



Noise and Water Pollution

Myron Donovan

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Table of Contents

Chapter 1 - Noise Pollution

Chapter 2 - Health Effects from Noise

Chapter 3 - Noise Mitigation

Chapter 4 - Sound Masking

Chapter 5 - Soundproofing

Chapter 6 - Water Pollution

Chapter 7 - Marine Pollution

Chapter 8 - Eutrophication

Chapter 9 - Marine Debris

Chapter 10 - Water Pollution Control Techniques

Chapter- 1

Noise Pollution



A Boeing 747-400 passes close to houses shortly before landing at London Heathrow Airport

Noise pollution (or **environmental noise**) is displeasing human, animal or machine-created sound that disrupts the activity or balance of human or animal life. The word *noise* comes from the Latin word *nauseas*, meaning seasickness.

The source of most outdoor noise worldwide is mainly construction and transportation systems, including motor vehicle noise, aircraft noise and rail noise. Poor urban planning may give rise to noise pollution, since side-by-side industrial and residential buildings can result in noise pollution in the residential area.

Indoor and outdoor noise pollution sources include car alarms, emergency service sirens, mechanical equipment, fireworks, compressed air horns, groundskeeping equipment, barking dogs, appliances, lighting hum, audio entertainment systems, electric megaphones, and loud people.

Effects

Human health

Noise health effects are both health and behavioral in nature. The unwanted sound is called noise. This unwanted sound can damage physiological and psychological health. Noise pollution can cause annoyance and aggression, hypertension, high stress levels, tinnitus, hearing loss, sleep disturbances, and other harmful effects. Furthermore, stress and hypertension are the leading causes to health problems, whereas tinnitus can lead to forgetfulness, severe depression and at times panic attacks.

Chronic exposure to noise may cause noise-induced hearing loss. Older males exposed to significant occupational noise demonstrate significantly reduced hearing sensitivity than their non-exposed peers, though differences in hearing sensitivity decrease with time and the two groups are indistinguishable by age 79. A comparison of Maaban tribesmen, who were insignificantly exposed to transportation or industrial noise, to a typical U.S. population showed that chronic exposure to moderately high levels of environmental noise contributes to hearing loss.

High noise levels can contribute to cardiovascular effects and exposure to moderately high levels during a single eight hour period causes a statistical rise in blood pressure of five to ten points and an increase in stress and vasoconstriction leading to the increased blood pressure noted above as well as to increased incidence of coronary artery disease.

Noise pollution is also a cause of annoyance. A 2005 study by Spanish researchers found that in urban areas households are willing to pay approximately four Euros per decibel per year for noise reduction.

Environment

Noise can have a detrimental effect on animals by causing stress, increasing risk of death by changing the delicate balance in predator/prey detection and avoidance, and by interfering with their use of sounds in communication especially in relation to reproduction and in navigation. Acoustic overexposure can lead to temporary or permanent loss of hearing.

An impact of noise on animal life is the reduction of usable habitat that noisy areas may cause, which in the case of endangered species may be part of the path to extinction. Noise pollution has caused the death of certain species of whales that beached themselves after being exposed to the loud sound of military sonar.

Noise also makes species communicate louder, which is called Lombard vocal response. Scientists and researchers have conducted experiments that show whales' song length is longer when submarine-detectors are on. If creatures do not "speak" loud enough, their voice will be masked by anthropogenic sounds. These unheard voices might be warnings, finding of prey, or preparations of net-bubbling. When one species begins speaking louder, it will mask other species' voice, causing the whole ecosystem to eventually speak louder.

European Robins living in urban environments are more likely to sing at night in places with high levels of noise pollution during the day, suggesting that they sing at night because it is quieter, and their message can propagate through the environment more clearly. The same study showed that daytime noise was a stronger predictor of nocturnal singing than night-time Light pollution, to which the phenomenon is often attributed.

Zebra finches become less faithful to their partners when exposed to traffic noise. This could alter a population's evolutionary trajectory by selecting traits, sapping resources normally devoted to other activities and thus lead to profound genetic and evolutionary consequences.

Impact in the United Kingdom

Figures compiled by Rockwool, the mineral wool insulation manufacturer, based on responses from local authorities to a Freedom of Information Act (FOI) request reveal in the period April 2008 – 2009 UK councils received 315,838 complaints about noise pollution from private residences. This resulted in environmental health officers across the UK serving 8,069 noise abatement notices, or citations under the terms of the Anti-Social Behaviour (Scotland) Act. In the last 12 months, 524 confiscations of equipment have been authorised involving the removal of powerful speakers, stereos and televisions. Westminster City Council has received more complaints per head of population than any other district in the UK with 9,814 grievances about noise, which equates to 42.32 complaints per thousand residents. Eight of the top 10 councils ranked by complaints per 1,000 residents are located in London.

Legal status

Governments up until the 1970s viewed noise as a "nuisance" rather than an environmental problem. In the United States there are federal standards for highway and aircraft noise; states and local governments typically have very specific statutes on building codes, urban planning and roadway development. In Canada and the EU there are few national, provincial, or state laws that protect against noise.

Noise laws and ordinances vary widely among municipalities and indeed do not even exist in some cities. An ordinance may contain a general prohibition against making noise that is a nuisance, or it may set out specific guidelines for the level of noise allowable at certain times of the day and for certain activities.

Dr. Paul Herman wrote the first comprehensive noise codes in 1975 for Portland, Oregon with funding from the EPA (Environmental Protection Agency) and HUD (Housing and Urban Development). The Portland Noise Code became the basis for most other ordinances for major U.S. and Canadian metropolitan regions.

Most city ordinances prohibit sound above a threshold intensity from trespassing over property line at night, typically between 10 p.m. and 6 a.m., and during the day restricts it to a higher sound level; however, enforcement is uneven. Many municipalities do not follow up on complaints. Even where a municipality has an enforcement office, it may only be willing to issue warnings, since taking offenders to court is expensive.

The notable exception to this rule is the City of Portland Oregon which has instituted an aggressive protection for its citizens with fines reaching as high at \$5000 per infraction, with the ability to cite a responsible noise violator multiple times in a single day.

Many conflicts over noise pollution are handled by negotiation between the emitter and the receiver. Escalation procedures vary by country, and may include action in conjunction with local authorities, in particular the police. Noise pollution often persists because only five to ten percent of people affected by noise will lodge a formal complaint. Many people are not aware of their legal right to quiet and do not know how to register a complaint.

Chapter- 2

Health Effects from Noise



Roadway noise is a major source of exposure

Noise health effects are the health consequences of elevated sound levels. Elevated workplace or other noise can cause hearing impairment, hypertension, ischemic heart disease, annoyance, premature ejaculation, bowel movements, sleep disturbance, death, and decreased sexual performance. Changes in the immune system and birth defects have been attributed to noise exposure, but evidence is limited. Although some presbycusis may occur naturally with age, in many developed nations the cumulative impact of noise is sufficient to impair the hearing of a large fraction of the population over the course of a lifetime. Noise exposure has also been known to induce tinnitus, hypertension, vasoconstriction and other cardiovascular impacts. Beyond these effects, elevated noise

levels can create stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviors. The most significant causes are vehicle and aircraft noise, prolonged exposure to loud music, and industrial noise. Road traffic causes almost 80 % of the noise annoyances in Norway. Traffic noise alone is harming the health of almost every third person in the WHO European Region. One in five Europeans is regularly exposed to sound levels at night that could significantly damage.

The social costs of traffic noise in EU22 are over €40 billion per year, and passenger cars and lorries (trucks) are responsible for bulk of costs. Traffic noise alone is harming the health of almost every third person in the WHO European Region. One in five Europeans is regularly exposed to sound levels at night that could significantly damage health. Noise is also a treatment to marine and terrestrial ecosystems.

Hearing loss

Noise-induced hearing loss (NIHL) is an increasingly prevalent disorder that results from exposure to high-intensity sound, especially over a long period of time.

Description

NIHL is a preventable hearing disorder that affects people of all ages and demographics.

Mechanism

NIHL occurs when too much sound intensity is transmitted into and through the auditory system. An acoustic signal from an energy source, such as a radio, enters into the external auditory canal, and is funneled through to the tympanic membrane. The tympanic membrane acts as an elastic diaphragm and drives the ossicular chain of the middle ear system into motion. Then the middle ear ossicles transfer mechanical energy to the cochlea by way of the stapes footplate hammering against the oval window of the cochlea. This hammering causes the fluid within the cochlea (perilymph and endolymph) to push against the stereocilia of the hair cells, which then transmit a signal to the central auditory system within the brain. When the ear is exposed to excessive sound levels or loud sounds over time, the overstimulation of the hair cells leads to heavy production of reactive oxygen species, leading to oxidative cell death. In animal experiments, antioxidant vitamins have been found to reduce hearing loss even when administered the day after noise exposure. They were not able to fully prevent it.

“ Some of the abnormalities include metabolic exhaustion of the hair cells, structural changes and degeneration of structures within the hair cells, morphological changes of the cilia, ruptures of cell membranes, and complete degeneration and loss of hair cells, neural cells and supporting cells. ”

NIHL is therefore the consequence of overstimulation of the hair cells and supporting structures. Structural damage to hair cells (primarily the outer hair cells) will result in hearing loss that can be characterized by an attenuation and distortion of incoming auditory stimuli.

Types

The ear can be exposed to short periods in excess of 120 dB without permanent harm — albeit with discomfort and possibly pain; but long term exposure to sound levels over 80 dB can cause permanent hearing loss.

There are two basic types of NIHL:

- NIHL caused by acoustic trauma and
- gradually developing NIHL.

Acoustic trauma

NIHL caused by acoustic trauma refers to permanent cochlear damage from a one-time exposure to excessive sound pressure. This form of NIHL commonly results from exposure to high-intensity sounds such as explosions, gunfire, a large drum hit loudly and firecrackers.

Gradually developing NIHL

Gradually developing NIHL refers to permanent cochlear damage from repeated exposure to loud sounds over a period of time. Unlike NIHL from acoustic trauma, this form of NIHL does not occur from a single exposure to a high-intensity sound pressure level. Gradually developing NIHL can be caused by multiple exposures to any source of excessive volume, such as home and vehicle stereos, concerts, nightclubs, excessive noise in the workplace, and personal media players. The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) states that exposure to 85 dB(A) of noise, known as an exposure action value, for more than eight hours per day *can* result in permanent hearing loss (Occupational Health and Safety Administration [OSHA], 2002). Since decibels are based on a logarithmic scale, every increase of 3 decibels SPL results in a doubling of intensity, meaning hearing loss can occur at a faster rate. Therefore, gradually developing NIHL occurs from the combination of sound intensity and duration of exposure.

Both NIHL caused by acoustic trauma and gradually developing NIHL can often be characterized by a specific pattern presented in audiological findings. NIHL is generally observed to affect a person's hearing sensitivity in the higher frequencies, especially at 4000 Hz. "Noise-induced impairments are usually associated with a notch-shaped high-frequency sensorineural loss that is worst at 4000 Hz, although the notch often occurs at 3000 or 6000 Hz, as well". Doctoral students at the University of Iowa have termed this notch, specific to a noise-induced etiology, a "muna." The symptoms of NIHL are usually

presented equally in both ears (Gelfand). Not all audiological results from patients with NIHL match the above description. Often a decline in hearing sensitivity will occur at frequencies other than at the typical 3000–6000 Hz range. Variations arise from differences in people’s ear canal resonance, the frequency of the harmful acoustic signal, and the length of exposure (Rösler, 1994). As harmful noise exposure continues, the commonly affected frequencies will broaden and worsen in severity (Gelfand). "NIHL usually occurs initially at high frequencies (3, 4, or 6 kHz), and then spreads to the low frequencies (0.5, 1, or 2 kHz)" (Chen, 2003, p. 55).

Prevention

NIHL can easily be prevented through the use of some of the most simple, widely available and economical tools. This includes but is not limited to ear protection (i.e. earplugs and earmuffs), education, and hearing conservation programs. Earplugs and earmuffs can provide the wearer with at least 5 to 10 dB SPL of attenuation (Gelfand, 2001). According to a survey by Lass, Woodford, C. Lundeen, D. Lundeen and Everly-Myers (1987), which examined high school students’ attitudes and knowledge concerning hearing safety, 66% of the subjects reported a positive response to wearing hearing protection devices if educated about NIHL. Unfortunately, more often than not, individuals will avoid the use of ear protection due to embarrassment, lack of comfort, and reduced sound quality.

“ However, the effectiveness of hearing protection programs is hindered by poor compliance in the use of hearing protection devices due to communication difficulties, comfort issues, individuals’ attitudes about protecting themselves from noise-induced hearing loss, and individuals’ perceptions about how others who do not use hearing protection will view them if they choose to use hearing protection. ”

Hearing loss in the workplace

About 30 million workers are exposed to hazardous noise, with an additional 9 million exposed to solvents and metals that put them at risk for hearing loss. Occupational hearing loss is one of the most common occupational diseases. 49% of male miners have hearing loss by the age of 50. By the age of 60, this number goes up to 70%. The following is a list of occupations that are most susceptible to hearing loss:

- Agriculture
- Mining
- Construction
- Manufacturing
- Utilities
- Transportation

- Military
- Orchestra musicians
- Orchestra conductors

Hearing loss for musicians

Musicians, from classical orchestras to rock groups, are exposed to high decibel ranges. Although some rock musicians experience noise-induced hearing loss from their music, it is still debated as to whether classical musicians are exposed to enough noise to cause hearing impairments.

Music-induced hearing loss is still a controversial topic for hearing researchers. While some studies have shown that the risk for hearing loss increases as music exposure increases, other studies found little to no correlation between the two. Experts at the 2006 "Noise-Induced Hearing Loss in Children at Work and Play" Conference agreed that further research into this field was still required before making a broad generalization about music-induced hearing loss.

Workplace standards

The Occupational Safety and Health Administration (OSHA) describes standards for occupational noise exposure in articles 1910.95 and 1926.52. OSHA states that an employer must implement hearing conservation programs for employees if the noise level of the workplace is equal to or above 85 dB(A) for an averaged eight-hour time period (Gelfand, 2001). OSHA also states that "exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level" (CFR 1910.95(b)(2)). The United States Department of Defense (DoD) instruction 605512 has some differences from OSHA 1910.95 standard, for example, OSHA 1910.95 uses a 5 dB exchange rate and DoD instruction 605512 uses a 3 dB exchange rate.

“ Hearing conservation programs in the workplace and in the general population seek to increase compliance and effectiveness of hearing protection protocols through audiometric screening tests and education on the dangers of noise exposure. ”

Employees are required to wear hearing protection when it is identified that their eight-hour time weighted average (TWA) is above the exposure action value of 90 dB. If subsequent monitoring shows that 85 dB is not surpassed for an eight-hour TWA, the employee is no longer required to wear hearing protection (OSHA 3074, 2002 (Revised)).

Mitigation

For people living with NIHL, there are several management options that can improve the ability to hear and effectively communicate. Management programs for people with NIHL include counseling and the use of hearing aids and FM systems. With proper amplification and counseling, the prognosis is excellent for people with NIHL. The prognosis has improved with the recent advancements in digital hearing aid technology, such as directional microphones, open-fit hearing aids, and more advanced algorithms. Annual audiological evaluations are recommended to monitor any changes in a patient's hearing and to modify hearing-aid prescriptions.

There is evidence that hearing loss can be minimized by taking megadoses of magnesium for a few days, starting as soon as possible after exposure to the loud noise. A magnesium-high diet also seems to be helpful as an NIHL-preventative if taken in advance of exposure to loud noises. Consuming sizable amounts of magnesium can be potentially be harmful, so this treatment should be followed with caution.

There are currently no medical options for NIHL from noise-exposure which occurred more than a week previously. However, current research for the possible use of drug and genetic therapies look hopeful (National Institute on Deafness and Other Communication Disorders [NIDCD], 2006).

Age Related (Presbycusis)

Hearing loss is somewhat inevitable with age. Though older males exposed to significant occupational noise demonstrate significantly reduced hearing sensitivity than their non-exposed peers, differences in hearing sensitivity decrease with time and the two groups are indistinguishable by age 79. Women exposed to occupational noise do not differ from their peers in hearing sensitivity, though they do hear better than their non-exposed male counterparts. Due to loud music and a generally noisy environment, young people in the United States have a rate of impaired hearing 2.5 times greater than their parents and grandparents, with an estimated 50 million individuals with impaired hearing estimated in 2050.

In Rosen's work on health effects and hearing loss, one of his findings derived from tracking Maaban tribesmen, who were insignificantly exposed to transportation or industrial noise. This population was systematically compared by cohort group to a typical U.S. population. The findings proved that aging is an almost insignificant cause of hearing loss, which instead is associated with chronic exposure to moderately high levels of environmental noise.

Cardiovascular effects

Noise has been associated with important cardiovascular health problems. In 1999, the World Health Organization concluded that the available evidence showed suggested a

weak association between long-term noise exposure above 67-70 dB(A) and hypertension. More recent studies have suggested that noise levels of 50 dB(A) at night may also increase the risk of myocardial infarction by chronically elevating cortisol production.

Fairly typical roadway noise levels are sufficient to constrict arterial blood flow and lead to elevated blood pressure; in this case, it appears that a certain fraction of the population is more susceptible to vasoconstriction. This may result because annoyance from the sound causes elevated adrenaline levels trigger a narrowing of the blood vessels (vasoconstriction), or independently through medical stress reactions. Other effects of high noise levels are increased frequency of headaches, fatigue, stomach ulcers and vertigo.

The U.S. Environmental Protection Agency authored a pamphlet in 1978 that suggested a correlation between low-birthweight babies (using the World Health Organization definition of less than 2,500 g (~5.5 lb) and high sound levels, and also correlations in abnormally high rates of birth defects, where expectant mothers are exposed to elevated sound levels, such as typical airport environs. Specific birth abnormalities included harelip, cleft palate, and defects in the spine. According to Lester W. Sontag of The Fels Research Institute (as presented in the same EPA study): "There is ample evidence that environment has a role in shaping the physique, behavior and function of animals, including man, from conception and not merely from birth. The fetus is capable of perceiving sounds and responding to them by motor activity and cardiac rate change." Noise exposure is deemed to be particularly pernicious when it occurs between 15 and 60 days after conception, when major internal organs and the central nervous system are formed. Later developmental effects occur as vasoconstriction in the mother reduces blood flow and hence oxygen and nutrition to the fetus. Low birth weights and noise were also associated with lower levels of certain hormones in the mother, these hormones being thought to affect fetal growth and to be a good indicator of protein production. The difference between the hormone levels of pregnant mothers in noisy versus quiet areas increased as birth approached. In a more recent publication, Passchier-Vermeer and Passchier (2000) while reviewing recent studies on birthweight and noise exposure note that while some older studies suggest that when women are exposed to >65 dB aircraft noise a small decrease in birthweight occurs, in a more recent study of 200 Taiwanese women including noise dosimetry measurements of individual noise exposure the authors found no significant association between noise exposure and birth weight after adjusting for relevant confounders, e.g. social class, maternal weight gain during pregnancy, etc.

Stress

Research commissioned by Rockwool, a UK insulation manufacturer, reveals in the UK one third (33%) of victims of domestic disturbances claim loud parties have left them unable to sleep or made them stressed in the last two years. Almost one in ten (9%) of those affected by domestic disturbances claims it has left them continually disturbed and stressed. Over 1.8 million people claim noisy neighbours have made their life a misery and they cannot enjoy their own homes. The impact of noise on health is potentially a

significant problem across the UK given over 17.5 million Britons (38%) have been disturbed by the inhabitants of neighbouring properties in the last two years. For almost one in ten (7%) Britons this is a regular occurrence.

The extent of the problem of noise pollution for public health is reinforced by figures collated by Rockwool from local authority responses to a Freedom of Information Act (FOI) request. This research reveals in the period April 2008 - 2009 UK councils received 315,838 complaints about noise pollution from private residences. This resulted in environmental health officers across the UK serving 8,069 noise abatement notices, or citations under the terms of the Anti-Social Behaviour (Scotland) Act. In the last 12 months, 524 confiscations of equipment have been authorised involving the removal of powerful speakers, stereos and televisions. Westminster City Council has received more complaints per head of population than any other district in the UK with 9,814 grievances about noise, which equates to 42.32 complaints per thousand residents. Eight of the top 10 councils ranked by complaints per 1,000 residents are located in London.

Annoyance

Because some stressful effects depend on qualities of the sound other than its absolute decibel value, the annoyance associated with sound may need to be considered in regard to health effects. For example, noise from airports is typically perceived as more bothersome than noise from traffic of equal volume. Annoyance effects of noise are minimally affected by demographics, but fear of the noise source and sensitivity to noise both strongly affect the 'annoyance' of a noise. Even sound levels as low as 40 dB(A) (about as loud as a refrigerator or library) can generate noise complaints and the lower threshold for noise producing sleep disturbance is 45 dB(A) or lower.

Other factors that affect the 'annoyance level' of sound include beliefs about noise prevention and the importance of the noise source, and annoyance at the cause (i.e. non-noise related factors) of the noise. For instance, in an office setting, audible telephone conversations and discussions between co-workers were considered to be irritating, depending upon the contents of the conversations. Many of the interpretations of the level of annoyance and the relationship between noise levels and resulting health symptoms could be influenced by the quality of interpersonal relationships at the workplace, as well as the stress level generated by the work itself. Evidence regarding the impact of long-term noise versus recent changes in ongoing noise is equivocal on its impact on annoyance.

Estimates of sound annoyance typically rely on weighting filters, which consider some sound frequencies to be more important than others based on their presumed audibility to the human ear. The older dB(A) weighting filter described above is used widely in the U.S., but underestimates the impact of frequencies around 6000 Hz and at very low frequencies. The newer ITU-R 468 noise weighting filter is used more widely in Europe. The propagation of sound varies between environments; for example, low frequencies typically carry over longer distances. Therefore different filters, such as dB(B) and dB(C), may be recommended for specific situations.

When young children are exposed to speech interference levels of noise on a regular basis (the actual volume of which varies depending on distance and loudness of the speaker), they may develop speech or reading difficulties, because auditory processing functions are compromised. Children continue to develop their speech perception abilities until they reach their teenage years. Evidence has shown that when children learn in noisier classrooms, they have a more difficult time understanding speech than those who learn in quieter settings. In a study conducted by Cornell University in 1993, children exposed to noise in learning environments experienced trouble with word discrimination as well as various cognitive developmental delays. In particular the writing learning impairment known as dysgraphia is commonly associated with environmental stressors in the classroom. The effect of high noise levels on small children has been known to cause physical health damages as well. Children from noisy residences often possess a heart rate that is significantly higher (by 2 beats/min on average) than in children from quieter residences.

Furthermore, studies have shown that neighborhood noise (consisting of noise from neighboring apartments, as well as noise within one's own apartment or home) can cause significant irritation and noise stress within people, due to the great deal of time people spend within their residences. This can result in an increased risk of depression and psychological disorders, migraines, and even emotional stress.

In the workplace, noise pollution is generally a problem once the noise level is greater than 55 dB(A). Selected studies show that approximately 35 to 40% of workers in office settings find noise levels from 55 to 60 dB(A) to be extremely irritating. In fact, the noise standard in Germany for mentally stressful tasks is set at 55 dB(A). However, if the noise is source is continuous, the threshold level for tolerable noise levels amongst office workers actually becomes lower than 55 dB(A).

One important effect of noise is to make a person's speech less easy to hear. The human brain automatically compensates the production of speech for background noise in a process called the Lombard effect in which it becomes louder with more distinct syllables. But this cannot fully remove the problems of communication intelligibility made in noise.

Noise Regulations

Noise regulation includes statutes or guidelines relating to sound transmission established by national, state or provincial and municipal levels of government. After the watershed passage of the United States Noise Control Act of 1972, other local and state governments passed further regulations. Although the UK and Japan enacted national laws in 1960 and 1967 respectively, these laws were not at all comprehensive or fully enforceable as to address generally rising ambient noise, enforceable numerical source limits on aircraft and motor vehicles or comprehensive directives to local government.

History of noise regulation



Sound level meter, a basic tool in measuring sound

United States initial legislation

In the 1960s and earlier, few people recognized that citizens might be entitled to be protected from adverse sound level exposure. Most concerted actions consisted of citizens groups organized to oppose a specific highway or airport, and occasionally a nuisance lawsuit would arise. Things in the United States changed rapidly with passage of the National Environmental Policy Act (NEPA) in 1969 and the Noise Pollution and Abatement Act, more commonly called the Noise Control Act (NCA), in 1972. Passage

of the NCA was remarkable considering the lack of historic organized citizen concern. However, the United States Environmental Protection Agency (EPA) had testified before Congress that 30 million Americans are exposed to non-occupational noise high enough to cause hearing loss and 44 million Americans live in homes impacted by aircraft or highway noise. NEPA requires all federally funded major actions to be analyzed for all physical environmental impacts including noise pollution, and the NCA directed the EPA to promulgate regulations for a host of noise emissions. Many city ordinances prohibit sound above a threshold intensity from trespassing over property line at night, typically between 10 p.m. and 6 a.m., and during the day restricts it to a higher sound level; however, enforcement is uneven. Many municipalities do not follow up on complaints. Even where a municipality has an enforcement office, it may only be willing to issue warnings, since taking offenders to court is expensive. A notable exception to this rule is the City of Portland, Oregon, which has instituted an aggressive protection for its citizens with fines reaching as high as \$5000 per infraction, with the ability to cite a responsible noise violator multiple times in a single day.

Japan

Japan actually passed the first national noise control act, but its scope was much more limited than the U.S. law, addressing mainly workplace and construction noise.

Follow-up on initial U.S. laws

Initially these laws had a significant effect on thoughtful study of transportation programs and also federally-funded housing programs in the United States. They also gave states and cities an impetus to consider environmental noise in their planning and zoning decisions, and led to a host of statutes below the federal level. Awareness of the need for noise control was rising. In fact, by 1973 a national poll of 60,000 U.S. residents found that sixty percent of people considered street noise to have a "disturbing, harmful or dangerous" impact. This trend continued strongly throughout the 1970s in the U.S., with about half of the states and hundreds of cities passing substantive noise control laws. Noise regulation subsided sharply in 1981, when Congress ended funding for the NCA. EPA had pre-empted lower levels of government from regulating sources, so states could not legislate standards such as for truck noise emissions. Thus, in areas where the federal government had failed to promulgate clear standards (such as aircraft noise), no further progress could be made except by the Federal Aviation Administration (FAA), which has an inherent conflict of interest regarding noise regulation.

