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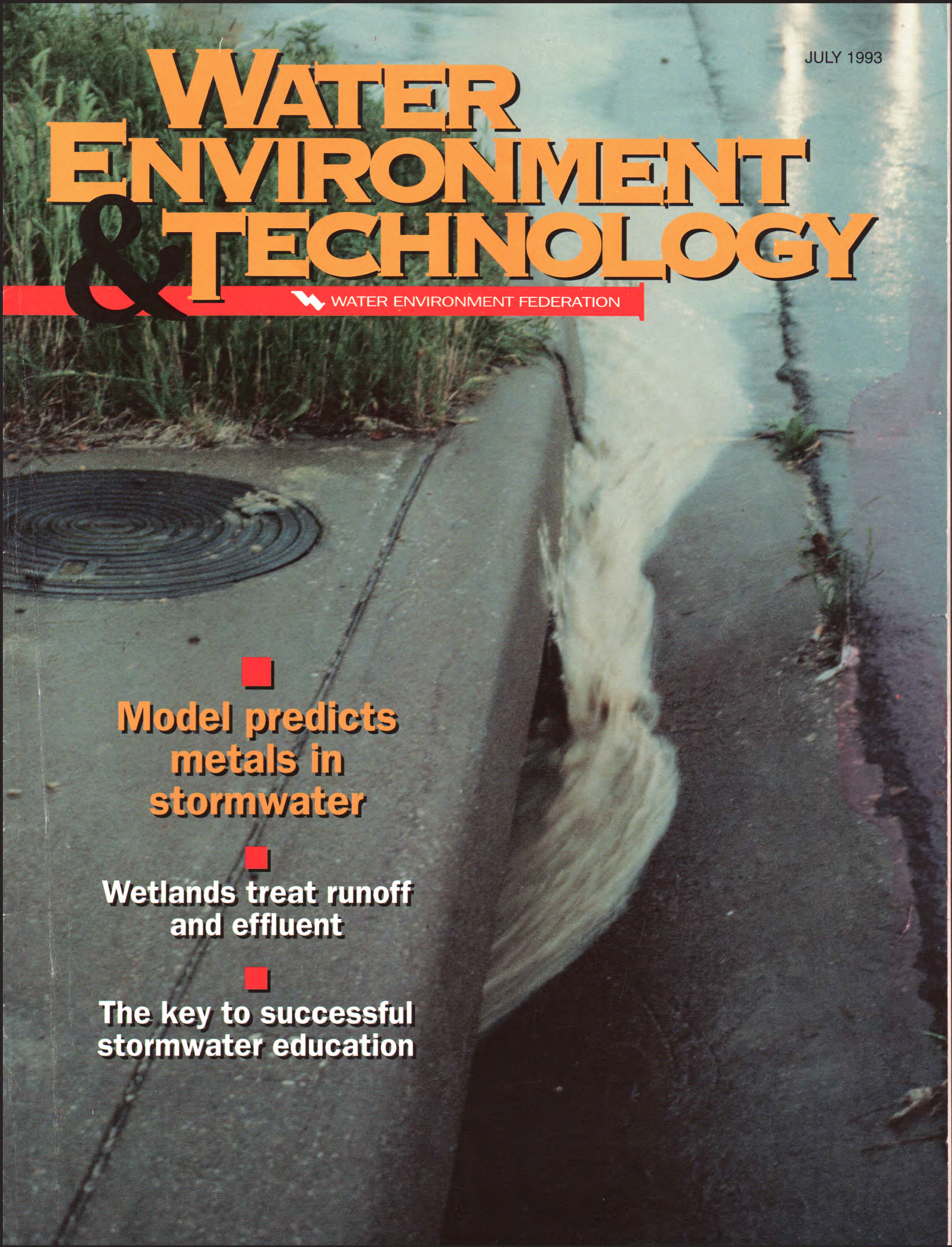
WATER ENVIRONMENT & TECHNOLOGY

WATER ENVIRONMENT FEDERATION



Model predicts metals in stormwater

Wetlands treat runoff and effluent

The key to successful stormwater education

Wetlands For Stormwater Treatment

Developers of a residential site on Lacamas Lake (Wash.), used a wetland system to treat stormwater runoff from the lake watershed.

