Effects of Detergent Use on Water Quality in Kathmandu, Nepal

by

Amanda Richards

BS Chemical Engineering
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Submitted to the Department of Civil and Environmental Engineering in Partial
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ABSTRACT

The Guheshwori wastewater treatment plant in Kathmandu, Nepal, experiences foaming problems. Engineers from the facility attribute the foaming to synthetic detergent use, suspecting that the anionic surfactants used in local laundry detergents exhibit poor biodegradation properties. In particular, the use of the highly branched form of alkylbenzene sulfonate (ABS) is assumed.

Eighteen synthetic laundry detergents were collected from around Kathmandu, representing 10 companies and 3 countries of origin. The detergent analysis followed the methylene blue active substance (MBAS) procedure. The representative total anionic surfactant concentration is estimated to be 6.6 weight percent. After two weeks of degradation, the average remaining surfactant concentration is 0.5 weight percent. The author suggests that this level is enough to play some, but not a significant role in the foaming at the Guheshwori WWTP. Potential major contributors to foaming at the Guheshwori facility are industrial detergents, especially those used by the textile and carpet industry and filamentous bacteria.

The detergent samples were also examined for orthophosphates, with a representative concentration of 402 mg/kg detergent. This value was compared to monitoring data from the Bagmati River, as part of the South Asia Trans-boundary Water Quality Monitoring Program (SATWQM). The author concludes from the data that phosphates from synthetic detergents do not significantly contribute to eutrophication of the Bagmati River.

Thesis Supervisor: Susan Murcott
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Acknowledgements

First and foremost, thanks to Will for his incredible patience, support and love. You are my everything, and I am tingly with anticipation when I think of the wonders the next few weeks hold in store for us. Thanks also to my family and soon-to-be family, whose endless encouragement and prayers have been and continue to be immeasurably valuable. Thanks to Susan for her tireless leadership, advice and guidance. Thanks to the entire Nepal-03 Team, and especially the Wastewater Group for the camaraderie and great memories. Thanks finally to the staff at ENPHO for making us feel so welcome and comfortable during our visit to Nepal.

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1. Introduction

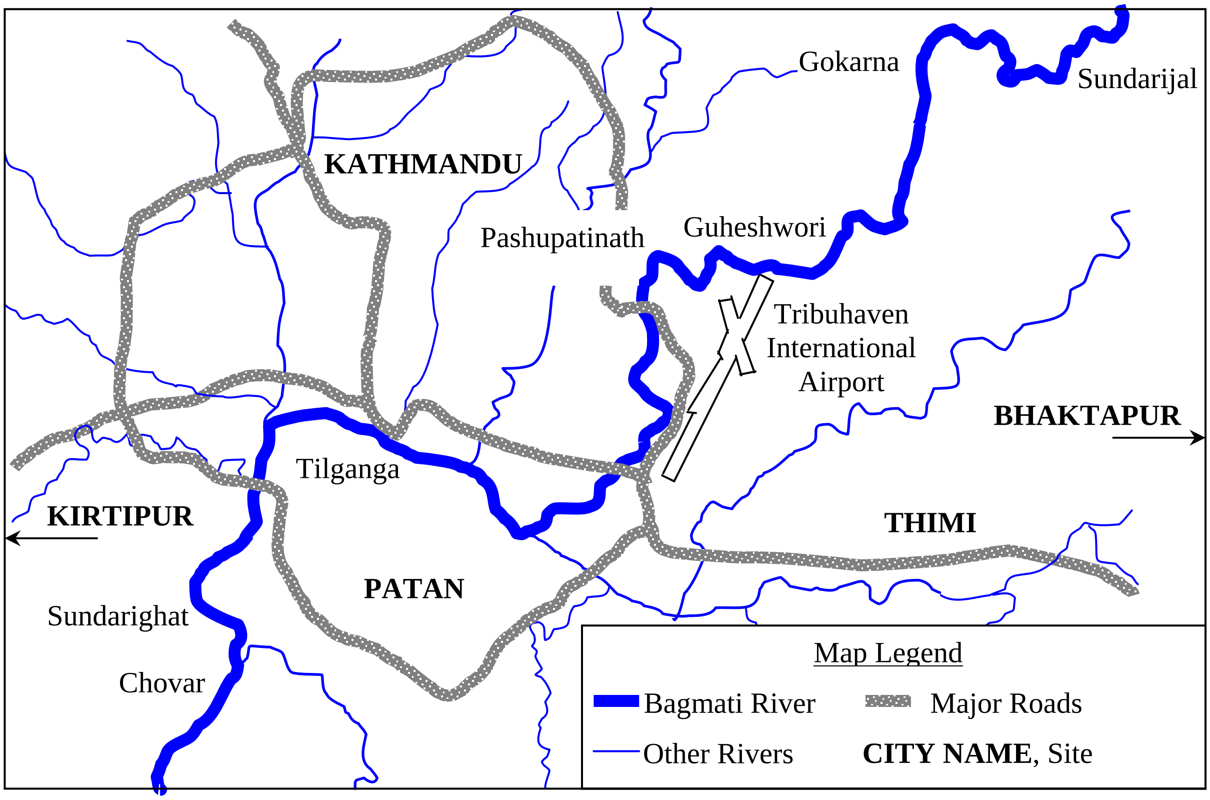
1.1 Description of Bagmati River

The Bagmati River is one of Nepal's most important and culturally significant bodies of water. Not only is it the largest river in Kathmandu Valley, it holds special religious value for both Hindus and Buddhists. Flowing from its sources in the foothills northeast of Kathmandu through the Terai and into India, the banks of the Bagmati River accommodate several notable centers of worship. Upstream of Kathmandu Valley, the pristine river tumbles over the boulders at Sundarijal, the site of a 13th century cave shrine to Mahadevi (Great Goddess).

A few miles downstream the Bagmati River runs through the Gokarna Mahadev (Great God) Temple Complex. The Hindu god Shiva's secret goddess, Shatidevi, and other female deities are worshipped at the Guheshwori Temple, and just downstream Shiva himself is worshipped at Pashupatinath. The dead are cremated daily on the riverbanks at Pashupatinath, one of the most holy religious centers for all Hindus.

As the Bagmati River enters the city of Patan (Lalitpur) just south of Kathmandu, it flows past numerous Buddhist temples, monasteries and stupas. Where the river finally leaves Kathmandu Valley at the Chovar Gorge, it passes the Jal Binayak Temple dedicated to the Hindu elephant god, Ganesh. Figure 1.1 displays the path of the Bagmati River as it flows through Kathmandu Valley, highlighting many of the locations mentioned above.

Figure 1.1: Map of Bagmati River flowing through Kathmandu Valley[1]



Kathmandu Valley is comprised of five cities: Nepal's capital city, Kathmandu, Patan, Bhaktapur, Kirtipur and Thimi. These cities appear above in Figure 1.1. As of February 2000, the Valley claimed about 1.3 million residents, with a projected population growth of 4 to 5 percent yearly (Metcalf & Eddy , 2000). The City of Kathmandu contains approximately 500,000 of these residents and covers more than 31.5 mi^2 (50.7 km^2) (Finlay, 2001). The growth of both Kathmandu Valley and Kathmandu City are attributed to high birth rates, but also to a heavy influx of families from outlying and rural areas.

Approximately 90% of Nepal's population lives in rural areas, existing as subsistence farmers with little or no participation in the cash economy (Finlay, 2001). As of 2000, Nepal's per capita GDP is only $240 US. Figure 1.2 shows the major contributors to Nepal's gross domestic product (GDP)[2].

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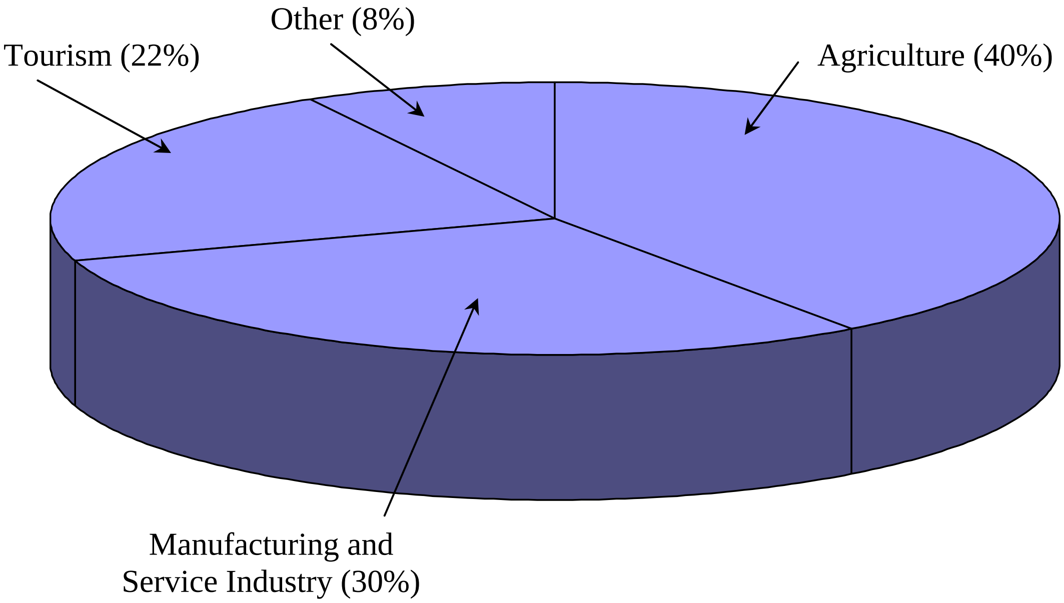
[1] Figure 1.1 is a reproduction of Figure IV-2, from Metcalf & Eddy, 2000

[2] Data used in Figure 1.2 comes from Finlay, 2001.

Figure 1.2: Nepali GDP Contributors[2]



Industrial development in Nepal is still in an early stage. As shown in Figure 1.2, the first major industry of Nepal is tourism, accounting for approximately 22% of the kingdom's GDP. The second major industry of Nepal is the carpet business. The success of carpet manufacturers has waned in recent years, however, largely due economic hardship, especially a decline in tourism. Other factors include negative publicity connecting the industry with child labor practices and the use of dangerous synthetic dyes (Finlay, 2001). MIT Nepal Project team member, Hillary Green, examined Nepal's carpet industry and its effects on water quality in her thesis "The Effects of Carpet Dye on the Bagmati River" (2003). Other industries worthy of mention include garments and textiles, leather products, paper and cement. Some production takes place in large, modern factories, but most businesses are small-scale, often run out of cottages or open areas protected by makeshift, sheet metal fences.

As Kathmandu Valley continues to develop industrially and as the city grows in population and expands into outlying areas, the Bagmati River and other urban surface waters are becoming more and more polluted. Quality of life in Kathmandu has not advanced proportionately with industrial development. One reason among others is that Kathmandu lacks adequate solid waste and wastewater collection and treatment systems. The February 2000 ADB Report of Urban Water Supply Reforms in the Kathmandu Valley maintains that the current wastewater collection system covers only 35 percent of households in the Valley (Metcalf & Eddy, 2000).

Kathmandu also does not have proper drinking water treatment and supply systems. Tap water and public water sources are generally contaminated but still essential. "Some households receive water for only 1-2 hours per day in the dry season – and some receive none at all" (Metcalf & Eddy, 2000). Shortages during the dry season, leaks in distribution pipelines and illegal taps into water mains are some of the principal causes leading to a continual deficiency.

Those without other resources rely on local surface water, namely the Bagmati River, for bathing, washing clothes and food, and even for drinking and as a public toilet. Furthermore, the River has become a sewage discharge site for municipal wastewater and an industrial dumping grounds for local businesses with no other means of disposal.

1.2 *Overall Wastewater Treatment Situation in Kathmandu*

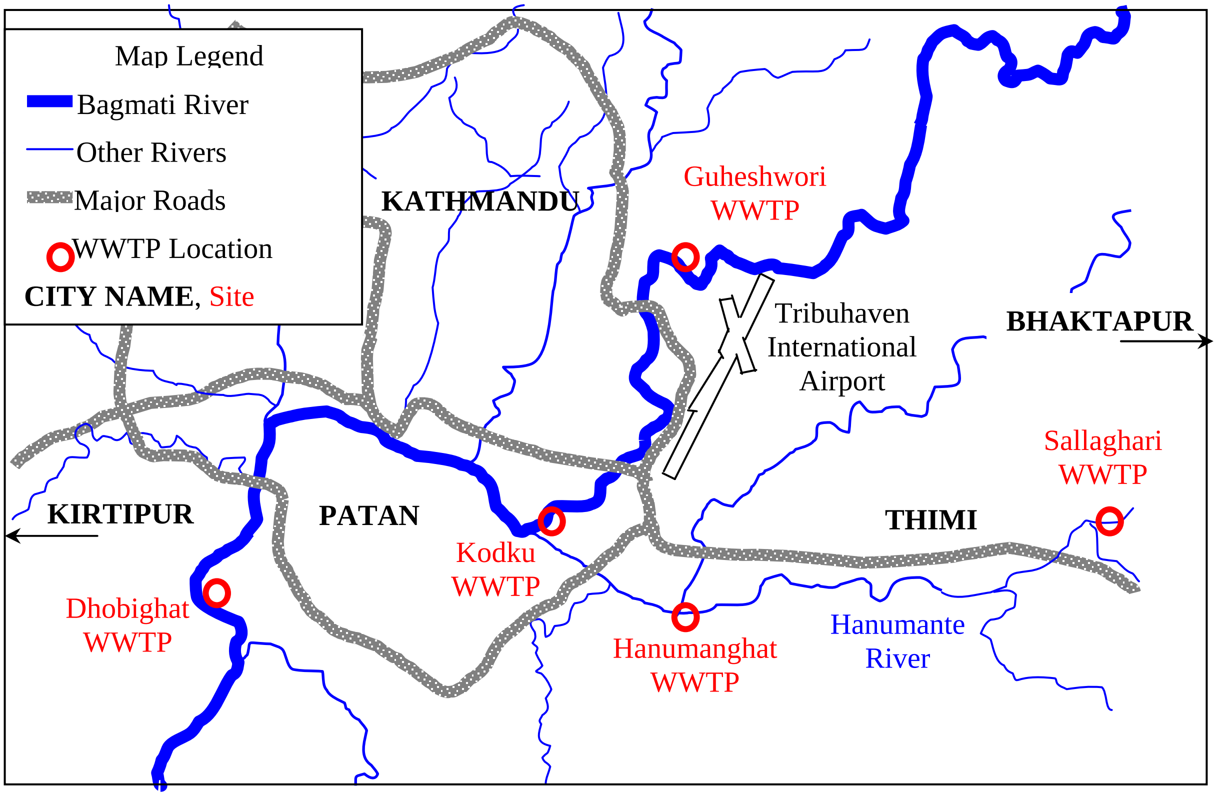
Kathmandu Valley currently has five municipal wastewater treatment facilities: an activated sludge plant at Guheshwori, non-aerated lagoons at Kodku and Dhobighat, and aerated lagoons at Sallaghari and Hanumanghat. Of the five, the only wastewater treatment plant in operation as of January 2003 is the activated sludge system at Guheshwori (discussed in detail below in Section 1.3).

The wastewater treatment plants at Kodku and Dhobighat were constructed under the World Bank-funded "Water Supply and Sewage Project" in 1978. This project marked the introduction of a modern sewage collection and treatment system in Kathmandu (Darnal, 2002).

Kodku lies along the Bagmati River in the city of Patan (Figure 1.3). The Kodku plant is a non-aerated lagoon facility with a design capacity of 1.1 MLD (Metcalf & Eddy, 2000). The 2000 ADB Report lists the plant's status as "partially operational." In his report "Wastewater in the Greater Kathmandu," MIT Nepal Project member Tetsuji Arata confirms the operational status of the Kodku WWTP in January 2003, observing that effluent discharged into the Bagmati River "was bubbling" and smelled "just like that of sewer water" (Arata, 2003).

The Dhobighat facility is positioned downstream from Kodku, in the southwest area of Kathmandu Valley (Figure 1.3). As such, the wastewater treatment plant at Dhobighat is the furthest downstream of the five treatment facilities in Greater Kathmandu. Designed in 1978, the plant was built with a capacity of 15.4 MLD (Metcalf & Eddy , 2000). Today, estimated sewage flow for the area exceeds 120 MLD (Darnal, 2002). In this plant, gravity-driven sewage flows to a sump well in Sundarighat, where it is pumped to the plant at Dhobighat, consisting two non-aerated lagoons and one facultative pond. The pump station at Sundarighat, the pump main and the interceptors along the Bagmati and Bishnumati Rivers are all broken in places, so untreated wastewater drains directly into the Rivers (Darnal, 2002). As of January 2003, this plant was used as a pasture for cattle (Arata, 2003).

Figure 1.3: Map of Wastewater Treatment Plants in Kathmandu Valley[3]



Sallaghari and Hanumanghat both lie along the Hanumante River in Bhaktapur, upstream from its junction with the Bagmati River near Kodku (Figure 1.3). These treatment facilities were designed as aerated lagoons, with capacities of 2.0 and 0.5 MLD, respectively (Metcalf &

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[3] Figure 1.3 is a reproduction of Figure IV-2 from Metcalf & Eddy, 2000.

Eddy, 2000). The 2000 ADB Report describes both plants as partially operating and in need of rehabilitation.

Tetsuji Arata observes in January 2003 that the aeration systems from both facilities were removed and sold. He describes that the Sallaghari plant originally had two collection mains: a northern main with a pump feed, and a southern one using gravity feed. Since the shutdown of the plant, local farmers have removed the pump from the northern main and plugged the southern main so that inflowing, untreated wastewater could be used for irrigation purposes. Also, the Hanumanghat site is now used as a crop field (Arata, 2003).

Figure 1.4 summarizes the reported capacities and present operating status of the wastewater treatment facilities discussed above. A small discrepancy exists between the capacity of the Guheshwori WWTP reported in Metcalf & Eddy, 2000 (shown in Figure 1.4 as 4.6 MGD) and that reported in the BASP Introduction Pamphlet, 2002 (listed in Figure 1.6 as 4.3 MGD). The author of this thesis uses 4.3 MGD as the capacity of the Guheshwori treatment facility.

Figure 1.4: Operating Capacity and Status of WWTP in Kathmandu Valley[4]

Plant	Reported Capacity MLD	Status ADB Report, Feb 2000	MIT Nepal Team, Jan 2003
Guheshwori	17.3 (4.6 MGD)	Under Construction	Operating
Hanumanghat	0.5 (0.13 MGD)	Partially Operating	Not Operating
Sallaghari	2.0 (0.53 MGD)	Partially Operating	Not Operating
Kodku	1.1 (0.29 MGD)	Partially Operating	Partially Operating
Dhobighat	15.4 (4.1 MGD)	Not Operating	Not Operating

In addition to the collection systems noted above, Kathmandu Valley contains 43,000 septic tanks. Eight collection vehicles with a capacity of 1.5 m^3/vehicle service the tanks, and the septage is treated using low-energy treatment systems. Upwards of 35 truckloads of sewage a day should be collected, but “septic tank cleaning is generally performed too infrequently” (Metcalf & Eddy , 2000).

One such low-energy treatment method gaining popularity in Kathmandu and elsewhere is the constructed wetland system. Constructed wetlands treatment systems are designed to mimic and optimize the natural removal processes of wetlands. In such systems, suspended solids are filtered as the wastewater flows through the wetland soil. Also, bacteria, fungi and other organisms indigenous to wetlands decompose biodegradable compounds in the wastewater.

Aquatic plants take an active role in wastewater treatment, acting as a source of oxygen and a sink for nitrogen, phosphorus and other nutrients.

These systems are gaining popularity throughout Nepal and other developing nations because of their low cost and maintenance requirements. MIT Nepal Project team member, Saik-Choon Poh, explores constructed wetlands in his thesis "Assessment of Constructed Wetland Systems in Nepal" (2003) and their applicability in developing countries like Nepal.