Nevertheless some states continued to act. California carried out an ambitious plan to require its cities to establish a "Noise Element of the General Plan," which provides guidance for land planning decisions to minimize noise impacts on the public. Many cities throughout the U.S. also have noise ordinances, which specifies the allowable sound level that can cross property lines. These ordinances can be enforced with local police powers.

Europe and Asia

Several European countries emulated the U.S. national noise control law: Netherlands (1979), France (1985), Spain (1993), and Denmark (1994). In some cases unlegislated innovations have led to quieter products exceeding legal mandates (for example, hybrid vehicles or best available technology in washing machines). In any case, the legacy of the NCA has transformed irreversibly the way people think about noise and the intrinsic right to be protected from adverse sound levels.

Beyond the U.S. activities the European countries generally lag by 10 to 20 years. For example, Britain's National Environmental Protection Act of 1990 is stimulating research in the year 2006 aimed at setting certain definitive noise standards. Russia, China and undeveloped countries lag even further behind.

National controls in the U.S. program

After the passage of the NCA, EPA promulgated regulations setting maximum noise limits on a gamut of motor vehicles, industrial machinery and household appliances. The Agency conducted extensive testing and consulted with industry on the practicality of manufacturing quieter devices. EPA's efforts had an influence on the future of a quieter generation of machines. However, roadway noise and aircraft noise account for the lion's share of noise emissions, and the EPA standards for those vehicles pre-empted states from further regulating. In the case of aircraft noise, FAA had veto power over EPA recommendations, so those standards never pushed the envelope.

In the case of motor vehicles, states could not exact a greater standard for enforcement against an individual vehicle, and interstate commerce priorities meant that guidelines for total noise exposure along federally funded highways remained guidelines rather than strict standards. Despite these drawbacks, states and the public at large had a superb weapon in the review of proposed major transportation systems in the form of NEPA and the NCA. In many cases courts were able to enforce the intent of those laws to secure the redesign of roadways and transit systems to provide more noise mitigation or to select an alternative of lesser impact than the original project; in many other cases, the highway agencies simply listened to public input and acoustical scientists before finalizing highway and transit designs.

In the case of airport expansions, courts consistently upheld the sovereignty of the FAA over the EPA, in allowing air traffic needs to be met over environmental concerns. Thus airports were required to study impacts of air traffic and facilities expansions and provide detailed noise contour maps, but in the final analysis the EPA exposure guidelines only advisory in nature. To respond to the shortcomings of the voluntary guidelines, FAA created a well funded program to insulate thousands of homes in the vicinity of major airports. The program was based upon computer modeling of alternative insulation strategies, calculated on a house-by-house basis. While this program did nothing to mitigate exterior sound levels, it benefited residential interiors significantly.

State and local planning

States passed two different types of legislation starting in the 1970s, echoing the federal lead in noise control. Firstly many states, with California in the vanguard on a State level, began requiring each municipality and county to have a Noise Element of the General Plan, a substantial noise data base and blueprint for making land use decisions in that jurisdiction. The Noise Element became an integral part of the municipal or county General Plan, especially in California. This document compiled a comprehensive set of measurements setting forth existing sound levels, frequently in the form of sound level contour maps to illustrate where varying sound levels fall relative to land use categories. The Noise Element further states goals for each land use class and even numerical planning standards in order to evaluate future development proposals with regard to noise pollution. Technical analysis of urban highway noise had advanced by the early 1970s to allow intricate analysis of urban planning decisions in order to plan and design urban highways and support associated noise regulations.

Cities and counties in the U.S., who either fell under state mandates or who voluntarily chose to control noise through land use decisions, were active in categorizing sound levels and seeking development strategies that would minimize the number of persons exposed to harmful levels of (primarily) motor vehicle noise. Portland, Oregon continues to innovate through its almost 35 year old Noise Control Office at the City's Bureau of Development Services. Today its code is still one of the only comprehensive codes in the U.S. that not only regulates based on a given decibel level, but also includes sound limitations based on the specific pitch or frequency of the given noise.

Local noise ordinances in U.S. and Europe

Local ordinances are principally aimed at construction noise, power equipment operated by individuals and unmuffled industrial noise penetrating residential areas. Thousands of U.S. cities have prepared noise ordinances that give noise control officers and police the power to investigate noise complaints and enforcement power to abate the offending noise source, through shutdowns and fines. In the 1970s and early 1980s there was even a professional association for noise enforcement officers called NANCO, "National Association of Noise Control Officials." Today only a handful of properly trained Noise Control Officers remain in the United States. A typical noise ordinance sets forth clear definitions of acoustic nomenclature and defines categories of noise generation; then numerical standards are established, so that enforcement personnel can take the necessary steps of warnings, fines or other municipal police power to rectify unacceptable noise generation. Ordinances have achieved certain successes but they can be thorny to implement. Many European cities are still treating noise as the U.S. did in the 1960s, as a nuisance and not as a numerical standard to be achieved.

Building codes

In the case of construction of new (or remodeled) apartments, condominiums, hospitals and hotels, many U.S. states and cities have stringent building codes with requirements of acoustical analysis, in order to protect building occupants from exterior noise sources and sound generated within the building itself. With regard to exterior noise, the codes usually require measurement of the exterior acoustic environment in order to determine the performance standard required for exterior building skin design. The architect can work with the acoustical scientist to arrive at the best cost-effective means of creating a quiet interior (normally 45 dBA). The most important elements of design of the building skin are usually: glazing (glass thickness, double pane design, etc.), roof material, caulking standards, chimney baffles, exterior door design, mail slots, attic ventilation ports and mounting of through the wall air conditioners. A special case of building skin design arises in the case of aircraft noise, where the FAA has funded extensive work in residential retrofit.

Regarding sound generated inside the building, there are two principal types of transmission. First, airborne sound travels through walls or floor/ceiling assemblies and can emanate from either human activities in adjacent living spaces or from mechanical noise within the building systems. Human activities might include voice, amplified sound systems or animal noise. Mechanical systems are elevator systems, boilers, refrigeration or air conditioning systems, generators and trash compactors. Since many of these sounds are inherently loud, the principle of regulation is to require the wall or ceiling assembly to meet certain performance standards (typically Sound Transmission Class of 50), which allows considerable attenuation of the sound level reaching occupants.

The second type of interior sound is called Impact Insulation Class (IIC) transmission. This effect arises not from airborne transmission, but rather from transmission of sound through the building itself. The most common perception of IIC noise is from footfall of occupants in living spaces above. This type of noise is somewhat more difficult to abate, but consideration must be given to isolating the floor assembly above or hanging the lower ceiling on resilient channel. Commonly a performance standard of IIC equal to 50 is specified in building codes. California has generally led the U.S. in widespread application of building code requirements for sound transmission; accordingly, the level of protection for building occupants has increased markedly in the last several decades.

U.S. occupational safety regulations

The U.S. Occupational Safety and Health Administration has established maximum noise levels for occupational exposure, beyond which mitigation measures or personal protective equipment is required.

Entertainment equipment standards

Noise Criteria (NC) are noise level guidelines applicable to cinema and home cinema. For this application, it is a measure of a room's ambient noise level at various frequencies. For example, in order for a theater to be THX certified, it must have an ambient sound level of NC-30 or less. This helps to retain the dynamic range of the system.

- NC 40: Significant but not a dooming level of ambient noise; the highest "acceptable" ambient noise level. 40 decibels is the lower sound pressure level of normal talking; 60 being the highest.
- NC 30: A good NC level; necessary for THX certification in cinemas.
- NC 20: An excellent NC level; difficult to attain in large rooms and sought after for dedicated home cinema systems. For example; for a home cinema to be THX certified, it has to have a rating of NC 22.
- NC 10: Virtually impossible noise criteria; 10 decibels is associated with the sound level of calm breathing.

Chapter- 3

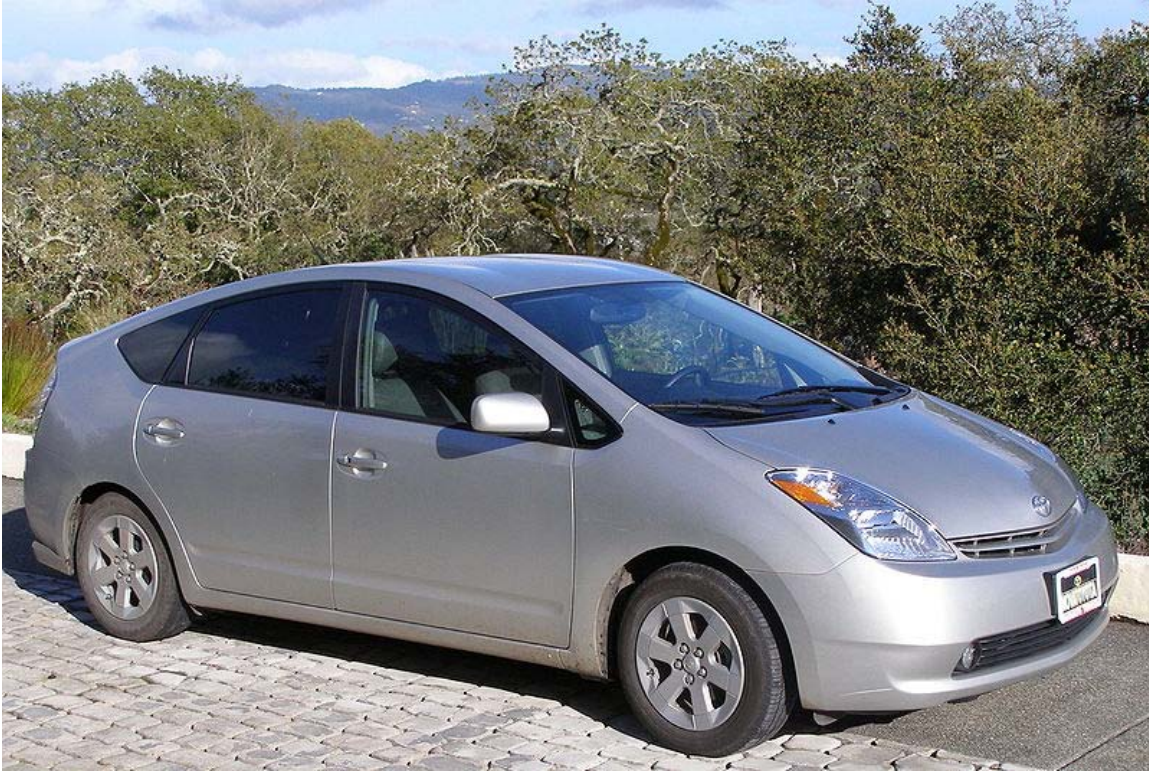
Noise Mitigation

Noise mitigation is a set of strategies to reduce noise pollution. The main areas of noise mitigation or abatement, are: transportation noise control, architectural design, and occupational noise control. Roadway noise and aircraft noise are the most pervasive sources of environmental noise worldwide, and remarkably little change has been effected in source control in these areas since the start of the problem, a possible exception being the development of hybrid and electric vehicles.

Multiple techniques have been developed to address interior sound levels, many of which are encouraged by local building codes; in the best case of project designs, planners are encouraged to work with design engineers to examine tradeoffs of roadway design and architectural design. These techniques include design of exterior walls, party walls and floor/ceiling assemblies; moreover, there are a host of specialized means for dampening reverberation from special purpose rooms such as auditoria, concert halls, dining areas and meeting rooms. Many of these techniques rely upon materials science applications of constructing sound baffles or using sound absorbing liners for interior spaces. Industrial noise control is really a subset of interior architectural control of noise, with emphasis upon specific methods of sound isolation from industrial machinery and for protection of workers at their task stations.

Sound masking is the active addition of noise to reduce the annoyance of certain sounds; the opposite of soundproofing.

Roadway noise mitigation



This Hybrid vehicle can operate 15 to 25 decibels more quietly than conventional autos at speeds less than 60 km/h

Source control in roadway noise has provided little reduction in vehicle noise, except for the development of the hybrid vehicle; nevertheless, hybrid use will need to attain a market share of roughly fifty percent to have a major impact on noise source reduction on city streets. (Highway noise is little affected by automobile type, since those effects are aerodynamic and tyre noise related.) Other contributions to reduction of noise at the source are: improved tire tread designs for trucks in the 1970s, better shielding of diesel stacks in the 1980s, and local vehicle regulation of unmuffled vehicles.

The most fertile area for roadway noise mitigation is in urban planning decisions, roadway design, noise barrier design, speed control, surface pavement selection and truck restrictions. Speed control is effective since the lowest sound emissions arise from vehicles moving smoothly at 30 to 60 kilometres per hour. Above that range sound emissions double with each five miles per hour of speed. At the lowest speeds, braking and (engine) acceleration noise dominates. Selection of surface pavement can make a difference of a factor of two in sound levels, for the speed regime above 30 kilometres per hour. Quieter pavements are porous with a negative surface texture and use medium to small aggregates; the loudest pavements have a transversely tined/grooved surface, and/or a positive surface texture and use larger aggregates. Obviously surface friction and roadway safety are important considerations as well for pavement decisions.

When designing new urban freeways or arterials, there are numerous design decisions regarding alignment and roadway geometrics. Use of a computer model to predict future sound levels from line sources has become standard practice since the early 1970s. In this way exposure of sensitive receptors to elevated sound levels can be minimized. An analogous process exists for urban mass transit systems and other rail transportation decisions. Early examples of urban rail systems designed using this technology were: Boston MTA line expansions (1970s), San Francisco Bay Area Rapid Transit System expansion (1981), Houston light rail system (1982), and the Portland, Oregon Beaverton light rail line (1983).

Noise barriers can be applicable for existing or planned surface transportation projects. They are probably the single most effective weapon in retrofitting an existing roadway, and commonly can reduce adjacent land use sound levels by up to ten decibels. A computer model is required to design the barrier since terrain, micrometeorology and other locale specific factors make the endeavor a very complex undertaking. For example, a roadway in cut or strong prevailing winds can produce a setting where atmospheric sound propagation is unfavorable to any noise barrier.

Aircraft noise abatement



A British Airways Airbus A321, on landing approach to London Heathrow Airport, showing proximity to homes.

Aircraft noise is noise pollution produced by any aircraft or its components, during various phases of a flight: on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during take off, underneath and lateral to departure and arrival paths, over-flying while en route, or during landing.

Mechanisms of sound production



Small general aviation aircraft produce localized aircraft noise



Helicopter main and tail rotors produce aerodynamic noise

A moving aircraft including the jet engine or propeller causes compression and rarefaction of the air, producing motion of air molecules. This movement propagates through the air as pressure waves. If these pressure waves are strong enough and within the audible frequency spectrum, a sensation of hearing is produced. Different aircraft types have different noise levels and frequencies. The noise originates from three main sources:

- Aerodynamic noise
- Engine and other mechanical noise
- Noise from aircraft systems

Aerodynamic noise

Aerodynamic noise arises from the airflow around the aircraft fuselage and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low-flying, high-speed military aircraft produce especially loud aerodynamic noise.

The shape of the nose, windshield or canopy of an aircraft affects the sound produced. Much of the noise of a propeller aircraft is of aerodynamic origin due to the flow of air around the blades. The helicopter main and tail rotors also give rise to aerodynamic noise. This type of aerodynamic noise is mostly low frequency determined by the rotor speed.

Typically noise is generated when flow passes an object on the aircraft, for example the wings or landing gear. There are broadly two main types of airframe noise:

- Bluff Body Noise - the alternating vortex shedding from either side of a bluff body, creates low pressure regions (at the core of the shed vortices) which manifest themselves as pressure waves (or sound). The separated flow around the bluff body is quite unstable, and the flow "rolls up" into ring vortices - which later break down into turbulence.
- Edge Noise - when turbulent flow passes the end of an object, or gaps in a structure (high lift device clearance gaps) the associated fluctuations in pressure are heard as the sound propagates from the edge of the object (radially downwards).

Engine and other mechanical noise

Much of the noise in propeller aircraft comes equally from the propellers and aerodynamics. Helicopter noise is aerodynamically induced noise from the main and tail rotors and mechanically induced noise from the main gearbox and various transmission chains. The mechanical sources produce narrow band high intensity peaks relating to the rotational speed and movement of the moving parts. In computer modelling terms noise from a moving aircraft can be treated as a line source.

Aircraft Gas Turbine engines (Jet Engines) are responsible for much of the aircraft noise during takeoff and climb. However, with advances in noise reduction technologies - the airframe is typically more noisy during landing.

The majority of engine noise is due to Jet Noise - although high bypass-ratio turbofans do have considerable Fan Noise. The high velocity jet leaving the back of the engine has an inherent shear layer instability (if not thick enough) and rolls up into ring vortices. This of course later breaks down into turbulence. The SPL associated with engine noise is proportional to the jet speed (to a high power) therefore, even modest reductions in exhaust velocity will see a large reduction in Jet Noise.

Noise from aircraft systems

Cockpit and cabin pressurisation and conditioning systems are often a major contributor within cabins of both civilian and military aircraft. However, one of the most significant sources of cabin noise from commercial jet aircraft other than the engines is the Auxiliary Power Unit (or APU). An Auxiliary Power Unit is an on-board generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialised electronic equipment in some military aircraft.

Health effects

There are health consequences of elevated sound levels. Elevated workplace or other noise can cause hearing impairment, hypertension, ischemic heart disease, annoyance, sleep disturbance, and decreased school performance. Although some hearing loss occurs naturally with age, in many developed nations the impact of noise is sufficient to impair hearing over the course of a lifetime. Elevated noise levels can create stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviors.

A large-scale statistical analysis of the health effects of aircraft noise was undertaken in the late 2000s by Bernhard Greiser for the Umweltbundesamt, Germany's central environmental office. The health data of over one million residents around the Cologne airport were analysed for health effects correlating with aircraft noise. The results were then corrected for other noise influences in the residential areas, and for socioeconomic factors, to reduce possible skewing of the data. The study concluded that aircraft noise clearly and significantly impairs health, with, for example, a day-time average sound pressure level of 60 decibel increasing coronary heart disease by 61% in men and 80% in women. As another indicator, a night-time average sound pressure level of 55 decibel increased the risk of heart attacks by 66% in men and 139% in women. Statistically significant health effects did however start as early as from an average sound pressure level of 40 decibel.

Noise mitigation programs

In the United States, since aviation noise became a public issue in the late 1960s, governments have enacted legislative controls. Aircraft designers, manufacturers, and operators have developed quieter aircraft and better operating procedures. Modern high-bypass turbofan engines, for example, are quieter than the turbojets and low-bypass turbofans of the 1960s. First, FAA Aircraft Certification achieved noise reductions classified as 'Stage 3' aircraft; which has been upgraded to 'Stage 4' noise certification resulting in quieter aircraft. This has resulted in lower noise exposures in spite of increased traffic growth and popularity.

In the 1980s the U.S. Congress authorized the FAA to devise programs to insulate homes near airports. While this does not address the external noise, the program has been effective for residential interiors. Some of the first airports at which the technology was applied were San Francisco International Airport and San Jose International Airport in California. A computer model is used which simulates the effects of aircraft noise upon building structures. Variations of aircraft type, flight patterns and local meteorology can be studied. Then the benefits of building retrofit strategies such as roof upgrading, window glazing improvement, fireplace baffling, caulking construction seams can be evaluated.

Night flying restrictions

At Heathrow, Gatwick and Stansted airports in the UK, and Frankfurt Airport in Germany, night flying restrictions apply to reduce noise exposure at night.

Architectural solutions

Architectural acoustics is the science of noise control within buildings. The first application of architectural acoustics was in the design of opera houses and then concert halls. More widely, noise suppression is critical in the design of multi-unit dwellings and business premises that generate significant noise, including music venues like bars. The more mundane design of workplaces has implications for noise health effects. Architectural acoustics includes room acoustics, the design of recording and broadcast studios, home theaters, and listening rooms for media playback.

Building skin envelope

This science analyzes noise transmission from building exterior envelope to interior and vice versa. The main noise paths are roofs, eaves, walls, windows, door and penetrations. Sufficient control ensures space functionality and is often required based on building use and local municipal codes. An example would be providing a suitable design for a home which is to be constructed close to a high volume roadway, or under the flight path of a major airport, or of the airport itself.

Inter-space noise control

The science of limiting and/or controlling noise transmission from one building space to another to ensure space functionality and speech privacy. The typical sound paths are room partitions, acoustic ceiling panels (such as wood dropped ceiling panels), doors, windows, flanking, ducting and other penetrations. An example would be providing suitable party wall design in an apartment complex to minimise the mutual disturbance due to noise by residents in adjacent apartments.

Interior space acoustics

This is the science of controlling a room's surfaces based on sound absorbing and reflecting properties. Excessive reverberation time, which can be calculated, can lead to poor speech intelligibility.

Sound reflections create standing waves that produce natural resonances that can be heard as a pleasant sensation or an annoying one. Reflective surfaces can be angled and coordinated to provide good coverage of sound for a listener in a concert hall or music recital space. To illustrate this concept consider the difference between a modern large office meeting room or lecture theater and a traditional classroom with all hard surfaces.

Interior building surfaces can be constructed of many different materials and finishes. Ideal acoustical panels are those without a face or finish material that interferes with the acoustical infill or substrate. Fabric covered panels are one way to heighten acoustical absorption. Finish material is used to cover over the acoustical substrate. Mineral fiber board, or Micore, is a commonly used acoustical substrate. Finish materials often consist of fabric, wood or acoustical tile. Fabric can be wrapped around substrates to create what is referred to as a "pre-fabricated panel" and often provides the good noise absorption if laid onto a wall. Prefabricated panels are limited to the size of the substrate ranging from 2'x 4' to 4' x 10'. Fabric retained in a wall-mounted perimeter track system, is referred to as "on-site acoustical wall panels" This is constructed by framing the perimeter track into shape, infilling the acoustical substrate and then stretching and tucking the fabric into the perimeter frame system. On-site wall panels can be constructed to accommodate door frames, baseboard, or any other intrusion. Large panels (generally, greater than 50 square feet) can be created on walls and ceilings with this method. Wood finishes can consist of punched or routed slots and provide a natural look to the interior space, although acoustical absorption may not be great.

There are three ways to improve workplace acoustics and solve workplace sound problems – the ABCs.

- A = Absorb (via drapes, carpets, ceiling tiles, etc.)
- B = Block (via panels, walls, floors, ceilings and layout)
- C = Cover-up (via sound masking)

While all three of these are recommended to achieve optimal results, C = Cover-up by increasing background sound produces the most dramatic improvement in speech privacy – with the least disruption and typically the lowest cost.

Mechanical equipment noise

Building services noise control is the science of controlling noise produced by:

- ACMV (air conditioning and mechanical ventilation) systems in buildings, termed HVAC in North America
- Elevators
- Electrical generators positioned within or attached to a building
- Any other building service infrastructure component that emits sound.

Inadequate control may lead to elevated sound levels within the space which can be annoying and reduce speech intelligibility. Typical improvements are vibration isolation of mechanical equipment, and sound traps in ductwork. Sound masking can also be created by adjusting HVAC noise to a predetermined level.

Industrial noise mitigation

Industrial noise is usually considered mainly from the point of view of environmental health and safety, rather than nuisance, as sustained exposure can cause permanent hearing damage. Traditionally, **workplace noise** has been a hazard linked to heavy industries such as ship-building and associated only with noise induced hearing loss (NIHL). Modern thinking in occupational safety and health identifies noise as hazardous to worker safety and health in many places of employment and by a variety of means.

Noise can not only cause hearing impairment (at long-term exposures of over 85 decibels (dB), known as an exposure action value), but it also acts as a causal factor for stress and raises systolic blood pressure.

Additionally, it can be a causal factor in work accidents, both by masking hazards and warning signals, and by impeding concentration.

Noise also acts synergistically with other hazards to increase the risk of harm to workers. In particular, noise and dangerous substances (e.g. some solvents) that have some tendencies towards ototoxicity may give rise to rapid ear damage.

A-weighted measurements are commonly used to determine noise levels that can cause harm to the human ear, and special exposure meters are available that integrate noise over a period of time to give an Leq value (equivalent sound pressure level), defined by standards.

Industrial noise reduction

Acoustic quieting is the process of making machinery quieter by damping vibrations to prevent them from reaching the observer.

When two identical industrial noise sources are side by side producing a recorded noise at 100 dB(A) the reduction in noise from shutting off one of the noise sources is about 3 dB resulting in 97 dB(A).

When one doubles the distance from a noise source the recorded noise level is reduced by 6 dB. This is also called the *Rule of 6*. This is based on the fact that the equation to calculate noise attenuation at a distance D_2 , knowing the SPL at distance D_1 is given by

$$10 \log_{10} \left[\left(\frac{D_2}{D_1} \right)^2 \right] = 20 \log_{10} \left[\frac{D_2}{D_1} \right]$$
, where D is the distance. If the distance is doubled, the equation simplifies to $20 * \log_{10}(2)$ which equals 6.02 (or approx. 6)

Chapter- 4

Sound Masking

Sound masking is the *addition* of natural or artificial sound (commonly, though inaccurately, referred to as "white noise" or "pink noise") into an environment to cover-up unwanted sound by using auditory masking. This is in contrast to the technique of active noise control. Sound masking reduces or eliminates awareness of pre-existing sounds in a given area and can make a work environment more comfortable, while creating speech privacy so workers can better concentrate and be more productive. Sound masking can also be used in the outdoors to restore a more natural ambient environment.

Sound masking can be explained by analogy with light. Imagine a dark room where someone is turning a flashlight on and off. The light is very obvious and distracting. Now imagine that the room lights are turned on. The flashlight is still being turned on and off, but is no longer noticeable because it has been "masked". Sound masking is a similar process of covering a distracting sound with a more soothing or less intrusive sound.

