Frederic R. Siegel

# Demands of Expanding Populations and Development Planning

## Clean Air, Safe Water, Fertile Soils

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*To dedicate this book is to acknowledge researchers and educators globally who provide a cornucopia of knowledge that is continually expanding. This serves the needs of those who draw upon this well of knowledge and understanding when assembling information for a text. These contributors are to be lauded. I dedicate this book to my wife, Felisa, and to our grandchildren Naomi, Coby and Noa Benveniste, and Solomon Gold. They, and other children worldwide, deserve to live in clean environments and stable societies as they grow up, study, and prepare for future endeavours.*

*If, when reading this book, demographers or development planners pick out one concept, one bit of information that improves their projects to meet the "now" clean air, safe water, and fertile soil needs of our populations, the time and effort in putting the text together will have been well spent. I dedicate this book as well to those individuals and organizations that have as priorities focused investments in development programs that will bring grand segments of global populations out of poverty, yet maintain a good quality of life for those who are presently fortunate to have it.*

# Preface

## Population: Answering the Needs and Demands

The world's human population is 6.6+ billion people and growing (by 80 million in 2005). Most of the growth is in less developed nations. The Population Reference Bureau (2006) estimates that the global population will reach 7.9 billion people by 2025. It is projected to stabilize at 9.2+ billion people by 2050. Governments strive to attract industrial, manufacturing, services, and other projects to advance their economies and thus cope with existing social and political problems and future challenges heightened by expanding populations. They are encouraged in these efforts by international lending and development organizations such as the World Bank and the International Finance Corporation. These and other multilateral, regional and sub-regional development banks make funds available for economic and social improvement programs in developing countries (Table p.1). Well-planned projects can stimulate economic growth and create wealth in a society. This wealth can be used to promote the health, education, and general welfare status of its members, and their employment opportunities even as populations expand.

There are many theories that define and expound on economic development. Malizia and Feser (1999) summarize the theories in terms of their essential dynamics, strengths and weaknesses, and how they are applied to achieve growth. All theories agree that economic advancement is based on investing capital in projects that can flourish and yield financial gain over extended periods of time. Agriculture, energy, industry/manufacturing, transportation, forestry, fisheries, and other sectors are the foundations for local and national economic progress via domestic consumption and/or exported commodities. Solely or grouped, sector contributions to development of an economy often change over time. Greater diversity in the bases of economies and emerging markets they can reach gives them greater stability and promise of long-term growth. At the same time, well-planned projects allow for socio-political evolution and an improved quality of life for existing and expanding populations in environmentally clean and safe ecosystems under traditional, but oft times slowly moderating, cultural norms.

A limiting factor in economic expansion is the availability of natural resources. In context of growing populations with greater purchasing power and thirst for goods

**Table p.1** International groups that can make funds available via loans or grants for the advancement of carefully planned and transparent economic and social development programs in developing nations

| |
|---|
| **Multilateral Development Banks** |
| The World Bank |
| (International Bank for Reconstruction and Development) |
| International Finance Corporation |
| European Bank for Research and Development |
| Interamerican Development Bank |
| African Development Bank |
| Asian Development Bank |
| **Multilateral Financial Institutions (Focus on Special Sectors or Activities)** |
| European Commission |
| European Investment Bank |
| Nordic Development Fund |
| Nordic Investment Bank |
| Islamic Development Bank |
| International Fund for Agricultural Development |
| OPEC Fund for International Development |
| **Sub-Regional Groups** |
| Caribbean Development Bank |
| Andean Development Corporation |
| Central American Bank for Economic Integration |
| East African Development Bank |
| West African Development Bank |
| **Aid Granting Organization** |
| U. S. Agency for International Development |

and services, renewable natural resources must be utilized at sustainable rates if they are to be available to future generations. Extraction-based commodities (e.g., mineral ores, fossil fuels) are ever decreasing. The implication is non-sustainability for these. Their availability can be extended if consumers cover the higher costs for extraction and production.