An innovative wetland design filters stormwater and reduces phosphorus loading to adjacent lake

Mark F. Bautista
N. Stan Geiger

A four-year water quality monitoring program has shown that this system is an effective biofilter that reduces nutrient and sediment loading to the lake. Many issues must be addressed during the design and implementation of a wetland system, including permitting, water quality standards, treatment performance, cost, maintenance, and expected treatment life.

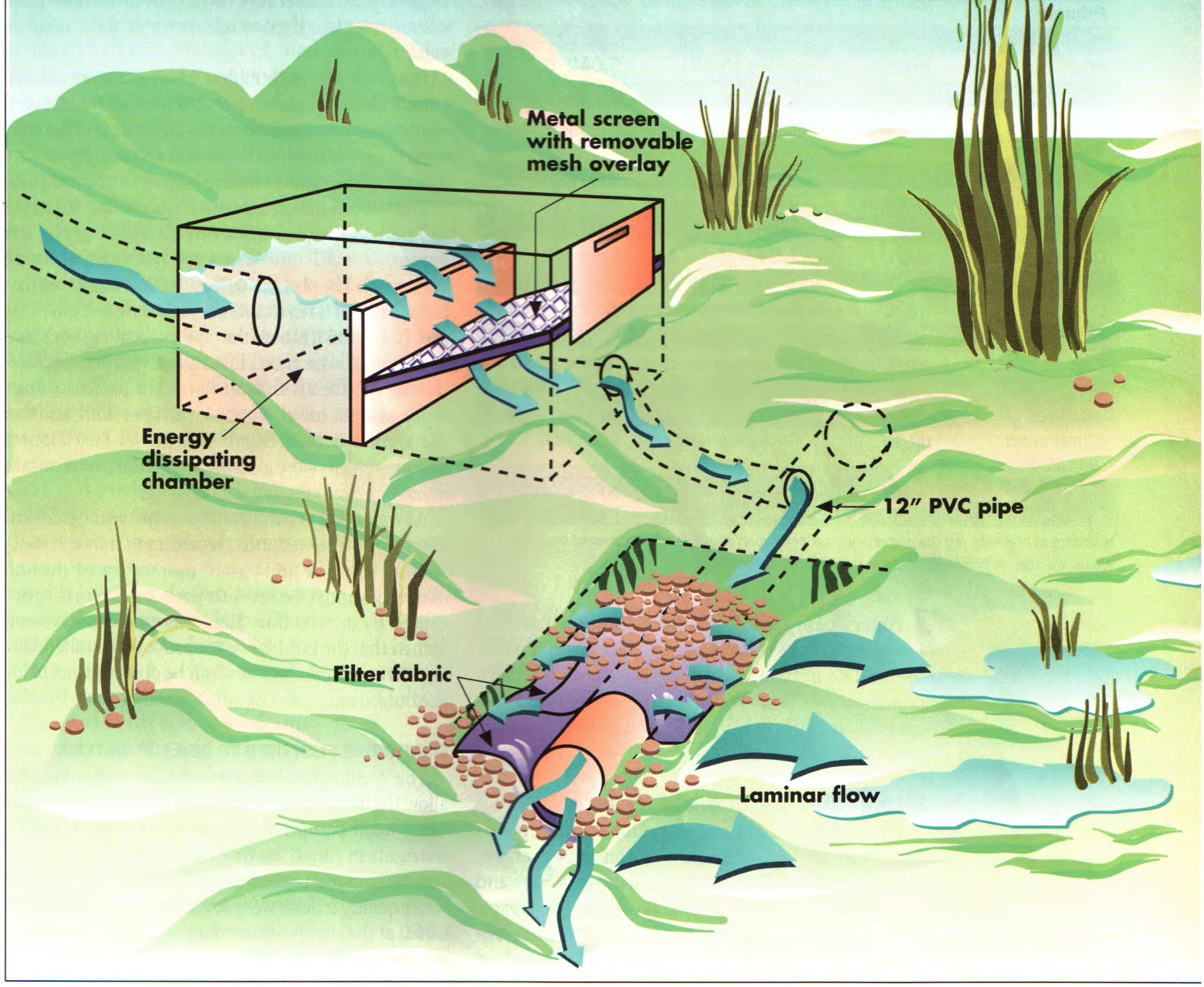
The Lacamas Lake watershed, which includes the adjoining Round Lake, is located just north of Camas, Wash., 19 km (12 mi) west of Vancouver, Wash. The availability of sanitary sewers for the Lacamas Shores development eliminated the potential for contamination of the lake by septic tank systems. However, there was still an increased volume of runoff and concomitant pollutant load from the development during storm events. Municipal storm sewers were not available to receive runoff from the development, so runoff would have to be discharged to the lake.