1.3 *Guheshwori Wastewater Treatment Plant*

In 1995 the Nepali government developed a Master Plan with the goal of monitoring and rehabilitating the Bagmati River and established a "High Powered Committee for Implementation and Monitoring of the Bagmati Area Sewerage Construction and Rehabilitation Project (BASP)". The Committee designated the section of the Bagmati between Gokarna and Tilganga as its highest priority, as this is an area of both heavy human use and of great religious importance. In particular, the temple areas of Pashupatinath and Guheshwori fall within this section. Figure 1.1 illustrates a layout of the area between Gokarna and Tilganga. To address the area's pollution problem, the Committee installed interceptor drains to reduce the flow of raw sewage into the Bagmati River. These sewers run from Gokarna and Mitrapark and connect to a municipal wastewater treatment plant near the Guheshwori Temple.

In operation since January 2001, the wastewater treatment plant at Guheshwori is the first municipal treatment plant of its size in Nepal. Up to 0.19 m^3/s (4.3 MGD) wastewater is treated here using an activated sludge process, but the design lacks a primary sedimentation tank. The plant's project manager, Ram Deep Shah, explains that primary sedimentation was neglected by the Committee to avoid having to invest in costly anaerobic sludge digesters (Shah, 2003). Figure 1.5 provides a layout of the unit processes involved in treatment at the Guheshwori WWTP.

When the wastewater first enters the treatment plant, a mechanical bar rack removes large particles from the influent. The facility has a manual back-up rack should the mechanical one fail. The removed particles are dumped onto the ground, and the wastewater continues to the grit chamber.

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[4] Data for Figure 1.4 from Metcalf & Eddy, 2000 and Arata, 2003.

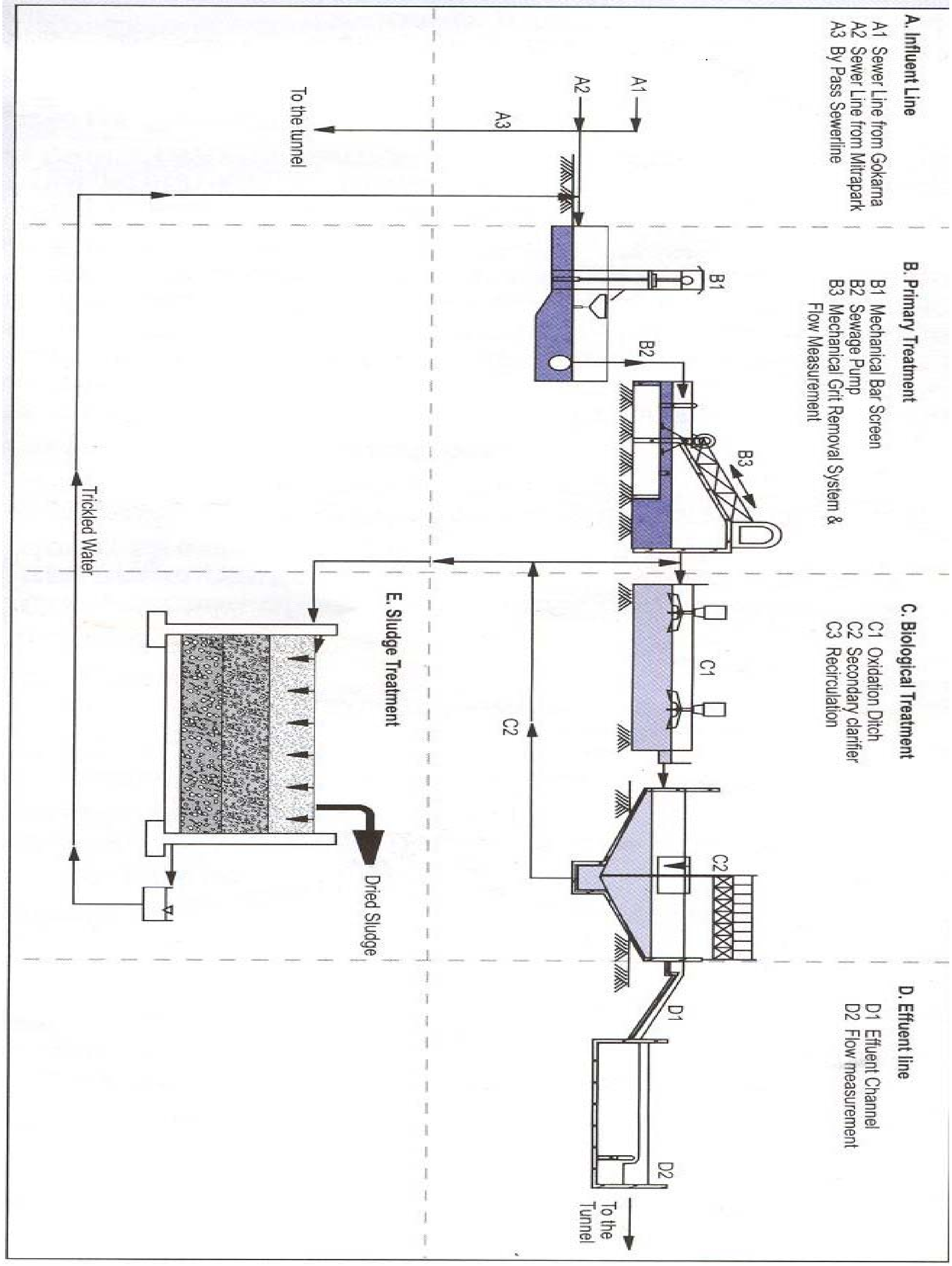
In the grit chamber, smaller particles such as sand settle to the bottom of the tank. The settled matter is mechanically scraped from the bottom of the tank and dumped on the ground adjacent to the tank.

The wastewater is next biologically treated. The plant at Guheshwori has two carrousel-type oxidation ditches each with three aerators. With a capacity of 10,400 m^3 water, the total oxygen demand is 355 kg/hr. 60 HP are required to drive the aerators.

Wastewater flows from the biological unit to two secondary sedimentation clarifiers. Up to 2,500 MLSS sludge is pumped from the clarifiers back to the oxidation ditches to be metabolized by microorganisms, and any excess sludge is diverted to one of fourteen drying beds. According to plant personnel, sludge production has not exceeded 2,500 MLSS since the plant has been in operation, so the drying beds have seen no use. It is improbable that all of the sludge is utilized in the oxidation ditches, so the solids are likely either building up in the oxidation ditches or leaving the treatment facility with the effluent.

The municipal wastewater treatment plant has a design capacity of 0.19 m^3/s (4.3 MGD), but the actual flow of sewage often exceeds this rate during the monsoon season. Sewage and stormwater collection systems are not separated, so the wastewater flow attains a maximum of 0.5 m^3/s (11.3 MGD) during Nepal's wet season. Untreated water in excess of 0.19 m^3/s (4.3 MGD) bypasses around the wastewater treatment plant and mixed with the treated effluent. The treated and untreated water is pumped underground through a tunnel from the treatment facility and joins the Bagmati River at a location 572 m downstream from the plant. This is done reduce the pollution to the most holy areas of the Bagmati River, those adjacent to the Guheshwori and Pashupatinath temples.

Figure 1.5: Flowchart of Guheshwori Wastewater Treatment Process[5]



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[5] Figure 1.5 reproduced from BASP Introduction Pamphlet, 2002.

Figure 1.6: Design and Performance Parameters for Guheshwori WWTP[6]

Guheshwori WWTP Design Parameters	
Service Area	5.37 km^2 (3.28 mi^2)
Service Population (1996)	58,000
Projected Population (2021)	198,000
Wastewater Produced	80 L/cap-d
WWTP Footprint	51 m^2 (164 ft^2)
Energy Consumption	2.3 KW-hr/kg BOD
Annual Operating Costs	$167,000 US
Design Flow	0.19 m^3/s (4.3 MGD)
MLSS	3,500 mg/L
F/M	0.34

Guheshwori WWTP Performance			
Parameter	*Influent*	*Effluent*	*Removal*
BOD_5	270 mg/L	25 mg/L	91%
COD	1150 mg/L	250 mg/L	78%
TSS	216 mg/L	100 mg/L	54%
TKN	48 mg/L	30 mg/L	38%
NH_4-N	41.7 mg/L	22.1 mg/L	47%
P	6.71 mg/L	3.2 mg/L	52%

It is a hotly debated question among wastewater professionals whether conventional activated sludge wastewater treatment plants are appropriate treatment technologies suitable for developing countries like Nepal (Harleman, 2001). Operation and maintenance of the facility at Guheshwori costs an estimated 12.5 million NRs/year ($167,000 US/year) (BASP Introduction Pamphlet, 2002). With costs like this, it is unclear how much longer the plant will be in operation (Shrestha, 2003). The major reason that operation costs of the Guheshwori WWTP are so high is because electricity is very expensive in Nepal. Electricity costs 7 NRs ($0.01 US) per unit (kW-hr) in Nepal, averaging 1,000 NRs ($13 US) per month for residents whose monthly income is only 5,000 NRs ($67 US) (Phuyal, 2002). Nepal has few exploitable fossil fuel sources, so electricity production efforts have been primarily focused on hydroelectric plants. Even this source, however, is largely untapped.

In addition to financial concerns, a few serious technical issues arise in the Guheshwori treatment plant. Touring the wastewater treatment plant, an observer notices a thin film of feathers floating atop the water in the oxidation ditches. The feathers from slaughtered chickens and other birds are washed into the Bagmati River and into sewer drains, and the feathers are carried all the way to the treatment plant. The presence of feathers in treated effluent is dangerous, because they can harbor harmful microorganisms in otherwise clean water. The two major removal processes employed at the Guheshwori plant are ineffective against feathers. The feather structure prevents it from sinking like grit, and microorganisms are not effective in breaking feathers down. Because the facility has no mechanism for their removal, feathers are presently manually skimmed from the oxidation ditches.

A second technical issue, and the one on which this thesis focuses, is the problem of foaming. On cold nights and mornings, especially during the winter season, the 3.5 m (10.9 ft) deep oxidation tanks have up to 1 m (3.3 ft) of foam on the water surface. This is a problem, because wastewater foaming prevents oxygen transfer. Also, foam can be blown around by wind, creating dangerous and slippery working conditions for plant workers as well as an airborne source of recontamination downstream. As with the feathers, operators and technicians make-do with manual and temporary solutions to the problem. Every morning they spray water from hoses at the foam to dissipate it. Ram Deep Shah attributes this foaming to the use of synthetic detergents, both on a household level and by industries, namely carpet and textile manufacture (Shah, 2003). Because industrial wastewater pretreatment and treatment are rare in Kathmandu, the carpet and garment industries, including wool dyeing and washing, contribute high levels of detergents and fine textile fibers to receiving waters, which aid in foaming (Shah, 2002).

1.4 *Thesis Objective*

This thesis considers two types of water pollution possibly arising from the use of synthetic laundry detergents in Kathmandu, Nepal. The author first seeks to confirm or refute a connection between foaming problems in the Guheshwori Wastewater Treatment Plant and the anionic surfactants present in synthetic laundry detergents locally sold in Kathmandu. In particular, the author analyzes these laundry detergents for the branched and linear forms of the surfactant alkylbenzene sulfonate (ABS and LAS, respectively) and estimates the load of each to the Guheshwori WWTP and to the Bagmati River.

The author further examines controversy surrounding synthetic laundry detergents by comparing phosphate concentrations in these detergents to those in the Bagmati River and by evaluating the contribution of laundry washing to nutrient loading and eutrophication of the River.

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[6] Figure 1.6 is a compilation of data from BASP, 2002; Shah, 2002 and Darnal, 2002.

2. South Asia Trans-Boundary Water Quality Monitoring Program

2.1 *Program Overview*

Water quality management and water pollution abatement are significant and complex issues. These concerns become even more complicated when one considers that many of a nation's rivers and streams are not fully contained by that single nation, but are trans-boundary waters. A particular country must contend not only with pollution originating within its boundaries, but it must also anticipate the flux of pollution to and from neighboring nations through air and water flow.

With these concerns in mind, researchers and organizations from four South Asian nations joined Sandia National Laboratories' Cooperative Monitoring Center in establishing an experimental trans-boundary monitoring program. Since February of 2002, Bangladesh, India, Nepal and Pakistan have been monitoring rivers that act as major tributaries to the Indus and Ganges Rivers. Specifically, the South Asia Trans-Boundary Water Quality Monitoring Program (SATWQM) has focused on the Bagmati and Narayani Rivers flowing between Nepal and India and the Ganges River flowing between Bangladesh and India, and the Ravi River flowing between Pakistan and India (Sandia National Laboratories, undated).

The non-government organization ENPHO (Environment and Public Health Organization) is responsible for data collection in Nepal. ENPHO engineers and staff monitor the Narayani River monthly at seven locations and the Bagmati River monthly at six locations. The monitoring sites for the Bagmati River are at Sundarijal, Pashupati, Tilganga, Sundarighat, Chovar and Gaur, shown in Figure 2.1.

The first Bagmati River sampling location is at Sundarijal, an area upstream of Kathmandu Valley with low levels of anthropogenic pollution. The Pashupatinath Temple described in Chapter 1 is in a section of Kathmandu called Pashupati, the second sampling site. This location along the Bagmati River is heavily used by Hindus, but is also a priority site for restoration by the Nepali government. Tilganga lies in the heart of Kathmandu and suffers much human pollution; it is also the site where the effluent from the Guheshwori WWTP mixes with the River. Sundarighat, the fourth sampling location, is in the southwest part of the Greater Kathmandu Urban Area, Chovar at the outlet from Kathmandu Valley, and Gaur in the Terai near the Indian border. Figure 2.2 displays the water quality parameters exceeding WHO (World

Health Organization) guidelines for these sites and lists the suggested uses of the Bagmati River from each location.

Figure 2.1: SATWQM Sampling Locations along the Bagmati River[7]

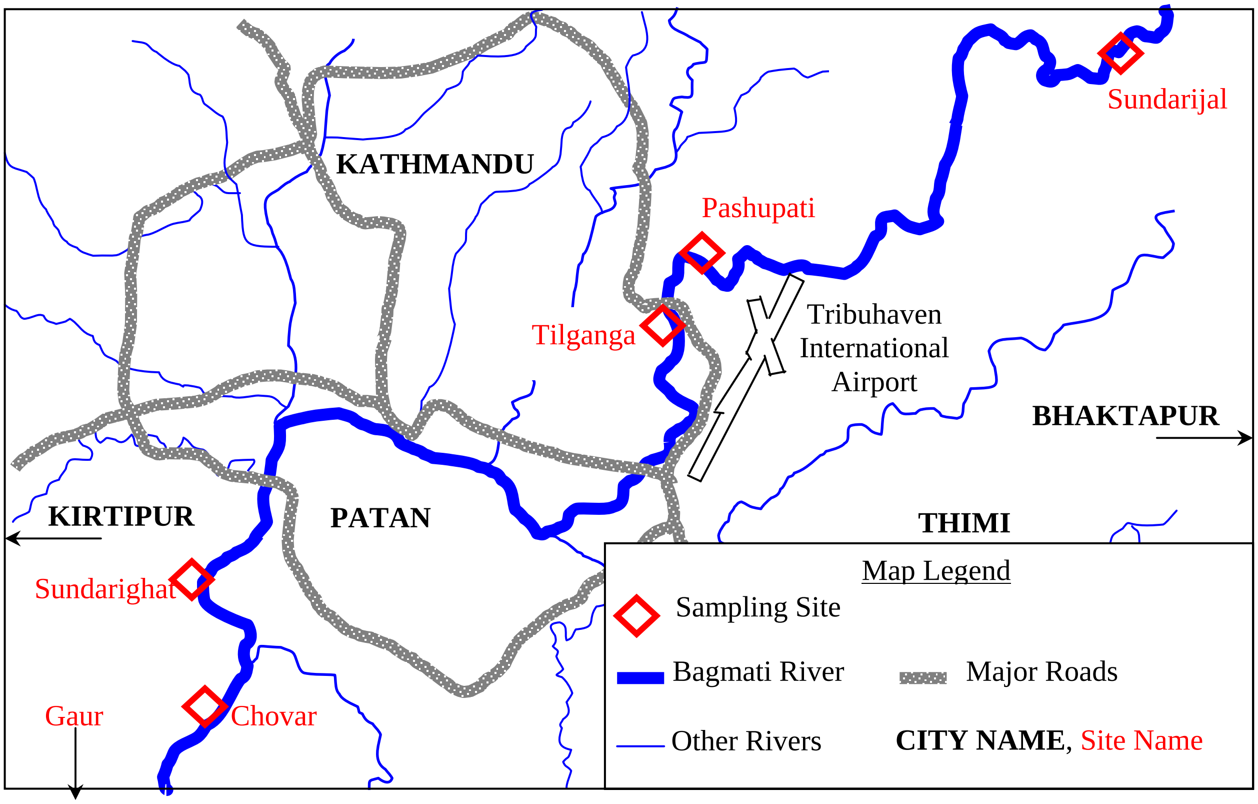

Figure 2.2: General Water Quality and Usage Zones along the Bagmati River[8]

Sampling Site	Parameters exceeding WHO Standards	Potential Use Based on Pollution Level
Sundarijal	None	drinking water supply
Pashupati	COD, PO_4	recreation, fish breeding
Tilganga	COD, NH_3, PO_4 and conductivity	industrial use, irrigation
Sundarighat	COD, BOD, NH_3, PO_4, NO_3, Cl and conductivity	industrial use, irrigation
Chovar	COD, BOD, NH_3	no assigned use

The data presented in Section 2.2 of this thesis was collected as part of SATWQM. The data is intended as public information and will be made available on the Sandia National Laboratories web site, http://sandia.gov[9].

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[7] Figure 2.1 is a reproduction of Figure IV-2 from Metcalf & Eddy, 2000.

[8] Data for Figure 2.2 compiled using Shakya, 2001 and Upadhyay, 1999.

2.2 *Monitoring Equipment*

In the analysis of the SATWQM samples, ENPHO staff first visited each site to take measurements using a MiniSonde® 4a Hydrolab® multiprobe. This equipment is capable of measuring many parameters simultaneously, including the following: water temperature, dissolved oxygen (DO) concentration, water salinity, pH, specific conductivity and redox potential at the sampling site. Also, turbidity is measured on location using a turbidity tube. For the determination of nitrate, ammonia, phosphate, fecal coliform, BOD and COD concentrations, samples are collected and brought back to ENPHO's lab.

2.3 *Data and Analysis*

The following section displays eight plots of water quality characteristics of the Bagmati River, stressing variations between sampling points and throughout the year. The water quality parameters addressed and discussed below include flow rate, dissolved oxygen (DO) concentration, pH, total suspended solids (TSS), fecal coliform concentration, biological oxygen demand (BOD), chemical oxygen demand (COD), and orthophosphate concentration.

Figure 2.3[10] plots flow rate of the Bagmati River for Gokarna, Pashupati and Sundarighat. The River flow is relatively low during winter (January) and dry season (May) sampling and peaks during monsoon (July) and post-monsoon (October) sampling. Flow through Gokarna and Pashupati is very low compared to that at Sundarighat, especially during the monsoon season. Besides the fact that Sundarighat is the furthest downstream of the three sites, the large flow rate at Sundarighat can be attributed to the junction of the Bagmati River with the Hanumante River (see Figures 1.3 and 2.1) upstream from Sundarighat.

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[9] We are grateful to Anjali Manandhar, Juna Shrestha and Nirita Giri at ENPHO for their generosity in sharing the data for use in this thesis and for allowing the author to accompany them in taking samples.

[10] Data for Figure 2.3 comes from Metcalf & Eddy, 2000.