Investment in research and development of alternatives to or substitutes for over-exploited and shrinking natural resources, if successful, can preserve product costs or lower them. This then becomes a major planning factor. Another component of successful project design to maintain or increase productivity is to have proactive management responsive to people and resource realities. Management must accept the concept that a limitation to growth may be real in some sectors whereas advances in technologies and product design and evolution can support growth in others.

## Earth Chemistry: Preserving the Nature of Ecosystems

Air, water, soil and sediments are surface/near-surface phases with chemistries that define the viability of terrestrial and aqueous environments. To a great degree, the chemistries determine an ecosystem's capacity to nurture and support the biochemical needs of its inhabitants. Intrusion of surface and near-surface gaseous, liquid, and solid earth phases by potentially toxic chemicals and particles from agricultural, manufacturing, industrial, and other activities can degrade them and reduce the optimum vitality levels of ecosystems.

The pathways of pollutants to ecosystems and their inhabitants are at or near the earth's surface in the air, water bodies (fluvial, aquifer, estuarine, marine) and their associated wetlands, soils and rocks (Fig. p.1). Humans ingest pollutants via primary and secondary routes. One is from breathing (toxic gases, acid aerosols, potentially toxic metals). Another is through drinking, cooking with, washing with, and irrigating food crops with contaminated water. A third is through foods grown in polluted soils or food animals that eat tainted cultivated forage, or through food fish. Bioaccumulation of potentially toxic chemical elements or compounds over time can harm human health, physical condition, and mental acuity. This will lessen a population's contributions to economic and social progress. Other ecosystem life forms suffer the same effects.

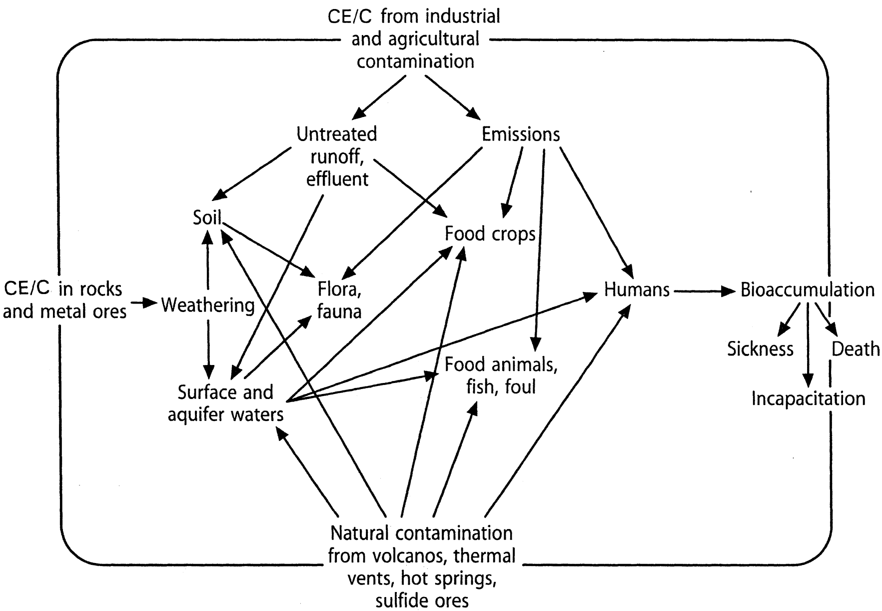


**Fig. p.1** Pathways of potentially toxic chemical elements or compounds (CE/C) in the ecosystem that originate from natural and anthropogenic sources (after Siegel, 2001)

Ideally, to be able to provide life-sustaining essentials to expanding populations, especially in developing regions, an effort must be made to preserve land and water sources in their natural and fertile states. Land and water cannot withstand degradation by overuse, over harvesting, or from intrusion by contaminant chemicals, and still remain productive to nurture vital ecosystems. Yet, in developing and many developed nations, environments and the ecosystems they contain are polluted with toxic chemicals and ravished by overuse often by corporations with short-term profits as their goal. This lacks foresight. If environmental abusers continue operations that damage the land, and pollute waters and air to improve their financial gain, they will lose productivity and the expectation of long-term profits. The sustainable use of terrestrial and aqueous ecosystems and the natural resources they nourish depends on proactive planning that protects them from chemical, biological, and physical intrusions that can harm their integrity.