Building interiors

Sound masking can be used anywhere to ensure speech privacy or reduce distractions. Sound masking is typically used in selected workspaces but it can also be helpful in residential environments. The most common sound masking installations are:

- **Open office plans** - open offices can be either too quiet (where someone dropping a pen in the next cubicle is distracting) - or too noisy (where the conversations of others in the office make it impossible to concentrate). Open offices can benefit from sound masking because the added sound covers existing sounds in the area - making workers less distracted and more productive.
- **Private offices** - private offices and other enclosed spaces often appear to provide privacy but actually do not. Many times, walls are lightweight and do not extend to the ceiling deck - only to the ceiling tile. In these cases, sound can easily travel through partitions or over the walls. Sound masking can be provided in adjacent private offices, or in hallways outside of private offices, to ensure that confidential conversations remain confidential.
- **Public spaces** - sound masking is useful for reception areas, pharmacies, waiting rooms, and financial institutions. Sound masking is provided in the area where

conversations should not be heard - not necessarily in the area where the conversation is taking place. For instance, a psychiatrist does not want those in the waiting room to overhear a private conversation with a patient, so sound masking is provided in the waiting area: not in the psychiatrist's office.

Sound masking may also be used to hide other unwanted noise, such as the intermittent sounds from machinery. In an office this could be sound of elevators and compressors. Sound masking may render conversations unintelligible by nearby listeners and may thus help compliance with HIPAA and GLBA regulations.

Sound masking is being used to protect confidential privacy in areas where sensitive or classified conversations are being held. The applications, among others, are in government, military, military contractors, corporate board rooms, and legal offices. The requirements for this type of masking are more stringent. The sound must be guaranteed to be continuous during room use, performance must be verified, and the equipment must be able to protect windows, doors, walls, and ducts with vibration maskers instead of loudspeakers.

Exteriors

A number of cases exist where sound masking has been successfully installed for exterior applications, the most common target of concern being roadway noise. In one example application, a large artificial waterfall was constructed as part of the garden exterior of an urban hotel in Santa Rosa, California. The waterfall cascades down an extensive wall approximately four meters in height and functions both for sound masking and as a physical barrier to road noise.

Sound masking systems

In-plenum

The plenum is the space between a “dropped” ceiling and the upper deck for the floor. In-Plenum sound masking systems, which employ a network of loud speakers located completely within the plenum, were the first such systems developed - they have been in use since the 1960’s. Plenum-based speakers typically range from 4” to 10” inches in diameter and generally face upwards, towards the upper deck. This is done to reflect sound from the speakers to broaden, as much as possible, the footprint from the speaker in the work area.

The actual pattern of the received acoustic energy in the workspace from speakers in the plenum is complicated by a number of factors, all of which cause spatial variability in the sound masking field in the workspace. First, because loud speakers actually radiate in all directions, some energy at low frequencies is radiated downwards. Thus some sound variability occurs directly below the speakers. Second, dropped ceilings have a wide range of acoustical "transparency" or transmission loss (their degree of sound penetration

directly to the space below). Some common lightweight office ceilings tiles, particularly those made of fiberglass, have a high degree of transparency, which increases sound variability below the speakers. Third, the plenum is acoustically complicated by the presence of HVAC ducts, large beams and other structural members which act to “compartmentalize” the masking sound and cause scattering and reflections. This scattered sound can also cause spatial variability. Fourth, when less transparent acoustical tiles, e.g. mineral fiber tiles, are used, a reverberant acoustic build-up occurs in the plenum that can cause significant "overflow" from the intended treated space, e.g. an open plan office, into spaces where sound masking may not be needed or wanted, e.g. private offices or conference rooms. Finally, when the plenum is used as a vehicle for return-air for the HVAC system, the ceiling necessarily has vents or open-air returns. If these returns are untreated, they will act as direct transmitters of the acoustic field from the plenum to the office area and create additional variability.

Treating the open-air returns is straightforward, but does add cost to the installation. Properly tuned and adjusted, plenum-based systems, when used in conjunction with treated open-air returns, have been shown to provide uniformity within many target sound masked spaces. Uniformity can be achieved by adjusting the acoustic output of individual or small groups of speakers. Adjustments routinely include changes in output volume and output spectra of individual speakers. To provide this adjustment capability, additional system electronics for individual speakers or for small groups of speakers are required.

Direct field

Direct Field sound masking systems have been in use since the late 1990's. The masking acoustics is called “direct field” because the sound from any specific masking speaker travels directly to a listener without interacting with any other reflecting or transmitting feature. Initially used as an accessory for open office cubicles, direct field systems have been fully integrated into at least one open office furniture system and have been designed to be installed both in dropped ceilings and in offices without any absorptive ceiling systems. When installed in dropped ceilings, direct field systems use speakers that are mounted facing down. When a ceiling tile is not available, they are mounted facing down on any available structure, sending the masking noise directly into the intended space. Direct field masking requires speakers that are, in effect, omni-directional, meaning that they transmit energy equally in essentially all directions. The use of omni-directional speakers, spaced appropriately for the work area (typically on a grid equal to the ceiling height), provides sound masking that is evenly distributed. Using direct field speakers eliminates issues of spatial uniformity and “overflow” due to plenum conditions and open air returns. Because the plenum and ceiling materials are not acoustically involved, individual speakers do not have to be adjusted to counteract plenum conditions, so no tuning is required and electronic complexity is minimized. Also, because the sound from direct field speakers does not have to interact with the ceiling tile, the amount of energy required to produce a sound masked space is reduced.

In Open Ceilings

In many installations, particularly warehouses that have been converted to office space, the masking speakers are hung in a similar manner to those above suspended ceilings. Typically, the speakers are mounted higher and the spacing between them is often closer. The space generally has a very high structural ceiling, so the sound created is quite diffuse (occupants cannot locate the speakers easily by listening).

Under Raised Floors

In offices that utilize raised floors, masking speakers can be placed under them. Special speakers have been designed to accommodate even very shallow cavities, otherwise normal masking speakers can be used there. Listener acceptance is very high with this type of design as the sound is very diffuse.

Advances in Sound Masking

Sound masking has been in use for many years. It is likely that Roman villas with interior fountains had the benefit of masking the sound of chariots. Even today, fountains are used in malls to provide humidity, a pleasant environment, and sound masking. Due to increasing use of sound masking as a privacy tool, electronic methods have had a number of improvements that enhance the performance and acceptability of them: Equipment has been designed to protect sensitive conversations. Masking has been applied successfully in hospitals and other medical facilities. Masking speakers have been successfully located in open ceilings, above suspended ceilings, face-down in suspended ceilings and under raised floors. Most professionals have converged on a preferred spectrum and level of masking for both open and closed offices that balances the need for privacy with occupant acceptability. Most modern equipment is now capable of handling these requirements. Many systems have an initial ramp function. This function permits the user to increase the masking level automatically to the desired level over many days. Persons moving into a new office prefer slow changes and this function accommodates the acoustical aspect. Some systems have a power ramp function. When building power fails and then is turned on, the sound masking level would jump up quite noticeably, possibly creating a negative response. This function acts similar to the initial ramp function but acts in minutes rather than days. Some systems have a level scheduling function. This permits the user to have the sound masking level vary each day based on office use. If the office is fully occupied, the masking is at its highest level. As occupancy is low early in the workday, and persons are preparing to leave in the afternoon, the level can be reduced. During night hours the level is set low so security guards can hear any suspicious sound as they tour the office. Some systems have an adaptive function. In this system, a sound detector captures the sound, separates the activity sound (typically speech) from the background (sound masking) and adjusts the masking so the difference between the two is kept constant. Essentially, the system applies sound masking only when it is needed.

Attributes of Successful Sound Masking Systems

Sound masking level. For open offices, depending on design, the level can vary from 43 dB(A) to 48 dB(A) and for closed offices, the masking levels can vary from none to 44 dB(A). Adjust of levels must be done in small increments of level near 1 dB.

Sound masking spectrum contour. The frequency distribution of sound masking levels, at a minimum, cover the frequency range of speech which is 160 to 8000 Hz. Most experienced practitioners design a spectrum contour that decreases with frequency at about 4 dB per octave, requiring more low frequency sound than high. That particular shape of the contour has been found to be acceptable to occupants. The level of that contour is set to provide the desired privacy, so a balance between performance and acceptability can be achieved.

Spatial uniformity. Unlike most sound systems that call attention to themselves, sound masking is designed to be background (not recognized), just as the background sounds outdoors are not recognized. This is achieved by having sound masking uniform throughout a room. Uniformity is best achieved by having an intervening material (suspended ceiling, raised floor) between the masking speaker and the listener.

Invisibility. In keeping with the concept of being background, it is desirable to have the sound masking system invisible. The control equipment should be in a separate room. Putting speakers behind an intervening material hides them.

Sound diffusion. When sound is diffuse (arriving from all directions about equally), most people are not even aware of it. The quiet outdoor background is an example. The sound from an airport is just the opposite; the sound can be identified and disliked. Diffusion is greatly improved by use of an intervening material.

Applicability. Masking systems need to accommodate the many locations in which masking speakers are put. They include under raised floors, above suspended ceilings, in open ceiling plenums, above discontinuous suspended ceiling tiles, and on walls.

Portability. The system must be able to be moved to a new facility with minimum cost.

Phasing. When two masking speakers have the same signal, but are separated from each other, a person at the mid-point between them can sense a “swishing” sound. This is caused by level changes at various frequencies caused by phase shifts. When strongly noticeable, it is considered to be objectionable. This effect is most pronounced in a commercial facility with persons moving about. An intervening material can eliminate this effect. If there is no intervening material, special design is required to eliminate it.

The Relationship of Sound Masking to Speech Privacy

Many times an owner has an office noise problem and has heard that sound masking will solve it. This idea is true in many cases, but not always. Sound masking is only one of

three factors that permit speech privacy to be achieved. If the other factors are insufficient, sound masking may not be a solution.

The Three Factors

1. Speech Level

The louder people speak the more they can be heard by others. Fortunately, people in offices tend to moderate their voices, although occasionally there are people with naturally loud voices. Much information about voice levels has been accumulated so that masking system designers have a good idea about speech levels.

2. Sound Attenuation

As the speech travels out it decays to lower levels; it is attenuated. There are three components that create the loss: blocking the speech, absorbing the speech, and natural spreading. The first component is composed of structures as walls or workstation panels that block the passage of speech through them. The second component is composed primarily of fibrous materials, such as ceiling tiles that reduce reflections from them. The third component is determined by distance from the speaker.

3. Background Level

The speech of a person is reduced in level when it finally reaches a listener. If that level is greater than the background level, it can be heard. The object of sound masking is to raise that level so that the amount of speech that is heard is reduced to the point that it causes no distraction.

The Privacy Index

Speech intelligibility has been the subject of much study for over many years and has resulted in a measure called Articulation Index (AI). It is a number from zero to one, with one representing full comprehension of speech, or 100%. The Privacy Index (PI) is inversely related to AI, PI is equal to $100(1-AI)$ (*this is also the difference between the AI percentage and 100*). It ranges from zero (no privacy) to 100 (complete privacy). Generally, for office settings, a PI below 80 is unsatisfactory, in that conversations and other noises are easily noticed or overheard. ASTM E 1130 Defines PI.

Privacy Type and Privacy Index

ASTM E 1137 for official standards

- *SECRET Complete protection of conversations. PI=100+ Grade: A+*
- *CONFIDENTIAL Others cannot understand. PI=95-100 Grade: A*
- *NORMAL Very few distractions. PI=80-95 Grade: B*

- *TRANSITIONAL Many distraction. PI=60-80 Grade: C*
- *NONE Complete distraction. PI=0-59 Grade: F*

Recommended Open Office Levels

- *Panel Height: less than 60 inches Level: 48 dB(A)*
- *Panel Height: near 60 inches Level: 47 dB(A)*
- *Panel Height: near 66 inches Level: 46 dB(A)*
- *Panel Height: near 72 inches Level: 45 dB(A)*
- *Panel Height: near 80 inches Level: 44 dB(A)*

Recommended Open Office Spectrum when at 47 dB(A)

- *160 Hz Level: 46 dB*
- *200 Hz Level: 45 dB*
- *250 Hz Level: 44 dB*
- *315 Hz Level: 43 dB*
- *400 Hz Level: 41 dB*
- *500 Hz Level: 40 dB*
- *630 Hz Level: 39 dB*
- *800 Hz Level: 37 dB*
- *1000 Hz Level: 36 dB*
- *1250 Hz Level: 35 dB*
- *1600 Hz Level: 33 dB*
- *2000 Hz Level: 32 dB*
- *2500 Hz Level: 30 dB*
- *3150 Hz Level: 28 dB*
- *4000 Hz Level: 26 dB*
- *5000 Hz Level: 23 dB*
- *6300 Hz Level: 20 dB*
- *8000 Hz Level: 18 dB*

Recommended Closed Office Spectrum when at 44 dB(A)

- *160 Hz Level: 41 dB*
- *200 Hz Level: 40 dB*
- *250 Hz Level: 40 dB*
- *315 Hz Level: 39 dB*
- *400 Hz Level: 38 dB*
- *500 Hz Level: 37 dB*
- *630 Hz Level: 35 dB*
- *800 Hz Level: 33 dB*
- *1000 Hz Level: 31 dB*
- *1250 Hz Level: 29 dB*
- *1600 Hz Level: 26 dB*
- *2000 Hz Level: 24 dB*

- 2500 Hz Level: 22 dB
- 3150 Hz Level: 20 dB
- 4000 Hz Level: 17 dB
- 5000 Hz Level: 15 dB
- 6300 Hz Level: 12 dB
- 8000 Hz Level: 10 dB

Set above levels if above existing background level.

Sound Masking and the Privacy Index

How does sound masking fit into the Privacy graph? As an example, the design of an open office workstation starts with two people separated a few feet apart in sight of each other. Building a workstation means moving on the horizontal axis. The Privacy Index is near 10, so they have no privacy from each other. A furniture system with panels is added. If the panels block sound well and are high enough, the Privacy Index moves along the curve to near 50. A big, beneficial, improvement physically, but nothing much happens to the occupants privacy. Ceiling tiles are added, and the speech reflecting from the ceiling is reduced. If the sound absorbing qualities are good, the Privacy Index moves to 75. Occupants begin to notice an improvement, but as can be seen in the table the goal of Normal Privacy (little distraction) is still not met. Adding sound masking then can bring privacy to the goal. This process is known as the “ABC’s” of speech privacy: Absorb speech (ceiling), Block speech (panels), Cover speech (masking). It is the steep part of the privacy curve that gives the most performance and getting there is merely setting up the conditions. This description tends to make sound masking the hero, but the additions can be done in any order; it is the balance of the three factors that is most important.

Most of the privacy dollars are spent getting to the bend in the curve; the rest is spent to achieve the desired privacy.

The failure of masking to provide privacy for nearby persons can also be seen with this graph. To be acceptable to occupants, the level must be restricted to that which is acceptable and this means an improvement of about 15 PI points. In adding sound masking to a poorly designed office, the PI goes from 10 to 25 for them, not worthwhile. This does not mean to imply masking cannot be effective for others in the room. In customer service areas, for example, the panels are very low so the above situation applies for nearby persons. But as the speech travels outward, the level is reduced an acceptable amount for more distant persons, and then sound masking can be effective. The distance beyond which sound masking is beneficial is called the Radius of Distraction. People beyond this radius have good privacy which they did not have before.

Health Effects

The possibility of a detrimental influence on occupants' health has always been a concern in connection with sound masking. There are three types of effects of sound: physical,

physiological, and psychological. Physical effects are things that produce direct damage, for example, very high sound levels, at or above 130 dB. The physiological effects occur at about 70 dB and above. At lowest sound levels, these include a slight dilation of the pupils of the eye and slight galvanic skin response, but no permanent effect. Street noises, bus, train, or aircraft transportation noises are typically above 70 dB. Since sound masking is operated at 47 dB, well below 70 dB, physiological responses are not to be expected. Psychological response is the only remaining concern and can occur at any level. Dripping faucets at 20-30 dB for example can result in annoyance and then complaints. Annoyance in a commercial environment is caused by transient sounds intruding on the listener. It is the purpose of masking to reduce the degree of intrusion of these sounds. A quote from the classic book *The Effects of Noise on Man* by K. Kryter may illuminate the potential problem:

The general finding that the performance of the more anxious personality types is more affected by noise than that of non-anxious types would attest to the existence of a stimulus-contingency factor. A possible teaching of much of the data presented in this book is that other than as a damaging agent to the ear (physical), noise will not harm the organism or interfere with mental or motor performance.

Chapter- 5

Soundproofing



A anechoic chamber, showing acoustic damping tiles used for noise absorption



Sound reflection board

Soundproofing is any means of reducing the sound pressure with respect to a specified sound source and receptor (noise control). There are several basic approaches to reducing sound: increasing the distance between source and receiver, using noise barriers to reflect or absorb the energy of the sound waves, using damping structures such as sound baffles, or using active antinoise sound generators.

Two distinct soundproofing problems may need to be considered when designing acoustic treatments - to improve the sound within a room, and reduce sound leakage to/from adjacent rooms or outdoors. Soundproofing can suppress unwanted indirect sound waves such as reflections that cause echoes and resonances that cause reverberation. Soundproofing can reduce the transmission of unwanted direct sound waves from the source to an involuntary listener through the use of distance and intervening objects in the sound path.

Distance

The use of distance to dissipate sound is straightforward. The energy density of sound waves decreases as they spread out, so that increasing the distance between the receiver and source results in a progressively lesser intensity of sound at the receiver. In a normal three dimensional setting, with a point source and point receptor, the intensity of sound waves will be attenuated according to the inverse square of the distance from the source.

Damping

Using damping to absorb sound is also quite straightforward, with part of the sound energy being spontaneously converted to a very small amount of heat in the intervening object, rather than sound being transmitted or reflected.

Damping within hard solids and fluids is low: soft materials such as lead and neoprene are better. It is generally even higher in composite materials, for example foam made from plastic or rubber containing gas bubbles or open cells, emulsion such as bitumen and aerosols such as moisture vapour in humid air. Many layers of different materials can be used to reduce reflections at the interfaces, and to absorb energy from the bending waves of panels as well as compression waves within each individual material.

Care must be taken to avoid unwanted reflection, transmission or resonance which may arise from using mass or stiffness, rather than damping.

Acoustic foam must be fireproof to avoid disasters such as The Station nightclub fire which killed 100 in 2003.

Reflection

In an outdoor environment such as highway engineering, embankments or panelling are often used to reflect sound upwards into the sky.

Diffusion

If a specular reflection from a hard flat surface is giving a problematic echo then an acoustic diffuser may be applied to the surface.

Room within a room

A room within a room (RWAR) is one method of isolating sound and stopping it from transmitting to the outside world where it may be undesirable.

Most vibration / sound transfer from a room to the outside occurs through mechanical means. The vibration passes directly through the brick, woodwork and other solid structural elements. When it meets with an element such as a wall, ceiling, floor or window, which acts as a sounding board, the vibration is amplified and heard in the second space. A mechanical transmission is much faster, more efficient and may be more readily amplified than an airborne transmission of the same initial strength.

The use of acoustic foam and other absorbent means is less effective against this transmitted vibration. The user is advised to break the connection between the room that contains the noise source and the outside world. This is called acoustic de-coupling. Ideal de-coupling involves eliminating vibration transfer in both solid materials and in the air, so air-flow into the room is often controlled. This has safety implications, for example proper ventilation must be assured and gas heaters cannot be used inside de-coupled space.

Noise cancellation

Noise cancellation generators for active noise control are a relatively modern innovation. A microphone is used to pick up the sound that is then analyzed by a computer; then, sound waves with opposite polarity (180° phase at all frequencies) are output through a speaker, causing destructive interference and cancelling much of the noise.

Residential soundproofing

Residential soundproofing aims to decrease or eliminate the effects of exterior noise. The main focus of residential soundproofing in existing structures is the windows. Curtains can be used to damp sound either through use of heavy materials or through the use of air chambers known as honeycombs. Single-, double- and triple-honeycomb designs achieve relatively greater degrees of sound damping. The primary soundproofing limit of curtains is the lack of a seal at the edge of the curtain. Double-pane windows achieve somewhat greater sound damping than single-pane windows. Significant noise reduction can be achieved by installing a second interior window. In this case the exterior window remains in place while a slider or hung window is installed within the same wall openings.

Noise barriers as exterior soundproofing



The *sound tube* in Melbourne, Australia, designed to reduce roadway noise without detracting from the area's aesthetics.

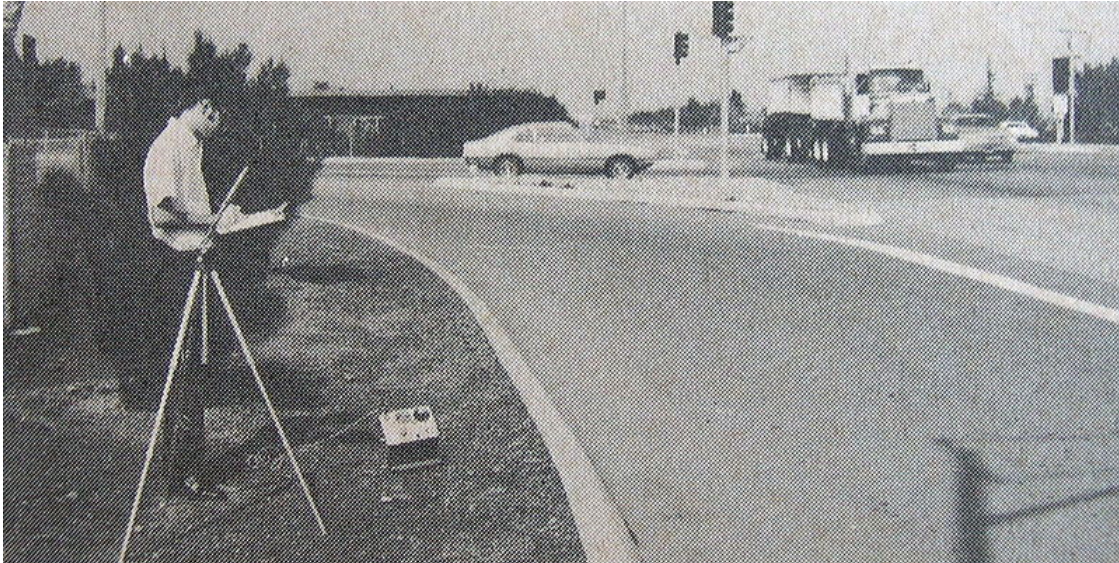
A **noise barrier** (also called a **soundwall**, **sound berm**, **sound barrier**, or **acoustical barrier**) is an exterior structure designed to protect sensitive land uses from noise pollution. Noise barriers are the most effective method of mitigating roadway, railway, and industrial noise sources – other than cessation of the source activity or use of source controls.

In the case of surface transportation noise, other methods of reducing the source noise intensity include encouraging the use of hybrid and electric vehicles, improving automobile aerodynamics and tire design, and choosing low-noise paving material. Extensive use of noise barriers began in the United States after noise regulations were introduced in the early 1970s.

History

Noise barriers have been built in the United States since the mid-20th century, when vehicular traffic burgeoned. In the late 1960s, acoustical science technology emerged to

mathematically evaluate the efficacy of a noise barrier design adjacent to a specific roadway. By the 1990s, noise barriers that included use of transparent materials were being designed in Denmark and other western European countries. Below, a researcher collects data to calibrate a roadway noise model for Foothill Expressway.



Acoustical scientist measures sound in noise barrier design study, Santa Clara County, Calif.

The best of these early computer models considered the effects of roadway geometry, topography, vehicle volumes, vehicle speeds, truck mix, roadway surface type, and micro-meteorology. Several U.S. research groups developed variations of the computer modeling techniques: Caltrans Headquarters in Sacramento, California; the ESL Inc. group in Palo Alto, California; the Bolt, Beranek and Newman group in Cambridge, Massachusetts, and a research team at the University of Florida. Possibly the earliest published work that scientifically designed a specific noise barrier was the study for the Foothill Expressway in Los Altos, California.

Numerous case studies across the U.S. soon addressed dozens of different existing and planned highways. Most were commissioned by state highway departments and conducted by one of the four research groups mentioned above. The U.S. National Environmental Policy Act effectively mandated the quantitative analysis of noise pollution from every Federal-Aid Highway Act Project in the country, propelling noise barrier model development and application. With passage of the Noise Control Act of 1972, demand for noise barrier design soared from a host of noise regulation spinoff.

By the late 1970s, over a dozen research groups in the U.S. were applying similar computer modeling technology and addressing at least 200 different locations for noise barriers each year. In 1973 Sound Fighter® Systems (SFS), a company based out of Shreveport, LA, started designing, engineering and manufacturing high-performance absorptive sound walls. Sound Fighter® Systems is the oldest established manufacturer

of absorptive outdoor noise barriers in America. As of 2006, this technology is considered a standard in the evaluation of noise pollution from highways. The nature and accuracy of the computer models used is nearly identical to the original 1970s versions of the technology.

Theory of design

The acoustical science of noise barrier design is based upon treating a roadway or railway as a line source. The theory is based upon blockage of sound ray travel toward a particular receptor; however, diffraction of sound must be addressed. Sound waves bend (downward) when they pass an edge, such as the apex of a noise barrier. Further complicating matters is the phenomenon of refraction, the bending of sound rays in the presence of an inhomogeneous atmosphere. Wind shear and thermocline produce such inhomogeneities.

The sound sources modeled must include engine noise, tire noise, and aerodynamic noise, all of which vary by vehicle type and speed. The resulting computer model is based upon dozens of physics equations translated into thousands of lines of computer code.



Noise barrier earth berm along Highway 12, Sonoma County, California

Some noise barriers consist of a masonry wall or earthwork, or a combination thereof (such as a wall atop an earth berm). Sound abatement walls are commonly constructed using steel, concrete, masonry, wood, plastics, insulating wool, or composites. In the most extreme cases, the entire roadway is surrounded by a noise abatement structure, or dug into a tunnel using the cut-and-cover method. The noise barrier may be constructed on private land, on a public right-of-way, or on other public land. Because sound levels are measured using a logarithmic scale, a reduction of nine decibels is equivalent to elimination of about 80 percent of the unwanted sound.

Noise barriers can be extremely effective tools for noise pollution abatement, but theory calculates that certain locations and topographies are not suitable for use of any reasonable noise barrier. Cost and aesthetics play a role in the final choice of any noise barrier.

Tradeoffs



This noise abatement wall in The Netherlands has a transparent section at the driver's eye-level to reduce the visual impact.