Figure 2.3 [10]**: Flow Rates along the Bagmati River**

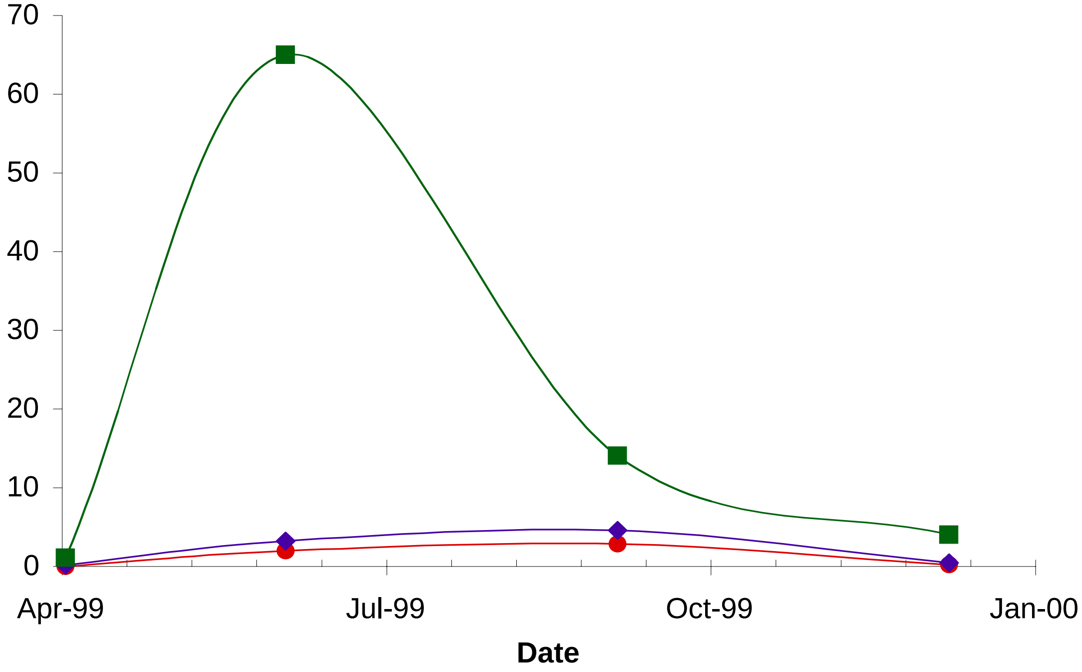


Figure 2.4 below plots dissolved oxygen concentration against sample month for the six Bagmati River monitoring sites. As expected, the DO levels are highest at Sundarijal where the water is very clean and pollution levels are low. Dissolved oxygen concentrations decrease as the River flows through Kathmandu and reach a minimum at Sundarighat. At Chovar, the dissolved oxygen levels have rebounded to some extent, and the River is almost completely restored of dissolved oxygen at Gaur. It is also worthwhile to note the large peak in dissolved oxygen at Sundarighat from July until October. This period is monsoon season in Nepal, so the large amount of rainfall serves to dilute the effect of the water pollution and contribute oxygen to anaerobic waters.

Figure 2.4: Dissolved Oxygen Concentrations in the Bagmati River

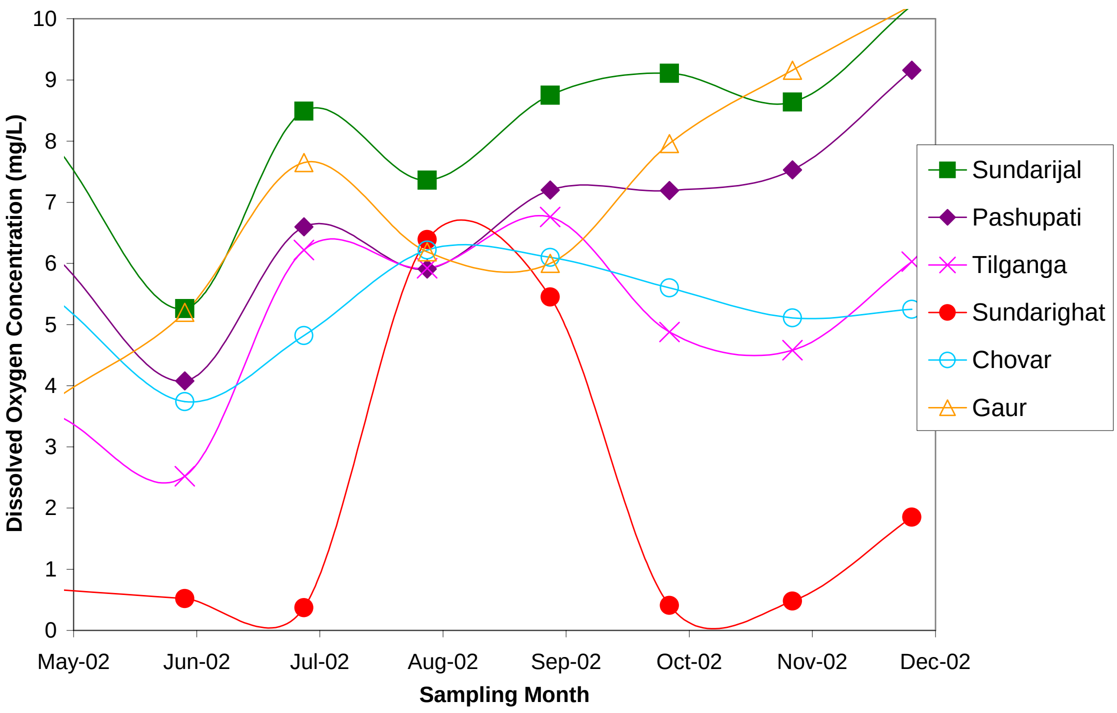
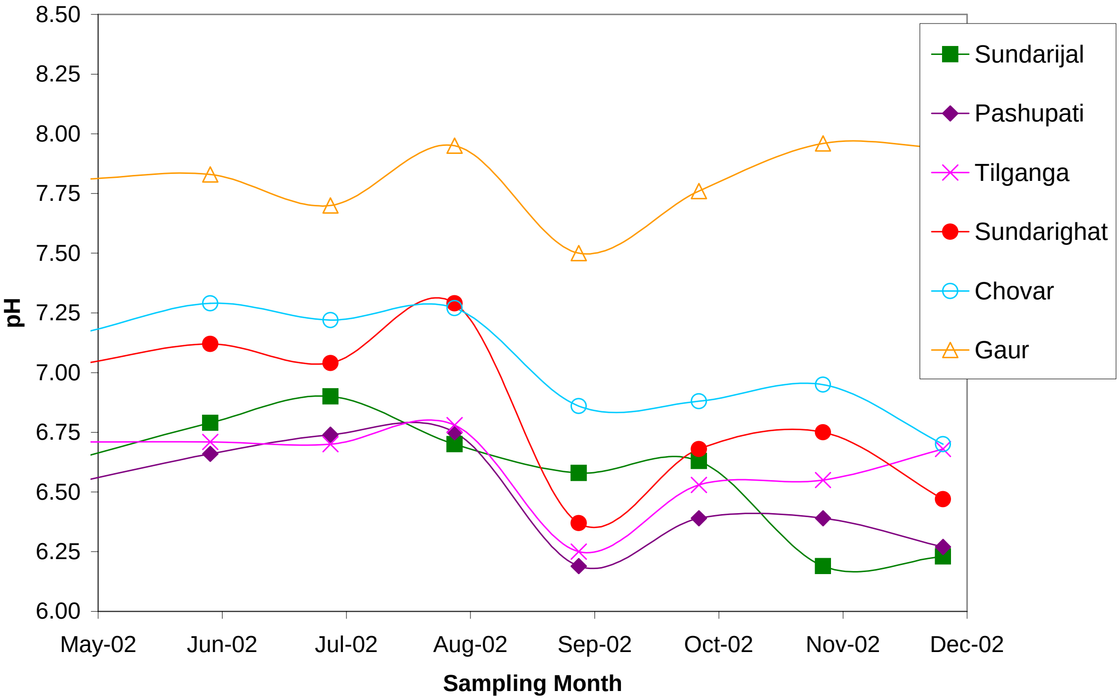


Figure 2.5 presents variations in pH versus sampling month and site.

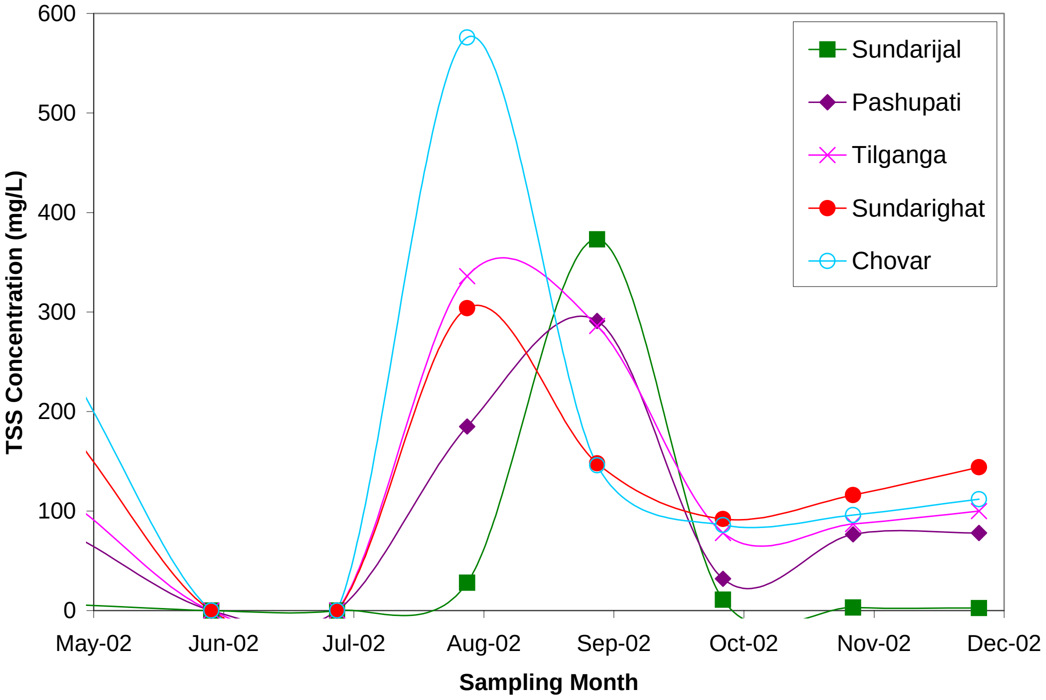
Figure 2.5: pH in the Bagmati River



At all sampling sites, the pH is fairly stable between 6.5 and 8 throughout the period of monitoring. One visible trend is the pH increase in August followed by a decrease in September for all sampling sites.

Figure 2.6 shows total suspended solids (TSS) concentrations for all the Bagmati sampling sites except Gaur. TSS values are fairly consistent from one monitoring site to another, though higher in Chovar than at the other areas. The Bagmati River flows through Chovar Gorge just upstream of this site, so it is reasonable that the turbulent water flow kicks up sediment from the river bed.

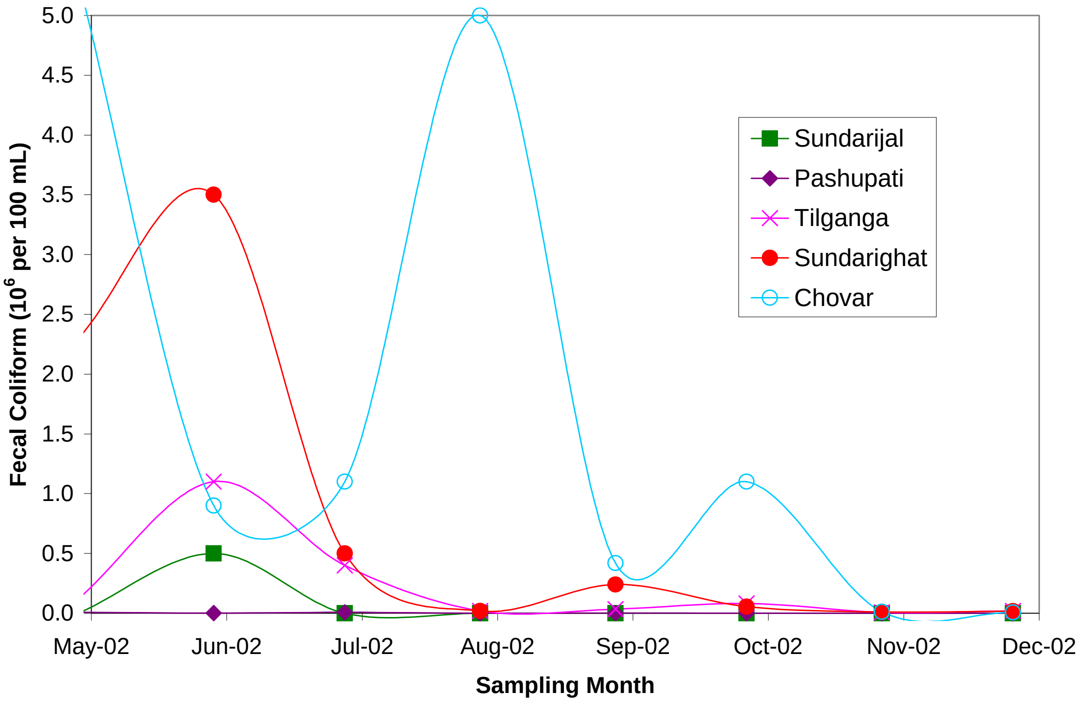
Figure 2.6: TSS Concentrations in the Bagmati River



It is interesting to note that Tilganga, Sundarighat and Chovar peak in TSS concentrations during the month of August, while Sundarijal and Pashupati peak in September. One might expect the upstream sampling sites, Sundarijal and Pashupati, to experience a disturbance in TSS levels before the downstream sites, Tilganga, Sundarighat and Chovar. One explanation for this behavior is that the disturbances causing peak TSS levels in Tilganga, Sundarighat and Chovar originate after the Pashupati sampling site. Also, the disturbance causing peaks in September for Sundarijal and Pashupati may have dissipated before reaching Tilganga.

Fecal coliform concentrations are presented in Figure 2.7. High levels are observed at Sundarighat and Chovar, while the River at Sundarijal and Pashupati have much less fecal coliform.

Figure 2.7: Fecal Coliform Concentrations in the Bagmati River



Figures 2.8 to 2.10 examine the trends of biological oxygen demand, chemical oxygen demand and phosphate concentrations in the Bagmati River. In all three graphs, measured concentrations are highest at Tilganga, Sundarighat and Chovar, the most central sites in Kathmandu. Likewise, all three parameters exhibit minima from July to September, during Nepal’s monsoon season.

Figure 2.8: BOD Concentrations in the Bagmati River

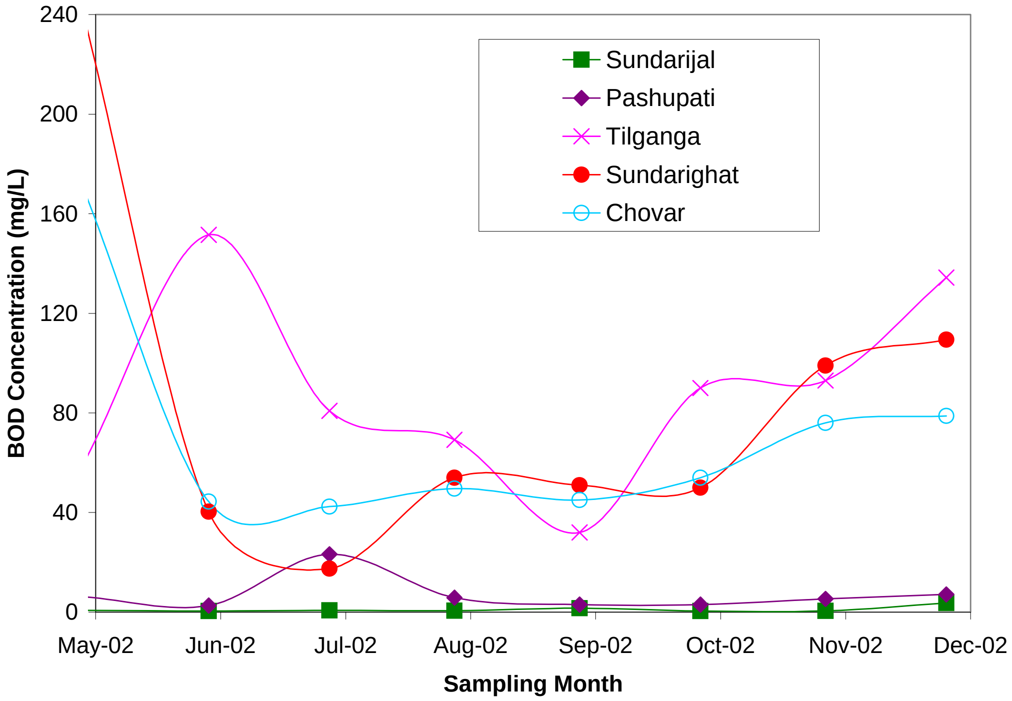


Figure 2.9: COD Concentrations in the Bagmati River

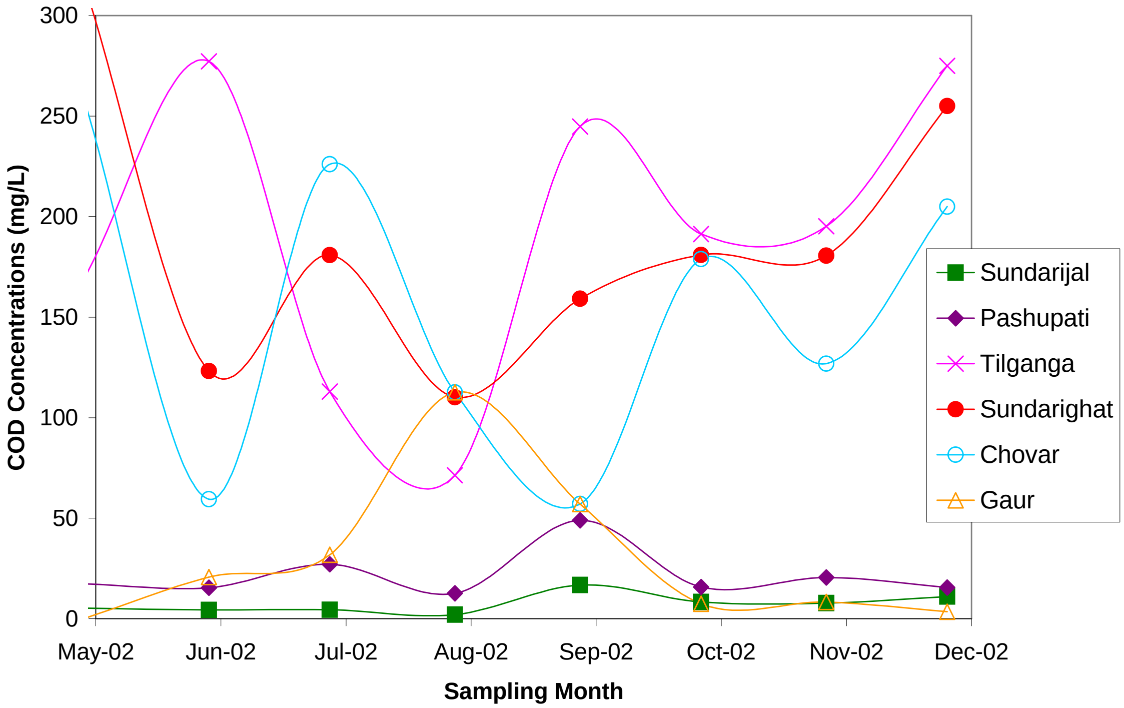
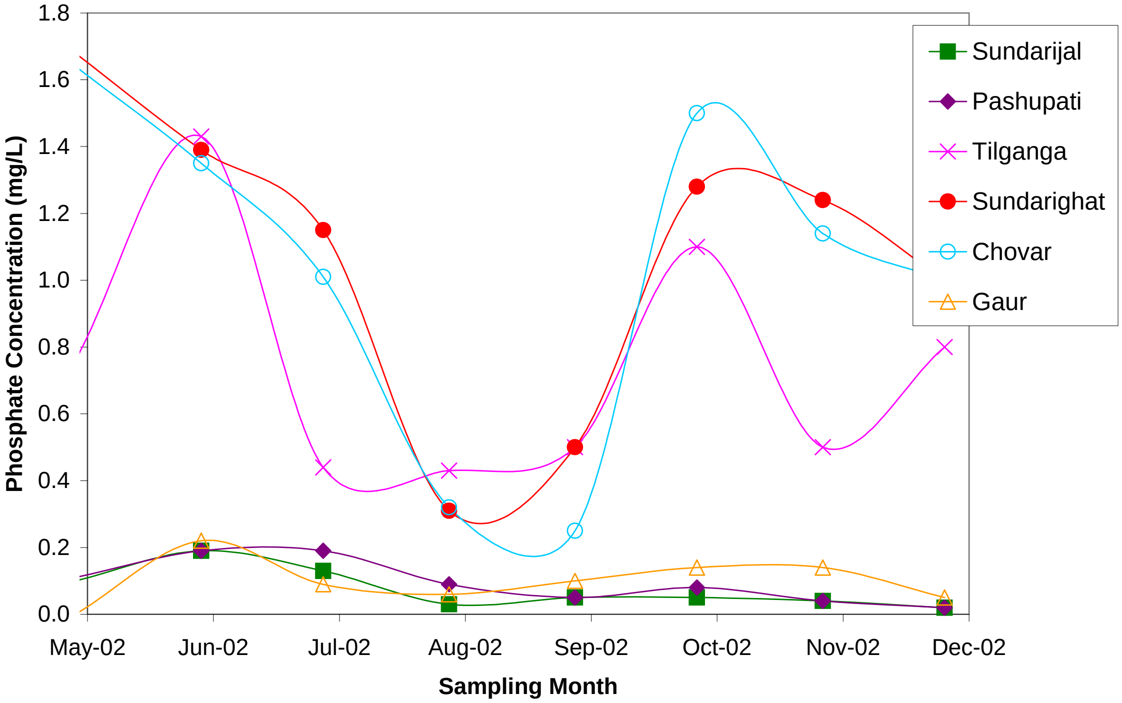


Figure 2.10: Phosphate Concentrations in the Bagmati River



3. Foaming in WWTP's and Surface Water

3.1 *Foaming Overview*

Foaming is a major operational problem in wastewater treatment, especially in activated sludge treatment plants. It occurs mostly in aerated units, where oxygen is supplied to the wastewater to support microbial activity. In activated sludge treatment facilities, two common mechanisms exist for wastewater aeration: bubbling of air or oxygen through the wastewater and agitation of wastewater at the air/water interface (Metcalf & Eddy, 2003). Either way, the aim is to maximize the interfacial area between the wastewater and the oxygen to promote the dissolution of oxygen into the water.

