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of surfactant molecules on the surface, there will be a tendency for the surface to flow opposite the stretching. This increases the damping and causes the oscillations of surfactant-bearing drops (Fig. 2*b*, *c*) to die out more quickly than those of pure water (Fig. 2*a*). This excess damping will be less if the surfactant molecule can move rapidly between the surface and the inside of the drop to help restore the surface equilibrium. Bovine serum albumin is a large protein molecule which actually changes shape when it gets to the surface, and thus cannot move very rapidly either along the surface or between the bulk and the surface. The result is a dramatic damping of the oscillations (Fig. 2*c*). This effect has been recognized for centuries. Ancient Greek divers routinely poured olive oil on the surface of the sea in order to damp the surface waves and enable them to see into the water more easily.

When the initial deformation is very large, the oscillations become very nonlinear (**Fig. 3**). Such highly nonlinear oscillations are much more difficult to describe mathematically even for a pure liquid; nevertheless, they will provide a stringent test for theoretical models which incorporate both the fluid dynamics of a single-component liquid drop and the effects of surfactants dissolved in the liquid.

Applications. Over 100 h of drop oscillation experiments were conducted during the flight of *STS 73*. One goal of this research is to validate a theoretical surfactant transport modeling approach for the ideal case in order to be able to extend the modeling to include the effects of a constant high-amplitude acoustic field. This validation will allow research to be conducted in Earth-based levitators, where the acoustic field necessary to hold very small drops (1 mm or 0.04 in. in diameter) results in both a static deformation and a nonlinear, amplitude-dependent restoring force for oscillations, which can mask surfactant effects on the oscillations. Ultimately, the space experiments described here will yield information on surface diffusivity and frequency-dependent sorption rate constants for surfactants. Such information, incorporated into the theoretical model, will allow the prediction of macroscopic rheological effects in very practical industrial situations from the specification of fundamental structural and transport properties of a given surfactant species.

For background information *see* ACOUSTIC LEVITATION; ACOUSTIC RADIATION PRESSURE; DAMPING; SURFACE TENSION; SURFACTANT; VIBRATION; WEIGHTLESSNESS in the McGraw-Hill Encyclopedia of Science & Technology. R. Glynn Holt

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Wetlands

Water quality from point sources of pollution such as factories and city sewers has been regulated in the United States since the 1970s. Recently, nonpoint source effects on water quality have become important issues. Croplands and grazing lands are increasingly scrutinized for their contribution to nutrient loading of water bodies. While improvements in grazing management usually can reduce such loading, the nutrient loading contribution by grazing animals may be overestimated, and goals for reduction of nutrient loading may be unrealistic. Determining background levels is difficult but critical to setting realistic goals for nutrient loading.

Eutrophication. The process by which water bodies become rich in nutrients supporting abundant microbiotic growth is called eutrophication. This natural process can be accelerated by pollution or entry of excess phosphorus and other nutrients to shallow reservoirs or lakes. Nonpoint sources may equal or exceed the phosphorus load of point sources. Often the natural or background levels are unknown. The phosphorus load in a stream is a function of the geologic materials, soils, topography, vegetative cover, precipitation intensity, and water hydraulics. The contribution of phosphorus from natural sources can be difficult to differentiate from anthropogenic sources of stream phosphorus.

Phosphorus transport. Elevated phosphorus loading of wetlands, streams, lakes, and reservoirs can occur from nonpoint sources such as grazed uplands, wet meadows, seasonally flooded lands, and saturated wetlands. Erosion caused by livestock grazing or other activities will increase total phosphorus load in streams. However, herbivores can also harvest phosphorus from forage and export a portion of it from the watershed. Some land managers fail to recognize that phosphorus taken up by plants will continue to cycle through soil and water. Soluble phosphorus in water or phosphorus attached to soil particles suspended in water are the primary vectors of phosphorus movement in a watershed. Herbivores add another vector with more opportunities to export phosphorus from the watershed. Use of best-management practices such as rotational grazing, buffer strips next to wetlands, and proper irrigation management should reduce overland water flow and stream-bank erosion. Livestock grazing should harvest and remove a significant amount of phosphorus from an ecosystem by incorporating phosphorus into bone and tissue of growing animals and then exporting beef animals from the watershed.

Livestock grazing. Many high mountain valleys in the Northwest have subirrigated meadows which are typically used for summer grazing by cattle. During the spring cattle are moved into these watersheds, and in the fall they are moved out. Some riparian areas suffer from accelerated stream-bank erosion. Overland erosion rates may be as high as 0.1 ton/acre (200 kg/hectare) annually. Thousands of tons of sediment may be added annually to water bodies in moderate-sized watersheds (occupying more than 10,000 acres).