As part of the permitting process, a drainage plan was drafted to indicate how stormwater runoff would be collected and discharged from the site. The Washington Department of Ecology required that the quality and quantity of stormwater runoff from the development could not exceed predevelopment conditions. Therefore, runoff discharged to the lake had to be treated and detained in an on-site facility before discharge.

Runoff from the watershed provides the majority of water flowing into the lakes. Except for the shoreland area adjacent to the lakes (which accounts for 9.5% of the upland drainage), the primary input to the lakes is from Lacamas Creek and its tributaries. The lakes are popular recreational facilities for brown trout fishing, swimming, boating, and water skiing.

French Drain System for Wetland Stormwater Treatment

French drains, or "bubblers," are based on a level spreader design. As water flows to the bubblers, the trenches fill and overflow to the wetlands, resulting in a low-velocity, laminar flow of water.



EXISTING WATER QUALITY ISSUES

Because of the existing water quality in the Lacamas Lake watershed, there was some concern about the additional loading from stormwater runoff that the development would bring. An EPA Phase I diagnostic and restoration study showed that both Lacamas Lake and Round Lake suffer from severe overenrichment by nutrients, particularly from agricultural inputs and failing septic systems upstream of the lakes. Of these two sources, animal waste from the large number of dairy and animal-producing farms in the watershed is the primary contributor. Pollutants associated with septic failure have been increasing as residential development expands throughout the watershed.

Nearly 96% of the annual phosphorus loading to Lacamas Lake is from watershed sources, leaving a relatively minor contribution from precipitation, groundwater, or in-lake sources (for example, macrophytes and sediments). Lacamas Lake and Round Lake are classified as eutrophic to hypereutrophic based on this level of enrichment.

The resultant water quality problems in the lakes include severe dissolved oxygen depletion, poor water clarity, and extensive algal growth, particularly during the high-use summer recreational months.

At present, there are no limits for total phosphorus for the watershed area. The Clark County Water Quality Division has collected water quality data in the Lacamas Creek watershed in anticipation of such limits, but has not begun this type of analysis.

Compliance Criteria Determined from Site Monitoring

Parameter	Units	Compliance level[a]	
		Bubbler, wetland 1 (S4)	Bubbler, wetland 2 (S2)
Primary			
TP	mg/L	0.118 [0.223]	0.110 [0.251]
PO_4	mg/L	0.061 [0.131]	0.042 [0.090]
NO_3	mg/L	0.159 [0.565]	0.188 [0.607]
Secondary			
pH		6.3 [4.7–7.9]	6.1 [4.4–7.8]
Conductivity	µmho/cm	63 [97]	87 [135]
TSS	mg/L	19.4 [51.6]	25.8 [72.0]
Oil and grease	mg/L	1.5 [4.2]	1.8 [4.5]
Chromium	mg/L	Wash. wq stds.[b]	Wash. wq stds.
Copper	mg/L	Wash. wq stds.	Wash. wq stds.
Lead	mg/L	Wash. wq stds.	Wash. wq stds.
Zinc	mg/L	Wash. wq stds.	Wash. wq stds.
Organophosphate pesticides	µg/L	detection limit	detection limit
Chlorinated pesticides	µg/L	detection limit	detection limit
Chlorinated herbicides	µg/L	detection limit	detection limit

[a]Numbers in brackets are the compliance concentration plus twice the standard deviation.
[b]Wash. wq stds. = Washington state water quality standards.

Water quality data collected during the Lacamas Lake-Round Lake study suggested that phosphorus is the limiting nutrient controlling the amount of plant growth in the lakes. Thus, it was important that developers of the residential units control phosphorus loading in stormwater runoff.

FRENCH DRAINS DIRECT RUNOFF BELOW GRADE

The developers considered both detention ponds and grassy swales as treatment options; however, site constraints (including proximity to the lakeshore and existing forested wetlands) and the desire not to excavate adjacent to the lake eliminated the use of detention ponds. The use of a wetland biofilter resulted from an attempt to mimic the laminar flow of runoff that existed before development. In addition, the area above existing forested wetlands could be used to create additional wetlands to treat and detain the runoff. At the time of the design of the project, using wetlands for stormwater treatment was considered a beneficial use, on the same level as providing habitat, groundwater recharge, or recreation. In addition, wetlands were not considered waters of the state under the federal Clean Water Act and could therefore be used for stormwater discharges. However, the Washington Department of Ecology now requires that stormwater be pretreated before discharge to waters of the state, including wetlands.