Microorganisms and certain molecules with hydrophobic properties can attach bubbles of air at an air/water interface. If enough such microbes and molecules fasten to a single bubble, they can form a net around the bubble to stabilize it at the air/water interface. The stable bubbles accumulate to form a viscous foam that rests on the water surface. Figure 3.1 below demonstrates the severity of the foaming problem in the oxidation ditches at the Guheshwori Wastewater Treatment Plant.

Figure 3.1: Foaming in the oxidation ditches at Guheshwori WWTP[11]

A mixture of sludge solids, wastewater bacteria and grease can be trapped in the foam, thereby inhibiting efficient biological treatment. If the foam overspills the tank or is blown away by wind, it presents hazards to both worker safety and effluent quality. The foam is slippery even after settling, so walkways of affected treatment plants should be regularly washed. Also, foam blown from the aeration tanks can re-contaminate treated water in secondary sedimentation

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[11] Figure 3.1 reproduced from (Shah, 2002)

tanks. In addition to extra maintenance, effluent quality and the spread of pathogens, foaming is connected with reduction in oxygen transfer (Metcalf & Eddy, 2003).

The microorganisms and molecules responsible for foaming in wastewater plants are often not removed in activated sludge treatment. In this case, the lakes and rivers acting as receiving waters for treated wastewater can experience foaming similar to that in treatment facilities. The foaming is especially noticeable in receiving waters in areas of turbulent flow, where the water is well mixed with air.

The flow of the Bagmati River is especially turbulent at the Chovar Gorge (Figure 2.1), so one would expect foaming at this location if in fact surfactants have built up in the River. Figure 3.2 below shows small pockets of stable foam on the surface of the Bagmati River just after flowing through the Chovar Gorge. Figures 3.3 and 3.4, photographed by MIT Nepal member Tetsuji Arata in January 2003, demonstrate foaming in municipal wastewater. These pictures were taken of the Kodku Wastewater Treatment Plant (Figure 1.3) effluent streams.

Figure 3.2: Foaming in the Bagmati River, just past Chovar Gorge

Figure 3.3: Foaming in the Kodku WWTP effluent pipe[12]

Figure 3.4: Foaming in the Kodku WWTP effluent[12]

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[12] Figures 3.3 and 3.4 provided by MIT Nepal Group member Tetsuji Arata, 2003.

3.2 *Causes of Foaming – Filamentous Bacteria*

As mentioned above, the phenomena of foaming occurs when microorganisms and molecules with hydrophobic end groups trap air bubbles and prevent them from fully escaping the water. The microorganisms most commonly responsible for this behavior include two types of filamentous bacteria: *Microthrix parvicella* and *Gordona amarae*-like organisms (GALO, formerly classified as *Nocardia*) (Khanal, 2002). These bacteria are especially active in conditions of high oil and grease concentrations, low F/M (food to microorganism) ratio or long sludge age.

Microthrix parvicella are long, unbranched filamentous bacteria. Filaments of *M. parvicella* can grow to as long as 400 μm long. They have been described as "irregularly curved, appearing like spaghetti" (Santa Cruz Productions, 2000). When present in an activated sludge process, *M. parvicella* is often found outside the floc tangled with other structures. These microorganisms are non-pathogenic and most prevalent in foams throughout Europe, Australia and South Africa (Santa Cruz Productions, 2000).

GALO are shorter filaments than *M. parvicella* (at 10-20 μm) that branch at approximately right angles. Accounts describe the appearance of these organisms as "tumble weeds." (Santa Cruz Productions, 2000). Like *M. parvicella*, GALO are also non-pathogenic (Soddell, 1998).

3.3 *Causes of Foaming – Surfactants*

Foaming can be troublesome in wastewater treatment plants even when GALO and *Microthrix parvicella* growth is controlled. Municipal and industrial wastewaters usually contain synthetic detergents and cleansers – products containing chemicals specifically designed to foam. Detergents in wastewaters come from residences in the form of household detergents, from agricultural runoff in the form of herbicides and insecticides and from certain industries, including textiles, leather dying and finishing, and detergent and carpet manufacture ("The Pollution of Water by Detergents", 1964).

The detergent additives especially active in wastewater treatment plants are known as surface active agents, or surfactants. In particular, the highly branched anionic surfactant alkylbenzene sulfonate (ABS) foams at concentrations above 0.5 mg/L in wastewater. The branching of ABS makes it resistant to biological degradation and accounts for foaming in wastewater treatment plants and surface waters (Richard, 2003). Chapter 4 (page 32) examines ABS in greater detail and discusses measures taken by the United States and by other selected nations to minimize the foaming effect of surfactants.

3.3.1 *Surfactant Chemistry*

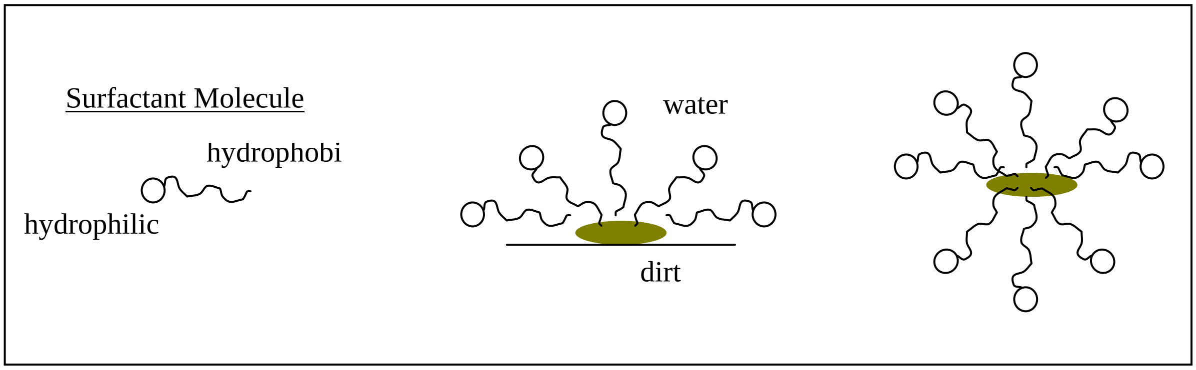
The word “detergent” is sometimes used to refer specifically to synthetic detergents, but in this thesis, “detergent” applies to any substance with cleaning abilities. Soaps are natural detergents, then, and man-made agents like laundry powders and dish-washing liquids are synthetic detergents.

Surfactants are organic chemicals added to synthetic detergents to decrease the surface tension of water. A successful surfactant contains at least one hydrophilic end (water-loving) and at least one hydrophobic end (water-hating). The free energy state of a surfactant/water/soiled clothing system is minimized when the surfactants exist at the interface of the organic material (oil, grease, dirt to be washed away) and the water. In this configuration, the hydrophilic remains in close contact with water molecules while the hydrophobic end avoids contact with water. In the same way, the free energy of a surfactant/water/air mixture is optimized when the hydrophilic part of the surfactant is in the water phase and the hydrophobic end is not in the water phase. This property allows surfactants to hold bubbles of air at the water surface.

Mechanical agitation loosens the hold between the dirt and the article being washed, and the arrangement of surfactant around the clumps of organic material prevents redeposition (Koch, 2001). Figure 3.5 demonstrates the process of dirt removal by surfactants.

The hydrophilic end of a surfactant can attract water in three ways: it may be charged, may be dipolar like water, or may contain hydrogen-bonding sites. In most synthetic detergents, sulfur trioxide, sulfuric acid and ethylene oxide are used as the hydrophilic portions of surfactants. Hydrophobic ends are hydrocarbon chains, generally derived from petroleum or animal fats and vegetable oils (Soap and Detergent Association, 1999).

Figure 3.5: Process of Dirt Removal by Surfactants



Surfactants are classified as anionic, nonionic, cationic or amphoteric by their ionic activity in water. Anionic surfactants carry a negative charge in aqueous solutions, giving them excellent cleaning properties and high foaming capabilities. These are most commonly used in synthetic laundry and hand dishwashing detergents, also in household cleaners.

Nonionic surfactants are used as rinse aids in synthetic laundry detergents, and cationic surfactants exist in fabric softeners and as disinfecting agents in some household cleaners. Amphoteric surfactants can behave as anionic, nonionic or cationic surfactants in water, depending on the pH of the solution. They are used as household cleaning items (Soap and Detergent Association, 1999).

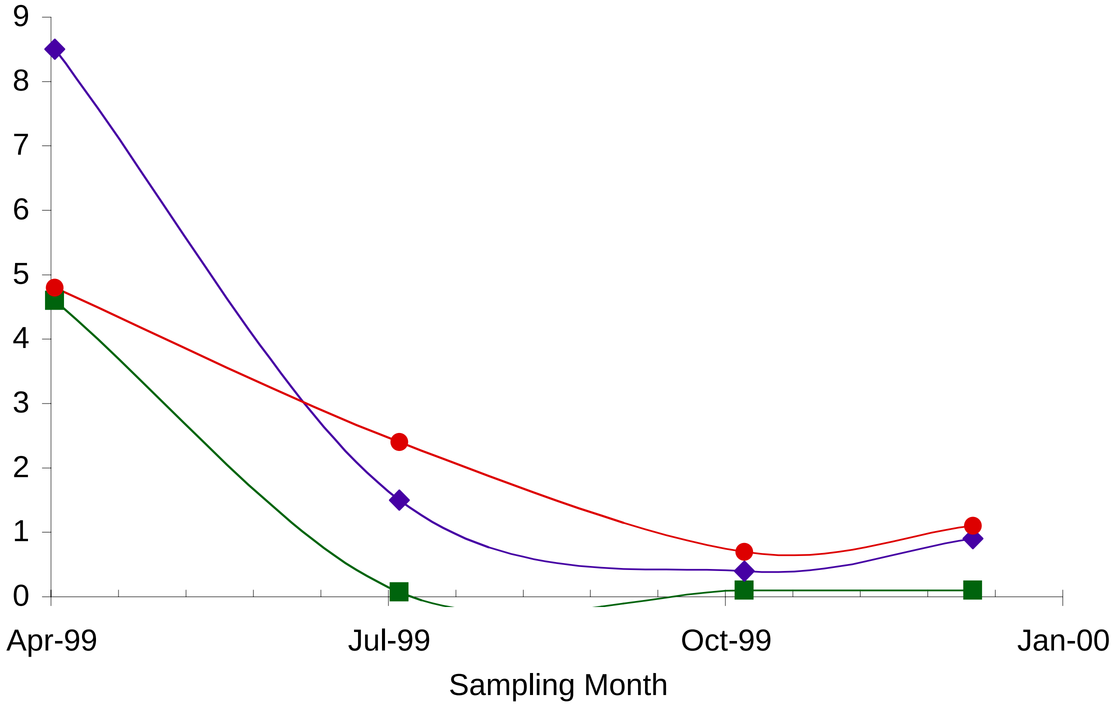
3.4 *Foaming Control Mechanisms*

3.4.1 *Regulation of Fats, Oils and Grease (FOG's)*

The filaments of GALO and *Microthrix parvicella* grow on oil and grease in the wastewater. Typical FOG concentrations range from 50 mg/L in low strength wastewaters to 100 mg/L in high strength wastewaters (Metcalf & Eddy, 2003). Communities that enforce grease and oil limitations or industries with low grease and oil waste content, then, experience less filamentous foaming than those without such regulations. Primary settling tanks remove grease and oil early in the treatment process, so treatment facilities without these units suffer greater filamentous foaming problems than those with (Richard, 2003). A variation in FOG concentration does not affect surfactant foaming.

As mentioned in Chapter 1, the Guheshwori Wastewater Treatment Plant lacks a primary setting tank. Primary clarifiers become less economical as wastewater plants get smaller, so this is not unusual in smaller treatment facilities, especially those utilizing oxidation ditches. A measure of FOG concentration at the Guheshwori WWTP is not available at this time, but Figure 3.6[13] below presents FOG concentrations in the Bagmati River at Gokarna, Pashupati and Sundarighat (see Figures 1.1 and 2.1).

Figure 3.6[13]: FOG Concentrations in the Bagmati River



3.4.2 *Management of Food to Microorganism Ratio (F/M)*

One of the most important design parameters of an activated sludge process is the food to microorganism (F/M) ratio, which balances the influent substrate concentration with the steady state effluent biomass concentration. Activated sludge process performance is compromised at F/M ratios above or below the optimum value. Too high of an F/M ratio can lead to low dissolved oxygen concentrations, filamentous bulking and poor BOD removal in the aeration tank. Alternatively, too low of an F/M ratio promotes foaming by GALO and *Microthrix parvicella*. Again, this control measure in ineffective against surfactant foaming.

For an extended aeration facility like Guheshwori, a typical F/M ratio is 0.4 g substrate/g biomass-day (Metcalf & Eddy, 2003). The wastewater treatment facility at Guheshwori utilizes

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[13] Data for Figure 3.8 from Metcalf & Eddy, 2000.

extended aeration, and reported F/M ratios at Guheshwori are 0.41 g substrate/ g biomass-day for the period from February to April 2002 and 0.27 g substrate/ g biomass-day for the period from May to June 2002 (Shah, 2002).

3.4.3 *Adjustment of Mean Cell Residence Time (MCRT)*

Filamentous foaming is commonly controlled by lowering the mean cell residence time (MCRT) of the affected tank. MCRT or sludge age is a ratio of biomass in the reactor to the rate of biomass leaving the reactor. The mean cell residence time is manipulated by varying the flow rate of wastewater into and out of biological treatment unit. Typical MCRT values for activated sludge treatment plants are 5 to 15 days for conventional treatment and 20 to 30 days for extended aeration treatment (Metcalf & Eddy, 2003).

When the mean cell residence time is reduced, problematic microorganisms like GALO and *Microthrix parvicella* can be washed out of the affected tank, depending on the growth rate of the particular organism. GALO's have a wide range of growth rates, so elimination by washout is difficult (Soddell, 1998). GALO is controlled in cold and moderate climates by MCRT reduction to less than 8 days, and by a reduction to less than 3 days in warmer climates (Barber, 1995). *M. parvicella* grow slowly, so decreasing sludge age is usually effective in removing the organisms (Soddell, 1998). To control *Microthrix parvicella* foaming, the New York State Department of Environmental Conservation suggests reducing a plant's MCRT to between 8 and 10 days (Barber, 1995). Reduction of sludge age is ineffective in eliminating surfactant foaming.

3.4.4 *Chemical Additives*

Antifoaming chemicals are not effective against GALO or *M. parvicella*, because the filaments of both bacteria physically interlock to form the foam. RAS chlorination is useful against *Microthrix parvicella*, but less so against GALO. This is because GALO are found within flocs, so chlorine doses high enough to reach the bacteria destroy the activated sludge floc in the process (Richard, 2003).

3.4.5 *Mechanical Removal*

The most effective means of eliminating foam caused by surfactants is to spray the foam with water. Drops of water act to dissipate the bubbles, especially when the spray hits the water surface at an angle of less than 45 degrees (Prat, 1964). In this case, “the foam is thus sliced at its base” (Prat, 1964). To reduce manual labor, small turbines can be used to spray water at the foam at a pressure of 5 to 6 kg/cm^2 (15 to 18 psi) (Prat, 1964). In addition to physically liberating the air bubble from the hold of surfactants, the addition of water assists by diluting the concentration of surfactants in the wastewater. Dilution to below the foaming threshold, which is largely dependant on the water composition and quality characteristics, eliminates the foaming problem.

4. History and Regulations of Surfactants in Synthetic Detergents

4.1 *History of Synthetic Detergents*

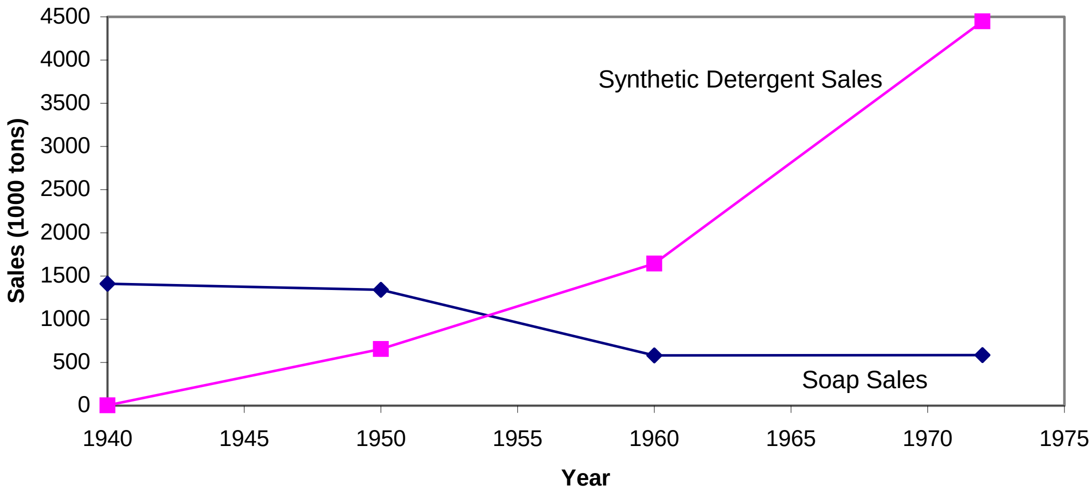
Animal and vegetable fats and oils were in short supply during the First World War, so the soap industry found itself in competition with the food and feed industries for the limited resources. Fat and oil prices rose so highly that soap making became uneconomical. Due to this struggle and natural soap's poor cleaning ability in hard waters, German scientists and engineers began experimenting with synthetic detergents. The products they developed, short-chain alkylnaphthalene sulfonates, were successful surfactants but second-rate detergents.

The petroleum industry was rapidly developing in the 1930s, and refinery waste products were generally disposed of by combustion. It was discovered, however, that propylene, a kerosene fraction, could be converted to a long chain 2-alkene, which then could be reacted with benzene and sulfuric acid. The product of this was neutralized with sodium hydroxide to form alkylbenzene sulfonate or ABS, which quickly became the favorite surfactant in synthetic laundry detergents (Kevlam, undated).