## Development: Driving it Forward

Human resources drive the engines of development and economic progress. This advancement is founded on ready access to a healthy, educated labor pool capable of doing assigned jobs effectively and efficiently. With continuing education as a management priority, a top labor force will acquire the knowledge and capability to take on new responsibilities. Thus, human resources must be supported physically, socially, and intellectually to sustain progressing economies. This demands forward-thinking leadership and management decisions to invest a significant portion of business profits along multiple lines. One decision line requires investment to champion healthy environments on the job and at home. A work force that suffers chronic illness or other maladies from dirty air, polluted water, and contaminated soils that yield tainted crops, will lose workdays or not be well enough to carry out tasks to reach targeted productivity levels. With health problems in labor force families, efficiency will decline because of workers' anxieties.

Other decisive steps that sustain economic development include investment in basic and applied research to update and refine production methodology and existing products, and to create new ones. In addition, incorporation of up-to-date pollution control technologies to sectors as they are proven effective is essential to an operation's efficiency, improvement, and profitability. These management steps are practical, humanistic, and focused on preserving and increasing productivity.

Successful national and local economic programs need socio-political stability as one main factor for development planning that benefits workers, management, and investors. This comes in part from reaching goals such as increased employment opportunities that in turn result in higher incomes, and a better quality of life (e.g., in health and education) for labor forces and their families. Thus, an increase in meaningful employment opportunities has to be another focus of development goals, especially in light of growing populations and their needs. When businesses with positive and increasing cash flows have well-defined profit investment strategies, these objectives can be reached.

## The Messages

This book reviews the problems associated with growing populations in terms of earth surface/near-surface chemistry and their basic needs. . .breathable air, useable water, and unadulterated food. The book relates this to economic growth and societal tranquility. It examines the natural and anthropogenic origins of various chemical contaminants in atmospheres, waters, and soils and tracks their likely pathways to ecosystems and to humans and other organisms. Examples in the text illustrate the impacts of chemically contaminated atmospheres, waters, and soils on humans and other living populations.

The concept of environment friendly or "green" laws and cases where they have improved environmental health provide guidance to development planners. The cases alert planners to how they can shape and work out projects that will yield good returns on investments over long periods of time yet preserve ecosystems and their natural resources. In light of this, the book examines methodologies that can be used to short-circuit pollutant pathways to living environments in order to maintain the cleanliness and vitality of ecosystem Earth. Further, it evaluates their effectiveness and short-term/long-term costs/benefits relations with pollution control technologies installed in new development projects or retrofitted into existing polluting facilities.

The text appraises the economic, social, and political benefits of reducing population growth and the passing and enforcement of laws that alleviate or eliminate chemical and other sources of pollution. Environmental awareness during development planning, and investment in best available cleansing technologies, can minimize the input of harmful chemical elements and compounds to stable, vital ecosystems. Such awareness benefits human populations, other life forms, and natural resources on which they depend. Properly focused environmental stewardship is a major factor that carries promise of ecosystem sustainability even as populations expand. Actions to confront pollution problems must become "now" imperatives. Acting now to initiate necessary changes in humans' attitudes and practices that set the betterment of viable ecosystems as goals can alleviate or even eliminate environmental threats be they local, national, regional, or global. This will sustain the natural balance of our planet for the good of all life for generations to come.

Washington, DC *Frederic R. Siegel*

# Contents

# Chapter 1
# The Ecosystem and Development

An ecosystem is a natural ecological niche with unique physical and chemical characteristics. It supports a complex community of dynamically interacting populations of organisms called a biome. The interactions involve the search and competition for food, the use of space and natural resources, and nutrient recycling through a food web. There is a natural mutual regulation of population size in the community that maintains an ecological balance and benefits all organisms. This natural ecological entity is wee or grand in size. Its biome or community of organisms is distinguished by vegetation. The ecosystem is defined by the adaptation of living populations to unique environmental attributes.