The Lacamas Lake wetlands biofilter was designed to release the collected stormwater to the wetland area at noneroding velocities [< 0.304 m/s (1 ft/s)]. Peak flows for storm events were estimated for the development area using the HEC-1 model, developed by the U.S. Army Corps of Engineers. (HEC stands for Hydrologic Engineering Center.) The distribution pipe system was then sized to release water at the required velocities.

French drains, or "bubblers," were designed to direct runoff below grade and create a sheet flow several centimeters deep that enters the upgradient edge of the emergent wetlands. The wetlands then "treat" the inflowing stormwater before it enters Lacamas Lake.

The bubbler design consists of a section of 0.3-m (12-in.) pipe embedded in 0.05 m (2 in.) of gravel (see Figure, *French Drain System for Wetland Stormwater Treatment*). The pipe has 0.01-m (0.5-in.) holes that have been drilled at 0.1-m (0.5-ft) intervals at mid-depth of the pipe [0.1 m (0.5 ft) above the pipe invert along both sides of the pipe]. The gravel-filled trench perpendicular to the slope is lined with filter cloth. The perforated pipe is placed in the trench, covered with filter cloth, and then the trench is back-filled with gravel (see Figure). Sediment traps were installed upstream from the bubblers to prevent them from clogging.

As water flows to the bubblers, the trenches fill and overflow to the wetlands, resulting in a low-velocity, laminar flow. The finish grade over the top of the bubbler pipes must be level to prevent channelization caused by uneven flow. Field observations have confirmed that the bubblers were properly installed; during storm events, sheet flow can be observed just below the bubblers.

MONITORING PLAN USED TO DEVELOP CRITERIA

The Washington Department of Ecology would not allow the use of a wetland system for stormwater treatment until compliance levels were established for nutrients in runoff leaving the site. In the absence of any state or local watershed loading limits, self-imposed water quality criteria were developed based on data collected at the site. A 5-year monitoring plan was implemented by the developer with input from the state Department of Ecology and the city of Camas. Data sets from the first 2 years of monitoring were used to develop the criteria (see Table, *Compliance Criteria Determined from Site Monitoring*). A total of 11 complete sampling periods provided water quality data from the wetland's surface water and groundwater, Lacamas Lake, and control creeks (creeks not receiving runoff from the development). Additional information from water-table measurements, observations on vegetation health and composition, and determination of pesticide, herbicide, and heavy metal levels was gathered regularly during the same period.

The monitoring plan was designed to obtain baseline water quality data for surface water and groundwater entering and exiting the wetlands, determine the effectiveness of the wetland system as a biofilter for stormwater runoff, and establish criteria for implementing contingency plans if water quality data indicated unacceptable levels.

During monitoring, stormwater was collected and distributed to the wetland so that the parameters of concern could be monitored at specific points as the water flowed into and out of the wetlands. These points were sampled during storm events to provide representative measurements of water quality before and after application to the wetland.

Transects were established to monitor water quality through the wetlands. As water flows from the bubblers through the wetland, the distance downstream from the bubblers is directly related to the length of time that the water was retained in the wetland.

Sites were selected along the two transects for monitoring groundwater levels, surface water and groundwater quality, and vegetative cover and composition (see Map for reference points). Water quality sampling points included the sediment traps above the wetlands (B1, B2), surface water flow into and out of the wetlands (S2, S3, S4), shallow groundwater wells (G1 through G7, plus G11), and two lake sites (L1, L2) just outside the mixing zone of each input channel from the wetlands. Transect 1 included B1 through S4 and terminated at L2. Groundwater in transect 1 was collected in G4 through G7 and G11. Transect 2 ran from B2 to S2, terminated at L1, and included groundwater wells G1 through G3.

To provide background information on the quality and quantity of surface water runoff, three control creeks were also sampled. Creek 1 (C1, Dwyer Creek) empties into lower Lacamas Creek above the lake, north of the development. Two unnamed creeks on the lake's eastern shore (C2 and C3) were also sampled and represent contributions from smaller, relatively undeveloped watersheds.