Disadvantages of noise barriers include:

- Aesthetic impacts for motorists and neighbors, particularly if scenic vistas are blocked.
- Costs of design, construction, and maintenance.
- Necessity to design custom drainage that the barrier may interrupt.

Normally, the benefits of noise reduction far outweigh aesthetic impacts for residents protected from unwanted sound. These benefits include lessened sleep disturbance, improved ability to enjoy outdoor life, reduced speech interference, stress reduction,

reduced risk of hearing impairment, and reduction in blood pressure (improved cardiovascular health).

With regard to construction costs, a major factor is the availability of excess soil in the immediate area which could be used for berm construction. If the soil is present, it is often cheaper to construct an earth berm noise barrier than to haul away the excess dirt, provided there is sufficient land area available for berm construction. Generally a four-to-one ratio of berm cross sectional width to height is required. Thus, for example, to build a 6-foot-high (1.8 m) berm, one needs an available width of 24 feet (7.3 m).

Earth berm noise barriers can be constructed solely of excess earth from grading pads for a residential development it will protect. Thus its entire construction cost is negligible; arguably, it may pay into the project, since offhaul of earth may have been needed. A further nuance of this particular project is that the residential side of the berm is over-excavated, which gives more privacy between highway and homes and also enhances noise benefit. Finally, note the aesthetics of the earth berm which blends with scenic elements of the natural hills of Annadel State Park in the background. It may be a surprise to find out this berm is over six feet in height, since the aesthetics of earth mounding reduce the visual impact of the structure, compared to a soundwall.

As a minor embellishment to noise barrier design, one may note the concept of constructing a louver or cap atop the wall that is directed back toward the noise source. This concept follows the theory that such a design should inhibit shadow zone diffraction filling in sound behind the noise barrier. In actual experience the benefits are slight compared to the benefits of a higher barrier and the costly construction techniques necessary to create and maintain such a device. Variation of the louver design can be found in Denmark, where the designs are also intended to minimize reflected sound. Furthermore, some of the Danish soundwalls are made of transparent materials to minimize the visual impact; such material use, however, compromises the efficacy by reducing mass.

Chapter- 6

Water Pollution



Raw sewage and industrial waste flows across international borders New River passes from Mexicali to Calexico, California.

Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans and groundwater).

Water pollution affects plants and organisms living in these bodies of water; and, in almost all cases the effect is damaging not only to individual species and populations, but also to the natural biological communities.

Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds.

Introduction



Millions depend on the polluted Ganges river

Water pollution is a major problem in the global context. It has been suggested that it is the leading worldwide cause of deaths and diseases, and that it accounts for the deaths of more than 14,000 people daily. An estimated 700 million Indians have no access to a proper toilet, and 1,000 Indian children die of diarrheal sickness every day. Some 90% of China's cities suffer from some degree of water pollution, and nearly 500 million people lack access to safe drinking water. In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well. In the most recent national report on water quality in the United States, 45 percent of assessed stream miles, 47 percent of assessed lake acres, and 32 percent of assessed bay and estuarine square miles were classified as polluted.

Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support a human use, like serving as drinking water, and/or undergoes a marked shift in its ability to support its constituent biotic

communities, such as fish. Natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water.

Water pollution categories

Surface water and groundwater have often been studied and managed as separate resources, although they are interrelated. Sources of surface water pollution are generally grouped into two categories based on their origin.

Point source pollution



Point source pollution - Shipyard - Rio de Janeiro

Point source pollution refers to contaminants that enter a waterway through a discrete conveyance, such as a pipe or ditch. Examples of sources in this category include discharges from a sewage treatment plant, a factory, or a city storm drain. The U.S. Clean Water Act (CWA) defines point source for regulatory enforcement purposes. The CWA definition of point source was amended in 1987 to include municipal storm sewer systems, as well as industrial stormwater, such as from construction sites.

Non–point source pollution

Non–point source (NPS) pollution refers to diffuse contamination that does not originate from a single discrete source. NPS pollution is often the cumulative effect of small amounts of contaminants gathered from a large area. The leaching out of nitrogen compounds from agricultural land which has been fertilized is a typical example. Nutrient runoff in stormwater from "sheet flow" over an agricultural field or a forest are also cited as examples of NPS pollution.

Contaminated storm water washed off of parking lots, roads and highways, called urban runoff, is sometimes included under the category of NPS pollution. However, this runoff is typically channeled into storm drain systems and discharged through pipes to local surface waters, and is a point source. However where such water is not channeled and drains directly to ground it is a non-point source.

Groundwater pollution

Interactions between groundwater and surface water are complex. Consequently, groundwater pollution, sometimes referred to as **groundwater contamination**, is not as easily classified as surface water pollution. By its very nature, groundwater aquifers are susceptible to contamination from sources that may not directly affect surface water bodies, and the distinction of point vs. non-point source may be irrelevant. A spill or ongoing releases of chemical or radionuclide contaminants into soil (located away from a surface water body) may not create point source or non-point source pollution, but can contaminate the aquifer below, defined as a toxin plume. The movement of the plume, a plume front, can be part of a Hydrological transport model or Groundwater model. Analysis of groundwater contamination may focus on the soil characteristics and site geology, hydrogeology, hydrology, and the nature of the contaminants.

Causes of water pollution

The specific contaminants leading to pollution in water include a wide spectrum of chemicals, pathogens, and physical or sensory changes such as elevated temperature and discoloration. While many of the chemicals and substances that are regulated may be naturally occurring (calcium, sodium, iron, manganese, etc.) the concentration is often the key in determining what is a natural component of water, and what is a contaminant.

Oxygen-depleting substances may be natural materials, such as plant matter (e.g. leaves and grass) as well as man-made chemicals. Other natural and anthropogenic substances may cause turbidity (cloudiness) which blocks light and disrupts plant growth, and clogs the gills of some fish species.

Many of the chemical substances are toxic. Pathogens can produce waterborne diseases in either human or animal hosts. Alteration of water's physical chemistry includes acidity (change in pH), electrical conductivity, temperature, and eutrophication. Eutrophication

is an increase in the concentration of chemical nutrients in an ecosystem to an extent that increases in the primary productivity of the ecosystem. Depending on the degree of eutrophication, subsequent negative environmental effects such as anoxia (oxygen depletion) and severe reductions in water quality may occur, affecting fish and other animal populations.

Pathogens



A manhole cover unable to contain a sanitary sewer overflow

Coliform bacteria are a commonly used bacterial indicator of water pollution, although not an actual cause of disease. Other microorganisms sometimes found in surface waters which have caused human health problems include:

- *Burkholderia pseudomallei*
- *Cryptosporidium parvum*
- *Giardia lamblia*
- *Salmonella*
- *Novovirus* and other viruses
- Parasitic worms (helminths).

High levels of pathogens may result from inadequately treated sewage discharges. This can be caused by a sewage plant designed with less than secondary treatment (more typical in less-developed countries). In developed countries, older cities with aging infrastructure may have leaky sewage collection systems (pipes, pumps, valves), which can cause sanitary sewer overflows. Some cities also have combined sewers, which may discharge untreated sewage during rain storms.

Pathogen discharges may also be caused by poorly managed livestock operations.

Chemical and other contaminants



Muddy river polluted by sediment

Contaminants may include organic and inorganic substances.

Organic water pollutants include:

- Detergents
- Disinfection by-products found in chemically disinfected drinking water, such as chloroform
- Food processing waste, which can include oxygen-demanding substances, fats and grease
- Insecticides and herbicides, a huge range of organohalides and other chemical compounds
- Petroleum hydrocarbons, including fuels (gasoline, diesel fuel, jet fuels, and fuel oil) and lubricants (motor oil), and fuel combustion byproducts, from stormwater runoff
- Tree and bush debris from logging operations
- Volatile organic compounds (VOCs), such as industrial solvents, from improper storage. Chlorinated solvents, which are dense non-aqueous phase liquids (DNAPLs), may fall to the bottom of reservoirs, since they don't mix well with water and are denser.
- Various chemical compounds found in personal hygiene and cosmetic products

Inorganic water pollutants include:

- Acidity caused by industrial discharges (especially sulfur dioxide from power plants)
- Ammonia from food processing waste
- Chemical waste as industrial by-products
- Fertilizers containing nutrients--nitrates and phosphates--which are found in stormwater runoff from agriculture, as well as commercial and residential use
- Heavy metals from motor vehicles (via urban stormwater runoff) and acid mine drainage
- Silt (sediment) in runoff from construction sites, logging, slash and burn practices or land clearing sites

Macroscopic pollution—large visible items polluting the water—may be termed "floatables" in an urban stormwater context, or marine debris when found on the open seas, and can include such items as:

- Trash (e.g. paper, plastic, or food waste) discarded by people on the ground, and that are washed by rainfall into storm drains and eventually discharged into surface waters
- Nurdles, small ubiquitous waterborne plastic pellets
- Shipwrecks, large derelict ships

Thermal Pollution



Potrero Generating Station discharges heated water into San Francisco Bay

Thermal pollution is the degradation of water quality by any process that changes ambient water temperature.

A common cause of thermal pollution is the use of water as a coolant by power plants and industrial manufacturers. When water used as a coolant is returned to the natural environment at a higher temperature, the change in temperature (a) decreases oxygen supply, and (b) affects ecosystem composition. Urban runoff--stormwater discharged to

surface waters from roads and parking lots--can also be a source of elevated water temperatures.

When a power plant first opens or shuts down for repair or other causes, fish and other organisms adapted to particular temperature range can be killed by the abrupt rise in water temperature known as 'thermal shock'.

Ecological effects — warm water

Elevated temperature typically decreases the level of dissolved oxygen (DO) in water. The decrease in levels of DO can harm aquatic animals such as fish, amphibians and copepods. Thermal pollution may also increase the metabolic rate of aquatic animals, as enzyme activity, resulting in these organisms consuming more food in a shorter time than if their environment were not changed. An increased metabolic rate may result in fewer resources; the more adapted organisms moving in may have an advantage over organisms that are not used to the warmer temperature. As a result one has the problem of compromising food chains of the old and new environments. Biodiversity can be decreased as a result.

It is known that temperature changes of even one to two degrees Celsius can cause significant changes in organism metabolism and other adverse cellular biology effects. Principal adverse changes can include rendering cell walls less permeable to necessary osmosis, coagulation of cell proteins, and alteration of enzyme metabolism. These cellular level effects can adversely affect mortality and reproduction.

Primary producers are affected by warm water because higher water temperature increases plant growth rates, resulting in a shorter lifespan and species overpopulation. This can cause an algae bloom which reduces oxygen levels.

A large increase in temperature can lead to the denaturing of life-supporting enzymes by breaking down hydrogen- and disulphide bonds within the quaternary structure of the enzymes. Decreased enzyme activity in aquatic organisms can cause problems such as the inability to break down lipids, which leads to malnutrition.

In limited cases, warm water has little deleterious effect and may even lead to improved function of the receiving aquatic ecosystem. This phenomenon is seen especially in seasonal waters and is known as **thermal enrichment**. An extreme case is derived from the aggregational habits of the manatee, which often uses power plant discharge sites during winter. Projections suggest that manatee populations would decline upon the removal of these discharges.

Ecological effects — cold water

Releases of unnaturally cold water from reservoirs can dramatically change the fish and macroinvertebrate fauna of rivers, and reduce river productivity. In Australia, where

many rivers have warmer temperature regimes, native fish species have been eliminated, and macroinvertebrate fauna have been drastically altered.

Control of thermal pollution



Cooling tower at Gustav Knepper Power Station, Dortmund, Germany

Industrial wastewater

In the United States, thermal pollution from industrial sources is generated mostly by power plants, petroleum refineries, pulp and paper mills, chemical plants, steel mills and smelters. Heated water from these sources may be controlled with:

- cooling ponds, man-made bodies of water designed for cooling by evaporation, convection, and radiation
- cooling towers, which transfer waste heat to the atmosphere through evaporation and/or heat transfer
- cogeneration, a process where waste heat is recycled for domestic and/or industrial heating purposes.

Some facilities use **once-through cooling** (OTC) systems which do not reduce temperature as effectively as the above systems. For example, the Potrero Generating

Station in San Francisco, which uses OTC, discharges water to San Francisco Bay approximately 10°C (20°F) above the ambient bay temperature.

Urban runoff

During warm weather, urban runoff can have significant thermal impacts on small streams, as stormwater passes over hot parking lots, roads and sidewalks. Stormwater management facilities that absorb runoff or direct it into groundwater, such as bioretention systems and infiltration basins, can reduce these thermal effects. Retention basins tend to be less effective at reducing temperature, as the water may be heated by the sun before being discharged to a receiving stream....

Transport and chemical reactions of water pollutants

Most water pollutants are eventually carried by rivers into the oceans. In some areas of the world the influence can be traced hundred miles from the mouth by studies using hydrology transport models. Advanced computer models such as SWMM or the DSSAM Model have been used in many locations worldwide to examine the fate of pollutants in aquatic systems. Indicator filter feeding species such as copepods have also been used to study pollutant fates in the New York Bight, for example. The highest toxin loads are not directly at the mouth of the Hudson River, but 100 kilometers south, since several days are required for incorporation into planktonic tissue. The Hudson discharge flows south along the coast due to coriolis force. Further south then are areas of oxygen depletion, caused by chemicals using up oxygen and by algae blooms, caused by excess nutrients from algal cell death and decomposition. Fish and shellfish kills have been reported, because toxins climb the food chain after small fish consume copepods, then large fish eat smaller fish, etc. Each successive step up the food chain causes a stepwise concentration of pollutants such as heavy metals (e.g. mercury) and persistent organic pollutants such as DDT. This is known as biomagnification, which is occasionally used interchangeably with bioaccumulation.



A polluted river draining an abandoned copper mine on Anglesey

Large gyres (vortexes) in the oceans trap floating plastic debris. The North Pacific Gyre for example has collected the so-called "Great Pacific Garbage Patch" that is now estimated at 100 times the size of Texas. Many of these long-lasting pieces wind up in the stomachs of marine birds and animals. This results in obstruction of digestive pathways which leads to reduced appetite or even starvation.

Many chemicals undergo reactive decay or chemically change especially over long periods of time in groundwater reservoirs. A noteworthy class of such chemicals is the chlorinated hydrocarbons such as trichloroethylene (used in industrial metal degreasing and electronics manufacturing) and tetrachloroethylene used in the dry cleaning industry (note latest advances in liquid carbon dioxide in dry cleaning that avoids all use of

chemicals). Both of these chemicals, which are carcinogens themselves, undergo partial decomposition reactions, leading to new hazardous chemicals (including dichloroethylene and vinyl chloride).

Groundwater pollution is much more difficult to abate than surface pollution because groundwater can move great distances through unseen aquifers. Non-porous aquifers such as clays partially purify water of bacteria by simple filtration (adsorption and absorption), dilution, and, in some cases, chemical reactions and biological activity: however, in some cases, the pollutants merely transform to soil contaminants. Groundwater that moves through cracks and caverns is not filtered and can be transported as easily as surface water. In fact, this can be aggravated by the human tendency to use natural sinkholes as dumps in areas of Karst topography.

There are a variety of secondary effects stemming not from the original pollutant, but a derivative condition. An example is silt-bearing surface runoff, which can inhibit the penetration of sunlight through the water column, hampering photosynthesis in aquatic plants.

Measurement of water pollution



Environmental Scientists preparing water autosamplers

Water pollution may be analyzed through several broad categories of methods: physical, chemical and biological. Most involve collection of samples, followed by specialized analytical tests. Some methods may be conducted *in situ*, without sampling, such as temperature. Government agencies and research organizations have published standardized, validated analytical test methods to facilitate the comparability of results from disparate testing events.

Sampling

Sampling of water for physical or chemical testing can be done by several methods, depending on the accuracy needed and the characteristics of the contaminant. Many contamination events are sharply restricted in time, most commonly in association with rain events. For this reason "grab" samples are often inadequate for fully quantifying contaminant levels. Scientists gathering this type of data often employ auto-sampler devices that pump increments of water at either time or discharge intervals.

Sampling for biological testing involves collection of plants and/or animals from the surface water body. Depending on the type of assessment, the organisms may be identified for biosurveys (population counts) and returned to the water body, or they may be dissected for bioassays to determine toxicity.

Physical testing

Common physical tests of water include temperature, solids concentration like total suspended solids (TSS) and turbidity.

Chemical testing

Water samples may be examined using the principles of analytical chemistry. Many published test methods are available for both organic and inorganic compounds. Frequently used methods include pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients (nitrate and phosphorus compounds), metals (including copper, zinc, cadmium, lead and mercury), oil and grease, total petroleum hydrocarbons (TPH), and pesticides.

Biological testing

Biological testing involves the use of plant, animal, and/or microbial indicators to monitor the health of an aquatic ecosystem.

Chapter- 7

Marine Pollution



While marine pollution can be obvious, as with the marine debris shown above, it is often the pollutants that cannot be seen that cause most harm.

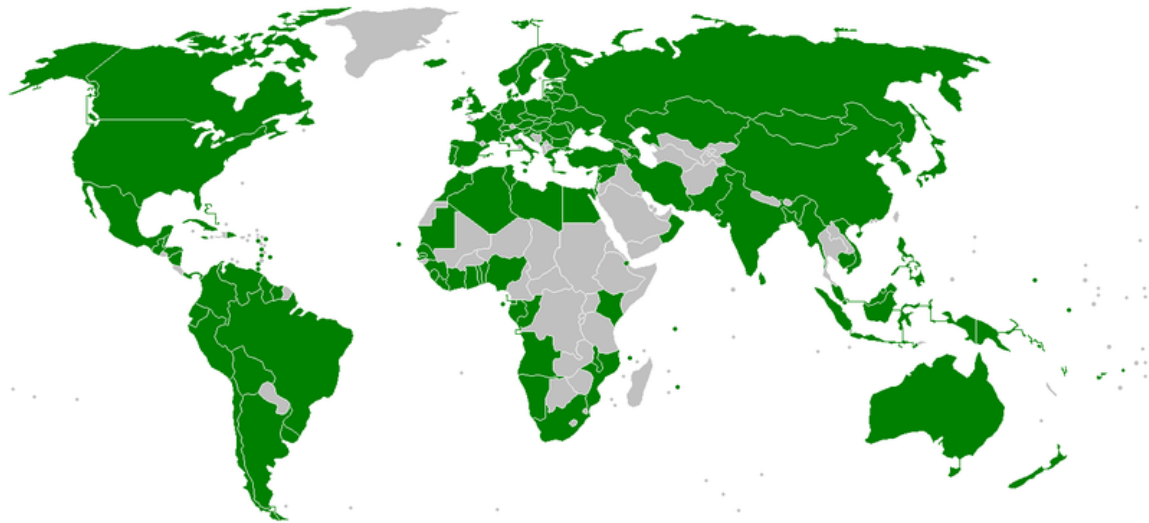
Marine pollution occurs when harmful effects, or potentially harmful effects, can result from the entry into the ocean of chemicals, particles, industrial, agricultural and residential waste, noise, or the spread of invasive organisms. Most sources of marine pollution are land based. The pollution often comes from nonpoint sources such as agricultural runoff and wind blown debris.

Many potentially toxic chemicals adhere to tiny particles which are then taken up by plankton and benthos animals, most of which are either deposit or filter feeders. In this way, the toxins are concentrated upward within ocean food chains. Many particles combine chemically in a manner highly depletive of oxygen, causing estuaries to become anoxic.

When pesticides are incorporated into the marine ecosystem, they quickly become absorbed into marine food webs. Once in the food webs, these pesticides can cause mutations, as well as diseases, which can be harmful to humans as well as the entire food web.

Toxic metals can also be introduced into marine food webs. These can cause a change to tissue matter, biochemistry, behaviour, reproduction, and suppress growth in marine life. Also, many animal feeds have a high fish meal or fish hydrolysate content. In this way, marine toxins can be transferred to land animals, and appear later in meat and dairy products.

History



Parties to the MARPOL 73/78 convention on marine pollution

Although marine pollution has a long history, significant international laws to counter it were enacted in the twentieth century. Marine pollution was a concern during several United Nations Conferences on the Law of the Sea beginning in the 1950s. Most

scientists believed that the oceans were so vast that they had unlimited ability to dilute, and thus render harmless, pollution.. In the late 1950s and early 1960s, there were several controversies about dumping radioactive waste off the coasts of the United States by companies licensed by the Atomic Energy Commission, into the Irish Sea from the British reprocessing facility at Windscale, and into the Mediterranean Sea by the French Commissariat à l'Energie Atomique. After the Mediterranean Sea controversy, for example, Jacques Cousteau became a worldwide figure in the campaign to stop marine pollution. Marine pollution made further international headlines after the 1967 crash of the oil tanker Torrey Canyon, and after the 1969 Santa Barbara oil spill off the coast of California. Marine pollution was a major area of discussion during the 1972 United Nations Conference on the Human Environment, held in Stockholm. That year also saw the signing of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, sometimes called the London Convention. The London Convention did not ban marine pollution, but it established black and gray lists for substances to be banned (black) or regulated by national authorities (gray). Cyanide and high-level radioactive waste, for example, were put on the black list. The London Convention applied only to waste dumped from ships, and thus did nothing to regulate waste discharged as liquids from pipelines.

Pathways of pollution



Septic river

There are many different ways to categorize, and examine the inputs of pollution into our marine ecosystems. Patin (n.d.) notes that generally there are three main types of inputs of pollution into the ocean: direct discharge of waste into the oceans, runoff into the waters due to rain, and pollutants that are released from the atmosphere.

One common path of entry by contaminants to the sea are rivers. The evaporation of water from oceans exceeds precipitation. The balance is restored by rain over the continents entering rivers and then being returned to the sea. The Hudson in New York State and the Raritan in New Jersey, which empty at the northern and southern ends of Staten Island, are a source of mercury contamination of zooplankton (copepods) in the open ocean. The highest concentration in the filter-feeding copepods is not at the mouths of these rivers but 70 miles south, nearer Atlantic City, because water flows close to the coast. It takes a few days before toxins are taken up by the plankton.

Pollution is often classed as point source or nonpoint source pollution. Point source pollution occurs when there is a single, identifiable, and localized source of the pollution. An example is directly discharging sewage and industrial waste into the ocean. Pollution such as this occurs particularly in developing nations. Nonpoint source pollution occurs when the pollution comes from ill-defined and diffuse sources. These can be difficult to regulate. Agricultural runoff and wind blown debris are prime examples.

Direct discharge



Acid mine drainage in the Rio Tinto River

Pollutants enter rivers and the sea directly from urban sewerage and industrial waste discharges, sometimes in the form of hazardous and toxic wastes.

Inland mining for copper, gold, etc., is another source of marine pollution. Most of the pollution is simply soil, which ends up in rivers flowing to the sea. However, some minerals discharged in the course of the mining can cause problems, such as copper, a common industrial pollutant, which can interfere with the life history and development of coral polyps. Mining has a poor environmental track record. For example, according to the United States Environmental Protection Agency, mining has contaminated portions of the headwaters of over 40% of watersheds in the western continental US. Much of this pollution finishes up in the sea.

Land runoff

Surface runoff from farming, as well as urban runoff and runoff from the construction of roads, buildings, ports, channels, and harbours, can carry soil and particles laden with carbon, nitrogen, phosphorus, and minerals. This nutrient-rich water can cause fleshy algae and phytoplankton to thrive in coastal areas, known as algal blooms, which have the potential to create hypoxic conditions by using all available oxygen.

Polluted runoff from roads and highways can be a significant source of water pollution in coastal areas. About 75 percent of the toxic chemicals that flow into Puget Sound are carried by stormwater that runs off paved roads and driveways, rooftops, yards and other developed land.

Ship pollution



A cargo ship pumps ballast water over the side

Ship pollution is the pollution of air and water by shipping. It is a problem that has been accelerating as trade has become increasingly globalized, posing an increasing threat to the world's oceans and waterways as globalization continues. It is expected that, "...shipping traffic to and from the USA is projected to double by 2020." Because of

increased traffic in ocean ports, pollution from ships also directly affects coastal areas. The pollution produced affects biodiversity, climate, food, and human health.

Sources and causes

Ships pollute the waterways and oceans in many ways. For instance, spills from oil and chemical tankers, and the ejection of sulfur dioxide, nitrogen dioxide, carbon dioxide, and black carbon into the atmosphere from exhaust fumes. Discharge of cargo residues from bulk carriers can pollute ports, waterways and oceans. Ships create noise pollution that disturbs natural wildlife, and water from ballast tanks can spread harmful algae and other invasive species. In many instances vessels due to a variety of reasons intentionally discharge illegal wastes despite foreign and domestic regulation prohibiting such actions.

Ballast water

When a larger vessel, such as a container ship or an oil tanker unloads cargo, seawater is pumped into compartments in the hull. Similarly, when a larger vessel is being loaded it discharges seawater from these compartments. The sea water is meant to help stabilize and balance a ship. Ballast discharges from ships are responsible for tar balls in the open oceans and seas, and can cause problems navigating tanker routes. Nevertheless, the discharge of ballast water only accounts for a small percentage of oil pollution in the marine environment.

Ships are also responsible for transporting harmful organisms in their ballast water. Meinesz believes that one of the worst cases of a single invasive species causing harm to an ecosystem can be attributed to a seemingly harmless jellyfish. *Mnemiopsis leidyi*, a species of comb jellyfish that inhabits estuaries from the United States to the Valdés peninsula in Argentina along the Atlantic coast, has caused notable damage in the Black Sea. It was first introduced in 1982, and thought to have been transported to the Black Sea in a ship's ballast water. The population of the jellyfish shot up exponentially and, by 1988, it was wreaking havoc upon the local fishing industry. "The anchovy catch fell from 204,000 tons in 1984 to 200 tons in 1993; sprat from 24,600 tons in 1984 to 12,000 tons in 1993; horse mackerel from 4,000 tons in 1984 to zero in 1993." Now that the jellyfish have exhausted the zooplankton, including fish larvae, their numbers have fallen dramatically, yet they continue to maintain a stranglehold on the ecosystem. Recently the jellyfish have been discovered in the Caspian Sea. Invasive species can take over once occupied areas, facilitate the spread of new diseases, introduce new genetic material, alter landscapes and jeopardize the ability of native species to obtain food. "On land and in the sea, invasive species are responsible for about 137 billion dollars in lost revenue and management costs in the U.S. each year".