## Ecosystem Characteristics

Ecosystems vary greatly in natural physical conditions (e.g., climate [temperature, precipitation]). They may be bathed in full sunlight, shielded from the sun, in shaded to dim light, or they may exist in dark conditions. Ecosystems in caves or in the deep oceans contain life that survives in total darkness. Chemical characteristics of ecosystem waters and soils vary markedly. Atmospheric chemistry varies less. Together, temperature, rainfall, and soil composition largely determine the vegetation assemblage in an environment. This creates ecological regimes in geographically distinct regions that sustain flourishing biomes or biomes in a constant struggle for survival.

## Gaia

The Gaia hypothesis suggests that biota have a principal, if not the prime control, over the physical/chemical features of ecosystems comprising the Earth's surface environments. This hypothesis is incomplete. It fails to take into account the influence of inorganic processes such as volcanic activity in the formation of the Earth's proto-atmosphere and surface waters with their initial physical and chemical

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characteristics. It further slights the role of inorganic reactions in atmosphere and water compositional changes over geologic time. For completeness, the hypothesis should incorporate rock chemical composition and the role of weathering (inorganic/organic disintegration and decomposition of rocks) in the formation of soils with macro- and micronutrients that nourish vegetation growth. Together, biotic and abiotic processes contribute to the evolution of atmospheric, water, and soil properties that govern Earth environments and support the grand spectrum of organisms in their ecosystems.

A contemporary Gaia hypothesis has no choice but to include an appreciation of the importance of human interactions with ecosystems. Historically and in modern times, humans have disrupted the meta-stable equilibrium of organic and inorganic processes that keep ecosystems vital. Most people recognize the damages human activities inflict on ecosystems and the imbalances they cause. Many people work to correct them.

## Ecosystem Needs

Terrestrial ecosystems with clean air to breathe, safe water for drinking and hygiene, and uncontaminated fertile soils sustain and nurture all living creatures. Vegetation that roots and grows with vigor, watered by rainfall or by irrigation, feeds humans and other life forms with its vegetables, grains, fruits, nuts, berries and leaves. It is a nutrient source for food animals (e.g., cattle, sheep, goats, fish, foul). Similarly, clean fluvial, lacustrine, estuarine and ocean ecosystems provide nutrition to sustain their communities of organisms.

Although air and water can be considered abiotic in a strict sense, the atmosphere contains airborne organisms such as *Roseobacteria* which aid in the formation of clouds by producing gases that nucleate water droplets (Shaw, 2007). The hydrosphere contains minute to large algae/vegetation species and a grand diversity of aqueous life. Soils sustain productivity with their nutrients (from rock/mineral decomposition) and the activity of bacteria and other organisms in soils. The so-called abiotic matter nourishes biotic forms from the lowest to the highest trophic levels. A continuum of this relationship preserves equilibrium in food chains and food webs, and in ecosystem vitality.

In order to attain and maintain a good standard of living and improve it, human populations have needs in addition to clean air, safe water, and untainted, fertile soils. Some of these are fibers, wood, metal ores, industrial rocks and minerals, and energy sources. Access to these and consumption of commodities and products crafted from them varies among global populations. Two principal factors that influence the variations are geographic location and economic status. Mineral deposits are an example of the former. They are small and irregularly and widely dispersed. An example of the latter is that economically advantaged groups have access to clean water from collection, treatment, and distribution networks at reasonable prices. This contrasts with poor groups who may have to use tainted water or elect to buy clean water at highly inflated prices from unscrupulous water vendors.

