ponds treating road runoff have not been studied previously. There is also a lack of water quality management data and guidelines for unplanted and planted infiltration ponds that are operated in parallel. Considering the increase in popularity of SUDS, urban planner and developer need to understand the design and operation constraints of systems such as infiltration basins and ponds.

### 29.2.2 Aim and objectives

The aim is to assess an experimental infiltration pond system (case study) designed according to SUDS guidelines (CIRIA, 2000; EPA, 1999). The objectives are to:

- Identify technical constraints associated with the design and operation of novel planted infiltration ponds;
- Assess the rainfall, runoff and infiltration relationships for unplanted infiltration ponds;
- Assess the water quality, and its management for unplanted and planted infiltration ponds;
- Assess passive and active filamentous green algal control strategies including the use of barley straw and *C. auratus*; and
- Promote the integration of SUDS into urban planning and development.

## 29.3 Methods

### 29.3.1 Design of the study site

The pilot plant was designed considering the SUDS guidelines (Building Research Establishment, 1991; Bettes, 1996; CIRIA, 2000; ATV-DVWK-Arbeitsgruppe, 2002) of the British Research Establishment (BRE), Construction Industry

Research and Information Association (CIRIA), and the German Association for Water, Wastewater and Waste (ATV-DVWK). The return period for allowed flooding is ten years. The total road area draining into the SUDS system is approximately 446 $m^2$. The SUDS is based on a combined wetland and infiltration pond design (Fig. 29.1).

Rainwater runoff from the University road (catchment area) flows directly into a silt trap (Scholz and Zettel, 2004). The silt trap has a maximum capacity of 0.2 $m^3$. Water from the silt trap overflows via a gravel ditch into the constructed wetland (volume of 2.7 $m^3$), which also serves the purpose of a below-ground storage tank. If the wetland attenuation system is full, storage water flows over a dry stonewall into a swale and finally into the infiltration ponds.

The ponds can accommodate maximum volumes of 9.7 $m^3$each during heavy storm events before flooding of a nearby lawn would occur (Fig. 29.1). The maximum depths of the constructed wetland, and the unplanted and planted infiltration ponds are 0.85, 1.18 and 1.02 m, respectively.

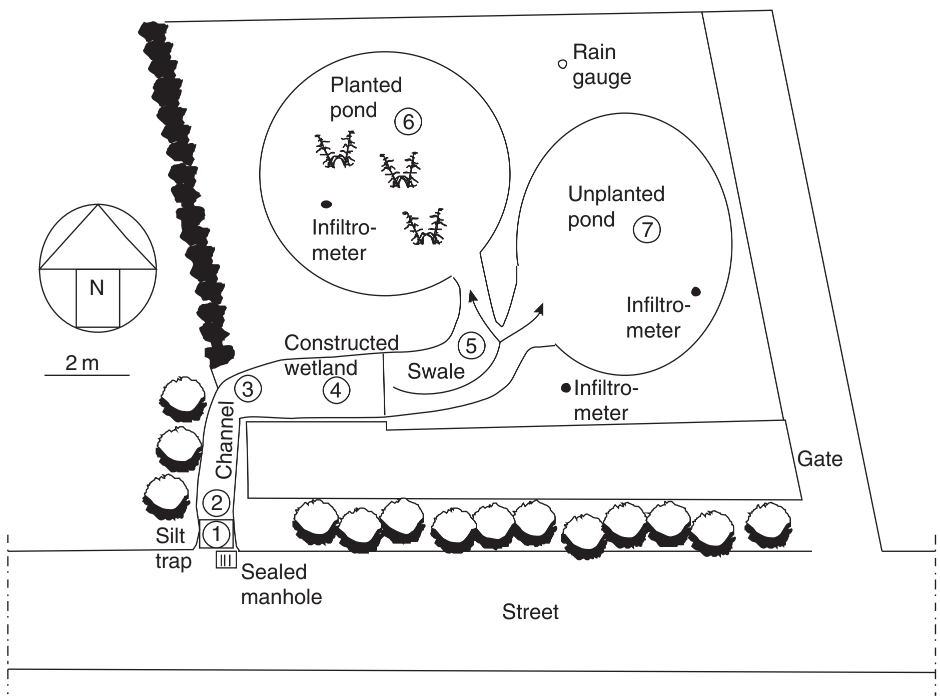


**Fig. 29.1 Case study: runoff flows from the road (only eastern part shown) into the silt trap (1), then via the gravel channel (2) into the constructed wetland (3 and 4) and finally via the swale (5) into the infiltration ponds (6 and 7).**