In addition to introducing non native species into new environments, ballast and bilge discharge from ships can spread human pathogens and other harmful diseases and toxins potentially causing health issues for humans and marine life alike. Discharges into coastal waters along with other sources of marine pollution have the potential to be toxic to marine plants, animals, and microorganisms causing alterations such as changes in

growth, disruption of hormone cycles, birth defects, suppression of the immune system, and disorders resulting in cancer, tumors, and genetic abnormalities or even death. They may also have the opposite effect upon some marine life stimulating growth and providing a source of food. Sources of seafood can become contaminated and unhealthy for consumption. Not surprisingly, cholera outbreaks have been attributed to ship operations. "Current research indicates that the bacterium responsible for causing cholera, *Vibrio cholerae* can spread through attachment to marine organisms in ship ballast water." Shellfish and drinking water can then be contaminated when the ship discharges its ballast water.

Exhaust emissions

Exhaust emissions from ships are considered to be a significant source of air pollution, with 18-30% of all nitrogen oxide and 9% of sulphur oxide pollution. The 15 biggest ships emit about as much sulphur oxide pollution as all cars combined. "By 2010, up to 40% of air pollution over land could come from ships." Sulfur in the air creates acid rain which damages crops and buildings. When inhaled the sulfur is known to cause respiratory problems and even increase the risk of a heart attack. According to Irene Blooming, a spokeswoman for the European environmental coalition Seas at Risk, the fuel used in oil tankers and container ships is high in sulfur and cheaper to buy compared to the fuel used for domestic land use. "A ship lets out around 50 times more sulfur than a lorry per metric tonne of cargo carried." Cities in the U.S. like Long Beach, Los Angeles, Houston, Galveston, and Pittsburgh see some of the heaviest shipping traffic in the nation and have left local officials desperately trying to clean up the air. Increasing trade between the U.S. and China is helping to increase the number of vessels navigating the Pacific and exacerbating many of the environmental problems. To maintain the level of growth China is currently experiencing, large amounts of grain are being shipped to China by the boat load. The number of voyages are expected to continue increasing.

3.5% to 4% of all climate change emissions are caused by shipping.

Oil spills

Most commonly associated with ship pollution are oil spills. While less frequent than the pollution that occurs from daily operations, oil spills have devastating effects. While being toxic to marine life, polycyclic aromatic hydrocarbons (PAHs), the components in crude oil, are very difficult to clean up, and last for years in the sediment and marine environment. Marine species constantly exposed to PAHs can exhibit developmental problems, susceptibility to disease, and abnormal reproductive cycles. One of the more widely known spills was the Exxon Valdez incident in Alaska. The ship ran aground and dumped a massive amount of oil into the ocean in March 1989. Despite efforts of scientists, managers, and volunteers over 400,000 seabirds, about 1,000 sea otters, and immense numbers of fish were killed.

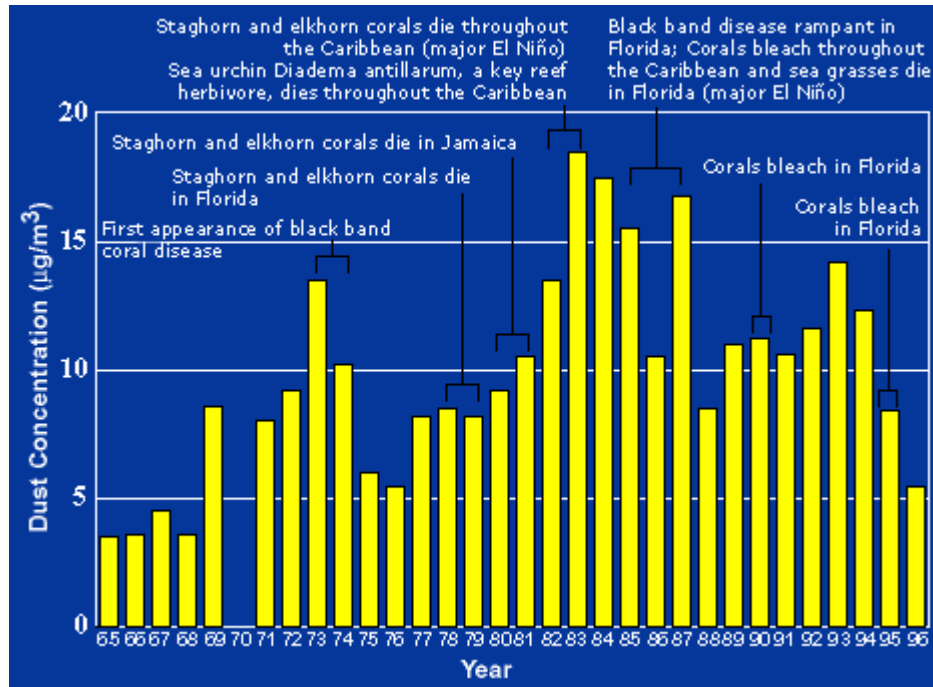
Cruise ships

Along with global trade the tourism industry has also seen growth in recent years. The cruise ship industry has seen 8 percent annual growth and continues to increase demand. With some cruise ships holding upwards of 5000 people, passengers and crew combined, these ships are likened to floating cities. “In one week, a typical cruise ship generates 210,000 gallons of black water (sewage), 1,000,000 gallons of gray water (shower, sink, dishwashing water), 37,000 gallons of oily bilge water, more than eight tons of solid waste, millions of gallons of ballast water containing potential invasive species, and toxic wastes from dry cleaning and photo processing laboratories.” This is also compounded with fuel emissions to have detrimental effects on the environment. From 1993 to 1998, cruise ships were involved in 104 confirmed cases of illegal discharge of oil, garbage, and hazardous wastes. One of the worst reported cases was by Royal Caribbean Cruises Ltd. Over several years, while in U.S. waters, they had been routinely and deliberately dumping waste oil, photo processing, dry cleaning, and print shop chemicals into coastal waters. Their ships were even fitted with concealed piping that would bypass pollution treatment equipment.

Regulation

Some of the major international efforts in the form of treaties are the Marine Pollution Treaty, Honolulu, which deals with regulating marine pollution from ships, and the UN Convention on Law of the Sea, which deals with marine species and pollution. While plenty of local and international regulations have been introduced throughout maritime history, much of the current regulations are considered inadequate. “In general, the treaties tend to emphasize the technical features of safety and pollution control measures without going to the root causes of sub-standard shipping, the absence of incentives for compliance and the lack of enforceability of measures.” Cruise ships for example are exempt from regulation under the Clean Water Act of 1972 (CWA) point source permitting system that requires compliance with U.S. federal standards through technological requirements. In the Caribbean, many ports lack proper waste disposal facilities, and many ships dump their waste at sea.

Atmospheric pollution



Graph linking atmospheric dust to various coral deaths across the Caribbean Sea and Florida

Another pathway of pollution occurs through the atmosphere. Wind blown dust and debris, including plastic bags, are blown seaward from landfills and other areas. Dust from the Sahara moving around the southern periphery of the subtropical ridge moves into the Caribbean and Florida during the warm season as the ridge builds and moves northward through the subtropical Atlantic. Dust can also be attributed to a global transport from the Gobi and Taklamakan deserts across Korea, Japan, and the Northern Pacific to the Hawaiian Islands. Since 1970, dust outbreaks have worsened due to periods of drought in Africa. There is a large variability in dust transport to the Caribbean and Florida from year to year; however, the flux is greater during positive phases of the North Atlantic Oscillation. The USGS links dust events to a decline in the health of coral reefs across the Caribbean and Florida, primarily since the 1970s.

Climate change is raising ocean temperatures and raising levels of carbon dioxide in the atmosphere. These rising levels of carbon dioxide are acidifying the oceans. This, in turn, is altering aquatic ecosystems and modifying fish distributions, with impacts on the sustainability of fisheries and the livelihoods of the communities that depend on them. Healthy ocean ecosystems are also important for the mitigation of climate change.

Deep sea mining

Deep sea mining is a relatively new mineral retrieval process that takes place on the ocean floor. Ocean mining sites are usually around large areas of polymetallic nodules or

active and extinct hydrothermal vents at about 1,400 - 3,700 meters below the ocean's surface. The vents create sulfide deposits, which contain precious metals such as silver, gold, copper, manganese, cobalt, and zinc. The deposits are mined using either hydraulic pumps or bucket systems that take ore to the surface to be processed. As with all mining operations, deep sea mining raises questions about environmental damages to the surrounding areas

Because deep sea mining is a relatively new field, the complete consequences of full scale mining operations are unknown. However, experts are certain that removal of parts of the sea floor will result in disturbances to the benthic layer, increased toxicity of the water column and sediment plumes from tailings. Removing parts of the sea floor disturbs the habitat of benthic organisms, possibly, depending on the type of mining and location, causing permanent disturbances. Aside from direct impact of mining the area, leakage, spills and corrosion would alter the mining area's chemical makeup.

Among the impacts of deep sea mining, sediment plumes could have the greatest impact. Plumes are caused when the tailings from mining (usually fine particles) are dumped back into the ocean, creating a cloud of particles floating in the water. Two types of plumes occur: near bottom plumes and surface plumes. Near bottom plumes occur when the tailings are pumped back down to the mining site. The floating particles increase the turbidity, or cloudiness, of the water, clogging filter-feeding apparatuses used by benthic organisms. Surface plumes cause a more serious problem. Depending on the size of the particles and water currents the plumes could spread over vast areas. The plumes could impact zooplankton and light penetration, in turn affecting the food web of the area.

Acidification



Island with fringing reef in the Maldives. Coral reefs are dying around the world.

The oceans are normally a natural carbon sink, absorbing carbon dioxide from the atmosphere. Because the levels of atmospheric carbon dioxide are increasing, the oceans are becoming more acidic. The potential consequences of ocean acidification are not fully understood, but there are concerns that structures made of calcium carbonate may become vulnerable to dissolution, affecting corals and the ability of shellfish to form shells..

Oceans and coastal ecosystems play an important role in the global carbon cycle and have removed about 25% of the carbon dioxide emitted by human activities between 2000 and 2007 and about half the anthropogenic CO₂ released since the start of the industrial revolution. Rising ocean temperatures and ocean acidification means that the capacity of the ocean carbon sink will gradually get weaker, giving rise to global concerns expressed in the Monaco and Manado Declarations.

A report from NOAA scientists published in the journal Science in May 2008 found that large amounts of relatively acidified water are upwelling to within four miles of the Pacific continental shelf area of North America. This area is a critical zone where most

local marine life lives or is born. While the paper dealt only with areas from Vancouver to northern California, other continental shelf areas may be experiencing similar effects.

A related issue is the methane clathrate reservoirs found under sediments on the ocean floors. These trap large amounts of the greenhouse gas methane, which ocean warming has the potential to release. In 2004 the global inventory of ocean methane clathrates was estimated to occupy between one and five million cubic kilometres. If all these clathrates were to be spread uniformly across the ocean floor, this would translate to a thickness between three and fourteen metres. This estimate corresponds to 500-2500 gigatonnes carbon (Gt C), and can be compared with the 5000 Gt C estimated for all other fossil fuel reserves.

Plastic debris



A mute swan builds a nest using plastic garbage

Marine debris is mainly discarded human rubbish which floats on, or is suspended in the ocean. Eighty percent of marine debris is plastic - a component that has been rapidly accumulating since the end of World War II. The mass of plastic in the oceans may be as high as one hundred million metric tons.

Discarded plastic bags, six pack rings and other forms of plastic waste which finish up in the ocean present dangers to wildlife and fisheries. Aquatic life can be threatened through entanglement, suffocation, and ingestion. Fishing nets, usually made of plastic, can be left or lost in the ocean by fishermen. Known as ghost nets, these entangle fish, dolphins, sea turtles, sharks, dugongs, crocodiles, seabirds, crabs, and other creatures, restricting movement, causing starvation, laceration and infection, and, in those that need to return to the surface to breathe, suffocation.



Remains of an albatross containing ingested flotsam

Many animals that live on or in the sea consume flotsam by mistake, as it often looks similar to their natural prey. Plastic debris, when bulky or tangled, is difficult to pass, and may become permanently lodged in the digestive tracts of these animals, blocking the passage of food and causing death through starvation or infection.

Plastics accumulate because they don't biodegrade in the way many other substances do. They will photodegrade on exposure to the sun, but they do so properly only under dry conditions, and water inhibits this process. In marine environments, photodegraded plastic disintegrates into ever smaller pieces while remaining polymers, even down to the molecular level. When floating plastic particles photodegrade down to zooplankton sizes, jellyfish attempt to consume them, and in this way the plastic enters the ocean food chain. Many of these long-lasting pieces end up in the stomachs of marine birds and animals, including sea turtles, and black-footed albatross.



Marine debris on Kamilo Beach, Hawaii, washed up from the Great Pacific Garbage Patch

Plastic debris tends to accumulate at the centre of ocean gyres. In particular, the Great Pacific Garbage Patch has a very high level of plastic particulate suspended in the upper water column. In samples taken in 1999, the mass of plastic exceeded that of zooplankton (the dominant animal life in the area) by a factor of six. Midway Atoll, in common with all the Hawaiian Islands, receives substantial amounts of debris from the garbage patch. Ninety percent plastic, this debris accumulates on the beaches of Midway where it becomes a hazard to the bird population of the island. Midway Atoll is home to two-thirds (1.5 million) of the global population of Laysan Albatross. Nearly all of these albatross have plastic in their digestive system and one-third of their chicks die.

Toxic additives used in the manufacture of plastic materials can leach out into their surroundings when exposed to water. Waterborne hydrophobic pollutants collect and magnify on the surface of plastic debris, thus making plastic far more deadly in the ocean than it would be on land. Hydrophobic contaminants are also known to bioaccumulate in fatty tissues, biomagnifying up the food chain and putting pressure on apex predators. Some plastic additives are known to disrupt the endocrine system when consumed, others can suppress the immune system or decrease reproductive rates. Floating debris can also absorb persistent organic pollutants from seawater, including PCBs, DDT and PAHs.

Aside from toxic effects, when ingested some of these are mistaken by the animal brain for estradiol, causing hormone disruption in the affected wildlife.

Toxins

Apart from plastics, there are particular problems with other toxins that do not disintegrate rapidly in the marine environment. Examples of persistent toxins are PCBs, DDT, pesticides, furans, dioxins, phenols and radioactive waste. Heavy metals are metallic chemical elements that have a relatively high density and are toxic or poisonous at low concentrations. Examples are mercury, lead, nickel, arsenic and cadmium. Such toxins can accumulate in the tissues of many species of aquatic life in a process called bioaccumulation. They are also known to accumulate in benthic environments, such as estuaries and bay muds: a geological record of human activities of the last century.

Specific examples

- Chinese and Russian industrial pollution such as phenols and heavy metals in the Amur River have devastated fish stocks and damaged its estuary soil.
- Wabamun Lake in Alberta, Canada, once the best whitefish lake in the area, now has unacceptable levels of heavy metals in its sediment and fish.
- Acute and chronic pollution events have been shown to impact southern California kelp forests, though the intensity of the impact seems to depend on both the nature of the contaminants and duration of exposure.
- Due to their high position in the food chain and the subsequent accumulation of heavy metals from their diet, mercury levels can be high in larger species such as bluefin and albacore. As a result, in March 2004 the United States FDA issued guidelines recommending that pregnant women, nursing mothers and children limit their intake of tuna and other types of predatory fish.
- Some shellfish and crabs can survive polluted environments, accumulating heavy metals or toxins in their tissues. For example, mitten crabs have a remarkable ability to survive in highly modified aquatic habitats, including polluted waters. The farming and harvesting of such species needs careful management if they are to be used as a food.
- Surface runoff of pesticides can alter the gender of fish species genetically, transforming male into female fish.
- Heavy metals enter the environment through oil spills - such as the Prestige oil spill on the Galician coast - or from other natural or anthropogenic sources.

- In 2005, the 'Ndrangheta, an Italian mafia syndicate, was accused of sinking at least 30 ships loaded with toxic waste, much of it radioactive. This has led to widespread investigations into radioactive waste disposal rackets.
- Since the end of World War II, various nations, including the Soviet Union, the United Kingdom, the United States, and Germany, have disposed of chemical weapons in the Baltic Sea, raising concerns of environmental contamination.

Noise pollution

Marine life can be susceptible to noise or sound pollution from sources such as passing ships, oil exploration seismic surveys, and naval low-frequency active sonar. Sound travels more rapidly and over larger distances in the sea than in the atmosphere. Marine animals, such as cetaceans, often have weak eyesight, and live in a world largely defined by acoustic information. This applies also to many deeper sea fish, who live in a world of darkness. Between 1950 and 1975, ambient noise in the ocean increased by about ten decibels (that is a ten-fold increase).

Noise also makes species communicate louder, which is called the Lombard vocal response. Whale songs are longer when submarine-detectors are on. If creatures don't "speak" loud enough, their voice can be masked by anthropogenic sounds. These unheard voices might be warnings, finding of prey, or preparations of net-bubbling. When one species begins speaking louder, it will mask other specie voices, causing the whole ecosystem to eventually speak louder.

According to the oceanographer Sylvia Earle, "Undersea noise pollution is like the death of a thousand cuts. Each sound in itself may not be a matter of critical concern, but taken all together, the noise from shipping, seismic surveys, and military activity is creating a totally different environment than existed even 50 years ago. That high level of noise is bound to have a hard, sweeping impact on life in the sea."

Adaptation and mitigation



Aerosol can polluting a beach

Much anthropogenic pollution ends up in the ocean. Bjorn Jenssen (2003) notes in his article, “Anthropogenic pollution may reduce biodiversity and productivity of marine ecosystems, resulting in reduction and depletion of human marine food resources” (p. A198). There are two ways the overall level of this pollution can be mitigated: either the human population is reduced, or a way is found to reduce the ecological footprint left behind by the average human. If the second way is not adopted, then the first way may be imposed as world ecosystems falter.

The second way is for humans, individually, to pollute less. That requires social and political will, together with a shift in awareness so more people respect the environment and are less disposed to abuse it. At an operational level, regulations, and international government participation is needed. It is often very difficult to regulate marine pollution because pollution spreads over international barriers, thus making regulations hard to create as well as enforce.

Perhaps the most important strategy for reducing marine pollution is education. Most are unaware of the sources, and harmful effects of marine pollution, and therefore little is done to address the situation. In order to inform the population of all the facts, in depth research must be done to provide the full scale of the situation. Then this information must be made public.

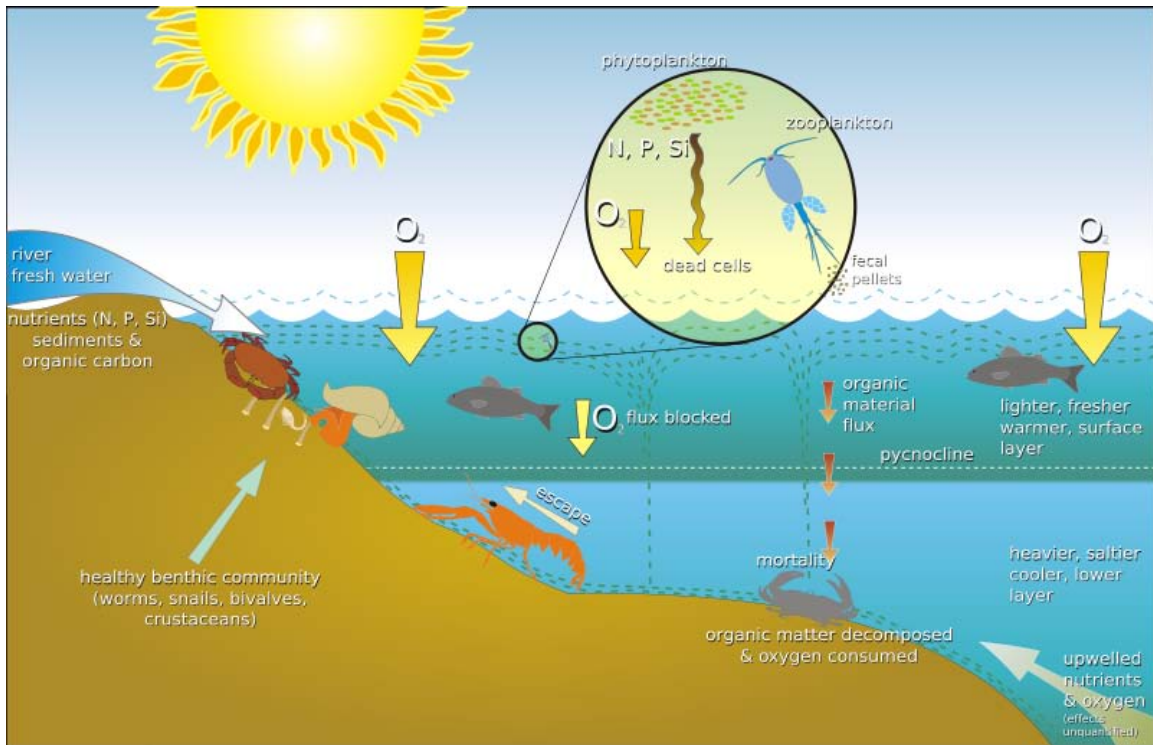
As expressed in Daoji and Dag's research, one of the reasons why environmental concern is lacking among the Chinese is because the public awareness is low and therefore should be targeted. Likewise, regulation, based upon such in-depth research should be employed. In California, such regulations have already been put in place to protect Californian coastal waters from agricultural runoff. This includes the California Water Code, as well as several voluntary programs. Similarly, in India, several tactics have been employed that help reduce marine pollution, however, they do not significantly target the problem. In Chennai city, India, sewage has been dumped further into open waters. Due to the mass of waste being deposited, open-ocean is best for diluting, and dispersing pollutants, thus making them less harmful to marine ecosystems.

Chapter- 8

Eutrophication



Polluted lagoon



Effect of eutrophication on marine benthic life



The eutrophication of the Potomac River is evident from its bright green water, caused by a dense bloom of cyanobacteria.

Eutrophication *eutrophia* healthy, adequate nutrition, development (Greek) *eutrope* (German) is a scientific term describing the overfertilization of lakes with nutrients and the changes that occur as a result, i.e. the primary productivity of the waterbody. In other terms, it is the "bloom" or great increase of phytoplankton in a water body. Negative environmental effects include particularly anoxia, or loss of oxygen in the water with severe reductions in fish and other animal populations. Other species (such as Nomura Jellyfish in Japanese waters) may experience an increase in population that negatively affects other species in the local ecosystem.

Lakes and rivers

Eutrophication can be human-caused or natural. Untreated sewage effluent and agricultural run-off carrying fertilizers are examples of human-caused eutrophication. However, it also occurs naturally in situations where nutrients accumulate (e.g. depositional environments), or where they flow into systems on an ephemeral basis. Eutrophication generally promotes excessive plant growth and decay, favouring simple algae and plankton over other more complicated plants, and causes a severe reduction in water quality. Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disrupts normal functioning of the ecosystem, causing a variety of problems such as a lack of oxygen needed for fish and shellfish to survive. The water becomes cloudy, typically coloured a shade of green, yellow, brown, or red. Eutrophication also decreases the value of rivers, lakes, and estuaries for recreation, fishing, hunting, and aesthetic enjoyment. Health problems can occur where eutrophic conditions interfere with drinking water treatment.

Eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the mid-20th century. Since then, it has become more widespread. Surveys showed that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America, 48%; in South America, 41%; and in Africa, 28%.

Although eutrophication is commonly caused by human activities, it can also be a natural process particularly in lakes. Eutrophy occurs in many lakes in temperate grasslands, for instance. Paleolimnologists now recognise that climate change, geology, and other external influences are critical in regulating the natural productivity of lakes. Some lakes also demonstrate the reverse process (meiotrophication), becoming less nutrient rich with time.

Eutrophication can also be a natural process in seasonally inundated tropical floodplains. In the Barotse Floodplain of the Zambezi River, the first floodwaters of the rainy season are usually hypoxic because of material such as cattle manure and previous decay of vegetation which grew during the dry season. These so-called "red waters" kill many fish. The process can be made worse by the use of fertilizers in crops such as maize, rice, and sugarcane grown on the floodplain.

Human activities can accelerate the rate at which nutrients enter ecosystems. Runoff from agriculture and development, pollution from septic systems and sewers, and other human-related activities increase the flow of both inorganic nutrients and organic substances into ecosystems. Elevated levels of atmospheric compounds of nitrogen can increase nitrogen availability. Phosphorus is often regarded as the main culprit in cases of eutrophication in lakes subjected to "point source" pollution from sewage pipes. The concentration of algae and the trophic state of lakes correspond well to phosphorus levels in water. Studies conducted in the Experimental Lakes Area in Ontario have shown a relationship between the addition of phosphorus and the rate of eutrophication. Humankind has increased the rate of phosphorus cycling on Earth by four times, mainly due to agricultural fertilizer production and application. Between 1950 and 1995, an estimated 600,000,000 tonnes of

phosphorus were applied to Earth's surface, primarily on croplands. Policy changes to control point sources of phosphorus have resulted in rapid control of eutrophication.

Ocean waters

Eutrophication is a common phenomenon in coastal waters. In contrast to freshwater systems, nitrogen is more commonly the key limiting nutrient of marine waters; thus, nitrogen levels have greater importance to understanding eutrophication problems in salt water. Estuaries tend to be naturally eutrophic because land-derived nutrients are concentrated where run-off enters a confined channel. Upwelling in coastal systems also promotes increased productivity by conveying deep, nutrient-rich waters to the surface, where the nutrients can be assimilated by algae.

The World Resources Institute has identified 375 hypoxic coastal zones in the world, concentrated in coastal areas in Western Europe, the Eastern and Southern coasts of the US, and East Asia, particularly Japan.

In addition to runoff from land, atmospheric fixed nitrogen can enter the open ocean. A study in 2008 found that this could account for around one third of the ocean's external (non-recycled) nitrogen supply, and up to 3% of the annual new marine biological production. It has been suggested that accumulating reactive nitrogen in the environment may prove as serious as putting carbon dioxide in the atmosphere.