In the years following the Second World War, carboxymethylcellulose (CMC) was added to synthetic detergents to reduce the redeposition of dirt, and orthophosphates were added to respond to calcium and magnesium cations in hard water. With these additions, the "detergent industry established itself and has never looked back." In the thirty years following the Second World War, soap sales in the United States decreased by a factor of two, and synthetic detergent sales increased a thousand-fold ("Detergent Chemistry – History", undated).

Figure 4.1 below illustrates the emergence of the synthetic detergent industry using data from the American Soap and Detergent Association ("Detergent Chemistry – History", undated).

Figure 4.1: Soap and Synthetic Detergent Sales in the US
1940 to 1972



4.2 *Regulations Concerning Alkylbenzene Sulfonate*

In the early 1950s, natural surface waters all over America and Europe were beginning to foam. In fact, "wherever water tumbled over stones or waterfalls, wherever winds rippled the surface, accumulations of bubbly froth were building up" (ReVelle, 1988). This is believable, as nearly 1 billion kg/yr (2.2 billion lbs/yr) of detergents were being used to wash clothes in the United States by the mid-1950s, and ABS was the major surfactant used in synthetic laundry detergent manufacture. Moreover, extensive testing showed that ABS's highly branched structure rendered it almost completely resistant to biological degradation, so only small amounts of the surfactant were removed in typical wastewater treatment facilities. Thirty-two American cities were monitored in 1959 for ABS, and "surface water-generated potable waters" averaged between 15 and 34 μg/L (Eichhorn, 2001).

Legal restrictions were quick to follow, led by the German Detergent Act of 1962 mandating primary degradation of anionic surfactants. Primary degradation refers to a loss of surfactant properties. In the United States, ABS was voluntarily banned by industry (Eichhorn, 2001). The United Kingdom also responded with a voluntary industrial initiative and passed legal requirements for biodegradability and laboratory test methods in 1973.

4.3 *Introduction of Linear Alkylbenzene Sulfonate*

In the 1960s, the commercialization of the Ziegler process for oligomerization of ethylene led to the development of linear hydrophobic molecules analogous to the branched hydrophobes used in ABS. The Ziegler process was devised in 1953 by a German chemist by the name of Karl Ziegler. The process makes use of transition metal catalysts, usually $TiCl_3$ or $TiCl_4$, and is applied in polyethylene formation, allowing the synthesis to operate at lower temperatures (60 ^oC, 140 ^oF) and pressures (1 atm) than in the original process ("Glossary of Chemical Terms", 2003).

Linear alkylbenzene sulfonate (LAS) was developed from these straight-chained molecules in 1964 as a biodegradable alternative structure to ABS. The new anionic surfactant readily breaks down in activated sludge wastewater treatment plants and all but eliminated the issue of foaming in surface waters. Specific cases of LAS biodegradability are described below for rivers in the United States and other nations, including England, Germany, Japan and Thailand.

- The Illinois River at Peoria averaged a 0.54 mg/L anionic surfactant concentration from 1959-1964. This concentration dropped to 0.22 mg/L in 1965 and 0.05 mg/L in 1968.
- Presently, 90% of over 500,000 United States river miles have less than 4 μg/L LAS.
- In England, surfactant concentrations in rivers decreased by a factor of 5 when LAS was introduced, and concentrations were at the lower limits of detection by 1966.
- In Germany, LAS levels are at 0.01 mg/L in the Rhine River.
- The Tama River in Japan averaged surfactant concentrations of 2.5 mg/L in1968 and decreased to 0.3 mg/L by 1981.
- Thailand officially switched from ABS to LAS in 1983. At the time, the anionic surfactant concentrations in the Chao Phraya River averaged 0.34 mg/L. One year later, the River averaged 0.095 mg/L. (Council for LAB/LAS Environmental Research (CLER), 1994)

In addition to improved environmental performance, LAS foams and cleans better than ABS. These properties allow manufacturers to reduce the concentration of surfactants in detergents without compromising performance. Also, LAS is less sensitive to calcium and magnesium ions than ABS, permitting reduced levels of phosphate-based builders in detergents (phosphate use discussed in Chapter 5). One important advantage of ABS is that raw materials for its production are less expensive than those for LAS. For this reason, branched alkylbenzene sulfonate is still used extensively in developing countries despite the enhanced performance of LAS (Eichhorn, 2001).

4.4 *Current Controversy Surrounding Linear Alkylbenzene Sulfonate*

4.4.1 *Biodegradability In Anoxic and Anaerobic Conditions*

Under aerobic conditions, LAS is readily biodegradable. In fact, a 1995 study determined the removal of LAS by municipal wastewater treatment plants in England to be 99.9%. Similar monitoring tests in Germany, Spain and the Netherlands demonstrated an average of 99.2% LAS removal. In developing nations like Nepal, clothes are regularly washed right in the local surface waters. In addition, untreated wastewater frequently finds its way to nearby surface waters. As a result, the receiving waters can have low dissolved oxygen concentrations (see SATWQM Data in Chapter 2), and aquatic activity is anoxic or anaerobic. Under anoxic conditions, LAS biodegrades very slowly; the surfactant is stable in anaerobic situations (Folke, 1999). In such cases, LAS can build up in receiving waters and cause foaming just as ABS does. If oxygen is reintroduced into anoxic waters, however, LAS biodegradation will resume.

4.4.2 *Adsorption to Sediments*

The partitioning of LAS among environmental media can be calculated by equating the fugacities at steady state. As a result, 97.5% of LAS is found to be distributed in water, 2% in sediments, suspended solids and biota, and small amounts in the soil and air (Folke, 1999). So while most of the LAS remains in the aqueous phase, the same surfactant properties that make it effective in grease and dirt removal cause LAS to build up on sediments and in aquatic organisms. Further, sorption of LAS onto solid particles is an irreversible process (Petrovic, 2002). In sewage treatment plants, considerable amounts of LAS adsorb onto wastewater solids and are removed in primary clarification. In activated sludge and other aerobic processes, the adsorbed LAS and aqueous LAS are both degraded by microorganisms. LAS content in these sludges is low, but sludge from anaerobic processes can contain as much as 10 g/kg LAS (Petrovic, 2002). Anaerobic sludge with high levels of LAS can be rendered unsuitable for soil improvement and fertilization and must ultimately be incinerated or sent to a landfill. In areas with inadequate wastewater treatment, the sediments of receiving waters can accumulate high levels of LAS.

4.4.3 *LAS and Byproduct Toxicity*

The primary degradation intermediates of LAS are sulfophenylcarboxylic acids (SPC). SPC's are more polar than LAS and do not retain their surfactant properties, so they do not sorb as readily to sediments as LAS do (Gonzalez-Mazo, 2002). Neither LAS nor SPC are toxic to humans, but they affect aquatic organisms at concentrations above 10 μg/L (Barber, 1995).

4.5 *LAS Regulations in Europe*

In Denmark, LAS has been named an "unwanted substance" and limitations have been placed on LAS content in sludge. As of July of 2000, sludges intended for agricultural use could not exceed LAS concentrations of 1.3 g/kg dry sludge. Almost no anaerobic sewage sludge satisfies these limits, so incineration and landfilling are the major alternatives. This limitation is somewhat controversial, because it seems to contradict objectives adopted both by the EU and Denmark, especially for the sustainable management of waste. This legislation calls for the reuse of organic wastes like sewage sludge. Other quality criteria established in Denmark are 1.5 g LAS/kg soil for the protection of human health, 5 mg LAS/kg soil for the protection of aquatic organisms and 0.1 mg/L water (measured as sulfate) as drinking water limits (Folke, 1999).

The "Swan Eco-Label" is an environmental product label established by the Scandinavian organization Nordic Swan. One requirement of the label is that approved products be anaerobically as well as aerobically biodegradable, so detergents containing LAS are not endorsed by the organization.

The strongest competitor for LAS in the world market today is the anionic surfactant methyl ester sulfonate (MES), developed from palm oils, coconut oils and tallow. The alternative surfactant has better degradation properties than LAS has, though historically MES is more expensive. Synthetic detergent manufacturers have recently begun adding MES to the total surfactant concentration or replacing fractions of LAS with MES. In addition to environmental incentives, studies demonstrate that LAS/MES blends perform better in terms of detergency than either surfactant alone. Other popular anionic surfactants include alcohol ether sulfates, alcohol sulfates and alpha-olefin sulfonates (Graff, 2003).

5. Phosphates in Synthetic Detergents and Eutrophication

5.1 *Role of Phosphates in Synthetic Detergents*

As mentioned in Chapter 3, surfactants or surface active agents are chemicals added to synthetic detergents to enhance the washing capability of water. Surfactants decrease the surface tension of water and are responsible for the suds that help remove grease and oil from the items being washed. When synthetic detergents are used in hard water, calcium and magnesium ions form strong and insoluble complexes with surfactants and precipitate out of solution (Folke, 1999). This reaction is undesired, because it compromises the cleaning ability of the detergent and forms a solid scum on the items being washed. To counter these effects of washing in hard waters, synthetic detergent manufacturers can either increase surfactant concentrations in detergents or add a constituent called a builder, with which calcium and magnesium ions preferentially react.

Surfactants are often the most expensive and sometimes the most toxic chemicals in detergents, so builders were developed as a means of dampening the effects of hard water ions without raising the product's price or threatening the user's health. Builders accomplish this task using one of several different mechanisms. Common reaction mechanisms between a builder and calcium and magnesium ions include sequestration, precipitation and ion exchange.

Sequestration is the formation of stable, soluble complexes with metal ions. In this way, calcium and magnesium ions remain in the aqueous solution, but they pose no threat to surfactants. Common sequestration builders include sodium tripolyphosphates and sodium citrates (Soap and Detergent Association, 1999).

Precipitating agents work by forming insoluble salts with the unwanted metal cations. This mechanism differs from sequestration in that the hard water ions are completely removed from the wash solution. Examples include sodium carbonate and sodium silicate (Soap and Detergent Association, 1999).

In the ion exchange process, an exchange occurs between cations in solution and cationic species attached to the builder. For example, a builder of the form NaX can react with Ca^{2+} in solution to form CaX_2 and $2Na^+$. The calcium and magnesium remain in solution, but no longer in cationic form. The zeolite builder sodium aluminosilicate is a popular ion exchange builder (Soap and Detergent Association, 1999).

Sodium tripolyphosphate ($Na_5P_3O_{10}$), traditionally the builder of choice, works by sequestration. In addition to its water softening properties, sodium tripolyphosphates have good buffering properties and a low toxicity. STPP is broken down easily into biologically available phosphates, and typical secondary wastewater treatment plants remove only a small percentage of phosphates from the water. With that level of treatment, much of the phosphates eventually end up in rivers and lakes and contribute to eutrophication.

5.2 *Eutrophication*

Eutrophication is a natural process in which surface waters are enriched with nutrients vital to the growth of plants and animals. The oversupply of these nutrients favors certain organisms over others, so while it increases biological activity of a lake or river, it tends also to decrease biodiversity. Opportunistic species like algae take advantage of the favorable conditions by rapidly reproducing. As a result, these organisms and their predators can overrun the rest of the lake population.

Algal blooms can have several negative effects on a body of water. Surface waters overpopulated with algae are aesthetically unpleasant and can be scummy or a cloudy green color. Also, decaying algae that has been washed or blown onto shore can cause foul odors. Algal blooms spread on the water surface to capture sunlight and photosynthesize, preventing light from reaching underwater photosynthesizing plants. These plants serve as food and shelter for various other aquatic organisms, so the damage is widespread throughout the lake or river ecosystem. When the algae complete their short life span, the organic matter accumulates and is eventually decomposed by bacteria. This process is aerobic and depletes a surface water’s dissolved oxygen levels. Organisms sensitive to oxygen concentrations cannot survive in the anoxic conditions, so the presence and decay of algal blooms can severely diminish the diversity and number of lake organisms.

5.2.1 *Causes of Eutrophication*

Carbon, hydrogen, oxygen, nitrogen as nitrates and phosphorus as phosphates are among the nutrients essential to plant growth (ReVelle, 1988). Carbon, hydrogen and oxygen are abundant in natural waters containing organic matter, so the nutrients capable of controlling plant and algae growth are nitrates and phosphates. In most freshwater systems, phosphates limit the rate of algal growth, even though algae cells are less than 1% phosphorus (Knud-Hansen, 1994). In fact, 1 kg (0.45 lb) of phosphorus is sufficient to grow 700 kg (318 lb) algae (Knud-Hansen, 1994).

Lakes often contain low nitrate and phosphate levels when first formed. After thousands of years of rainfall, erosion and seepage, high concentrations of nutrients accumulate, and the lakes become eutrophic. Through the process of algal growth and decay, lakes eventually fill with decaying organic matter and transform from marshland to dry land. This process is referred to as natural lake aging.

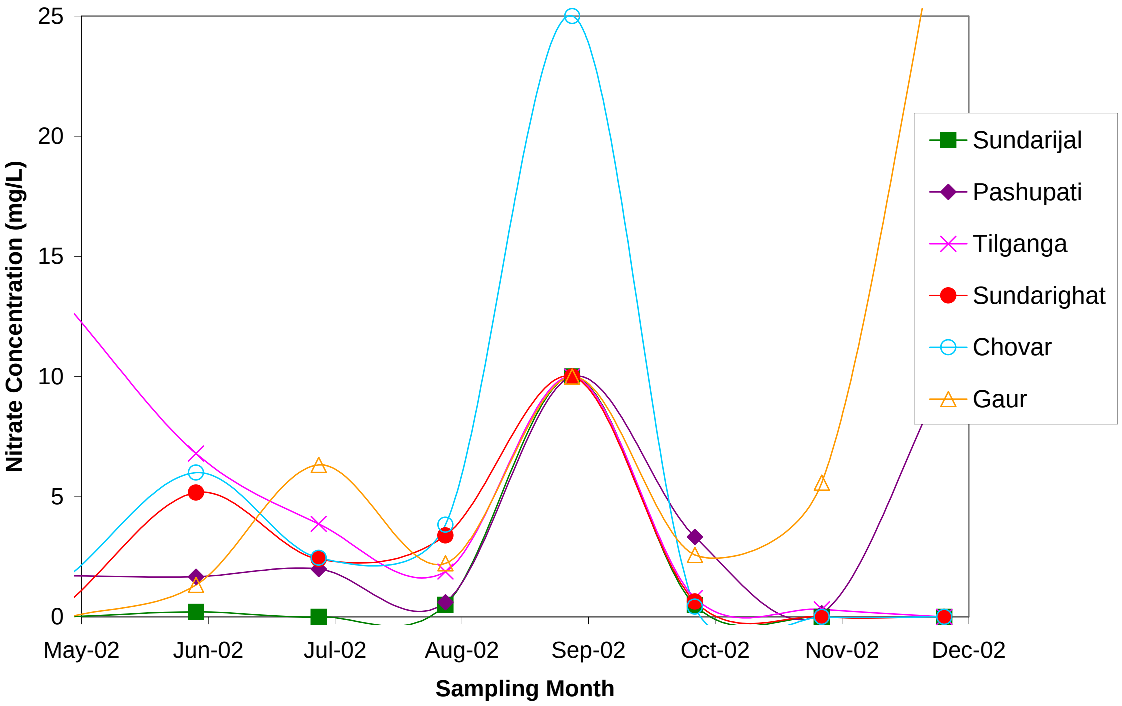
The eutrophication of lakes today is usually the result of human pollution and occurs over a much shorter time frame than natural lake aging. Nitrates and phosphates are components of the wastewater discharged by point sources such as municipal wastewater treatment plants and industry outlets or by non-point sources including agricultural areas and the atmosphere (McGucken, 2000).

Nitrates comprise of about half of human and animal wastes, so sewage and animal feedlots are major sources of nitrates in surface waters. Fertilizers also contain high nitrate levels, which can runoff into lakes and rivers. In addition, some blue-green algae can convert nitrogen from the atmosphere into nitrates.

Figure 5.1 displays nitrate levels in the Bagmati River since May 2002. The data for this chart comes from the South Asia Trans-boundary Water Quality Monitoring Project (SATWQM, see Chapter 2). Nitrate levels rapidly increase from November to December 2002. This trend is consistent with Figures 2.3 to 2.10 (Chapter 2), where variations in water quality are more dramatic during the dry winter season. Samples in August and September, however, are very high, in spite of the fact that these points fall during the rainy season. One explanation for this is that the heavy rains during the monsoon season increase the amount of nitrogen run-off from nonpoint sources.

According to the sources of nitrates addressed above, one might expect nitrate levels to be the highest as the Bagmati River flows through heavily populated areas like Tilganga, Sundarighat and Chovar. With the exception of Chovar in September, the nitrate levels seem to vary by only small amounts between heavily and lightly populated locations.

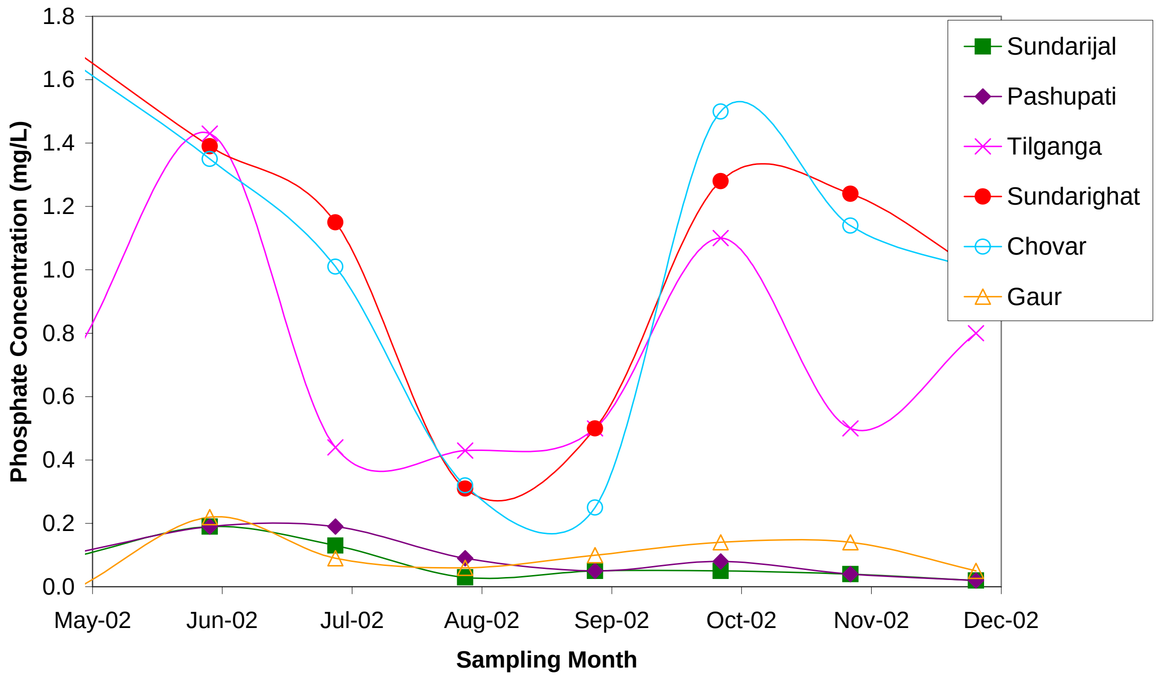
Figure 5.1: Nitrate Concentrations in the Bagmati River



In addition to nitrates, phosphate levels are also high in municipal wastewater. In the United States, about half of the phosphates in sewage come from human wastes, and 20-30% come from detergents (ReVelle, 1988). Phosphates are also abundant in animal feedlots and fertilizers.

Figure 2.10, illustrating SATWQM data for phosphates in the Bagmati River, is revisited below as Figure 5.2. The general tendencies demonstrated below are as one might expect. The highest phosphate levels occur at Tilganga, Sundarighat and Chovar, the most populated areas. Also, phosphate levels reach minimums at every location during Nepal's wet season between the months of July and September.