Sample dates included a range of high and low flows, the "first flush" episode following the summer dry season, and an early-winter sampling after the fall first flush to detect the presence and extent of any decrease in water quality levels. During each of the sample periods, the wetland areas between the bubblers and the outflow streams (S2 and S4) were inspected for channelization.

Sampling of storm events consisted of routine field measurements for temperature, conductivity, pH, and groundwater depths. Analyses of nutrient concentrations [total phosphorus, soluble phosphorus, and nitrate-nitrite] and total suspended solids were also performed.

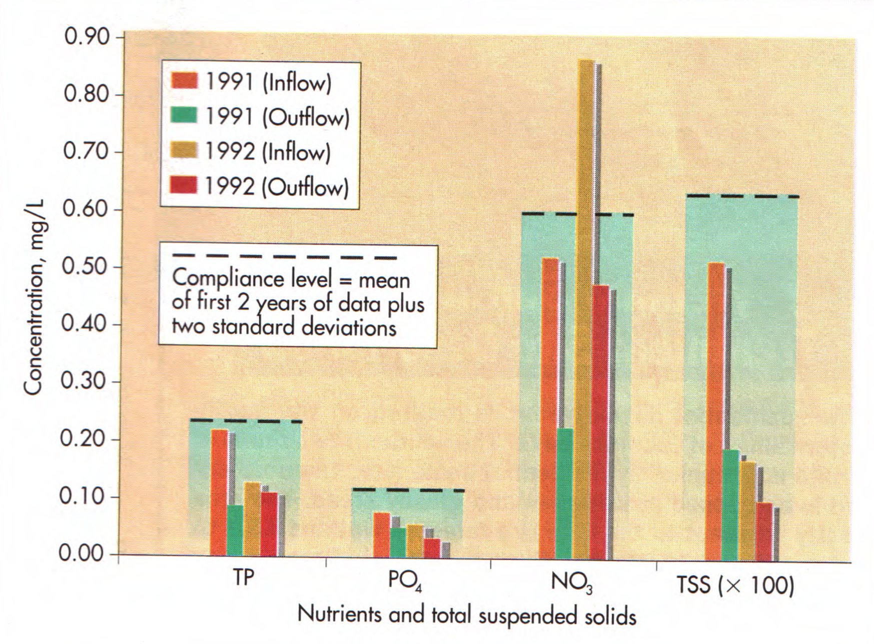
Additionally, samples from selected stations were analyzed during the first heavy rain of the fall, when accumulated sediment and contaminants are washed from roads and land surfaces. Levels of oil and grease, organophosphate pesticides, chlorinated herbicides, organochlorine pesticides, and dissolved metals (chromium, copper, lead, and zinc) were measured along with the other routine parameters.

A set of site-specific criteria derived from baseline water quality data was proposed to define acceptable wetland performance and vegetative change resulting from stormwater treatment. Water quality values more than two standard deviations from these baseline conditions were considered suspect and warranted further investigation into their origin and impact.