Terrestrial ecosystems

Terrestrial ecosystems are subject to similarly adverse impacts from eutrophication. Increased nitrates in soil are frequently undesirable for plants. Many terrestrial plant species are endangered as a result of soil eutrophication, such as the majority of orchid species in Europe. Meadows, forests, and bogs are characterized by low nutrient content and slowly growing species adapted to those levels, so they can be overgrown by faster growing and more competitive species. In meadows, tall grasses that can take advantage of higher nitrogen levels may change the area so that natural species may be lost. Species-rich fens can be overtaken by reed or reedgrass species. Forest undergrowth affected by run-off from a nearby fertilized field can be turned into a nettle and bramble thicket.

Chemical forms of nitrogen are most often of concern with regard to eutrophication, because plants have high nitrogen requirements so that additions of nitrogen compounds will stimulate plant growth. Nitrogen is not readily available in soil because N_2 , a gaseous form of nitrogen, is very stable and unavailable directly to higher plants. Terrestrial ecosystems rely on microbial nitrogen fixation to convert N_2 into other forms such as nitrates. However, there is a limit to how much nitrogen can be utilized. Ecosystems receiving more nitrogen than the plants require are called nitrogen-saturated. Saturated terrestrial ecosystems then can contribute both inorganic and organic nitrogen to freshwater, coastal, and marine eutrophication, where nitrogen is also typically a limiting

nutrient. This is also the case with increased levels of phosphorus. However, because phosphorus is generally much less soluble than nitrogen, it is leached from the soil at a much slower rate than nitrogen. Consequently, phosphorus is much more important as a limiting nutrient in aquatic systems.

Ecological effects



Eutrophication is apparent as increased turbidity in the northern part of the Caspian Sea, imaged from orbit.

Many ecological effects can arise from stimulating primary production, but there are three particularly troubling ecological impacts: decreased biodiversity, changes in species composition and dominance, and toxicity effects.

- Increased biomass of phytoplankton
- Toxic or inedible phytoplankton species
- Increases in blooms of gelatinous zooplankton
- Decreased biomass of benthic and epiphytic algae
- Changes in macrophyte species composition and biomass
- Decreases in water transparency (increased turbidity)
- Colour, smell, and water treatment problems
- Dissolved oxygen depletion
- Increased incidences of fish kills
- Loss of desirable fish species
- Reductions in harvestable fish and shellfish
- Decreases in perceived aesthetic value of the water body

Decreased biodiversity

When an ecosystem experiences an increase in nutrients, primary producers reap the benefits first. In aquatic ecosystems, species such as algae experience a population increase (called an algal bloom). Algal blooms limit the sunlight available to bottom-dwelling organisms and cause wide swings in the amount of dissolved oxygen in the water. Oxygen is required by all respiring plants and animals and it is replenished in daylight by photosynthesizing plants and algae. Under eutrophic conditions, dissolved oxygen greatly increases during the day, but is greatly reduced after dark by the respiring algae and by microorganisms that feed on the increasing mass of dead algae. When dissolved oxygen levels decline to hypoxic levels, fish and other marine animals suffocate. As a result, creatures such as fish, shrimp, and especially immobile bottom dwellers die off. In extreme cases, anaerobic conditions ensue, promoting growth of bacteria such as *Clostridium botulinum* that produces toxins deadly to birds and mammals. Zones where this occurs are known as dead zones.

New species invasion

Eutrophication may cause competitive release by making abundant a normally limiting nutrient. This process causes shifts in the species composition of ecosystems. For instance, an increase in nitrogen might allow new, competitive species to invade and out-compete original inhabitant species. This has been shown to occur in New England salt marshes.

Toxicity

Some algal blooms, otherwise called "nuisance algae" or "harmful algal blooms", are toxic to plants and animals. Toxic compounds they produce can make their way up the food chain, resulting in animal mortality. Freshwater algal blooms can pose a threat to

livestock. When the algae die or are eaten, neuro- and hepatotoxins are released which can kill animals and may pose a threat to humans. An example of algal toxins working their way into humans is the case of shellfish poisoning. Biotoxins created during algal blooms are taken up by shellfish (mussels, oysters), leading to these human foods acquiring the toxicity and poisoning humans. Examples include paralytic, neurotoxic, and diarrhoeic shellfish poisoning. Other marine animals can be vectors for such toxins, as in the case of ciguatera, where it is typically a predator fish that accumulates the toxin and then poisons humans.

Sources of high nutrient runoff

Characteristics of point and nonpoint sources of chemical inputs (modified from Novonty and Olem 1994)

Point sources

- Wastewater effluent (municipal and industrial)
- Runoff and leachate from waste disposal systems
- Runoff and infiltration from animal feedlots
- Runoff from mines, oil fields, unsewered industrial sites
- Overflows of combined storm and sanitary sewers
- Runoff from construction sites less than 20,000 m² (220,000 ft²)
- Untreated sewage

Nonpoint sources

- Runoff from agriculture/irrigation
- Runoff from pasture and range
- Urban runoff from unsewered areas
- Septic tank leachate
- Runoff from construction sites >20,000 m²
- Runoff from abandoned mines
- Atmospheric deposition over a water surface
- Other land activities generating contaminants

In order to gauge how to best prevent eutrophication from occurring, specific sources that contribute to nutrient loading must be identified. There are two common sources of nutrients and organic matter: point and nonpoint sources.

Point sources

Point sources are directly attributable to one influence. In point sources the nutrient waste travels directly from source to water. Point sources are relatively easy to regulate.

Nonpoint sources

Nonpoint source pollution (also known as 'diffuse' or 'runoff' pollution) is that which comes from ill-defined and diffuse sources. Nonpoint sources are difficult to regulate and usually vary spatially and temporally (with season, precipitation, and other irregular events).

It has been shown that nitrogen transport is correlated with various indices of human activity in watersheds, including the amount of development. Agriculture and development are activities that contribute most to nutrient loading. There are three reasons that nonpoint sources are especially troublesome:

Soil retention

Nutrients from human activities tend to accumulate in soils and remain there for years. It has been shown that the amount of phosphorus lost to surface waters increases linearly with the amount of phosphorus in the soil. Thus much of the nutrient loading in soil eventually makes its way to water. Nitrogen, similarly, has a turnover time of decades or more.

Runoff to surface water and leaching to groundwater

Nutrients from human activities tend to travel from land to either surface or ground water. Nitrogen in particular is removed through storm drains, sewage pipes, and other forms of surface runoff. Nutrient losses in runoff and leachate are often associated with agriculture. Modern agriculture often involves the application of nutrients onto fields in order to maximise production. However, farmers frequently apply more nutrients than are taken up by crops or pastures. Regulations aimed at minimising nutrient exports from agriculture are typically far less stringent than those placed on sewage treatment plants and other point source polluters.

Atmospheric deposition

Nitrogen is released into the air because of ammonia volatilization and nitrous oxide production. The combustion of fossil fuels is a large human-initiated contributor to atmospheric nitrogen pollution. Atmospheric deposition (e.g., in the form of acid rain) can also affect nutrient concentration in water, especially in highly industrialized regions.

Other causes

Any factor that causes increased nutrient concentrations can potentially lead to eutrophication. In modeling eutrophication, the rate of water renewal plays a critical role; stagnant water is allowed to collect more nutrients than bodies with replenished water supplies. It has also been shown that the drying of wetlands causes an increase in nutrient concentration and subsequent eutrophication blooms.

Prevention and reversal

Eutrophication poses a problem not only to ecosystems, but to humans as well. Reducing eutrophication should be a key concern when considering future policy, and a sustainable solution for everyone, including farmers and ranchers, seems feasible. While eutrophication does pose problems, humans should be aware that natural runoff (which causes algal blooms in the wild) is common in ecosystems and should thus not reverse nutrient concentrations beyond normal levels.

Effectiveness

Cleanup measures have been mostly, but not completely, successful. Finnish phosphorus removal measures started in the mid-1970s and have targeted rivers and lakes polluted by industrial and municipal discharges. These efforts have had a 90% removal efficiency. Still, some targeted point sources did not show a decrease in runoff despite reduction efforts.

Minimizing nonpoint pollution: future work

Nonpoint pollution is the most difficult source of nutrients to manage. The literature suggests, though, that when these sources are controlled, eutrophication decreases. The following steps are recommended to minimize the amount of pollution that can enter aquatic ecosystems from ambiguous sources.

Riparian buffer zones

Studies show that intercepting non-point pollution between the source and the water is a successful means of prevention. Riparian buffer zones are interfaces between a flowing body of water and land, and have been created near waterways in an attempt to filter pollutants; sediment and nutrients are deposited here instead of in water. Creating buffer zones near farms and roads is another possible way to prevent nutrients from traveling too far. Still, studies have shown that the effects of atmospheric nitrogen pollution can reach far past the buffer zone. This suggests that the most effective means of prevention is from the primary source.

Prevention policy

Laws regulating the discharge and treatment of sewage have led to dramatic nutrient reductions to surrounding ecosystems, but it is generally agreed that a policy regulating agricultural use of fertilizer and animal waste must be imposed. In Japan the amount of nitrogen produced by livestock is adequate to serve the fertilizer needs for the agriculture industry. Thus, it is not unreasonable to command livestock owners to clean up animal waste—which when left stagnant will leach into ground water.

Policy concerning the prevention and reduction of eutrophication can be broken down into four sectors: Technologies, public participation, economic instruments, and cooperation. The term technology is used loosely, referring to a more widespread use of existing methods rather than an appropriation of new technologies. As mentioned before, nonpoint sources of pollution are the primary contributors to eutrophication, and their effects can be easily minimized through common agricultural practices. Reducing the amount of pollutants that reach a watershed can be achieved through the protection of its forest cover, reducing the amount of erosion leeching into a watershed. Also, through the efficient, controlled use of land using sustainable agricultural practices to minimize land degradation, the amount of soil runoff and nitrogen-based fertilizers reaching a watershed can be reduced. Waste disposal technology constitutes another factor in eutrophication prevention. Because a major contributor to the nonpoint source nutrient loading of water bodies is untreated domestic sewage, it is necessary to provide treatment facilities to highly urbanized areas, particularly those in underdeveloped nations, in which treatment of domestic waste water is a scarcity. The technology to safely and efficiently reuse waste water, both from domestic and industrial sources, should be a primary concern for policy regarding eutrophication.

The role of the public is a major factor for the effective prevention of eutrophication. In order for a policy to have any effect, the public must be aware of their contribution to the problem, and ways in which they can reduce their effects. Programs instituted to promote participation in the recycling and elimination of wastes, as well as education on the issue of rational water use are necessary to protect water quality within urbanized areas and adjacent water bodies.

Economic instruments, "which include, among others, property rights, water markets, fiscal and financial instruments, charge systems and liability systems, are gradually becoming a substantive component of the management tool set used for pollution control and water allocation decisions." Incentives for those who practice clean, renewable, water management technologies are an effective means of encouraging pollution prevention. By internalizing the costs associated with the negative effects on the environment, governments are able to encourage a cleaner water management.

Because a body of water can have an effect on a range of people reaching far beyond that of the watershed, cooperation between different organizations is necessary to prevent the intrusion of contaminants that can lead to eutrophication. Agencies ranging from state governments to those of water resource management and non-governmental organizations, going as low as the local population, are responsible for preventing eutrophication of water bodies.

Nitrogen testing and modeling

Soil Nitrogen Testing (N-Testing) is a technique that helps farmers optimize the amount of fertilizer applied to crops. By testing fields with this method, farmers saw a decrease in fertilizer application costs, a decrease in nitrogen lost to surrounding sources, or both. By

testing the soil and modeling the bare minimum amount of fertilizer needed, farmers reap economic benefits while the environment remains clean and pure.

Organic farming

Researchers at the National Academy of Sciences found that organically fertilized fields "significantly reduce harmful nitrate leaching" over conventionally fertilized fields.

Chapter- 9

Marine Debris



Marine debris on the Hawaiian coast



The problem is global. This is Msasani Beach in Dar es Salaam, the capital of Tanzania, on the Indian Ocean

Marine debris, also known as **marine litter**, is human-created waste that has deliberately or accidentally become afloat in a lake, sea, ocean or waterway. Oceanic debris tends to accumulate at the centre of gyres and on coastlines, frequently washing aground, when it is known as **beach litter** or tidewrack.

Deliberate disposal of wastes at sea is called **ocean dumping**.

Some seeming forms of marine debris, such as driftwood, occur naturally, and human activities have been discharging similar material into the oceans for thousands of years. Recently however, with the increasing use of plastic, human influence has become an issue as many types of plastics do not biodegrade. Waterborne plastic is both unsightly and dangerous, and poses a serious threat to fish, seabirds, marine reptiles, and marine mammals, as well as to boats and coastal habitations. Ocean dumping, accidental container spillages, and wind-blown landfill waste are all contributing to this problem.

Types of debris



Debris collected from beaches on Tern Island in the French Frigate Shoals over one month

A wide variety of anthropogenic artifacts can become marine debris; plastic bags, balloons, buoys, rope, medical waste, glass bottles and plastic bottles, cigarette lighters, beverage cans, styrofoam, lost fishing line and nets, and various wastes from cruise ships and oil rigs are among the items commonly found to have washed ashore. Six pack rings, in particular, are considered a poster child of the damage that garbage can do to the marine environment.

Studies have shown that eighty percent of marine debris is plastic – a component that has been rapidly accumulating since the end of World War II. Plastics accumulate because they don't biodegrade as many other substances do; although they will photodegrade on exposure to sunlight, they do so only under dry conditions, as water inhibits photolysis.

Ghost nets

Fishing nets left or lost in the ocean by fishermen – ghost nets – can entangle fish, dolphins, sea turtles, sharks, dugongs, crocodiles, seabirds, crabs, and other creatures. Acting as designed, these nets restrict movement, causing starvation, laceration and infection, and, in animals that need to return to the surface to breathe, suffocation.

Nurdles and plastics bags

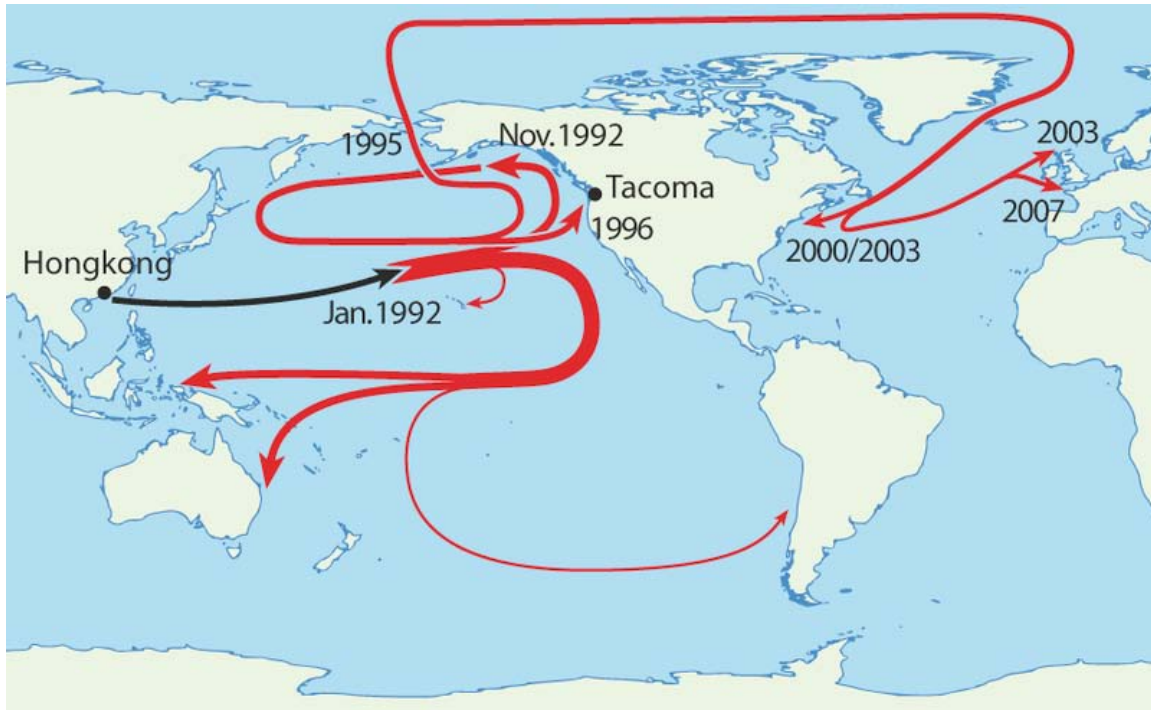


A handful of nurdles, spilt from a train in Pineville, Louisiana

Nurdles, also known as mermaids' tears, are plastic pellets typically under five millimetres in diameter, and are a major component of marine debris. They are used as a raw material in plastics manufacturing, and are thought to enter the natural environment after accidental spillages. Mermaids' tears are also created by the physical weathering of larger plastic debris. Nurdles strongly resemble fish eggs.

Plastic waste has reached all oceans around the world. This pollution harms and kills an estimated 100,000 sea turtles and marine mammals and 1,000,000 sea creatures each year. Pelagic plastic pieces in the center of our ocean's gyres outnumber live marine plankton, and are passed up the food chain to reach all marine life. Plastic shopping bags may clog digestive tracts when consumed and may cause starvation through restricting the movement of food, or by filling the stomach and tricking the animal into thinking it is full. A 1994 study of the seabed using trawl nets in the North-Western Mediterranean around the coasts of Spain, France and Italy reported a particularly high mean concentration of debris; an average of 1,935 items per square kilometre. Plastic debris accounted for 77%, of which 93% was plastic bags.

Source of debris



Travel of the Friendly Floatees

It has been estimated that container ships lose over 10,000 containers at sea each year (usually during storms). One famous spillage occurred in the Pacific Ocean in 1992, when thousands of rubber ducks and other toys went overboard during a storm. The toys have since been found all over the world; Curtis Ebbesmeyer and other scientists have used the incident to gain a better understanding of ocean currents. Similar incidents have happened before, with the same potential to track currents, such as when Hansa Carrier dropped 21 containers (with one notably containing buoyant Nike shoes). In 2007, MSC Napoli was beached in the English Channel, and dropped hundreds of containers, most of which washed up on the Jurassic Coast, a World Heritage Site.

Though it was originally assumed that most oceanic marine waste stemmed directly from ocean dumping, it is now thought that around four fifths of the oceanic debris is from rubbish blown seaward from landfills, and urban runoff washed down storm drains. In the 1987 Syringe Tide, medical waste washed ashore in New Jersey after having been blown from the Fresh Kills Landfill. Even on the remote sub-Antarctic island of South Georgia fishing related debris comprising of approximately 80% plastics have been found washed up and are responsible for the entanglement of large numbers of Antarctic fur seals.

Legality of ocean and river dumping

Ocean dumping is controlled by international law:

- The London Convention (1972) – a United Nations agreement to control ocean dumping
- MARPOL 73/78 – an international convention designed to minimize pollution of the seas, including dumping, oil and exhaust pollution

European law

In 1972 and 1974, conventions were held in Oslo and Paris respectively, and resulted in the passing of the OSPAR Convention, an international treaty controlling marine pollution in the north-east Atlantic Ocean around Europe. A similar Barcelona Convention exists to protect the Mediterranean Sea. The Water Framework Directive of 2000 is a European Union directive committing EU member states to make their inland and coastal waters free from human influence. In the United Kingdom, the Marine and Coastal Access Act is designed to "ensure clean healthy, safe, productive and biologically diverse oceans and seas, by putting in place better systems for delivering sustainable development of marine and coastal environment".



A sign above a sewer in Colorado Springs warning people to not pollute the local stream by dumping. Eighty percent of marine debris reaches the sea via rivers.

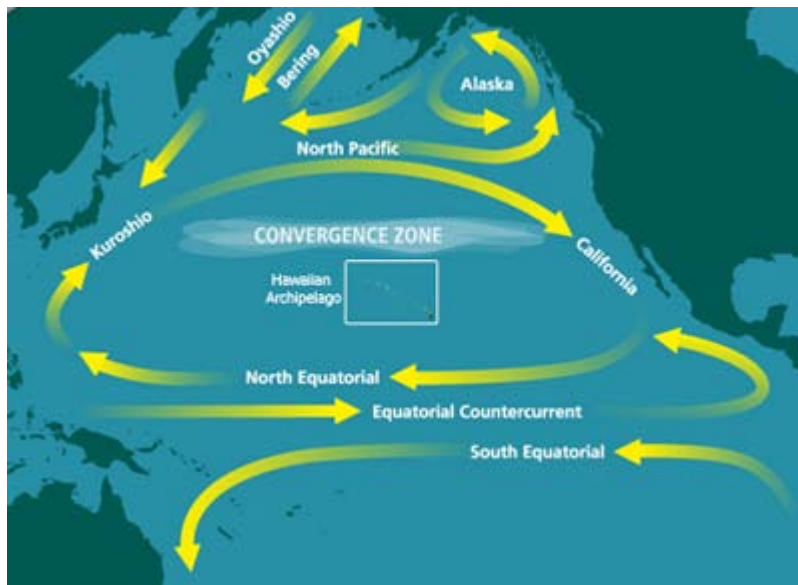
United States law

In 1972, the United States Congress passed the Ocean Dumping Act, giving the Environmental Protection Agency power to monitor and regulate the dumping of sewage sludge, industrial waste, radioactive waste and biohazardous materials into the nation's territorial waters. The Act was amended sixteen years later to include medical wastes. It is illegal to dispose of any plastic in all US waters. In 2008, the California State Legislature considered several bills aimed at reducing the sources of marine debris, following the recommendations of the California Ocean Protection Council.

Ownership of debris

Property law, admiralty law, and the law of the sea may be of relevance when lost, mislaid, and abandoned property is found at sea. Salvage law has as a basis that a salvor should be rewarded for risking his life and property to rescue the property of another from peril. On land the distinction between deliberate and accidental loss led to the concept of a "treasure trove". In the United Kingdom, shipwrecked goods should be reported to a Receiver of Wreck, and if identifiable, they should be returned to their rightful owner.

The Great Pacific Garbage Patch



The currents of the North Pacific Gyre spiral inwards, depositing debris in the convergence zone

Once waterborne, debris is far from immobile. Flotsam can be blown by the wind, or follow the flow of ocean currents, often ending up in the middle of oceanic gyres where currents are weakest. The Great Pacific Garbage Patch is one such example of this, comprising a vast region of the North Pacific Ocean rich with anthropogenic wastes.

Estimated to be double the size of Texas, the area contains more than 3 million tons of plastic. This means that there are approximately six pounds of plastic for every pound of plankton per cubic meter of seawater. The mass of plastic in our oceans may be as high as one hundred million tons.

Islands situated within gyres frequently have their coastlines ruined by the waste that inevitably washes ashore; prime examples are Midway and Hawaii. Clean-up teams around the world patrol beaches to clean up this environmental threat.

North Atlantic Garbage Patch

The currently next biggest known marine garbage patch is the *North Atlantic Garbage Patch*, estimated to be some hundreds of kilometres across in size.

Environmental impact



Remains of an albatross containing ingested flotsam

Many animals that live on or in the sea consume flotsam by mistake, as it often looks similar to their natural prey. Plastic debris, when bulky or tangled, is difficult to pass, and may become permanently lodged in the digestive tracts of these animals, blocking the passage of food and causing death through starvation or infection. Tiny floating particles also resemble zooplankton, which can lead filter feeders to consume them and cause them to enter the ocean food chain. In samples taken from the North Pacific Gyre in 1999 by the Algalita Marine Research Foundation, the mass of plastic exceeded that of zooplankton by a factor of six.



A turtle trapped in a ghost net, an abandoned fishing net

Toxic additives used in the manufacture of plastic materials can leach out into their surroundings when exposed to water. Waterborne hydrophobic pollutants collect and magnify on the surface of plastic debris, thus making plastic far more deadly in the ocean than it would be on land. Hydrophobic contaminants are also known to bioaccumulate in fatty tissues, biomagnifying up the food chain and putting great pressure on apex predators. Some plastic additives are known to disrupt the endocrine system when consumed; others can suppress the immune system or decrease reproductive rates.

Not all anthropogenic artefacts in the oceans are harmful however. Iron and concrete do little damage to the environment as they are generally immobile, and can even be used as scaffolding for the creation of artificial reefs, increasing the biodiversity of a coastal region. Entire ships have been deliberately sunk in coastal waters for that purpose. Some organisms have adapted to live on mobile plastic debris, which has allowed the inhabitants to disperse all over the world and become invasive species in remote ecosystems.

Debris removal



Two boats engaged in the collection of floating debris from the surface of the Pearl River in Guangzhou, keeping them from drifting into South China Sea

A variety of techniques are used to collect and remove marine (or riverine) debris by concerned jurisdictions or volunteer organizations. Besides collection by hand, some cities operate special beach-cleaning machines that collect trash deposited by the sea along the coast line. Other places (e.g. Baltimore) arrange for picking debris while it is still floating; such activities are often undertaken regularly where floating debris are perceived to pose danger to navigation. For example, the US Army Corps of Engineers reports removing 90 tons of "drifting material" from San Francisco Bay shipping lanes etc. every month. The Corps has been doing this work since 1942, when a seaplane carrying Admiral Chester W. Nimitz collided with a piece of floating debris and sank, resulting in the death of its pilot.

Elsewhere, various kinds of "trash traps" are installed on small rivers flowing into the sea, to capture waterborne debris before it reaches the sea. For example, South Australia's Adelaide operates a number of such traps, known as "trash racks" or "gross pollutant traps" on the Torrens River, which flows (during the wet season) into Gulf St Vincent.

Chapter- 10

Water Pollution Control Techniques

Sewage treatment



The objective of sewage treatment is to produce a disposable effluent without causing harm to the surrounding environment and prevent pollution.

Sewage treatment, or **domestic wastewater treatment**, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe

fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer).

Origins of sewage

Sewage is created by residential, institutional, and commercial and industrial establishments and includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. In many areas, sewage also includes liquid waste from industry and commerce.

The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets. Most sewage also includes some surface water from roofs or hard-standing areas and may include stormwater runoff.

Sewerage systems capable of handling stormwater are known as combined systems or combined sewers. Such systems are usually avoided now since they complicate and thereby reduce the efficiency of sewage treatment plants owing to their seasonality. The wide variability in flow, affected by precipitation, also leads to a need to construct much larger, more expensive, treatment facilities than would otherwise be required. In addition, heavy storms that contribute greater excess flow than the treatment plant can handle may overwhelm the sewage treatment system, causing a spill or overflow. Modern sewer developments tend to be provided with separate storm drain systems for rainwater.