Grazing affects phosphorus cycling. A portion of phosphorus from plants is retained by growing animals and incorporated into bone and soft tissue or into milk of lactating females. Undigested nutrients are excreted from the body in feces and urine. Proper grazing management is essential to reducing nutrient loadings to streams. Total phosphorus concentrations in surface runoff from continuously grazed watersheds may be three times higher than those from rotationally grazed watersheds because of greater soil loss. Since vacation home owners and recreationists seek property near water bodies and want excellent water quality, the perception is that the environmentally correct solution is the removal of livestock grazing from the watershed.

Nutrient cycling. Transport of phosphorus by overland flow depends on desorption, dissolution, and extraction of phosphorus from soil, and mineralization of plant material and feces. Temperature, precipitation, presence of anaerobic soil conditions, and evapotranspiration rates further influence the process. Much of the phosphorus enters the wetlands as a pulse during snow melt. Also, as plants die or become senescent, leaves, stems, and roots decompose by weathering and microbiotic assimilation of nutrients. Nutrients are recycled to the soil, where they remain until absorbed by plants or are leached from the soil into water bodies. About 75% of total phosphorus may be leached from dormant or dead vegetation. Plant species composition, precipitation, and decay rate affect the phosphorus leached from plant material. Soil phosphorus loss is dependent on the capacity and charge of ion-exchange sites on minerals and organic matter, pH, and concentrations and interactions of other elements.

In a system without herbivores, nutrients cycle from soil to soil water, to plants, to litter, and back to soil. Erosion of soil or leaching through the ground water transports phosphorus to streams and reservoirs. When herbivores are added to the ecosystem, phosphorus may be found in more chemical forms with varying solubility. Urine and feces return unabsorbed or unretained phosphorus to the soil surface to continue cycling. Livestock grazing does not create phosphorus. Livestock consume forage containing phosphorus that is susceptible to loading streams, regardless of the grazing. There is a need to determine the forms, solubilities, and rates of phosphorus release from plant material versus animal wastes.

Patterns of dung and urine deposition are not uniform. Such patterns may be more distinct with sheep, where 1-2 lb phosphorus/acre (1-2 kg/hectare) annually may be concentrated at ridges where sheep camp at night. Theoretically, a best-management practice of high-intensity and short-duration grazing should provide more uniform dung distribution. However, phosphorus is still accumulated in areas closest to shade and water, as a result of urine and feces deposition by livestock and wild ungulates. If the only source of shade and water is near a wetland or stream, deposition of animal waste could be a significant contributor of phosphorus to the wetland. It is clear that any activity accelerating erosion will increase total phosphorus load. It is not clear what effects grazing will have on soluble-phosphorus loading to streams and reservoirs.

PURGE model. The Phosphorus Uptake and Removal from Grazed Ecosystems (PURGE) simulation model was developed to estimate phosphorus uptake by grass and phosphorus retention in bodies of grazing cattle. The variables include known, approximate, and assumed values based on measurements, the literature, and personal experience.

The net phosphorus absorption by cattle is about 90% efficient in young calves and 55% efficient in cows. The phosphorus concentration of forage can vary between 0.18 and 0.30%, depending on soil series, temperature, interactions with other nutrients, fertilizer treatments, soil moisture, plant species, and plant growth stage.

The phosphorus composition of bone and soft tissues in cattle is highly predictable, and therefore the phosphorus export is easily calculated from weight gain by cattle while on the pastures. Bone ash contains 16-17% phosphorus, making up 75-80% of total body phosphorus (in the skeleton and teeth). Using moderate values in the PURGE simulation, the model produced an estimate for phosphorus removed from the watershed of 22 tons (20 megagrams), or 1 lb phosphorus removed per acre (1 kg/hectare).

The PURGE model clearly demonstrates that grazing livestock which are gaining weight in soft tissue and bone (either calves or cows with developing fetuses) will export phosphorus from the ecosystem when cattle are removed from the area. Hypothetically, the amount of phosphorus exported is significant and could be equal to the average load entering the reservoir. However, whether this export of phosphorus actually reduces phosphorus loading to the reservoir depends on good grazing management to protect stream banks from erosion and to limit deposit of feces and urine in the water. When properly managed, grazing cattle can remove phosphorus from the ecosystem, but improperly managed grazing can simultaneously increase phosphorus loading to streams and reservoirs. Even at the above predicted rates of phosphorus export, erosion and large runoff events would produce big phosphorus loads because of the enormous mass of the phosphorus pool in soil and minerals.