COMPLIANCE WITH SITE-SPECIFIC CRITERIA

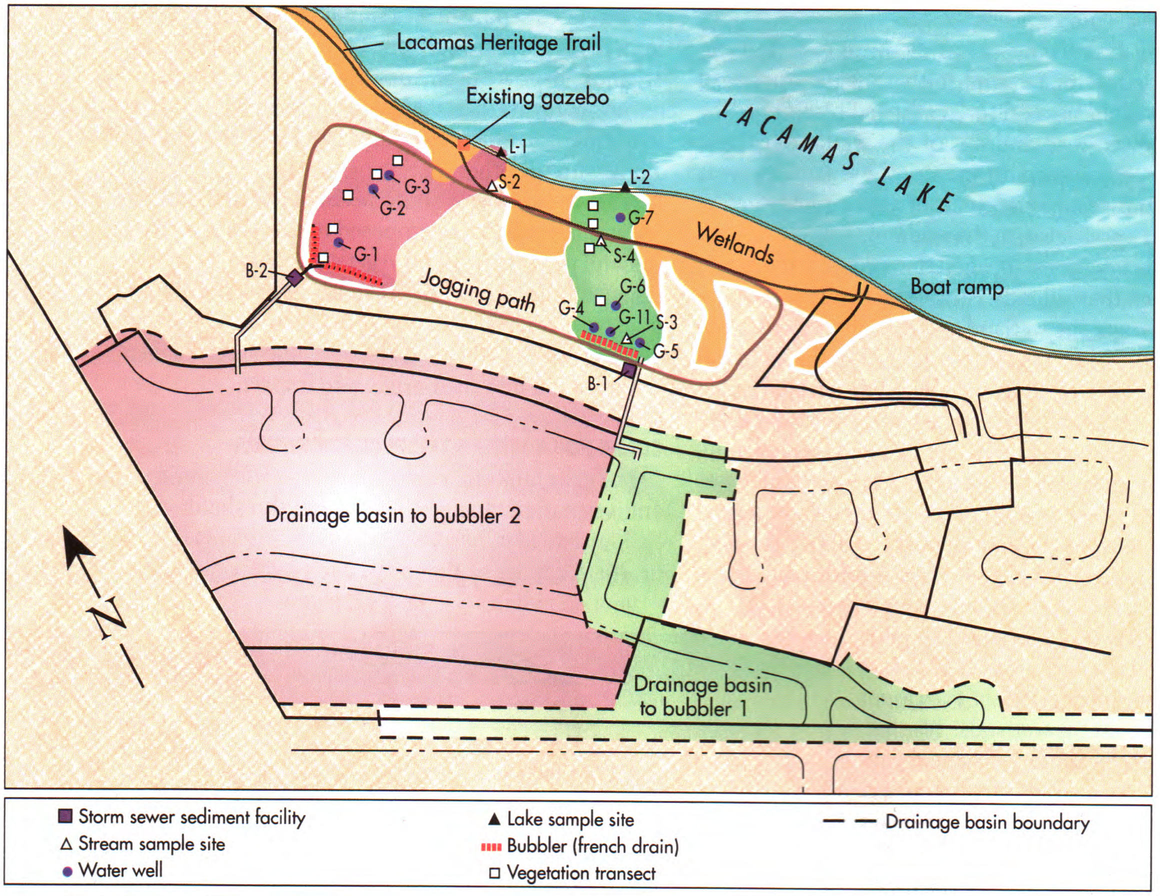
The most important criteria were related to nutrients and vegetation changes. Additional threshold criteria for pesticides, herbicides, metals, and biota (plant health and longevity) were used to evaluate the quality of the stormwater that passed through the wetlands before entering the lake during the subsequent 3 years of monitoring.

Concentrations in Inflow and Outflow of Lacamas Lake Wetlands



In the third and fourth years (1991 and 1992), a trend between the average annual inflow and outflow concentrations was apparent. Primary parameters (TP, PO_4, and NO_3/NO_2) and secondary TSS measured at outflows were less than inflow concentrations, indicating that the wetlands were removing nutrients and solids from stormwater runoff (see Figure, *Concentrations in Inflow and Outflow of Lacamas Lake Wetlands*).

Sampling Sites and Drainage Patterns for Lacamas Lake Stormwater Wetland Treatment



Wetland Stormwater Treatment Site Description

The residential development is located on the southwestern shore of Lacamas Lake. The southern two-thirds of the site is occupied by residential home lots. The northern third is composed of wetlands and grassy areas. The area directly adjacent to the lake is a forested wetland 15.2 to 30.4 m (50 to 100 ft) wide. From this forested area, areas of emergent wetlands extend southeast 121.6 to 182.4 m (400 to 600 ft).

The development site is steep. Surface elevation drops from 106.4 m (350 ft) at the south edge of the project to 57.8 m (190 ft) at the lakeshore. Before development, the area had five major surface-drainage features. As the site has been developed, stormwater runoff from paved surfaces and the flow in four streams has been collected by pipes and catch basins and discharged into the French drains ("bubblers") located along the upgradient edge of the wetlands. The four northern streams are spring-fed and usually flow during dry weather. The fifth stream adjacent to the road and the boat ramp is intermittent and flows only during periods of significant rainfall.

Total phosphorus in surface water flowing out of the wetlands (the limiting nutrient in the lake) was consistently below established compliance levels.

No herbicides or pesticides were detected in the first flush samples for 1991 and 1992. Dissolved metals (chromium and zinc) were detected in selected samples, but at levels equal to or less than EPA drinking water standards.