In summer 2004, the dominant aquatic plants of the planted infiltration pond were *Typha latifolia* (broadleaf cattail), *Sparganium erectum* (simplestem bur-reed) and *Iris pseudacorus* (paleyellow iris). *Typha latifolia* was planted in the infiltration pond to enhance infiltration. The constructed wetland was planted with *Phragmites australis* (common reed; Scholz et al., 2002), *I. pseudacorus* and *T. latifolia*.

### 29.3.2 Hydrological methods and water quality analysis

The daily rainfall was monitored by a tipping bucket ARG 100 rain gauge. The infiltration rate of road runoff into the infiltration ponds was determined by using a single-ring infiltrometer. A PN 623-8001 (0.8–2.0 bar) Boart Longyear Interfels total pressure data logger was used to estimate water depth variations in the unplanted pond.

Grab samples at up to seven locations (Fig. 29.1) were predominantly collected from the silt trap (1), constructed wetland (inflow (3) and outflow (4)) and both infiltration ponds (6 and 7). All analytical procedures to determine the water quality were performed according to the USA standard methods (Clesceri et al., 1998).

### 29.3.3 Fish experiment methodologies

Laboratory experiments with *C. auratus* and different aquatic plants (filamentous green algae, *Elodea canadensis* (Canadian waterweed) and *Callitriche stagnalis* (pond water-starwort)) were carried out in eight aquarium tanks filled up with a mixture of filtered (sieve having a pore diameter of 250 μm) pond water (50%) and tap water (50%): Tank 1: filamentous green algae; Tank 2: *E. canadensis*; Tank 3: *C. stagnalis*; Tank 4: filamentous green algae and *E. canadensis*; Tank 5: *E. canadensis* and *C. stagnalis*; Tank 6: filamentous green algae and *C. stagnalis*; Tanks 7 and 8: filamentous green algae, *E. canadensis* and *C. stagnalis*.

All tanks (except for Tank 8; control) contained six *C. auratus* of similar weight. The overall biomass of plant food per tank was 600 g, and equal proportions of different plants were used. The experiment was stopped after the food sources dropped to <20 g of plant matter.

Twenty healthy *C. auratus* of approximately 180 g total weight were introduced into each infiltration pond on 1 April 2004. The ponds were covered with a plastic mesh to prevent animals such as *Ardea cinerea* (grey heron) and *Felis cattus* (cat) to prey on *C. auratus*.

## 29.4 Results and discussion

### 29.4.1 Design and operation of infiltration ponds

The critical storm durations for the BRE, CIRIA and ATV-DVWK design calculations were 0.08, 0.25 and 0.08 h, respectively. The corresponding maximum infiltration pond height requirements were 0.38, 0.15 and 0.12 m, respectively. The estimated mean infiltration rate applied for all methods was 1.17 m/h. A storm duration of 15 min was associated with the maximum pond height and storage volume when CIRIA guidelines were applied (Bettess, 1996; CIRIA, 2000).

All calculated storage volumes ($<1$ m$^3$) are considerably lower than 9.7 m$^3$, so both ponds have more than sufficient storage volumes compared to the theoretical design volumes. It seems that the infiltration rate of 1.17 m/h (SD of 0.21 m/h) is an unrealistically high value for this SUDS system, considering the high spatial variability of the man-made soil at the study site. For example, the infiltration rate at water depths $<0.8$ m was frequently $<0.05$ m within 3 d (Fig. 29.2).