Recommendations of best-management practices. Grass buffer strips between pasture and stream can be effective in reducing phosphorus transport from pastures by increasing infiltration and sedimentation and decreasing overland flow. Off-stream water development and fencing of riparian areas should reduce stream-bank degradation, and deposit of feces and urine near streams. High-intensity rotational grazing systems should provide for a healthier pasture. Since degraded water quality is detrimental to recreationists, wildlife, homeowners, and agricultural producers, best-management practices and other scientific tools should be used to reduce phosphorus loading. Grazing activities that accelerate erosion will increase total phosphorus loading because of phosphorus adsorption to soil particles. However, with proper grazing management, livestock grazing should be part of a long-term solution to excess phosphorus loading of streams and thus improve water quality.

For background information *see* AGRICULTURAL SOIL AND CROP PRACTICES; EUTROPHICATION; FERTILIZER; PHOSPHORUS; SOIL CONSERVATION in the McGraw-Hill Encyclopedia of Science & Technology.

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Wideband optical amplification

Since the early 1970s there has been a general expectation that high-speed, long-distance communications would be dominated by optical-fiber technologies. This belief was based on the silica fiber's extremely low optical power loss and high information bandwidths (that is, data capacity) compared with coaxial cable. At an infrared wavelength of 1.55 micrometers, the loss minimum in silica fiber is as low as 0.2 decibel per kilometer (0.32 dB/mi), that is, less than 5% power loss after 1 km of light propagation (8% power loss after 1 mi). Furthermore, the fiber's data capacity in this low-loss region can be as high as 25,000 gigahertz of information, compared with the few kilohertz of information contained in a typical voice-generated telephone call. However, it was the lack both of a true all-optical amplifier and of the ability to transmit ultrahigh capacity on one fiber that made optical systems fall far short of the fiber's theoretical capacity.

That situation changed dramatically in the late 1980s. The advent of the erbium-doped fiber-optic amplifier (EDFA), which can amplify many signals simultaneously over a bandwidth greater than 3 terahertz (3000 GHz) heralded a revolution in capacity for optical communication systems. For the first time, amplification is truly all optical and covers a wide wavelength range. That, in turn, has made wide-bandwidth, all-optical, many-wavelength-channel multiplexing schemes practical. Such techniques allow the simultaneous transmission of many different channels, each of a different-colored wavelength, thereby greatly increasing the overall capacity of the fiber. Experimental systems have broken the terabit-per-second barrier over 150 km (90 mi) of transmission, with a bit of information being a transmitted digital 0 (light off) or 1 (light on) signal. Furthermore, systems transmitting 100 gigabits per second over thousands of kilometers are planned for commercial deployment.

The erbium-doped fiber amplifier is a key enabler for almost all fiber-based systems. In fact, much of the relevant advances in optical communication since 1987 can be traced to the incorporation of optical amplifiers.

Optoelectronic regenerators. Until 1987, no practical all-optical amplifier existed. Instead, optical signals were electronically regenerated every few tens of kilometers to overcome the optical fiber's inherent power attenuation as well as other losses originating from in-line components.

In optoelectronic regeneration, a weak optical signal is briefly stopped in its travel along a fiber to be detected, amplified, retimed, reshaped, and retransmitted at full strength, in perfect shape, and without any accumulated noises. Not only are electronic regenerators expensive, but they also waste time and power in converting the signal from photons to electrons and back again to photons. Moreover, the regenerator components limit a system's performance because each regenerator can operate at only one predetermined incoming bit rate, one data modulation format, and one wavelength of a single input channel.

The goal has been an all-optical amplifier. For optical communications, the ideal amplifier would function essentially as a transparent box that would accept parallel input optical signals over a broad range of wavelengths and amplify them simultaneously. Only with such wide bandwidth would it be practical to multiplex many channels at once and thus take full advantage of optical fiber's potential capacity. The ideal all-optical amplifier would provide gain to all the optical signals while being insensitive to their individual bit rate, modulation format, power level, or wavelength, and it would amplify them without introducing significant signal distortion or noise. It would be advantageous if the optical amplifier was also cheaper and more reliable than electronic regenerators.

Erbium-doped fiber amplifiers. In 1987, this list of objectives was almost completely fulfilled with the demonstration of the erbium-doped fiber amplifier. The erbium-doped fiber amplifier contains a meters-long length of silica glass fiber that has been filled with ions (atoms that have an electronic charge) of the rare-earth metal erbium. When the erbium ions are excited to a metastable higher-energy state in such a way as to create a population inversion (that is, there exist more atoms at the higher energy state than at the normal lowest-energy or ground state), the doped fiber acts not as a passive transmission medium but as an active amplifying medium. This amplification is achieved because a single incoming signal photon can stimulate an excited ion to fall to a lower energy level. The result is a new photon at the same wavelength and phase as (that is, coherent