Figure 5.2 (also 2.10): Phosphate Concentrations in the Bagmati River



Eutrophication is a complex process that cannot correctly be reduced to a function of nitrate and phosphate concentrations; it depends on many water quality parameters of the lake or river in question, including levels of other nutrients present, hydrological patterns and climatic factors. As such, it is difficult to conclude from Figures 5.1 and 5.2 alone whether or not the nitrate and phosphate levels in Bagmati River are sufficient to cause eutrophication. In a 1966 study considering eutrophication in Europe's inland waters, however, evidence suggested that a water body is "in danger" if it exhibits nitrate levels of 0.2 to 0.3 mg/L and phosphate levels of 0.01 mg/L (McGucken, 2000). Using these criteria, nitrate and phosphate concentrations are indeed great enough to cause eutrophication problems in the Bagmati River.

5.3 *Regulatory History*

By 1959, laundry detergents used in the United States contained between 14 and 57 weight percent sodium tripolyphosphate (STPP), and automatic dishwashing detergents contained from 35 to 55 weight percent (McGucken, 2000). This corresponds to between 4 and 15 weight percent phosphorus. The production of phosphate builder at the time was over 700,000 tons in the United States (McGucken, 2000). In addition, wastewater was often discharged directly into waterways, as many communities lacked wastewater treatment facilities. Consequently, rivers and lakes throughout the United States and other developed nations were choked with algae.

In the late 1960's, public concern about the nation's waterways was growing, and a suspicious eye was being cast toward the detergent industry. Waste streams from industrial and municipal sources accounted for half of the phosphorus flow into Lake Erie and Lake Ontario, and detergents comprised between 50 and 70% of these streams (Knud-Hansen, 1994). The public expected the detergent industry to rectify the algae problem as easily as it had the foaming problem a few years earlier, but the detergent industry maintained that it had no suitable replacement at the time.

With public and government pressure to reduce phosphate concentrations in laundry detergents, the synthetic detergent industry in the United States began phasing out phosphates as builders. The builder that would replace STPP was sodium nitrilotriacetate (NTA, $N(CH_2CHONa)_3$) (McGucken, 2000). In 1966, Proctor & Gamble began marketing in select areas an experimental laundry detergent product with NTA as 25% of the total builder concentration. Within two years, 10% of Proctor & Gamble detergents had this formulation, and use of the new builder was on the rise.

On December 18, 1970, however, the Surgeon General of the United States ordered that NTA use be suspended until further tests could be performed. NTA degradation products were suspected carcinogens, and in 1980 it was established that the cancer risk associated with NTA in drinking water was two in a million. The EPA deemed this risk too small for regulatory action to follow (Knud-Hansen, 1994).

The same year, the detergent industry voluntarily agreed to reduce phosphorus concentrations to 8.7 weight percent. In 1971, Connecticut, Florida, Indiana, Maine, Michigan and New York passed laws setting phosphorus limits in detergents at 8.7 percent, while certain municipalities in Indiana, New York, Vermont and Wisconsin totally banned phosphorus builders (ReVelle, 1988). Since 1971, certain states have also banned the use of NTA.

In light of the toxicity of alternative builders and the spread of advanced secondary and tertiary municipal wastewater treatment plants, the controversy surrounding STPP has faded to some extent, and the phosphate builder is still very common in laundry detergents. Alternative builders include sodium carbonate, sodium silicate and sodium aluminosilicate (zeolite).

6. Detergent Analysis

6.1 *Materials*

As described in Chapters 3 and 5, chemicals known as surfactants and builders are essential constituents of synthetic detergents. As such, surfactants and builders of different kinds are used in a range of proportions in synthetic detergents, depending on the manufacturer and the intended detergent user and purpose. This thesis focuses on laundry detergents intended for use in Nepalese households, especially in the Kathmandu Valley. Eighteen laundry detergents and one dishwashing detergent representing ten manufacturers from three countries of origin were collected from markets around Kathmandu. The analyzed detergents were in both bar and powder form and ranged from very inexpensive, 7 NRs ($0.09 US) for a 500-g (1.1-lb) bag of detergent, to rather pricey, 145 NRs ($1.93 US) for 500-g. Figure 6.1 below lists basic pricing information for each detergent analyzed.

Figure 6.1: Detergent Pricing Information

Detergent	Form	Company, Country	Price	Price/100 grams
Wheel	powder	Nepal Lever	16 NRs/500 g	3 NRs ($0.04 US)
Wheel w/ lemon	powder	Nepal Lever	16 NRs/500 g	3 NRs ($0.04 US)
Wheel w/ lemon	bar	Nepal Lever	7 NRs/250 g	3 NRs ($0.04 US)
Vim	bar	Nepal Lever	10 NRs/200 g	5 NRs ($0.07 US)
OK	bar	Nepal Lever	8 NRs/200 g	4 NRs ($0.05 US)
Surf Excel	powder	Hindustan Lever, India	53 NRs/200 g	27 NRs ($0.35 US)
Ariel	bar	Proctor & Gamble, India	50 NRs/250 g	20 NRs ($0.27 US)
Ariel	powder	Proctor & Gamble, India	145 NRs/500 g	29 NRs ($0.39 US)
Tide	powder	Proctor & Gamble, India	70 NRs/500 g	14 NRs ($0.19 US)
Mr. White	powder	Henkel, India	32 NRs/500 g	6 NRs ($0.09 US)
Henko Megastar	powder	Henkel, India	5 NRs/20 g	25 NRs ($0.33 US)
Diyo	powder	Aarti Detergent, Nepal	14 NRs/200 g	7 NRs ($0.09 US)
Diyo w/ lemon	bar	Aarti Detergent, Nepal	7 NRs/200 g	4 NRs ($0.05 US)
Diyo	bar	Aarti Detergent, Nepal	7 NRs/200 g	4 NRs ($0.05 US)
Fighter	powder	Polo Chemicals, Nepal	7 NRs/500 g	1 NRs ($0.02 US)
Super Current	powder	Goga Industries, Nepal	30 NRs/200 g	15 NRs ($0.20 US)
GoGo	powder	Nepal	25 NRs/500 g	5 NRs ($0.07 US)
Super Chek	bar	Detergents, India Limited	7 NRs/125 g	6 NRs ($0.07 US)
Jimnao	powder	China	24 NRs/300 g	8 NRs ($0.11 US)

6.2 *ABS Analysis*

6.2.1 *ABS Procedure*

Analysis of detergents for total anionic surfactants was performed using Hach® Procedure 8028. This test procedure makes use of crystal violet, a cationic triphenylmethane dye that complexes with the anionic surfactant molecules present in the detergent sample. The complexes prefer benzene to water as a solvent, so the dyed sample is extracted with benzene to isolate the surfactants from the rest of the aqueous phase. Using a spectrophotometer, one can identify the surfactant concentration from the coloration of the dyed benzene. Estimated detection limits range from 0.002-mg/L to 0.275-mg/L anionic surfactant using a Hach® DR2010 spectrophotometer.

It is vital in this thesis for the reader to recognize that ABS and other poorly degradable anionic surfactants cause foaming problems in wastewater treatment plants and receiving waters, while LAS and other easily biodegradable surfactants do not under aerobic conditions. In the analysis and discussion that follows, anionic surfactants present in the synthetic detergent samples are classified as non-biodegradable (or rather very slowly biodegradable) and readily biodegradable. These groups are notated ABS and LAS, respectively. While ABS and LAS are the most prevalent of the "hard" and "soft" surfactants, it is possible that additional anionic surfactants are used in the specific laundry detergents analyzed. This thesis does not address that possibility, but rather lumps other surfactants together with ABS and LAS.

Synthetic detergent samples are prepared and analyzed according to the following procedure:

1. Sample solution preparation
    a. Dissolve 0.4 g sample detergent in 100 mL tap water to make a 4 mg/mL solution.
    b. Add 10 mL of detergent solution prepared in step 1a to 290 mL Charles River water.
    c. Add 3 mL of detergent solution prepared in step 1b to 297 mL Charles River water.
    d. Each time Charles River water is collected, the raw water should be analyzed to measure background surfactants.

2. Extraction of surfactants with benzene
    a. Pour 10 mL sulfate buffer solution (Hach® #452-49) and solution prepared in step 1c to 500 mL separatory funnel. Shake funnel to mix solutions.
    b. Add 1 reagent powder pillow (Hach® #1008-68) to the funnel. Shake the funnel to dissolve the powder.

   c. Add 30 mL benzene to the solution in the funnel. Shake to thoroughly mix the layers, but do not shake excessively, as an emulsion may form.
   d. Wait 30 minutes for the organic and aqueous layers to separate.
   e. Drain the bottom aqueous layer, and discard into an appropriate organic waste container.

3. Sample analysis using Hach® DR2010 Spectrophotometer
   a. Choose program 710 when prompted. Turn dial to 605 nm.
   b. Zero with a pure benzene blank.
   c. Drain the top organic layer from the separatory funnel into a spectrophotometer sample cell and read.
   d. Discard benzene and organic layer into appropriate organic waste containers.

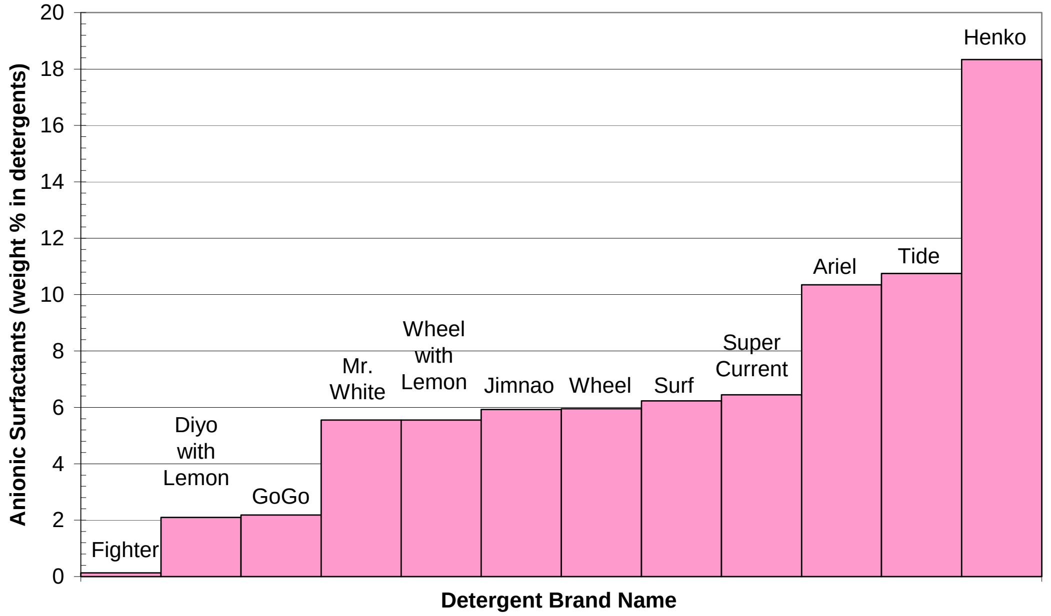
4. Detergent solution storage for monitoring of surfactant degradation
   a. Add 5 mL solution prepared in step 1b to 95 mL Charles River water.
   b. Prepare and store 2 such solutions from step 4a for each detergent analyzed.
   c. Shake stored samples several times a day, and leave containers open to the atmosphere to encourage aeration.

5. Analysis of stored detergent solutions
   a. Add 1 stored sample prepared in step 4a to 200 mL tap water.
   b. Follow procedures outlines in steps 2 and 3 to analyze surfactant concentrations in stored samples.

6.2.2 *ABS Results*

Figures 6.2 and 6.3 below illustrate the total anionic surfactant concentrations in the detergents analyzed. From the two charts, it appears that most detergents analyzed contain between 4 and 8 weight percent anionic surfactants. Detergents with considerably higher surfactant concentrations include Henko, Tide and the two varieties of Ariel. Using the pricing information listed in Figure 6.1, these detergents are also among the most expensive brands.

Figure 6.2: Total Anionic Surfactants in Powder Detergents Before Degradation



On the low end of the concentration axis, detergent brands Fighter, two of the three Diyo varieties and GoGo all contain very low levels of surfactants. In fact, in mixing sample solutions with these detergents, it was difficult to achieve any foaming even at high detergent concentrations. These brands fall in the lower range of detergent prices according to Figure 6.1.

Figure 6.3: Total Anionic Surfactants in Bar Detergents Before Degradation

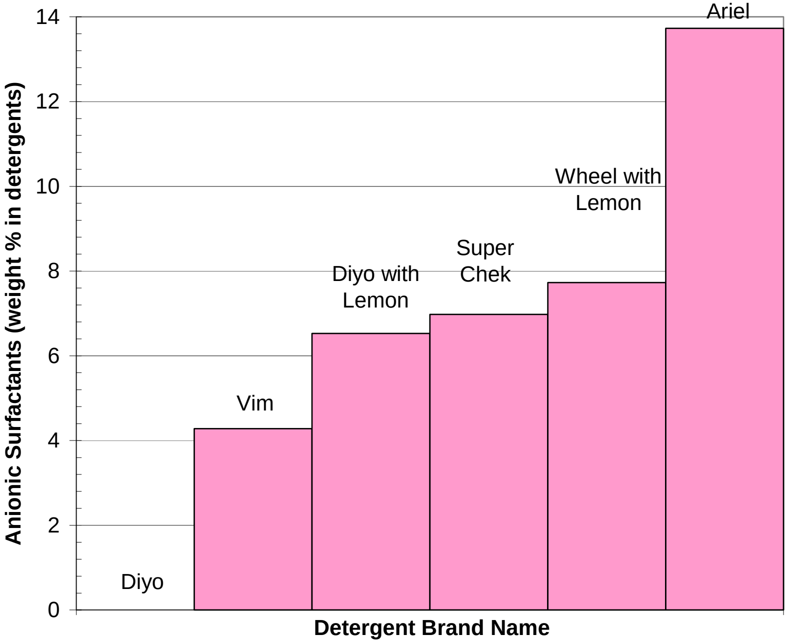
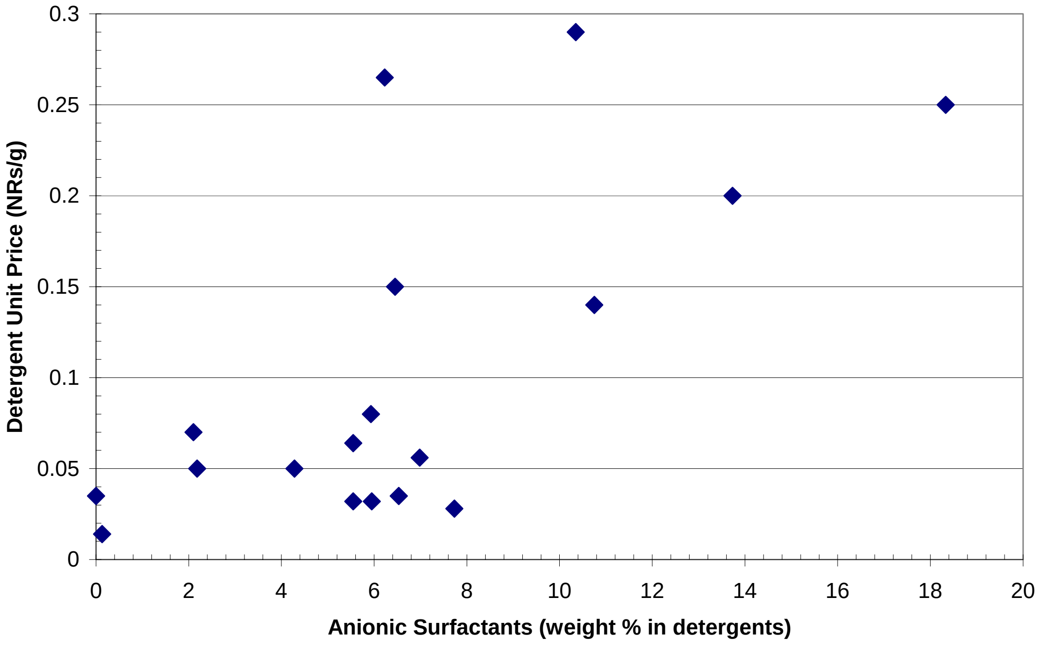


Figure 6.4 below compares price with surfactant concentration for all detergents tested.

Figure 6.4: Detergent Price vs Anionic Surfactant Concentration



The graph exhibits an overall increase in detergent price with surfactant concentrations. This trend is reasonable, as surfactants are some of the more costly detergent components.

A second round of detergents tests showed extensive amounts of surfactant degradation in all the detergent samples. Figures 6.5 and 6.6 illustrate the total anionic surfactant levels (also shown in Figures 6.2 and 6.3) and the concentrations remaining at the time of the second round of detergent tests.

Figure 6.5: Degraded and Non-degraded Fractions of Anionic Surfactants in Powder Detergents

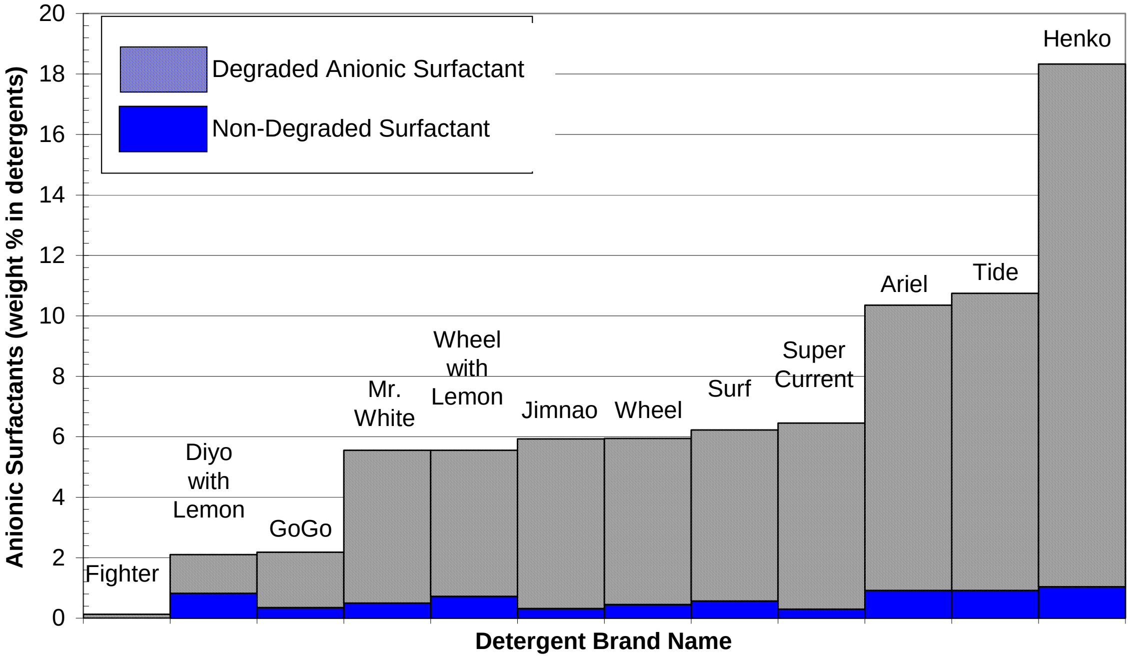
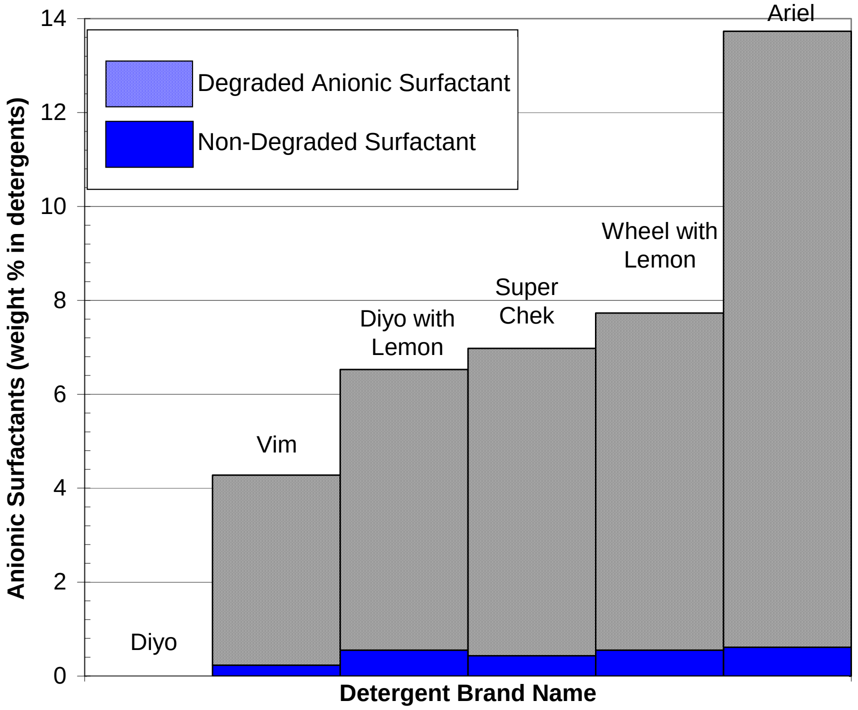


Figure 6.6: Degraded and Non-degraded Fractions of Anionic Surfactants in Bar Detergents



Regardless of total anionic surfactant concentration, almost all the samples degraded to less than 1 weight percent surfactant by the second round of testing. The exception to this trend is Wheel powder, which degraded to 2.4 weight percent surfactant by the second round of testing and to 0.45 weight percent in a third test.