The actual design depth for both infiltration ponds (1.10 m) was acceptable, when compared to the BRE (Building Research Establishment, 1991), CIRIA (Bettes, 1996) and ATV-DVWK (ATV-DVWK-Arbeitsgruppe, 2002) guidelines. Signs of system failure have not been observed. However, the strict application of all test guidelines would have led to system failures even during the first few

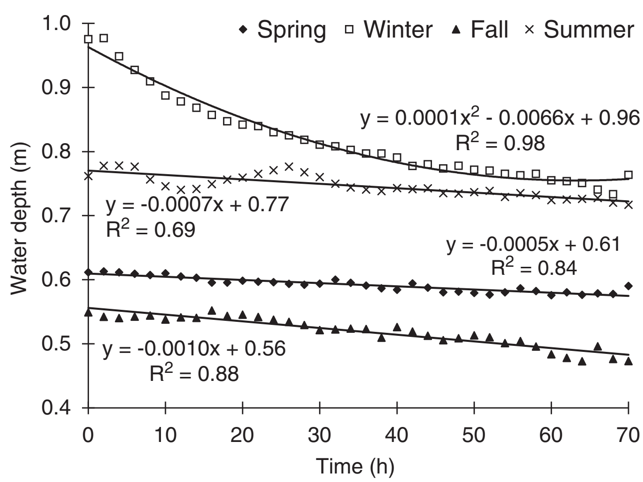


**Fig. 29.2 Water-depth changes as a function of the infiltration rates: spring (1 April 2004); summer (28 June 2004); autumn (30 September 2004); winter (28 January 2004).**

months of operation. These findings are similar to a previous case study in England discussed elsewhere (Scholz, 2003).

### 29.4.2 Rainfall, runoff and infiltration relationships

Figure 29.2 gives an indication of representative water-depth variations during periods of virtually no precipitation for all seasons. It can be seen that the infiltration is relatively low at water depths <0.8 m during all seasons except for winter. As a rule of thumb, Eq. (29.4.1) indicates the relationship between infiltration rate and water depth for water depth ranges between 0.3 m and 1 m of the unplanted infiltration pond:

$$\text{water depth (m)} = 100\ \text{(h)} \times \text{infiltration rate (m/h)} + 0.5\ \text{(m)} \qquad (29.4.1)$$

### 29.4.3 Water quality assessment and management

The water qualities of the constructed wetland inflow, the unplanted pond and the planted pond are shown in Tables 29.1, 29.2 and 29.3, respectively. After one

**Table 29.1 Summary statistics: water quality of the inflow to the constructed wetland (1 April 2003 – 30 September 2004)**

| Variable | Unit | No. | Mean | | | | Standard deviation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Time[1] | Time[2] | Time[3] | Time[4] | Time[1] | Time[2] | Time[3] | Time[4] |
| Temperature | °C | 104 | 11.9 | 12.3 | 8.9 | 14.0 | 5.5 | 2.3 | 4.1 | 3.8 |
| $BOD_5$[5] | mg/l | 86 | 17.0 | 12.3 | 26.4 | 16.0 | 18.2 | 10.4 | 25.8 | 9.8 |
| SS[6] | mg/l | 95 | 385.2 | 104.4 | 208.8 | 601.0 | 600.3 | 165.7 | 305.1 | 756.9 |
| Ammonia-N | mg/l | 67 | 0.6 | 0.5 | 0.5 | 0.8 | 0.8 | 0.4 | 0.9 | 0.8 |
| Nitrate-N | mg/l | 60 | 2.5 | 1.6 | 1.9 | 3.2 | 8.3 | 2.2 | 3.4 | 11.6 |
| Phosphate-P | mg/l | 67 | 0.2 | 0.0 | 0.1 | 0.3 | 0.2 | 0.0 | 0.1 | 0.2 |
| Conductivity | μS | 105 | 242.2 | 204.9 | 276.9 | 228.9 | 193.2 | 174.1 | 215 | 180.7 |
| Turbidity | N[8] | 106 | 224.0 | 133.5 | 90.5 | 368.6 | 442.3 | 227.0 | 119.7 | 605.7 |
| DO[7] | mg/l | 100 | 4.2 | 3.7 | 6.0 | 2.9 | 6.4 | 2.7 | 9.9 | 1.0 |
| pH | - | 106 | 7.0 | 7.0 | 7.0 | 7.1 | 0.6 | 0.2 | 0.9 | 0.2 |

[1]01/04/2003–30/09/2004.
[2]01/04/2003–30/09/2003.
[3]01/10/2003–31/03/2004.
[4]01/04/2004–30/09/2004.
[5] five-day @ 20°C N-Allylthiourea biochemical oxygen demand (BOD).
[6]suspended solids (SS).
[7]dissolved oxygen (DO).
[8]Nephelometric Turbidity Unit.