Compliance levels, excluding TP, were exceeded on two of the six monitoring dates during the third year of monitoring. The nitrate concentration at station S4 (below the bubbler in wetland 1) was slightly above the upper compliance level. The soluble phosphorus and nitrate criteria were also exceeded at S2 and S4, respectively. These two parameters were in compliance for the remainder of the monitoring season. Increased nitrate values during the winter warranted closer scrutiny during the fourth year of monitoring to see whether the trend continued.

During the fourth year, the compliance level for nitrate was exceeded on two of the four monitoring dates. As in the third monitoring year, the levels were exceeded in the winter sampling months, and nitrate values for the two transects were in compliance for the remainder of the monitoring season.

Phosphorus Loading Rates and Annual Phosphorus Load

Station	Drainage basin areas, ha[a]	1990 Loading rate, kg[b]/ha•yr	1990 Phosphorus load, kg	1991 Loading rate, kg/ha•yr	1991 Phosphorus load, kg	1992 Loading rate, kg/ha•yr	1992 Phosphorus load, kg
Bubbler, wetland 1 (S4)	4.1	0.702	2.9	0.724	3.0	0.690	2.8
Bubbler, wetland 2 (S2)	8.8	0.872	7.7	0.543	4.5	0.716	6.3
Dwyer Creek (C1)	324	1.002	325	1.373	445	1.359	440
Unnamed Creek (C2)	46.5	1.099	51	0.868	40	0.914	43
Unnamed Creek (C3)	66.8	1.292	86	1.131	76	1.222	82

[a]hectares x 2.471 = acres.

[b]kilograms x 2.205 = pounds.

ESTIMATING PHOSPHORUS LOADING

The impact on lake water quality from stormwater passing through the wetlands is only partially determined by comparing the compliance parameters of interest to the site-specific criteria. Determining the nutrient load contributed by various input streams can define the actual quantity of nutrients going to Lacamas Lake. Using TP as an indicator of nutrient loading, calculations of the annual phosphorus contributions per unit area for the second, third, and fourth monitoring years were made for the development and compared with inputs calculated from three control creeks (see Table, *Phosphorus Loading Rates and Annual Phosphorus Load*). In all cases, nutrient loading from the development is lower than from the three control creeks for these 3 years.

It is not possible to compare the actual phosphorus loading rates that were estimated for the development with established limits for the Lacamas Creek watershed because no regulatory framework for phosphorus loading limits exists. Moreover, there were no reports of other developments, residences, or businesses in the watershed currently monitoring loading to the lake. Data from the water quality sampling data collected will hopefully allow the county to begin developing loading limits for the Lacamas Lake watershed.

EVALUATING PERFORMANCE

One of the original concerns of using the wetlands for stormwater treatment was the ability of the system to reduce phosphorus loading to Lacamas Lake. All evidence to date indicates that the bubbler systems are reducing concentrations of phosphorus from the development to levels below site-specific criteria. An unanticipated consequence of sending stormwater to the treatment wetland has been the increased input of nitrate, with the site-specific criteria often exceeded during the winter months. However, the increased nitrate input is not in violation of state or local water quality standards and is occurring at a time when the lake is well flushed and there is reduced algal and plant growth. A diagnostic and restoration study also indicated that the lake was a phosphorus-limited system during the winter, so that added nitrate would not adversely affect the trophic level of the lake. In the absence of watershed loading limits for either nitrate or phosphorus, it is not possible to determine whether the winter nitrate contribution from the development is significant to the lake nutrient budget as a whole.

Future compliance with water quality criteria may entail alterations of the wetlands to optimize treatment. These alterations would increase the area of wetlands or increase the detention time of stormwater within the wetlands. Another approach to ensuring future compliance would be to limit the sources of nutrients flowing into the wetlands. A source control program including proper lawn and garden practices would provide opportunities for reducing the amount of nutrients in stormwater runoff and would be a vital component in the success and longevity of the wetland treatment system. ■

Courtesy of Scientific Resources, Inc.

Lacamas Lake's stormwater wetland treatment system has reduced nutrient and sediment loading to the lake.

Mark F. Bautista *is an aquatic ecologist and* ***N. Stan Geiger*** *is a senior ecologist and president of Scientific Resources, Inc., in Lake Oswego, Oreg.*

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Thank you for submitting your work to the magazine. Your contribution to the Water Environment Federation is greatly appreciated.

Sincerely,

Deborah K. Farmer

Deborah K. Farmer
Features Editor

601 Wythe Street • Alexandria, VA 22314-1994 • (703)684-2400 • FAX (703)684-2492