From Figures 6.2 and 6.3, the average concentration of anionic surfactants among the detergents tested is 6.6 weight percent. Further, the average amount of persistent anionic surfactant (shown in Figures 6.5 and 6.6) among the detergents is 0.5 weight percent. In this thesis, these average concentrations are considered to be representative of detergents used in Nepali households.

6.3 *Orthophosphate Analysis*

6.3.1 *Orthophosphate Procedure*

Analysis of detergents for orthophosphates was performed at ENPHO according to the following procedure:

1. Dissolve 1.0 g detergent sample in 100 mL deionized water to make a 10 mg/mL solution.

2. Add 10 mL of detergent solution prepared in step 1 to 40 mL deionized water to make 50 mL of 2 mg/mL detergent solution.

3. Prepare 0.1 mg/L, 0.2 mg/L, 0.4 mg/L and 0.8 mg/L of standard PO_4 solution using ENPHO's stock 100 mg/L PO_4 solution.
    a. Add 10 mL of 100 mg/L stock PO_4 solution to 90 mL deionized water to make 100 mL of 10 mg/L PO_4 solution.
        i. ENPHO's stock PO_4 solution prepared by dissolving 4.39 g KH_2PO_4 in deionized water to 1000 mL of solution
    b. Add 0.5 mL of the solution prepared in step 3a to 49.5 mL deionized water to make 50 mL of 0.1 mg/L solution.
    c. Add 1.0 mL of the solution prepared in step 3a to 49 mL deionized water to make 50 mL of 0.2 mg/L solution.
    d. Add 2.0 mL of the solution prepared in step 3a to 48 mL deionized water to make 50 mL of 0.4 mg/L solution.
    e. Add 4.0 mL of the solution prepared in step 3a to 46 mL deionized water to make 50 mL of 0.8 mg/L solution.

4. Prepare reagent
    a. For every 100 mL reagent needed, dissolve 1.08 g ascorbic acid in 20 mL deionized water.
    b. Add solution prepared in step 4a to 80 mL ENPHO's stock reagent.
        i. ENPHO's stock reagent prepared by first dissolving 3.75 g $H_{24}Mo_7N_6O_{24}$ in 400 mL deionized water.
        ii. 0.2150 g $C_4H_4KO_7Sb$ added to solution prepared in 4bi.
        iii. While stirring and cooling, 44 mL concentrated H_2SO_4 added to solution prepared in step 4bii.
        iv. Stock reagent stored in amber glass bottle and refrigerated.

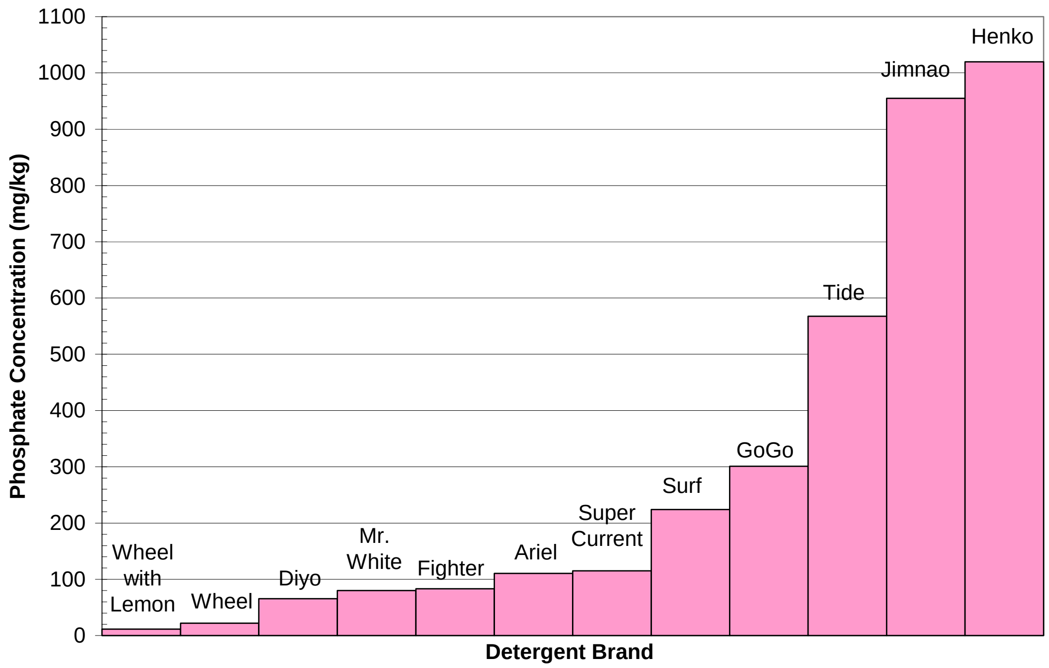
5. Add 8 mL reagent to each detergent sample, each standard solution and the blank (50 mL deionized water).

6. After 1 hr, analyze solutions using a spectrophotometer at 880 nm.

6.3.2 *Orthophosphate Results*

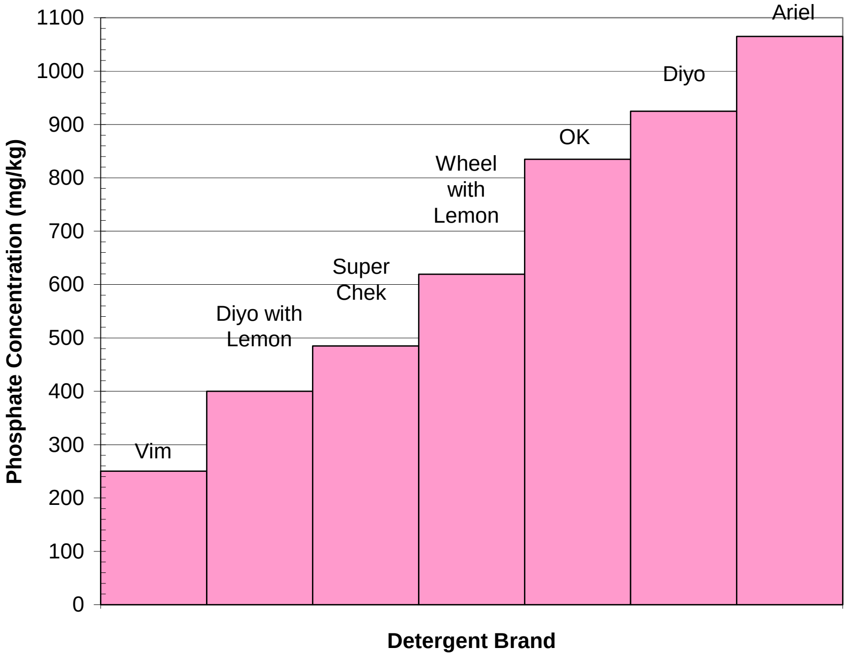
Figures 6.7 and 6.8 below illustrate the orthophosphate levels in the detergents analyzed. Phosphate concentrations range from almost zero to over 1,000 mg/kg. These concentrations are considerably lower than expected. A cluster exists among the powdered detergents around 100 mg/kg phosphates, but phosphate levels in the detergent bars display no such correlation.

Figure 6.7: Phosphate Concentration in Powder Detergents



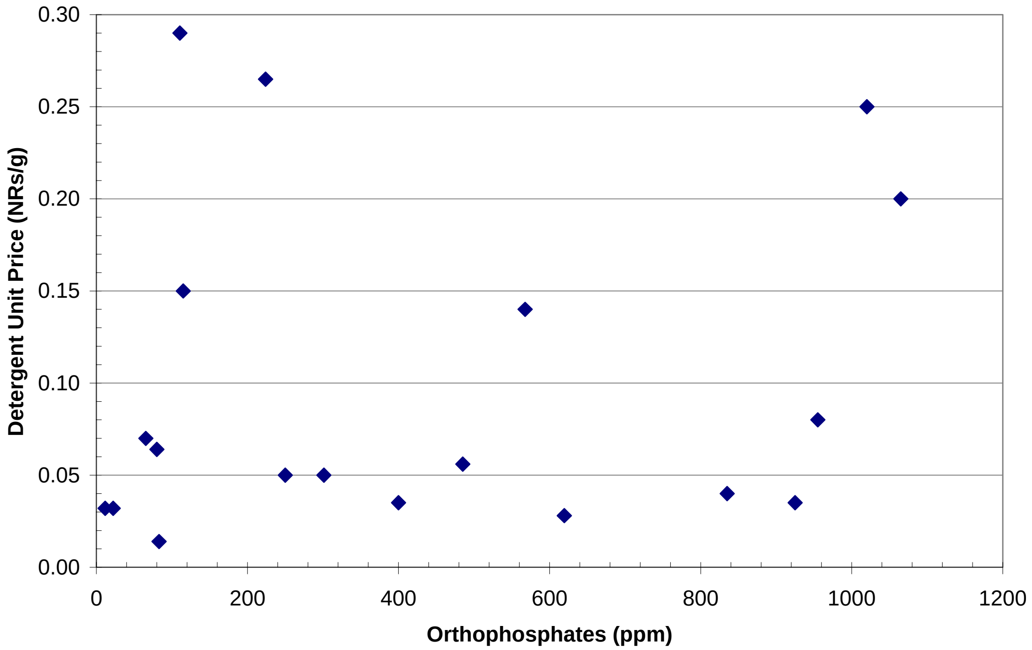
In Chapter 5, the author makes reference to regulations passed by individual states within the United States to limit phosphates in detergents to 8.7 weight percent. This is 87,000 mg phosphates/kg detergent – much higher than any values observed in these samples.

Figure 6.8: Phosphate Concentrations in Bar Detergents



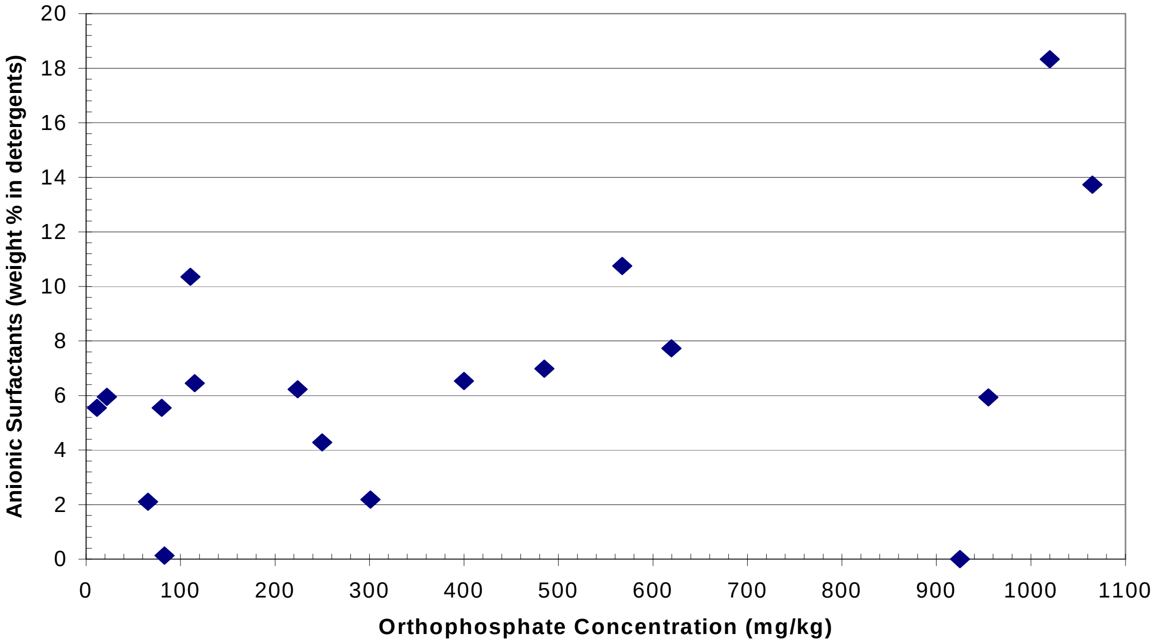
From Figures 6.7 and 6.8, the average phosphate concentration among the detergents tested is 402 mg/kg. As discussed in section 6.2.2, the characteristic detergent for the purposes of this thesis, then, contains 402 mg/kg orthophosphates.

Figure 6.9: Detergent Price vs Phosphate Concentration



Unlike with anionic surfactants, no direct relationship exists between phosphate concentration and detergent price, as displayed in Figure 6.9. Furthermore, in Figure 6.10, anionic surfactant levels are only weakly related to phosphate levels in the detergents tested.

Figure 6.10: Anionic Surfactant vs Orthophosphate Concentration



It is interesting to note that from Figure 6.10, the laundry detergents with the two highest surfactant concentrations, Henko Megastar and the bar form of Ariel, also have the two highest phosphate concentrations. This observation seems counterintuitive, because the role of phosphates as builders is to prevent hardness ions from complexing with surfactants – high phosphate levels should lower the required surfactant level.

7. Results and Discussion

7.1 *Conclusions Regarding Detergents and Foaming*

Using the manufacturers' recommendations on the detergent labels, a typical load of wash water is approximately 25 g (1 handful) detergent in 4 L (half bucket) of water. From the average total and non-biodegradable anionic surfactant levels estimated in Chapter 6, characteristic wash water for one load of laundry contains 6.25 g detergent/L, 413 mg total anionic surfactant/L and 32 mg ABS/L.

The minimum concentration at which anionic surfactants foam depends on both the medium and the level of pollution. For example, in distilled water, the foaming limit is 5 mg ABS/L. In typical wastewaters, surfactant foaming ceases at levels below 0.5 mg/L.

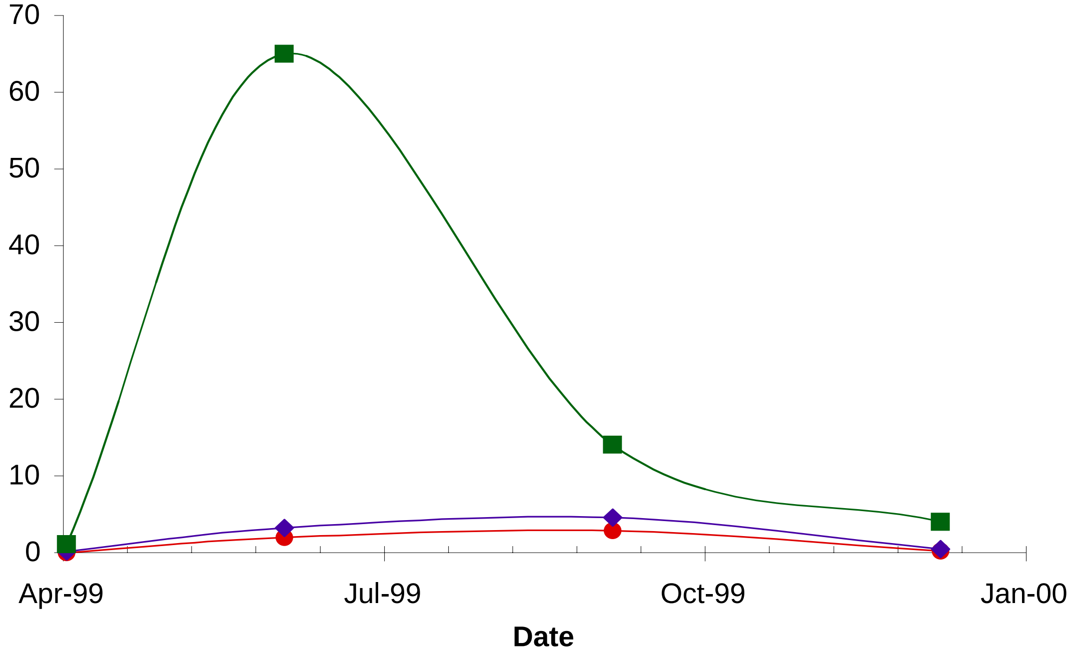
As mentioned in Chapter 1, Kathmandu City has a population of approximately 500,000 residents (Finlay, 2001). The average family size in Nepal is 6 people, so Kathmandu City is home to approximately 83,000 families. If one load of laundry is washed per family every week, using 4 L water for a load of laundry, 333 m^3 wash water is generated every week in Kathmandu City, or 5×10^{-4} m^3/s (0.011 MGD).

Figure 7.1 (repeat of Figure 2.3) displays flow rate data for specific sites along the Bagmati River. The lowest flow rates occur during the dry season (April) for all three sampling sites, at which time the Bagmati River flows at a rate of less than 1 m^3/s (22.6 MGD). If the worst case scenario is assumed, such that all of the wastewater generated by laundry washing is discharged into the Bagmati River, the wash water is diluted by a factor of about 2000. In such as case, the resulting total anionic surfactant concentration in the Bagmati River is about 0.2 mg/L, and the ABS concentration 0.016 mg/L, both below the limit of foaming.

For total anionic surfactant levels in the River to reach 0.5 mg/L, each family unit would have to wash 2.5 loads of laundry per week during the dry season. ADB estimates that residents of Kathmandu City use 25 L water/day-person (1,050 L water/week-family) (Metcalf & Eddy, 2000). It is entirely possible, then, that families would sacrifice 10 L/week for 2.5 loads of laundry/week.

The Bagmati River flow rates are at their highest between July and October, reaching peak flows of 4.6 m^3/s (104 MGD) at Pashupati and 65 m^3/s (1,470 MGD) at Sundarighat. For foaming problems to occur in the River at these flow rates, families would have to average more than 11 and 160 loads of laundry per week, respectively. The former situation of 11 laundry loads/week-family is possible though improbable, but the latter is absurd.

Figure 7.1 (also 2.3): Flow Rates along the Bagmati River



From the flow rate data displayed in Figure 1.7, the author concludes that detergents used to wash laundry could cause foaming in the Bagmati River. In fact, Figure 3.2 shows foam floating along the Bagmati River at Chovar (see Figure 2.1 for the location of Chovar). Aside from being aesthetically unpleasant, foaming in surface waters is not a serious water quality concern itself. It does, however, serve to indicate more significant pollution problems.

For example, if the dissolved oxygen (DO) levels in the Bagmati River were sufficient, microorganisms would degrade the labile portions of anionic surfactant, leaving behind concentrations well below the foaming limit. Figure 2.4 shows that the DO levels are low enough in certain areas of Kathmandu to inhibit aerobic microbial activity. Figure 2.8, plotting BOD concentrations, helps to explain why dissolved oxygen levels are so low in the River. BOD concentrations in the Bagmati River are on the same order as those in the influent sewage to the Guheshwori WWTP (influent BOD is 270 mg/L, see Figure 1.6) and likely use up much of the River's dissolved oxygen.