**Table 29.2 Summary statistics: water quality of the unplanted pond (1 April 2003 – 30 September 2004)**

| | | | Mean | | | | Standard deviation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Unit | No | Time[1] | Time[2] | Time[3] | Time[4] | Time[1] | Time[2] | Time[3] | Time[4] |
| Temperature | °C | 106 | 11.8 | 13.4 | 6.4 | 15.6 | 5.5 | 2.3 | 4.1 | 3.8 |
| $BOD_5$[5] | mg/l | 82 | 19.0 | 35.9 | 17.6 | 14.2 | 20.4 | 22.1 | 25 | 10.3 |
| SS[6] | mg/l | 92 | 26.4 | 29.2 | 24.1 | 27.1 | 50.3 | 24.3 | 60.1 | 49.7 |
| Ammonia-N | mg/l | 65 | 0.4 | 1.4 | 0.2 | 0.3 | 1.2 | 2.6 | 0.3 | 0.7 |
| Nitrate-N | mg/l | 63 | 1.6 | 0.3 | 1.3 | 2.2 | 6.4 | 0.1 | 2.9 | 9.0 |
| Phosphate-P | mg/l | 70 | 0.3 | 0.1 | 0.3 | 0.3 | 0.4 | 0.1 | 0.5 | 0.4 |
| Conductivity | μS | 107 | 215.6 | 246.8 | 207.1 | 210.2 | 121 | 87.9 | 156.4 | 95.2 |
| Turbidity | N[8] | 108 | 17.9 | 17.3 | 9.0 | 25.7 | 36.9 | 14.1 | 19.8 | 50.6 |
| DO[7] | mg/l | 102 | 5.1 | 3.8 | 7.4 | 3.5 | 7.9 | 3.3 | 12.1 | 1.2 |
| pH | - | 108 | 7.3 | 7.0 | 7.3 | 7.4 | 0.4 | 0.3 | 0.5 | 0.2 |

[1]01/04/2003–30/09/2004.
[2]01/04/2003–30/09/2003.
[3]01/10/2003–31/03/2004.
[4]01/04/2004–30/09/20004.
[5]five-day @ 20°C N-Allylthiourea biochemical oxygen demand (BOD).
[6]suspended solids (SS).
[7]dissolved oxygen (DO).
[8]Nephelometric Turbidity Unit.

**Table 29.3 Summary statistics: water quality of the planted pond (1 April 2003 – 30 September 2004)**

| | | | Mean | | | | Standard deviation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Unit | No | Time[1] | Time[2] | Time[3] | Time[4] | Time[1] | Time[2] | Time[3] | Time[4] |
| Temperature | °C | 106 | 11.6 | 13.2 | 6.6 | 15.1 | 5.5 | 2.3 | 4.1 | 3.8 |
| $BOD_5$[5] | mg/l | 88 | 26.5 | 26.3 | 41.8 | 13.9 | 32.9 | 19.4 | 43.4 | 17.5 |
| SS[6] | mg/l | 95 | 40.9 | 38.2 | 64.7 | 23.5 | 87.3 | 64.9 | 129.7 | 34.4 |
| Ammonia-N | mg/l | 65 | 0.2 | 0.6 | 0.3 | 0.1 | 0.4 | 1.0 | 0.3 | 0.1 |
| Nitrate-N | mg/l | 59 | 0.5 | 0.5 | 0.8 | 0.3 | 1.7 | 0.6 | 2.6 | 0.8 |
| Phosphate-P | mg/l | 67 | 0.2 | 0.1 | 0.2 | 0.3 | 0.3 | 0.1 | 0.1 | 0.3 |
| Conductivity | μS | 107 | 288.9 | 324.7 | 311.6 | 254.3 | 97.4 | 101.4 | 124.0 | 47.7 |
| Turbidity | N[8] | 108 | 17.6 | 22.6 | 16.4 | 16.7 | 30.6 | 24.9 | 16.9 | 40.5 |
| DO[7] | mg/l | 102 | 4.8 | 5.8 | 6.3 | 3.2 | 5.3 | 2.7 | 7.9 | 1.3 |
| pH | - | 107 | 7.2 | 7.1 | 7.2 | 7.2 | 0.3 | 0.3 | 0.4 | 0.1 |