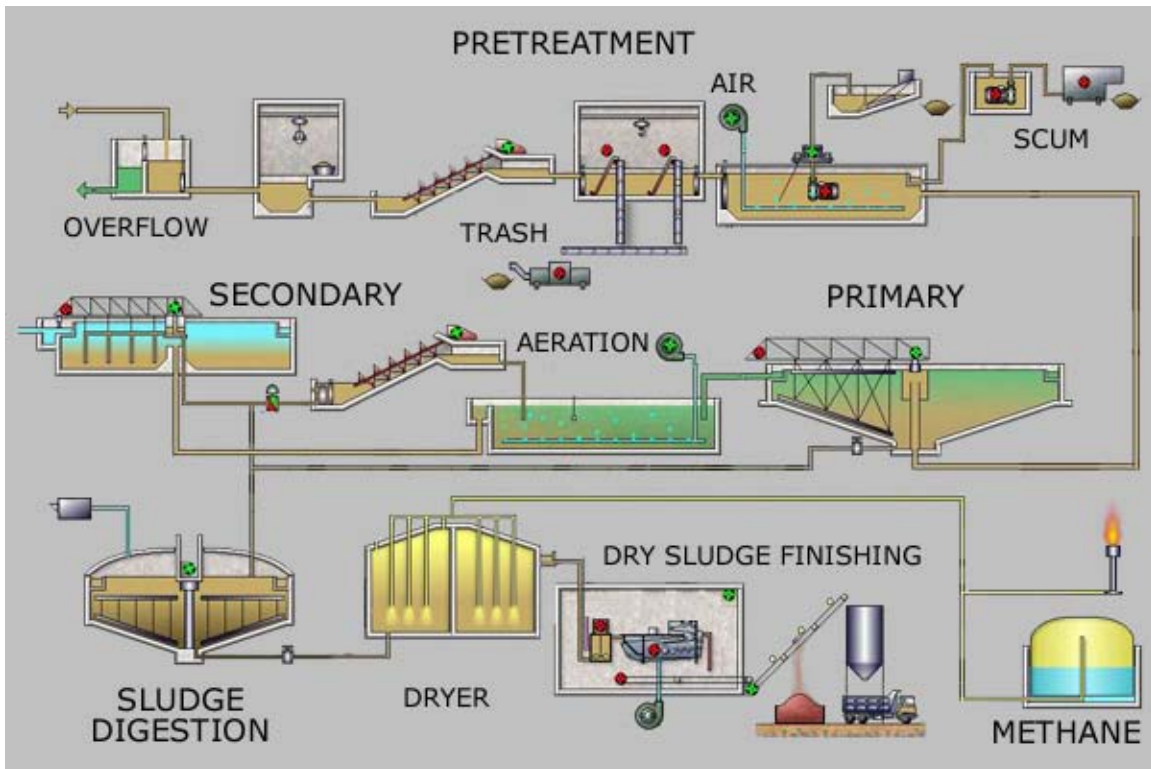
As rainfall travels over roofs and the ground, it may pick up various contaminants including soil particles and other sediment, heavy metals, organic compounds, animal waste, and oil and grease. Some jurisdictions require stormwater to receive some level of treatment before being discharged directly into waterways. Examples of treatment processes used for stormwater include retention basins, wetlands, buried vaults with various kinds of media filters, and vortex separators (to remove coarse solids). Sanitary sewers are typically much smaller than storm sewers, and they are not designed to transport stormwater. In areas with basements, backups of raw sewage can occur if excessive stormwater is allowed into a sanitary sewer system.

Process overview

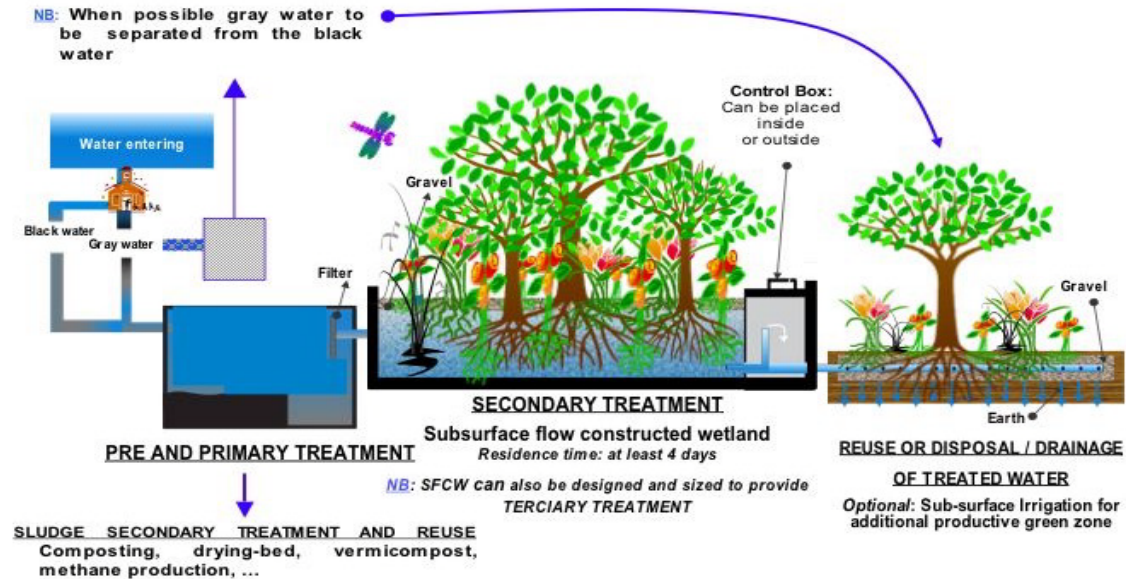
Sewage can be treated close to where it is created, a decentralised system, (in septic tanks, biofilters or aerobic treatment systems), or be collected and transported via a network of pipes and pump stations to a municipal treatment plant, a centralised system. Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Industrial sources of wastewater often require specialized treatment processes.

Sewage treatment generally involves three stages, called primary, secondary and tertiary treatment.

- *Primary treatment* consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.
- *Secondary treatment* removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- *Tertiary treatment* is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs,...). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.



Process Flow Diagram for a typical large-scale treatment plant



Process Flow Diagram for a typical treatment plant via Subsurface Flow Constructed Wetlands (SFCW)

Pre-treatment

Pre-treatment removes materials that can be easily collected from the raw wastewater before they damage or clog the pumps and skimmers of primary treatment clarifiers (trash, tree limbs, leaves, etc.).

Screening

The influent sewage water is screened to remove all large objects carried in the sewage stream. This is most commonly done with an automated mechanically raked bar screen in modern plants serving large populations, whilst in smaller or less modern plants a manually cleaned screen may be used. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow rate. The solids are collected and later disposed in a landfill or incinerated. Bar screens or mesh screens of varying sizes may be used to optimise solids removal. If gross solids are not removed they become entrained in pipes and moving parts of the treatment plant and can cause substantial damage and inefficiency in the process.

Grit removal

Pre-treatment may include a sand or grit channel or chamber where the velocity of the incoming wastewater is adjusted to allow the settlement of sand, grit, stones, and broken glass. These particles are removed because they may damage pumps and other equipment. For small sanitary sewer systems, the grit chambers may not be necessary, but grit removal is desirable at larger plants.



An empty sedimentation tank at the treatment plant in Merchtem, Belgium

Fat and grease removal

In some larger plants, fat and grease is removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. In most plants however, fat and grease removal takes place in the primary settlement tank using mechanical surface skimmers.

Primary treatment

In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks." The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities. Grease and oil from the floating material can sometimes be recovered for saponification.

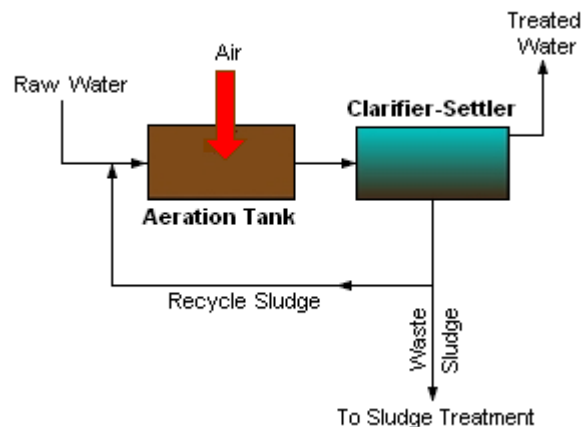
The dimensions of the tank should be designed to effect removal of a high percentage of the floatables and sludge. A typical sedimentation tank may remove from 60 to 65 percent of suspended solids, and from 30 to 35 percent of biochemical oxygen demand (BOD) from the sewage.

Secondary treatment

Secondary treatment is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require both oxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants (e.g. sugars, fats, organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into floc. Secondary treatment systems are classified as *fixed-film* or *suspended-growth* systems.

- **Fixed-film** or **attached growth** systems include trickling filters and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface.
- **Suspended-growth** systems include activated sludge, where the biomass is mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems.

Roughing filters are intended to treat particularly strong or variable organic loads, typically industrial, to allow them to then be treated by conventional secondary treatment processes. Characteristics include filters filled with media to which wastewater is applied. They are designed to allow high hydraulic loading and a high level of aeration. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes.



A generalized, schematic diagram of an activated sludge process

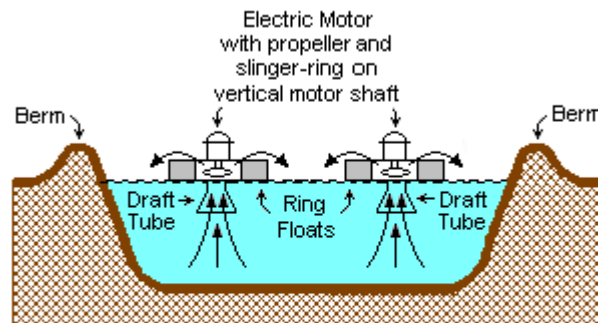
A filter removes a small percentage of the suspended organic matter, while the majority of the organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. With this aerobic oxidation and

nitrification, the organic solids are converted into coagulated suspended mass, which is heavier and bulkier, and can settle to the bottom of a tank. The effluent of the filter is therefore passed through a sedimentation tank, called a secondary clarifier, secondary settling tank or humus tank.

Activated sludge

In general, activated sludge plants encompass a variety of mechanisms and processes that use dissolved oxygen to promote the growth of biological floc that substantially removes organic material.

The process traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and ultimately to nitrogen gas.



A TYPICAL SURFACE – AERATED BASIN

Note: The ring floats are tethered to posts on the berms.

A Typical Surface-Aerated Basin (using motor-driven floating aerators)

Surface-aerated basins (Lagoons)

Many small municipal sewage systems in the United States (1 million gal./day or less) use aerated lagoons.

Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90 percent removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and use motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O₂/kW·h. However, they do not provide as good

mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

Constructed wetlands

Constructed wetlands (can either be surface flow or subsurface flow, horizontal or vertical flow), include engineered reedbeds and belong to the family of phytoremediation and ecotechnologies; they provide a high degree of biological improvement and depending on design, act as a primary, secondary and sometimes tertiary treatment. One example is a small reedbed used to clean the drainage from the elephants' enclosure at Chester Zoo in England; numerous CWs are used to recycle the water of the city of Honfleur in France and numerous other towns in Europe, the US, Asia and Australia. They are known to be highly productive systems as they copy natural wetlands, called the "Kidneys of the earth" for their fundamental recycling capacity of the hydrological cycle in the biosphere. Robust and reliable, their treatment capacities improve as time goes by, at the opposite of conventional treatment plants whose machinery ages with time. They are being increasingly used, although adequate and experienced design are more fundamental than for other systems and space limitation may impede their use.

Filter beds (oxidizing beds)

In older plants and those receiving variable loadings, trickling filter beds are used where the settled sewage liquor is spread onto the surface of a bed made up of coke (carbonized coal), limestone chips or specially fabricated plastic media. Such media must have large surface areas to support the biofilms that form. The liquor is typically distributed through perforated spray arms. The distributed liquor trickles through the bed and is collected in drains at the base. These drains also provide a source of air which percolates up through the bed, keeping it aerobic. Biological films of bacteria, protozoa and fungi form on the media's surfaces and eat or otherwise reduce the organic content. This biofilm is often grazed by insect larvae, snails, and worms which help maintain an optimal thickness. Overloading of beds increases the thickness of the film leading to clogging of the filter media and ponding on the surface. Recent advances in media and process micro-biology design overcome many issues with Trickling filter designs.

Soil Bio-Technology

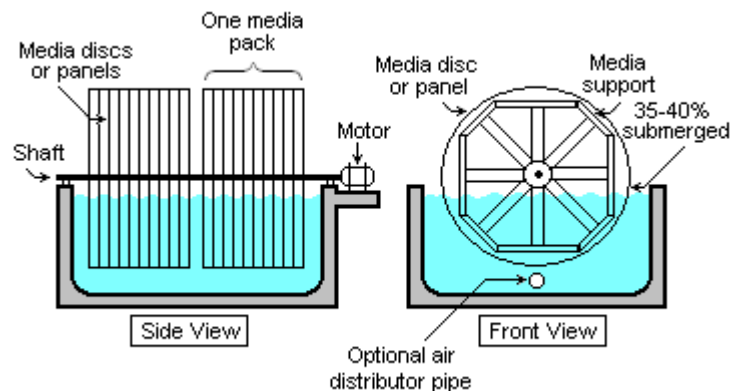
A new process called Soil Bio-Technology (SBT) developed at IIT Bombay has shown tremendous improvements in process efficiency enabling total water reuse, due to extremely low operating power requirements of less than 50 joules per kg of treated water. Typically SBT systems can achieve chemical oxygen demand (COD) levels less than 10 mg/L from sewage input of COD 400 mg/L. SBT plants exhibit high reductions in COD values and bacterial counts as a result of the very high microbial densities

available in the media. Unlike conventional treatment plants, SBT plants produce insignificant amounts of sludge, precluding the need for sludge disposal areas that are required by other technologies.

In the Indian context, conventional sewage treatment plants fall into systemic disrepair due to 1) high operating costs, 2) equipment corrosion due to methanogenesis and hydrogen sulphide, 3) non-reusability of treated water due to high COD (>30 mg/L) and high fecal coliform (>3000 NFU) counts, 4) lack of skilled operating personnel and 5) equipment replacement issues. Examples of such systemic failures has been documented by Sankat Mochan Foundation at the Ganges basin after a massive cleanup effort by the Indian government in 1986 by setting up sewage treatment plants under the Ganga Action Plan failed to improve river water quality.

Biological aerated filters

Biological Aerated (or Anoxic) Filter (BAF) or Biofilters combine filtration with biological carbon reduction, nitrification or denitrification. BAF usually includes a reactor filled with a filter media. The media is either in suspension or supported by a gravel layer at the foot of the filter. The dual purpose of this media is to support highly active biomass that is attached to it and to filter suspended solids. Carbon reduction and ammonia conversion occurs in aerobic mode and sometime achieved in a single reactor while nitrate conversion occurs in anoxic mode. BAF is operated either in upflow or downflow configuration depending on design specified by manufacturer.



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

Rotating biological contactors

Rotating biological contactors (RBCs) are mechanical secondary treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which break down and stabilise organic pollutants. To be

successful, micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the rotating discs in the sewage. Effluent from the RBC is then passed through final clarifiers where the micro-organisms in suspension settle as a sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel before passing through a media filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of microorganisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good at removing waste urea and ammonia excreted into the aquarium water by the fish and other animals.

Membrane bioreactors

Membrane bioreactors (MBR) combine activated sludge treatment with a membrane liquid-solid separation process. The membrane component uses low pressure microfiltration or ultra filtration membranes and eliminates the need for clarification and tertiary filtration. The membranes are typically immersed in the aeration tank; however, some applications utilize a separate membrane tank. One of the key benefits of an MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated sludge (CAS) processes. The technology permits bioreactor operation with considerably higher mixed liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge settling. The process is typically operated at MLSS in the range of 8,000–12,000 mg/L, while CAS are operated in the range of 2,000–3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus increased sludge retention times, usually exceeding 15 days, ensure complete nitrification even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. The technology has become increasingly popular for reliably pretreated waste streams and has gained wider acceptance where infiltration and inflow have been controlled, however, and the life-cycle costs have been steadily decreasing. The small footprint of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications.

Secondary sedimentation



Secondary Sedimentation tank at a rural treatment plant

The final step in the secondary treatment stage is to settle out the biological floc or filter material through a secondary clarifier and to produce sewage water containing low levels of organic material and suspended matter.

Tertiary treatment

The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing."

Filtration

Sand filtration removes much of the residual suspended matter. Filtration over activated carbon, also called *carbon adsorption*, removes residual toxins.

Lagooning



A sewage treatment plant and lagoon in Everett, Washington, United States

Lagooning provides settlement and further biological improvement through storage in large man-made ponds or lagoons. These lagoons are highly aerobic and colonization by native macrophytes, especially reeds, is often encouraged. Small filter feeding invertebrates such as *Daphnia* and species of *Rotifera* greatly assist in treatment by removing fine particulates.

Nutrient removal

Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release to the environment can lead to a build up of nutrients, called eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algal species produce toxins that contaminate drinking water supplies. Different treatment processes are required to remove nitrogen and phosphorus.

Nitrogen removal

The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia (nitrification) to nitrate, followed by denitrification, the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia (NH_3) to nitrite (NO_2^-) is most often facilitated by *Nitrosomonas* spp. (nitroso referring to the formation of a nitroso functional group). Nitrite oxidation to nitrate (NO_3^-), though traditionally believed to be facilitated by *Nitrobacter* spp. (nitro referring the formation of a nitro functional group), is now known to be facilitated in the environment almost exclusively by *Nitrospira* spp.

Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed beds can all be used to reduce nitrogen, but the activated sludge process (if designed well) can do the job the most easily. Since denitrification is the reduction of nitrate to dinitrogen gas, an electron donor is needed. This can be, depending on the wastewater, organic matter (from faeces), sulfide, or an added donor like methanol.

Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment.

Many sewage treatment plants use axial flow pumps to transfer the nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as *Internal Mixed Liquor Recycle* (IMLR) pumps.

Phosphorus removal

Phosphorus removal is important as it is a limiting nutrient for algae growth in many fresh water systems. It is also particularly important for water reuse systems where high phosphorus concentrations may lead to fouling of downstream equipment such as reverse osmosis.

Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20 percent of their mass). When the biomass enriched in these bacteria is separated from the treated water, these biosolids have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime. This may lead to excessive sludge production as hydroxides precipitates and the added chemicals can be expensive.

Chemical phosphorus removal requires significantly smaller equipment footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus removal. Another method for phosphorus removal is to use granular laterite.

Once removed, phosphorus, in the form of a phosphate-rich sludge, may be stored in a land fill or resold for use in fertilizer.

Disinfection

The purpose of disinfection in the treatment of wastewater is to substantially reduce the number of microorganisms in the water to be discharged back into the environment. The effectiveness of disinfection depends on the quality of the water being treated (e.g., cloudiness, pH, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time), and other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Generally, short contact times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, ultraviolet light, or sodium hypochlorite. Chloramine, which is used for drinking water, is not used in wastewater treatment because of its persistence.

Chlorination remains the most common form of wastewater disinfection in North America due to its low cost and long-term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Ultraviolet (UV) light can be used instead of chlorine, iodine, or other chemicals. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key disadvantages of UV disinfection are the need for frequent lamp maintenance and replacement and the need for a highly treated effluent to ensure that the target microorganisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect microorganisms from the UV light). In the United Kingdom, UV light is becoming the most common means of disinfection because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water. Some sewage treatment systems in Canada and the US also use UV light for their effluent water disinfection.

Ozone (O_3) is generated by passing oxygen (O_2) through a high voltage potential resulting in a third oxygen atom becoming attached and forming O_3 . Ozone is very unstable and reactive and oxidizes most organic material it comes in contact with, thereby destroying many pathogenic microorganisms. Ozone is considered to be safer than

chlorine because, unlike chlorine which has to be stored on site (highly poisonous in the event of an accidental release), ozone is generated onsite as needed. Ozonation also produces fewer disinfection by-products than chlorination. A disadvantage of ozone disinfection is the high cost of the ozone generation equipment and the requirements for special operators.

Odour Control

Odours emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition. Early stages of processing will tend to produce smelly gases, with hydrogen sulfide being most common in generating complaints. Large process plants in urban areas will often treat the odours with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the obnoxious gases. Other methods of odour control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

Package plants and batch reactors

To use less space, treat difficult waste and intermittent flows, a number of designs of hybrid treatment plants have been produced. Such plants often combine at least two stages of the three main treatment stages into one combined stage. In the UK, where a large number of wastewater treatment plants serve small populations, package plants are a viable alternative to building a large structure for each process stage. In the US, package plants are typically used in rural areas, highway rest stops and trailer parks.

One type of system that combines secondary treatment and settlement is the sequencing batch reactor (SBR). Typically, activated sludge is mixed with raw incoming sewage, and then mixed and aerated. The settled sludge is run off and re-aerated before a proportion is returned to the headworks. SBR plants are now being deployed in many parts of the world.

The disadvantage of the SBR process is that it requires a precise control of timing, mixing and aeration. This precision is typically achieved with computer controls linked to sensors. Such a complex, fragile system is unsuited to places where controls may be unreliable, poorly maintained, or where the power supply may be intermittent.

Package plants may be referred to as *high charged* or *low charged*. This refers to the way the biological load is processed. In high charged systems, the biological stage is presented with a high organic load and the combined floc and organic material is then oxygenated for a few hours before being charged again with a new load. In the low charged system the biological stage contains a low organic load and is combined with flocculate for longer times.

Sludge treatment and disposal

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. The purpose of digestion is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting. Incineration is also used albeit to a much lesser degree.

Sludge treatment depends on the amount of solids generated and other site-specific conditions. Composting is most often applied to small-scale plants with aerobic digestion for mid sized operations, and anaerobic digestion for the larger-scale operations.

Anaerobic digestion

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be *thermophilic* digestion, in which sludge is fermented in tanks at a temperature of 55°C, or *mesophilic*, at a temperature of around 36°C. Though allowing shorter retention time (and thus smaller tanks), thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

Anaerobic digestion is the most common (mesophilic) treatment of domestic sewage in septic tanks, which normally retain the sewage from one day to two days, reducing the BOD by about 35 to 40 percent. This reduction can be increased with a combination of anaerobic and aerobic treatment by installing *Aerobic Treatment Units* (ATUs) in the septic tank.

One major feature of anaerobic digestion is the production of biogas (with the most useful component being methane), which can be used in generators for electricity production and/or in boilers for heating purposes.

Aerobic digestion

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. The operating costs used to be characteristically much greater for aerobic digestion because of the energy used by the blowers, pumps and motors needed to add oxygen to the process.

Aerobic digestion can also be achieved by using diffuser systems or jet aerators to oxidize the sludge.

Composting

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest

both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

Incineration

Incineration of sludge is less common because of air emissions concerns and the supplemental fuel (typically natural gases or fuel oil) required to burn the low calorific value sludge and vaporize residual water. Stepped multiple hearth incinerators with high residence time and fluidized bed incinerators are the most common systems used to combust wastewater sludge. Co-firing in municipal waste-to-energy plants is occasionally done, this option being less expensive assuming the facilities already exist for solid waste and there is no need for auxiliary fuel.

Sludge disposal

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. There is no process which completely eliminates the need to dispose of biosolids. There is, however, an additional step some cities are taking to superheat sludge and convert it into small pelletized granules that are high in nitrogen and other organic materials. In New York City, for example, several sewage treatment plants have dewatering facilities that use large centrifuges along with the addition of chemicals such as polymer to further remove liquid from the sludge. The removed fluid, called centrate, is typically reintroduced into the wastewater process. The product which is left is called "cake" and that is picked up by companies which turn it into fertilizer pellets. This product is then sold to local farmers and turf farms as a soil amendment or fertilizer, reducing the amount of space required to dispose of sludge in landfills. Much sludge originating from commercial or industrial areas is contaminated with toxic materials that are released into the sewers from the industrial processes. Elevated concentrations of such materials may make the sludge unsuitable for agricultural use and it may then have to be incinerated or disposed of to landfill.

Treatment in the receiving environment



The outlet of a wastewater treating plant flows into a small river

Many processes in a wastewater treatment plant are designed to mimic the natural treatment processes that occur in the environment, whether that environment is a natural water body or the ground. If not overloaded, bacteria in the environment will consume organic contaminants, although this will reduce the levels of oxygen in the water and may significantly change the overall ecology of the receiving water. Native bacterial populations feed on the organic contaminants, and the numbers of disease-causing microorganisms are reduced by natural environmental conditions such as predation or exposure to ultraviolet radiation. Consequently, in cases where the receiving environment provides a high level of dilution, a high degree of wastewater treatment may not be required. However, recent evidence has demonstrated that very low levels of specific contaminants in wastewater, including hormones (from animal husbandry and residue from human hormonal contraception methods) and synthetic materials such as phthalates that mimic hormones in their action, can have an unpredictable adverse impact on the natural biota and potentially on humans if the water is re-used for drinking water. In the US and EU, uncontrolled discharges of wastewater to the environment are not permitted under law, and strict water quality requirements are to be met. A significant threat in the

coming decades will be the increasing uncontrolled discharges of wastewater within rapidly developing countries.

Effects on Biology

Sewage treatment plants can have multiple effects on nutrient levels in the water that the treated sewage flows into. These effects on nutrients can have large effects on the biological life in the water in contact with the effluent. Treatment ponds can include any of the following:

- Oxidation ponds, which are aerobic bodies of water usually 1-2 meters in depth that receive effluent from sedimentation tanks or other forms of primary treatment.
 - * Dominated by algae
- Polishing ponds are similar to oxidation ponds but receive effluent from an oxidation pond or from a plant with an extended mechanical treatment.
 - * Dominated by zooplankton
- Raw sewage lagoons or sewage lagoons are aerobic ponds where sewage is added with no primary treatment other than coarse screening.
- Anaerobic lagoons are heavily loaded ponds.
 - * Dominated by bacteria
- Sludge lagoons are aerobic ponds, usually 2-5 meters in depth, that receive anaerobically digested primary sludge, or activated secondary sludge under water.
 - * Upper layers are dominated by algae

Phosphorous limitation is a possible result from sewage treatment and results in flagellate-dominated plankton, particularly in summer and fall.