Using the same method of analysis as above, one can estimate the contribution of household detergent use to foaming problems at the Guheshwori WWTP. From Figure 1.6, the

Guheshwori treatment plant was designed in 1996 to serve a population of 58,000. Also, the facility has a treatment capacity of 0.19 m^3/s (4.3 MGD). If we again assume families of 6, then the wastewater facility serves 9,700 families. As before, 1 load of laundry/week-family contributes $5x10^{-4}$ m^3/s (0.011 MGD) wash water to the wastewater. The wash water is diluted 390 times in the wastewater influent, so the concentration of total anionic surfactant in the influent stream is 1.1 mg/L. Once the wastewater is aerated and labile surfactants degrade, 0.08 mg/L ABS remains in the waste stream.

For the ABS to cause foaming in the Guheshwori WWTP, 6 loads of laundry/week-family are required. As in the analysis of household detergent in the Bagmati River, it is certainly possible that surfactants exist in high enough concentrations to cause foaming in receiving waters. The author is skeptical, however, that the non-degraded surfactant portions reported in Chapter 6 are actually ABS. The test conditions under which the surfactants were analyzed ensured an aerobic environment, but they are not adequate for predicting the biodegradation of the surfactants in activated sludge treatment plant. Two important differences in the processes are the oxygen transfer rate and the bacterial concentration.

I believe that surfactants in household laundry detergents do play a role in the foaming problems at the Guheshwori WWTP, albeit a small one. Perhaps more serious contributors are surfactants from industrial detergents, especially those used in the carpet and textile industries. The author seeks to stress at this point that the environmental advantages associated with the use of LAS instead of ABS are only applicable in situations of adequate wastewater treatment and high quality receiving waters. LAS is readily biodegradable only under aerobic conditions; in anoxic and anaerobic circumstances, LAS is as stable as ABS.

Wastewater treatment is the best way of ensuring that waste streams contain adequate levels of dissolved oxygen, especially when alternative receiving waters like the Bagmati River are highly polluted. If the surfactants are not degraded, concentrations will accumulate until they surpass the foaming limit, and turbulent flow will result in foaming by LAS and ABS alike.

The real issue with foaming in the Guheshwori WWTP and in places along the Bagmati River is not a matter of the use of LAS versus ABS, but an indication of more serious water quality problems, namely poor surface water quality and inadequate wastewater treatment.

Moreover, the failure of the Guheshwori WWTP and of activated sludge treatment facilities in general to remove surfactants from wastewater illuminates a startling trend in foods, health and beauty products and cleaning agents alike. Consumer products and medicines are becoming ever-increasingly sophisticated and complex in chemical structure, and many constituents of these products pass right through treatment facilities without being detected, removed or changed in any way. These chemicals retain the properties that make them so useful in consumer products and have the potential to behave in the environment in ways we never intended. The passing of anionic surfactants through wastewater treatment plants and into rivers and lakes is hardly more than an aesthetic issue, but when considering prescription drugs or disinfecting agents, the issue can become a serious problem.

7.2 *Conclusions Regarding Detergents and Eutrophication*

Using, again, the manufacturer's recommendations from Section 7.1 (6.25 g detergent/ L wash water) and the representative phosphate concentration from Chapter 6 (402 mg orthophosphate/kg detergent), the wash water from an average load of laundry contains 2.5 mg/L orthophosphates.

If each family in Kathmandu City were to wash 1 load of laundry/week during the dry season (Bagmati River flow is about 1 m^3/s or 22.6 MGD) and discharge all their wash water into the Bagmati River, household laundry detergents would contribute 10^{-3} mg phosphates/L to the River. From Figure 2.10, phosphate levels in the Bagmati River were as high as 1.6 mg/L during May, 2001. Each family in Kathmandu would need to wash 100 loads of laundry per week even to contribute 0.1 mg/L to this 1.6 mg/L phosphates.

During other seasons of the year, the flow rate of the Bagmati River increases, so phosphates in laundry detergents pose even less of a threat. From these figures, I would conclude that household detergents do contribute to phosphate loading in the Bagmati River.

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Appendix A: SATWQM Data

Figure A.1: SATWQM Data from April to August, 2002

Location	DO (mg/L)	TDS (g/L)	pH	Turbidity NTU	NO_3 (mg/L)	PO_4 (mg/L)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)
April, 2002									
Sundarijal	7.94	0.03	na	25	na	na	na	6.24	
Sundarighat	0.31	0.36	na	10	na	na	na	226.72	
Gaur	7.56	0.19	na	10	<0.05	<0.05	na	na	
May, 2002									
Sundarijal	7.79	0.01	6.650	<10	0.000	0.100	5.6	0.72	5.28
Pashupati	6.01	0.05	6.550	50	1.710	0.110	71.3	6.15	17.42
Tilganga	3.48	0.29	6.710	100	12.850	0.760	101.0	59.80	168.96
Sundarighat	0.66	0.26	7.040	100	0.630	1.680	166.0	240.00	316.80
Chovar	5.33	0.24	7.170	100	1.710	1.640	222.0	170.00	258.72
Gaur	3.85	629	7.810	>100	na	na	na	na	na
June, 2002									
Sundarijal	5.26	0.01	6.79	<10	0.210	0.190	na	0.41	4.40
Pashupati	4.08	0.04	6.66	60.000	1.670	0.190	na	2.63	15.40
Tilganga	2.52	0.28	6.71	>100	6.800	1.430	na	151.50	277.20
Sundarighat	0.52	0.26	7.12	100.000	5.170	1.390	na	40.40	123.20
Chovar	3.74	0.25	7.29	100.000	6.000	1.350	na	44.40	59.40
Gaur	5.20	0.09	7.83	>100	1.330	0.220	na	na	20.68
July, 2002									
Sundarijal	8.49	0.01	6.90	<10	na	0.13	na	0.71	4.52
Pashupati	6.6	0.04	6.74	>100	1.99	0.19	na	23.20	27.12
Tilganga	6.22	0.11	6.70	>100	3.87	0.44	na	80.80	113.00
Sundarighat	0.37	0.23	7.04	>100	2.40	1.15	na	17.50	180.80
Chovar	4.82	0.23	7.22	>100	2.46	1.01	na	42.40	226.00
Gaur	7.65	0.10	7.70	>100	6.32	0.09	na	na	31.82
August, 2002									
Sundarijal	7.36	0.02	6.70	<10	0.50	0.03	28.0	0.54	2.04
Pashupati	5.91	0.11	6.75	>100	0.61	0.09	185.0	5.84	12.65
Tilganga	5.92	0.05	6.78	>100	1.89	0.43	336.0	69.20	71.40
Sundarighat	6.39	0.12	7.29	>100	3.39	0.31	304.0	54.00	110.16
Chovar	6.22	0.13	7.27	>100	3.83	0.32	576.0	49.60	112.61
Gaur	6.19	0.10	7.95	>100	2.23	0.06	na	na	112.61

Figure A.2: SATWQM Data from September to December, 2002

Location	DO (mg/L)	TDS (g/L)	pH	Turbidity NTU	NO_3 (mg/L)	PO_4 (mg/L)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)
September, 2002									
Sundarijal	8.75	0.01	6.58	500	10.00	0.05	373.0	1.60	16.73
Pashupati	7.20	0.03	6.19	100	10.00	0.05	291.0	3.00	48.96
Tilganga	6.76	0.06	6.25	200	10.00	0.50	286.0	32.00	244.80
Sundarighat	5.45	0.00	6.37	100	10.00	0.50	148.0	51.00	159.12
Chovar	6.10	0.16	6.86	100	25.00	0.25	146.0	45.00	57.12
Gaur	6.00	0.10	7.50	100	10.00	0.10	na	na	57.00
October, 2002									
Sundarijal	9.11	0.01	6.63	<5	0.49	0.05	11.0	0.40	8.32
Pashupati	7.19	0.04	6.39	20	3.33	0.08	32.0	3.00	15.81
Tilganga	4.88	0.22	6.53	60	0.79	1.10	78.0	90.00	191.36
Sundarighat	0.41	0.23	6.68	75	0.64	1.28	92.0	50.00	180.96
Chovar	5.60	0.22	6.88	75	0.42	1.50	86.0	54.00	178.88
Gaur	7.96	0.14	7.76	<10	2.58	0.14	na	na	7.42
November, 2002									
Sundarijal	8.64	0.01	6.19	<5	<.050	0.04	3.0	0.47	7.81
Pashupati	7.53	0.05	6.39	15	0.15	0.04	76.7	5.30	20.50
Tilganga	4.58	0.32	6.55	100	0.31	0.50	87.0	93.00	195.20
Sundarighat	0.48	0.26	6.75	85	<.050	1.24	116.0	99.00	180.56
Chovar	5.11	0.24	6.95	<100	<.050	1.14	96.0	76.00	126.88
Gaur	9.16	0.15	7.96	<10	5.59	0.14	na	na	8.30
December, 2002									
Sundarijal	10.22	0.01	6.23	<5	<10	0.02	2.5	3.65	11.00
Pashupati	9.16	0.00	6.27	>10	10.00	0.02	78.0	7.10	15.50
Tilganga	6.03	0.39	6.68	200	<10	0.80	100.0	134.40	275.00
Sundarighat	1.85	0.36	6.47	180	<10	1.00	144.0	109.40	255.00
Chovar	5.25	0.31	6.70	200	<10	1.00	112.0	78.80	205.00
Gaur	10.22	0.16	7.94	>5	30.00	0.05	na	na	3.50

Appendix B: Data from Surfactant Testing

3/25/03

Charles River Water:no dilution; spectrophotometer reading of 0.036 mg/L

Wheel:spectrophotometer reading of 0.168 mg/L

	0.0595	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	238	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	8.0	mg surfactant/L
	5	mL solution 2
added to	*295*	mL river water
to make solution 3:	0.168	mg surfactant/L

Tide:spectrophotometer reading of 0.179 mg/L

	0.1075	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	430	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	14.4	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.179	mg surfactant/L

Henko Megastar:spectrophotometer reading of 0.280 mg/L

	0.1833	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	733.2	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	24.5	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.280	mg surfactant/L

3/26/03

Charles River Water:no dilution; spectrophotometer reading of 0.059 mg/L

Jimnao:spectrophotometer reading of 0.138 mg/L

	0.0593	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	237.059	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	8.0	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.138	mg surfactant/L

Diyo w/ lemon powder:spectrophotometer reading of 0.087 mg/L

	0.0210	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	84.059	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	2.9	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.087	mg surfactant/L

Mr. White:spectrophotometer reading of 0.133 mg/L

	0.0555	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	222.059	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	7.5	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.133	mg surfactant/L

GoGo:spectrophotometer reading of 0.088 mg/L

	0.0218	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	87.059	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	3.0	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.088	mg surfactant/L

Vim:spectrophotometer reading of 0.116 mg/L

	0.0428	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	171.059	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	5.8	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.116	mg surfactant/L

Surf:spectrophotometer reading of 0.142 mg/L

	0.0623	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	249.059	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	8.4	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.142	mg surfactant/L

3/27/03

Charles River Water:no dilution; spectrophotometer reading of 0.041 mg/L

Super Current:spectrophotometer reading of 0.084 mg/L

	0.0645	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	258.041	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	8.6	mg surfactant/L
	1.5	mL solution 2
added to	*298.5*	mL river water
to make solution 3:	0.084	mg surfactant/L

Fighter: spectrophotometer reading of 0.045 mg/L

	0.0013	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	5.183857	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.2	mg surfactant/L
	7	mL solution 2
added to	*293*	mL river water
to make solution 3:	0.045	mg surfactant/L

Ariel: spectrophotometer reading of 0.110 mg/L

	0.1035	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	414.041	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	13.8	mg surfactant/L
	1.5	mL solution 2
added to	*298.5*	mL river water
to make solution 3:	0.110	mg surfactant/L

3/28/03

Charles River Water: no dilution; spectrophotometer reading of 0.043 mg/L

Wheel w/ Lemon (powder): spectrophotometer reading of 0.117 mg/L

	0.0555	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	222.043	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	7.4	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.117	mg surfactant/L

Diyo (bar):spectrophotometer reading of 0.041 mg/L

	-0.0015	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	-5.957	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	-0.2	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.041	mg surfactant/L

Ariel (bar):spectrophotometer reading of 0.226 mg/L

	0.1373	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	549.043	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	18.3	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.226	mg surfactant/L

Wheel w/ Lemon (bar):spectrophotometer reading of 0.146 mg/L

	0.0773	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	309.043	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	10.3	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.146	mg surfactant/L

Diyo w/ Lemon (bar):spectrophotometer reading of 0.130 mg/L

	0.0653	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	261.043	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	8.7	mg surfactant/L
	3	mL solution 2
added to	*297*	mL river water
to make solution 3:	0.130	mg surfactant/L

Super Chek: spectrophotometer reading of 0.105 mg/L

	0.0698	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	279.043	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	9.3	mg surfactant/L
	2	mL solution 2
added to	*298*	mL river water
to make solution 3:	0.105	mg surfactant/L

4/5/03

Wheel powder: spectrophotometer reading of 0.059 mg/L

	0.0242	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	96.80925	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	3.3	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.059	mg surfactant/L

Tide: spectrophotometer reading of 0.022 mg/L

	0.0092	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	36.79988	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	1.3	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.022	mg surfactant/L

4/7/03

Diyo with lemon:spectrophotometer reading of 0.026 mg/L

	0.0082	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	32.75189	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	1.1	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.026	mg surfactant/L

Ariel:spectrophotometer reading of 0.022 mg/L

	0.0092	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	36.79988	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	1.3	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.022	mg surfactant/L

4/9/03

Wheel w/ lemon (bar):spectrophotometer reading of 0.014 mg/L

	0.0055	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	22.1929	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.8	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.014	mg surfactant/L

Wheel w/ lemon (powder):spectrophotometer reading of 0.013 mg/L

	0.0050	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	19.95076	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.7	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.013	mg surfactant/L

Diyo w/ lemon (bar):spectrophotometer reading of 0.014 mg/L

	0.0055	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	21.89703	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.8	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.014	mg surfactant/L

Ariel (bar):spectrophotometer reading of 0.015 mg/L

	0.0061	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	24.3057	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.9	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.015	mg surfactant/L

4/11/03

Henko Megastar:spectrophotometer reading of 0.024 mg/L

	0.0104	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	41.56276	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	1.4	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.024	mg surfactant/L

Mr. White:spectrophotometer reading of 0.019 mg/L

	0.0072	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	28.91479	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	1.0	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.019	mg surfactant/L

5/2/03

Wheel:spectrophotometer reading of 0.011 mg/L

	0.0045	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	17.8744	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.6	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.011	mg surfactant/L

Vim:spectrophotometer reading of 0.007 mg/L

	0.0023	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	9.099959	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.4	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.007	mg surfactant/L

Surf:spectrophotometer reading of 0.016 mg/L

	0.0057	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	22.8409	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.8	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.015	mg surfactant/L

5/3/03

Jimnao:spectrophotometer reading of 0.009 mg/L

	0.0032	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	12.68891	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.5	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.009	mg surfactant/L

Gogo: spectrophotometer reading of 0.009 mg/L

	0.0035	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	14.19073	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.5	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.009	mg surfactant/L

Super Chek: spectrophotometer reading of 0.011 mg/L

	0.0043	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	17.05496	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.6	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.011	mg surfactant/L

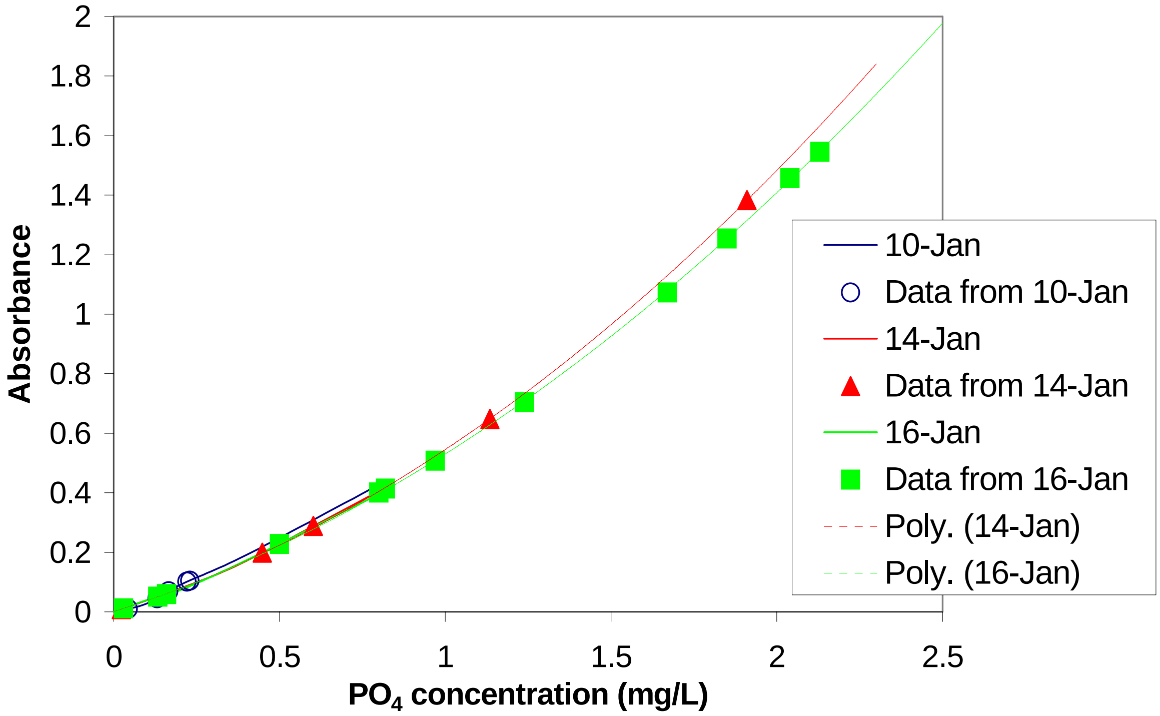
Super Current: spectrophotometer reading of 0.008 mg/L

	0.0030	g surfactant/g detergent
	0.4	g detergent
added to	*100*	mL tap water
to make solution 1:	4000	mg detergent/L
	12.11388	mg surfactant/L
	10	mL solution 1
added to	*290*	mL river water
to make solution 2:	0.4	mg surfactant/L
	5	mL solution 2
added to	*95*	mL river water **[stored]**
and	*200*	mL tap water
to make solution 3:	0.008	mg surfactant/L

Appendix C: Phosphate Analysis Data

Phosphate readings were calibrated against ENPHO stock phosphate solutions, and Figure C.1 shows the calibration curves used to convert absorbance readings into phosphate concentrations.

Figure C.1: Calibration Curve for Phosphate Analysis



Calibration, Jan 10

	PO_4 conc (mg/L)	absorbance @ 880 nm
blank	0	0
stock	0.1	0.028
stock	0.2	0.091
stock	0.4	0.191
stock	0.8	0.427
Diyo	0.131	0.046
Super Current	0.230	0.105
Ariel	0.221	0.102
Wheel	0.044	0.01
Fighter	0.166	0.069

Calibration, Jan 14

	PO_4 conc (mg/L)	absorbance @ 880 nm
blank	0.00001	0.00001
stock	0.1	0.039
stock	0.2	0.078
stock	0.4	0.171
stock	0.8	0.405
Wheel w/ lemon	0.023	0.009
GoGo	0.602	0.289
Tide	1.135	0.648
Jinmao	1.91	1.383
Surf Excel	0.448	0.199

Calibration, Jan 16

	PO_4 conc (mg/L)	absorbance @ 880 nm
blank	0.00001	0.00001
stock	0.1	0.04
stock	0.2	0.073
stock	0.4	0.173
stock	0.8	0.396
Wheel w/ lemon (bar)	1.239	0.704
Super Chek	0.97	0.508
Henko	2.04	1.457
Mr. White	0.16	0.06
Ariel (bar)	2.13	1.545
Super OK	1.67	1.073
Diyo (reg bar)	1.85	1.254
Diyo (bar with lemon)	0.8	0.401
Vim	0.5	0.228
WWTP influent	0.82	0.414
WWTP effluent	0.03	0.012
Tap Water	0.133	0.051