[1]01/04/2003–30/09/2004.
[2]01/04/2003–30/09/2003.
[3]01/10/2003–31/03/2004.
[4]01/04/2004–30/09/2004.
[5]five-day @ 20°C N-Allylthiourea biochemical oxygen demand.
[6]suspended solids.
[7]dissolved oxygen.
[8]Nephelometric Turbidity Unit.

year of operation, the water quality of the unplanted infiltration pond (Table 29.2) was acceptable for disposal and recycling according to discussions particularly on biochemical oxygen demand (BOD) and suspended solids (SS) threshold concentrations, elsewhere (Butler and Davies, 2000; Ellis et al., 2002; Scholz, 2003).

Variables indicating the organic strength of both ponds were frequently above international standards (i.e. thresholds of 20 mg/l for BOD and 30 mg/l for SS) for secondary treatment of wastewater (Tchobanoglous et al., 2003). However, water quality monitoring is currently not required for closed systems (zero discharge) in Scotland (CIRIA, 2000).

The BOD and SS concentrations are high in the constructed wetland inflow and both infiltration ponds due to high loads of organic material such as leaves. Removal efficiencies for the SS were $>93$ and $>89\%$ for the unplanted and planted pond, respectively (Tables 29.1 – 29.3). The pH values of the wetland inflow and both ponds are neutral, similar and stable due to algae control measures (see below).

Mats of algae are usually considered unpleasant in their appearance by the public. Therefore, it was necessary to use barley straw bales as a passive algae control method (Ball et al., 2001) for the second summer after system set-up. However, this method does only provide a temporary solution, and does not solve the problem of nutrient accumulation (nitrogen and phosphorus) within the pond sediment.

High temporal data variation indicates the need for at least weekly monitoring of SS to capture concentration peaks exceeding 30 mg/l. In comparison, the BOD concentrations were relatively stable (Scholz, 2003).

Nutrient harvesting was undertaken. The silt trap was regularly emptied and the total wet weight of silt was 55 kg per annum. Aquatic plants of 20 kg were harvested in November 2003. The purpose was to reduce the input of additional nutrients that would otherwise be released from decaying leaves into the planted pond. Furthermore, plant harvesting leads to a prolonged lifetime of the infiltration system by indirectly increasing the storage volume available for sediment during storm events (Scholz, 2003).

### 29.4.4 Active control of algae with *Carassius auratus*

*Carassius auratus* is classified as herbivores with wild specimens predominantly feeding on plants. This particularly applies to closed pond systems (Seaman, 1979). Therefore, *C. auratus* could be used to control aquatic weeds (Caquet et al., 1996) and potentially algae in ponds (Richardson et al., 1992). This hypothesis was subsequently tested in the laboratory.

Figure 29.3 indicates that the mean weights and associated SD of *C. auratus* for each aquarium tank appear to be similar at the beginning and end of the

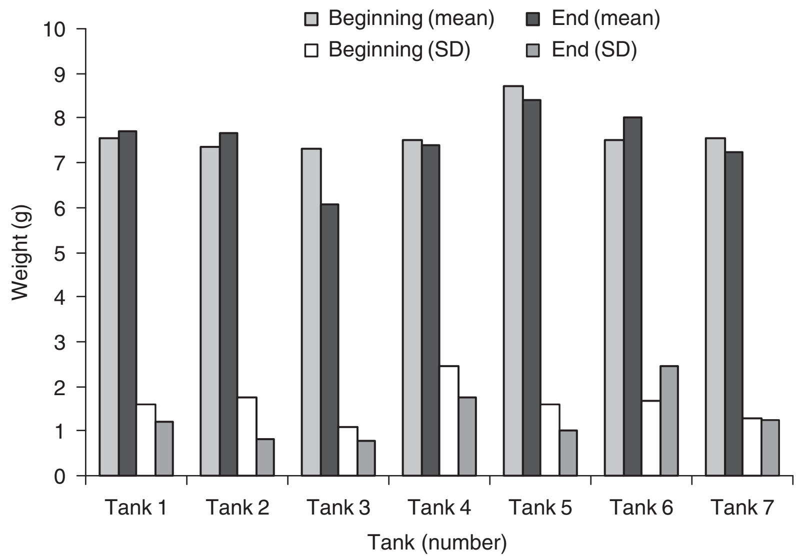


**Fig. 29.3 Comparison of means and standard deviations (SD) for weights *of C. auratus* (common goldfish) at the beginning (9 February 2004) and end (31 March 2004) of the laboratory experiment.**

controlled laboratory experiment. Moreover, an ANOVA showed that all tanks were significantly similar ($P < 0.05$) concerning their associated fish mean weights, which were measured on eight occasions each.