At the same time a different study found high nutrient concentrations linked to sewage effluents. High nutrient concentration leads to high chlorophyll a concentrations, which is a proxy for primary production in marine environments. High primary production means high phytoplankton populations and most likely high zooplankton populations because zooplankton feed on phytoplankton. However, effluent released into marine systems also leads to greater population instability.

A study done in Britain found that the quality of effluent effected the planktonic life in the water in direct contact with the wastewater effluent. Turbid, low-quality effluents either did not contain ciliated protozoa or contained only a few species in small numbers. On the other hand, high-quality effluents contained a wide variety of ciliated protozoa in

large numbers. Due to these findings, it seems unlikely that any particular component of the industrial effluent has, by itself, any harmful effects on the protozoan populations of activated sludge plants.

The planktonic trends of high populations close to input of treated sewage is contrasted by the bacterial trend. In a study of *Aeromonas* spp. in increasing distance from a wastewater source, greater change in seasonal cycles was found the furthest from the effluent. This trend is so strong that the furthest location studied actually had an inversion of the *Aeromonas* spp. cycle in comparison to that of fecal coliforms. Since there is a main pattern in the cycles that occurred simultaneously at all stations it indicates seasonal factors (temperature, solar radiation, phytoplankton) control of the bacterial population. The effluent dominant species changes from *Aeromonas caviae* in winter to *Aeromonas sobria* in the spring and fall while the inflow dominant species is *Aeromonas caviae*, which is constant throughout the seasons.

Sewage treatment in developing countries

Few reliable figures on the share of the wastewater collected in sewers that is being treated in the world exist. In many developing countries the bulk of domestic and industrial wastewater is discharged without any treatment or after primary treatment only. In Latin America about 15% of collected wastewater passes through treatment plants (with varying levels of actual treatment). In Venezuela, a below average country in South America with respect to wastewater treatment, 97 percent of the country's sewage is discharged raw into the environment. In a relatively developed Middle Eastern country such as Iran, Tehran's majority of population has totally untreated sewage injected to the city's groundwater.

In Israel, about 50 percent of agricultural water usage (total use was 1 billion cubic metres in 2008) is provided through reclaimed sewer water. Future plans call for increased use of treated sewer water as well as more desalination plants.

Most of sub-Saharan Africa is without wastewater treatment.

Industrial wastewater treatment

Industrial wastewater treatment covers the mechanisms and processes used to treat waters that have been contaminated in some way by anthropogenic industrial or commercial activities prior to its release into the environment or its re-use.

Most industries produce some wet waste although recent trends in the developed world have been to minimise such production or recycle such waste within the production

process. However, many industries remain dependent on processes that produce wastewaters.

Sources of industrial wastewater

Agricultural waste

Iron and steel industry

The production of iron from its ores involves powerful reduction reactions in blast furnaces. Cooling waters are inevitably contaminated with products especially ammonia and cyanide. Production of coke from coal in coking plants also requires water cooling and the use of water in by-products separation. Contamination of waste streams includes gasification products such as benzene, naphthalene, anthracene, cyanide, ammonia, phenols, cresols together with a range of more complex organic compounds known collectively as polycyclic aromatic hydrocarbons (PAH).

The conversion of iron or steel into sheet, wire or rods requires hot and cold mechanical transformation stages frequently employing water as a lubricant and coolant. Contaminants include hydraulic oils, tallow and particulate solids. Final treatment of iron and steel products before onward sale into manufacturing includes *pickling* in strong mineral acid to remove rust and prepare the surface for tin or chromium plating or for other surface treatments such as galvanisation or painting. The two acids commonly used are hydrochloric acid and sulfuric acid. Wastewaters include acidic rinse waters together with waste acid. Although many plants operate acid recovery plants, (particularly those using Hydrochloric acid), where the mineral acid is boiled away from the iron salts, there remains a large volume of highly acid ferrous sulfate or ferrous chloride to be disposed of. Many steel industry wastewaters are contaminated by hydraulic oil also known as *soluble oil*.

Mines and quarries



Mine wastewater effluent with neutralized pH from tailing runoff. Taken in Peru.

The principal waste-waters associated with mines and quarries are slurries of rock particles in water. These arise from rainfall washing exposed surfaces and haul roads and also from rock washing and grading processes. Volumes of water can be very high, especially rainfall related arisings on large sites. Some specialized separation operations, such as coal washing to separate coal from native rock using density gradients, can produce wastewater contaminated by fine particulate haematite and surfactants. Oils and hydraulic oils are also common contaminants. Wastewater from metal mines and ore recovery plants are inevitably contaminated by the minerals present in the native rock formations. Following crushing and extraction of the desirable materials, undesirable materials may become contaminated in the wastewater. For metal mines, this can include unwanted metals such as zinc and other materials such as arsenic. Extraction of high value metals such as gold and silver may generate slimes containing very fine particles in where physical removal of contaminants becomes particularly difficult.

Food industry

Wastewater generated from agricultural and food operations has distinctive characteristics that set it apart from common municipal wastewater managed by public or private wastewater treatment plants throughout the world: it is biodegradable and

nontoxic, but that has high concentrations of biochemical oxygen demand (BOD) and suspended solids (SS). The constituents of food and agriculture wastewater are often complex to predict due to the differences in BOD and pH in effluents from vegetable, fruit, and meat products and due to the seasonal nature of food processing and postharvesting.

Processing of food from raw materials requires large volumes of high grade water. Vegetable washing generates waters with high loads of particulate matter and some dissolved organics. It may also contain surfactants.

Animal slaughter and processing produces very strong organic waste from body fluids, such as blood, and gut contents. This wastewater is frequently contaminated by significant levels of antibiotics and growth hormones from the animals and by a variety of pesticides used to control external parasites. Insecticide residues in fleeces is a particular problem in treating waters generated in wool processing.

Processing food for sale produces wastes generated from cooking which are often rich in plant organic material and may also contain salt, flavourings, colouring material and acids or alkali. Very significant quantities of oil or fats may also be present.

Complex organic chemicals industry

A range of industries manufacture or use complex organic chemicals. These include pesticides, pharmaceuticals, paints and dyes, petro-chemicals, detergents, plastics, paper pollution, etc. Waste waters can be contaminated by feed-stock materials, by-products, product material in soluble or particulate form, washing and cleaning agents, solvents and added value products such as plasticisers. Treatment facilities that do not need pH control of their effluent typically opt for a type of aerobic treatment, ie. Aerated Lagoons.

Nuclear industry

The waste production from the nuclear and radio-chemicals industry is dealt with as *Radioactive waste*.

Water treatment

Water treatment for the production of drinking water is dealt with elsewhere. Many industries have a need to treat water to obtain very high quality water for demanding purposes. Water treatment produces organic and mineral sludges from filtration and sedimentation. Ion exchange using natural or synthetic resins removes calcium, magnesium and carbonate ions from water, replacing them with hydrogen and hydroxyl ions. Regeneration of ion exchange columns with strong acids and alkalis produces a wastewater rich in hardness ions which are readily precipitated out, especially when in admixture with other wastewaters.

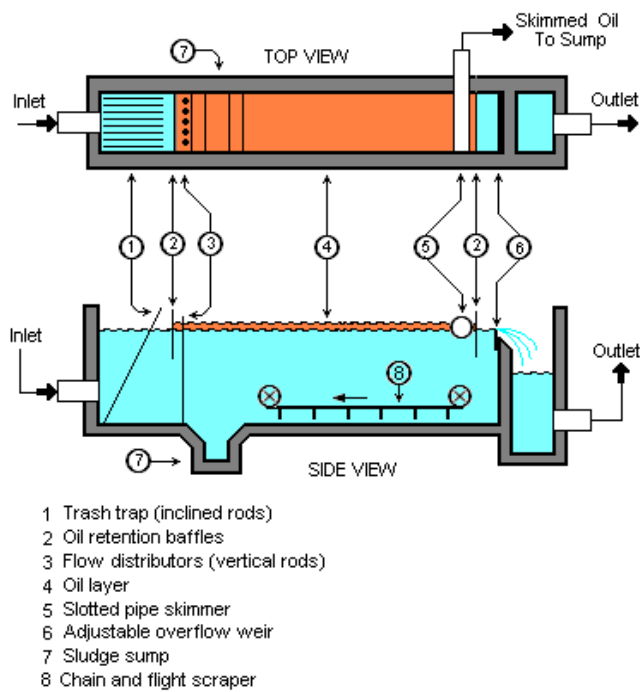
Treatment of industrial wastewater

The different types of contamination of wastewater require a variety of strategies to remove the contamination.

Solids removal

Most solids can be removed using simple sedimentation techniques with the solids recovered as slurry or sludge. Very fine solids and solids with densities close to the density of water pose special problems. In such case filtration or ultrafiltration may be required. Although, flocculation may be used, using alum salts or the addition of polyelectrolytes.

Oils and grease removal



A typical API oil-water separator used in many industries

Many oils can be recovered from open water surfaces by skimming devices. Considered a dependable and cheap way to remove oil, grease and other hydrocarbons from water, oil skimmers can sometimes achieve the desired level of water purity. At other times, skimming is also a cost-efficient method to remove most of the oil before using membrane filters and chemical processes. Skimmers will prevent filters from blinding prematurely and keep chemical costs down because there is less oil to process.

Because grease skimming involves higher viscosity hydrocarbons, skimmers must be equipped with heaters powerful enough to keep grease fluid for discharge. If floating

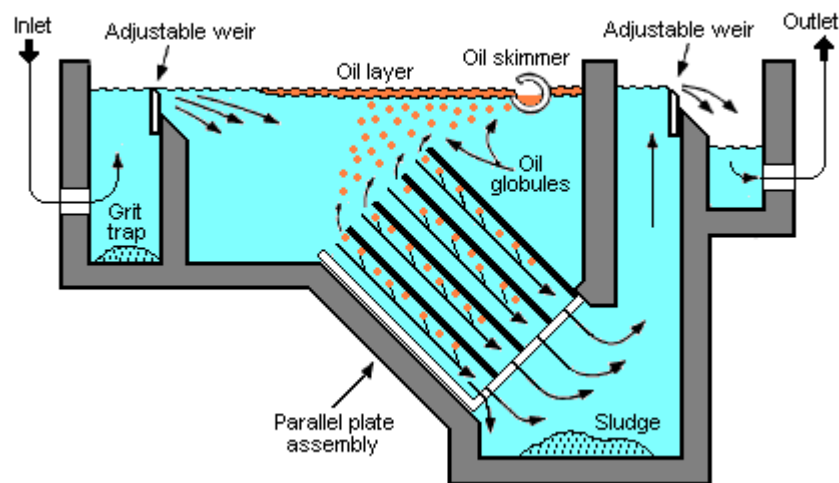
grease forms into solid clumps or mats, a spray bar, aerator or mechanical apparatus can be used to facilitate removal.

However, hydraulic oils and the majority of oils that have degraded to any extent will also have a soluble or emulsified component that will require further treatment to eliminate. Dissolving or emulsifying oil using surfactants or solvents usually exacerbates the problem rather than solving it, producing wastewater that is more difficult to treat.

The wastewaters from large-scale industries such as oil refineries, petrochemical plants, chemical plants, and natural gas processing plants commonly contain gross amounts of oil and suspended solids. Those industries use a device known as an API oil-water separator which is designed to separate the oil and suspended solids from their wastewater effluents. The name is derived from the fact that such separators are designed according to standards published by the American Petroleum Institute (API).

The API separator is a gravity separation device designed by using Stokes Law to define the rise velocity of oil droplets based on their density and size. The design is based on the specific gravity difference between the oil and the wastewater because that difference is much smaller than the specific gravity difference between the suspended solids and water. The suspended solids settle to the bottom of the separator as a sediment layer, the oil rises to top of the separator and the cleansed wastewater is the middle layer between the oil layer and the solids.

Typically, the oil layer is skimmed off and subsequently re-processed or disposed of, and the bottom sediment layer is removed by a chain and flight scraper (or similar device) and a sludge pump. The water layer is sent to further treatment consisting usually of a Electroflotation module for additional removal of any residual oil and then to some type of biological treatment unit for removal of undesirable dissolved chemical compounds.



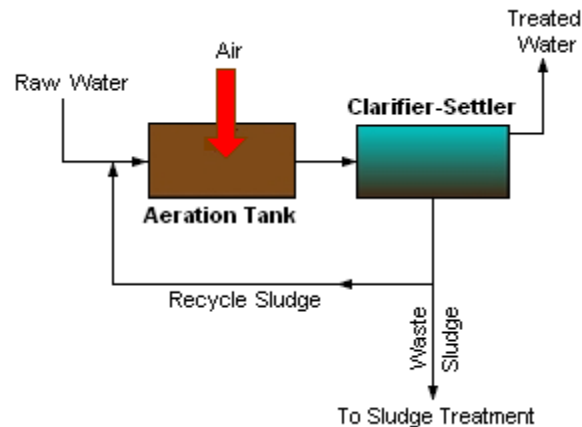
A typical parallel plate separator

Parallel plate separators are similar to API separators but they include tilted parallel plate assemblies (also known as parallel packs). The parallel plates provide more surface for suspended oil droplets to coalesce into larger globules. Such separators still depend upon the specific gravity between the suspended oil and the water. However, the parallel plates enhance the degree of oil-water separation. The result is that a parallel plate separator requires significantly less space than a conventional API separator to achieve the same degree of separation.

Removal of biodegradable organics

Biodegradable organic material of plant or animal origin is usually possible to treat using extended conventional wastewater treatment processes such as activated sludge or trickling filter. Problems can arise if the wastewater is excessively diluted with washing water or is highly concentrated such as neat blood or milk. The presence of cleaning agents, disinfectants, pesticides, or antibiotics can have detrimental impacts on treatment processes.

Activated sludge process



A generalized, schematic diagram of an activated sludge process

Activated sludge is a biochemical process for treating sewage and industrial wastewater that uses air (or oxygen) and microorganisms to biologically oxidize organic pollutants, producing a waste sludge (or floc) containing the oxidized material. In general, an activated sludge process includes:

- An aeration tank where air (or oxygen) is injected and thoroughly mixed into the wastewater.
- A settling tank (usually referred to as a "clarifier" or "settler") to allow the waste sludge to settle. Part of the waste sludge is recycled to the aeration tank and the remaining waste sludge is removed for further treatment and ultimate disposal.

Trickling filter process

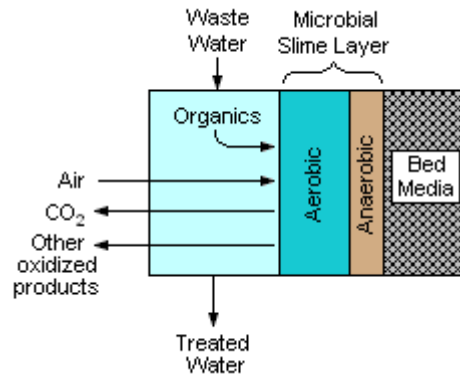
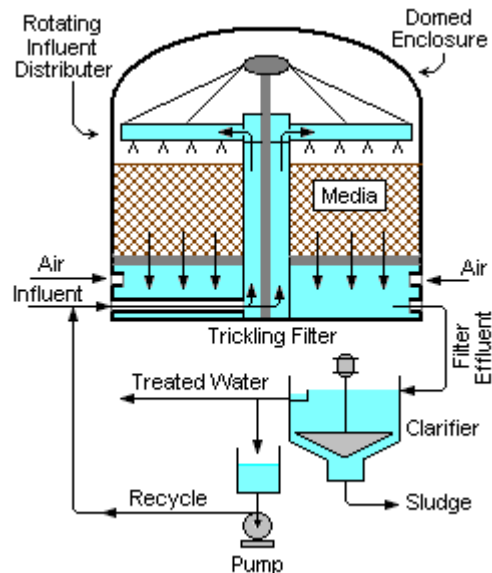


Image 1: A schematic cross-section of the contact face of the bed media in a trickling filter



A typical complete trickling filter system

A **trickling filter** consists of a bed of rocks, gravel, slag, peat moss, or plastic media over which wastewater flows downward and contacts a layer (or film) of microbial slime covering the bed media. Aerobic conditions are maintained by forced air flowing through the bed or by natural convection of air. The process involves adsorption of organic compounds in the wastewater by the microbial slime layer, diffusion of air into the slime layer to provide the oxygen required for the biochemical oxidation of the organic compounds. The end products include carbon dioxide gas, water and other products of the oxidation. As the slime layer thickens, it becomes difficult for the air to penetrate the layer and an inner anaerobic layer is formed.

The components of a complete trickling filter system are: fundamental components:

- A bed of filter medium upon which a layer of microbial slime is promoted and developed.
- An enclosure or a container which houses the bed of filter medium.
- A system for distributing the flow of wastewater over the filter medium.
- A system for removing and disposing of any sludge from the treated effluent.

The treatment of sewage or other wastewater with trickling filters is among the oldest and most well characterized treatment technologies.

A trickling filter is also often called a *trickle filter*, *trickling biofilter*, *biofilter*, *biological filter* or *biological trickling filter*.

Treatment of other organics

Synthetic organic materials including solvents, paints, pharmaceuticals, pesticides, coking products and so forth can be very difficult to treat. Treatment methods are often specific to the material being treated. Methods include Advanced Oxidation Processing, distillation, adsorption, vitrification, incineration, chemical immobilisation or landfill disposal. Some materials such as some detergents may be capable of biological degradation and in such cases, a modified form of wastewater treatment can be used.

Treatment of acids and alkalis

Acids and alkalis can usually be neutralised under controlled conditions. Neutralisation frequently produces a precipitate that will require treatment as a solid residue that may also be toxic. In some cases, gasses may be evolved requiring treatment for the gas stream. Some other forms of treatment are usually required following neutralisation.

Waste streams rich in hardness ions as from de-ionisation processes can readily lose the hardness ions in a buildup of precipitated calcium and magnesium salts. This precipitation process can cause severe *furring* of pipes and can, in extreme cases, cause the blockage of disposal pipes. A 1 metre diameter industrial marine discharge pipe serving a major chemicals complex was blocked by such salts in the 1970s. Treatment is by concentration of de-ionisation waste waters and disposal to landfill or by careful pH management of the released wastewater.

Treatment of toxic materials

Toxic materials including many organic materials, metals (such as zinc, silver, cadmium, thallium, etc.) acids, alkalis, non-metallic elements (such as arsenic or selenium) are generally resistant to biological processes unless very dilute. Metals can often be precipitated out by changing the pH or by treatment with other chemicals. Many, however, are resistant to treatment or mitigation and may require concentration followed by landfilling or recycling. Dissolved organics can be *incinerated* within the wastewater by Advanced Oxidation Process.

Agricultural wastewater treatment



Riparian buffer lining a creek in Iowa

Agricultural wastewater treatment relates to the treatment of wastewaters produced in the course of agricultural activities. Agriculture is a highly intensified industry in many parts of the world, producing a range of wastewaters requiring a variety of treatment technologies and management practices.

Nonpoint source pollution

Nonpoint source pollution from farms is caused by surface runoff from fields during rain storms. Agricultural runoff is a major source of pollution, in some cases the only source, in many watersheds.

Sediment runoff



Highly erodible soils on a farm in Iowa

Soil washed off fields is the largest source of agricultural pollution in the United States. Excess sediment causes high levels of turbidity in water bodies, which can inhibit growth of aquatic plants, clog fish gills and smother animal larvae.

Farmers may utilize erosion controls to reduce runoff flows and retain soil on their fields. Common techniques include:

- contour plowing
- crop mulching
- crop rotation
- planting perennial crops
- installing riparian buffers. pp. 4-95 – 4-96

Nutrient runoff



Manure spreader

Nitrogen and phosphorus are key pollutants found in runoff, and they are applied to farmland in several ways:

- commercial fertilizer
- animal manure
- municipal or industrial wastewater (effluent) or sludge.

These chemicals may also enter runoff from crop residues, irrigation water, wildlife, and atmospheric deposition.^{p. 2-9}

Farmers can develop and implement nutrient management plans to mitigate impacts on water quality:

- map and document fields, crop types, soil types, water bodies
- develop realistic crop yield projections
- conduct soil tests and nutrient analyses of manures and/or sludges applied
- identify other significant nutrient sources (e.g. irrigation water)
- evaluate significant field features such as highly erodible soils, subsurface drains, and shallow aquifers

- apply fertilizers, manures, and/or sludges based on realistic yield goals and using precision agriculture techniques.^{pp. 4-37–4-38}

Pesticides



Aerial application (crop dusting) of pesticides over a soybean field in the U.S.

Pesticides are widely used by farmers to control plant pests and enhance production, but chemical pesticides can also cause water quality problems. Pesticides may appear in surface water due to:

- direct application (e.g. aerial spraying or broadcasting over water bodies)
- runoff during rain storms
- aerial drift (from adjacent fields).^{p.2-22}

Some pesticides have also been detected in groundwater.^{p.2-24}

Farmers may use Integrated Pest Management (IPM) techniques (which can include biological pest control) to maintain control over pests, reduce reliance on chemical pesticides, and protect water quality.

There are few safe ways of disposing of pesticide surpluses other than through containment in well managed landfills or by incineration. In some parts of the world, spraying on land is a permitted method of disposal.

Point source pollution

Farms with large livestock and poultry operations, such as factory farms, can be a major source of point source wastewater. In the United States, these facilities are called *concentrated animal feeding operations* or *confined animal feeding operations* and are being subject to increasing government regulation.

Animal wastes



Confined Animal Feeding Operation in the United States

The constituents of animal wastewater typically contain

- Strong organic content — much stronger than human sewage
- High solids concentration
- High nitrate and phosphorus content
- Antibiotics
- Synthetic hormones
- Often high concentrations of parasites and their eggs
- Spores of *Cryptosporidium* (a protozoan) resistant to drinking water treatment processes
- Spores of *Giardia*
- Human pathogenic bacteria such as *Brucella* and *Salmonella*

Animal wastes from cattle can be produced as solid or semisolid manure or as a liquid slurry. The production of slurry is especially common in housed dairy cattle.

Treatment

Whilst solid manure heaps outdoors can give rise to polluting wastewaters from runoff, this type of waste is usually relatively easy to treat by containment and/or covering of the heap.

Animal slurries require special handling and are usually treated by containment in lagoons before disposal by spray or trickle application to grassland. Constructed wetlands are sometimes used to facilitate treatment of animal wastes, as are anaerobic lagoons. Excessive application or application to sodden land or insufficient land area can result in direct runoff to watercourses, with the potential for causing severe pollution. Application of slurries to land overlying aquifers can result in direct contamination or, more commonly, elevation of nitrogen levels as nitrite or nitrate.

The disposal of any wastewater containing animal waste upstream of a drinking water intake can pose serious health problems to those drinking the water because of the highly resistant spores present in many animals that are capable of causing disabling disease in humans. This risk exists even for very low-level seepage via shallow surface drains or from rainfall run-off.

Some animal slurries are treated by mixing with straws and composted at high temperature to produce a bacteriologically sterile and friable manure for soil improvement.

Piggery waste



Hog confinement barn or piggery

Piggery waste is comparable to other animal wastes except that many piggery wastes contain elevated levels of copper that can be toxic in the natural environment. Ascarid

worms and their eggs are also common and can infect humans if wastewater treatment is ineffective.

Treatment

As for general animal waste, although the liquid fraction of the waste is frequently separated off and re-used in the piggery to avoid the prohibitively expensive costs of disposing of a copper-rich liquor.

Silage liquor

Fresh or wilted grass or other green crops can be made into the semi-fermented product called silage which can be stored and used as winter forage for cattle and sheep. The production of silage often involves the use of an acid conditioner such as sulfuric acid or formic acid. The process of silage making frequently produces a yellow-brown strongly smelling liquid which is very rich in simple sugars, alcohol, short-chain organic acids and silage conditioner. This liquor is one of the most polluting organic substances known. The volume of silage liquor produced is generally in proportion to the moisture content of the ensiled material.

Treatment

Silage liquor is best treated through prevention by wilting crops well before silage making. Any silage liquor that is produced can be used as part of the food for pigs. The most effective treatment is by containment in a slurry lagoon and by subsequent spreading on land following substantial dilution with slurry. Containment of silage liquor on its own can cause structural problems in concrete pits because of the acidic nature of silage liquor.

Milking parlour (dairy farming) wastes

Although milk has a deserved reputation as an important and valuable food product, its presence in wastewaters is highly polluting because of its organic strength, which can lead to very rapid de-oxygenation of receiving waters. Milking parlour wastes also contain large volumes of wash-down water, some animal waste together with cleaning and disinfection chemicals.

Treatment

Milking parlour wastes are often treated in admixture with human sewage in a local sewage treatment plant. This ensures that disinfectants and cleaning agents are sufficiently diluted and amenable to treatment. Running milking wastewaters into a farm slurry lagoon is a possible option although this tends to consume lagoon capacity very quickly. Land spreading is also a treatment option.

Slaughtering waste

Wastewater from slaughtering activities is similar to milking parlour waste (see above) although considerably stronger in its organic composition and therefore potentially much more polluting.

Treatment

As for milking parlour waste (see above).

Vegetable washing water

Washing of vegetables produces large volumes of water contaminated by soil and vegetable pieces. Low levels of pesticides used to treat the vegetables may also be present together with moderate levels of disinfectants such as chlorine.

Treatment

Most vegetable washing waters are extensively recycled with the solids removed by settlement and filtration. The recovered soil can be returned to the land.

Firewater

Although few farms plan for fires, fires are nevertheless more common on farms than on many other industrial premises. Stores of pesticides, herbicides, fuel oil for farm machinery and fertilizers can all help promote fire and can all be present in environmentally lethal quantities in firewater from fire fighting at farms.

Treatment

All farm environmental management plans should allow for containment of substantial quantities of firewater and for its subsequent recovery and disposal by specialist disposal companies. The concentration and mixture of contaminants in firewater make them unsuited to any treatment method available on the farm. Even land spreading has produced severe taste and odour problems for downstream water supply companies in the past.