## Ecosystem Changes/Disruptions – Responses and Effects Changes

Terrestrial ecological niches with limited vegetation, wildlife, and human populations exist in extreme conditions. These are in arctic and antarctic regions, and in deserts that receive little or sometimes no annual precipitation. The arctic and desert regions are bordered respectively by tundra-muskeg-vegetated periglacial regions and by lightly vegetated semi-arid zones, respectively. The harsh arctic and desert environments transition to lush temperate, sub-tropical, tropical, and equatorial zones with fir, mixed, and deciduous forests, and grasslands (savanna, prairie).

Aqueous ecological niches occupy shallow to deep waters. The waters and juxtaposed wetlands range from fresh water to brackish water to salt water environments, respectively, in streams, rivers, ponds and lakes, in riverine and fjord estuaries, and in seas and oceans. Salt lakes, the Dead Sea, and what remains of the Aral Sea, represent extreme aqueous environments with specialized biomes. The Aral Sea genesis as a hypersaline mass of water is the result of an anthropogenic action that wreaked environmental damage. The former Soviet Union diverted the rivers that fed the Aral Sea for irrigation of cotton cultivation. The sea was already suffering from contamination by wastes from weapons testing, industrial projects, and fertilizer runoff that eradicated many native fish species. Because of water diversion, the sea surface area shrunk by more than 60% and the water volume by more than 80% (Fig. 1.1). This slowly but surely and knowingly choked the life from the fishing industry, leaving 10,000 fishermen without their livelihood and 10s of thousands working in fish canneries out of work. Tourism vanished as well. These were the economic base for the people inhabiting the areas proximate to the shore. This is an example of inept planning that destroyed existing productive operations. The rapidity with which change can take place is illustrated in Fig. 1.1. The cities of Muynak and Uchsay, located on a peninsula in the Aral Sea in 1960, were 40 km from the sea in 2000. After the disintegration of the Soviet Union, the sea, partly in Uzbekistan and partly in Kazakhstan, has been subject to a restoration program supported by ~$350 million in funds from the World Bank. The program is having a slow but positive measurable result. The Aral Sea water volume is gradually increasing with a concurrent increase in surface area.

In addition to the environmental differences cited above, ecosystem conditions may change with season from hot to warm to cool to cold and back again. They can be wet to moist to dry and back again, and have diverse light exposure from twilight to darkness to dawn to light, and from strong light to less light and back again. The changes are rhythmic.

### *Response to Changes in Environmental Conditions*

Environments with biomes in ecological balance can be stable throughout the year or vary seasonally. Life forms adjust to changing natural or anthropogenic-induced physical and/or chemical properties in ecosystems in different ways to reproduce and survive. Organisms may adapt to changes and stay as inhospitable