*Carassius auratus* seem to feed on all three aquatic plants including filamentous green algae such as *Odeogonium* spp. and *Ulothrix* spp., which were also naturally present in the pond system. However, the greatest drop in fish weights was observed for Tank 3 containing *C. stagnalis* only. Considering that the associated SD was also the lowest, and that *C. stagnalis* belongs to the group of floating aquatic plants that are only accessible by fish below the water level, it can be assumed that *C. auratus* would not have chosen this plant as a preferred food source, if alternative submerged aquatic plants would have been abundant.

Concerning the field experiment, relatively high numbers of filamentous green algae (Chlorophyta) were counted in pond samples taken on 29 March 2004. The dominant alga present was *O. capillare*, which is cosmopolitan in freshwater. *Odeogonium capillare* can form mats in small ponds, and is often mistaken for the more common *Cladophora glomerata* (blanket weed).

*Carassius auratus* was introduced into both ponds on 1 April 2004 to control filamentous green algae, and to increase public acceptance of SUDS. Concerning algae samples taken on 4 October 2004, both ponds were less dominated by *O. capillare* in comparison to March 2004.

Moreover, the unplanted pond developed a greater diversity of filamentous green algae if compared to the planted pond. This may be due to the absence of macrophytes that would compete with algae for nutrients. Moreover, large macrophytes provide shade leading to a reduction of sunlight penetrating the water, and subsequently reducing the growth of algae.

### 29.4.5 Integration of SUDS into urban planning and development

The environmental impacts of urban constructions can be reduced with innovative approaches such as 'smart growth' and sustainable urban and green planning (Galuzzi and Pflaum, 1996). Flood protection management and recreational value can be improved by integrating infiltration pond design and operation (in contrast to conventional drainage) into the urban planning and development processes (Campbell and Ogden, 1999; Scholz, 2003). Recreational activities may include watching birds and ornamental fish such as *C. auratus*, walking, fishing, boating, holding picnics and teaching children about aquatic ecology (Galuzzi and Pflaum, 1996).

The confidence of town planners towards SUDS and public acceptance of infiltration ponds can both be increased by correct dimensioning of systems to avoid flooding (Zheng and Baetz, 1999), enhance water pollution control by using a robust pre-treatment train (e.g., silt trap, constructed wetland and swale) and control algae by biological (e.g., *C. auratus*) and not chemical (e.g., copper sulphate) means (Ellis et al., 2002). Moreover, stormwater can be reused for watering gardens and flushing toilets as part of an urban water resources protection strategy.

## 29.5 Conclusions

This case study described the design and operation of a novel stormwater pond system during the first eighteen months of operation (April 2003 – October 2004). During this period, the SUDS would only have complied with design guidelines if local environmental conditions such as spatial infiltration patterns had been fully considered. Infiltration through the base of both ponds was virtually absent (despite the presence of macrophytes in the planted pond), and should therefore be neglected during the design.

The water qualities of the infiltration ponds were generally unacceptable for water reuse immediately after the set-up period of the SUDS. Biochemical oxygen demand and SS concentrations, in particular, frequently exceeded recognized international secondary wastewater treatment standards, which are, however, not applicable for closed systems with zero discharge. At least weekly water quality monitoring was required to capture temporal data variations.

A bloom of filamentous green algae dominated by *O. capillare* during spring 2004 was observed. Barley straw reduced the growth of algae. Moreover, experiments with *C. auratus* have shown that they eat filamentous green algae equally well as *C. stagnalis* and *E. canadensis*. The presence of tall macrophytes reduced the growth and biodiversity of filamentous green algae.

A successful integration of SUDS into urban regeneration and development can be achieved, if potential design, operation and water quality management problems are addressed during the planning phase. Moreover, current international guidelines for the design and management of infiltration ponds require alterations to avoid system failure as shown in this case study.