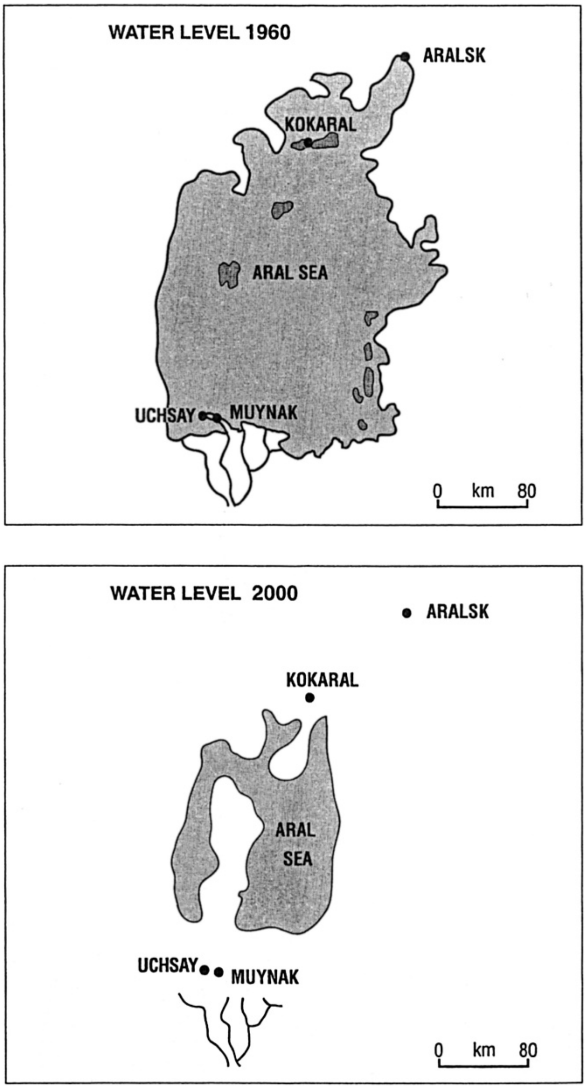


**Fig. 1.1** The reach of the Aral Sea waters in 1960 before river diversion, and in 2000 as the result of river diversion
(Source: http://visearth.ucsd.edu/VisE_Int/aralsea/aral_muynak.html)

conditions evolve, perhaps with a slow down of activity. Some mobile species move away to find favorable ecological conditions. Others do not readily adapt to a deteriorating ecosystem and try to survive environmental intrusions despite high death tolls in their populations. When ecosystem conditions return to "livable", organisms revive from their survival modes to reestablish their biorhythms and natural activities.

## *Response to Ruptures in a Biome*

Ecosystem degradation can cause a rupture in the interrelationships between populations dependent on each other symbiotically or as a source of nutrition along a food chain or within a food web. Sometimes this can be overcome. When there is a great diversity of organisms, predators that lose their prey may switch to other prey. In ecosystems with limited diversity, a rupture between dependent populations can endanger biome niches or threaten organism survival within the ecological system.

Ultimately, if a cascading effect of changing conditions (e.g., salinity, drought, wildfires) or missing biological links in the food chain/food web continues, more organism populations can decline and an ecosystem can crash. Even with a crash, there will be survivors that adapt to the new conditions and live on. Others do not adapt and will either move to habitable ecosystems or die.

## *Ecosystem Renewal*

Examples of survival after ecosystem disruption from natural disasters or human failures are exemplified by two events. One is the grand eruption of Mount St. Helens and the secondary hazards it triggered. The second is the explosion and massive radioactivity release at the Chernobyl nuclear power facility.

In areas that have suffered from natural or anthropogenic disasters that devastated an area, ecological conditions can regularize in relatively short times. The result is that healthy communities of organisms come back, reestablish dependent or independent interrelationships, and renew vital ecosystems. For example, the Mount St. Helens explosive volcanic eruption severely damaged ecosystems by radiative (heat/blasts) leveling of forests, mudflows that buried terrain and dammed rivers. Large volume and widespread ash falls covered vegetation and contaminated streams, rivers, lakes and ponds. The eruption triggered fires, massive landslides, and extensive flooding. Fortunately, areas impacted by the violent eruption were very sparsely inhabited. People did not have to be resettled and reconstruction was not an issue. In part, because of this and non-intervention by humans, ecosystems reestablished themselves in about a decade and spread to include extensive areas. This happened in the past and will happen in the future.

The explosion and resulting failure of the containment roof at the Chernobyl nuclear power facility released radioactive gases and particles to the atmosphere. These moved with wind currents over large areas of Ukraine and Belarus, and transnational areas, to precipitate in rain or settle as atmospheric sediment poisoning the atmosphere, water, and soils. Hundreds of people died, 4000 suffered radiation sickness, and thousands may be at long-term health risk from exposure to harmful doses of radioactivity. Other organisms suffered as well. The radioactivity levels in some areas are so high that human populations cannot live there and work the fields. However, vegetation, wild pigs and other animals are thriving in quarantined areas and have populations larger than existed before the Chernobyl disaster. This is due to the absence of humans, the principal exploiters/predators who are prohibited from inhabiting the ecosystem where they previously harvested crops and hunted prey. Many ecosystems affected by radioactive fallout will not return to their natural background radiation levels until several half-lives of deposited radioisotopes pass (decades to 100s or more years).

Globally, recovery from large scale ecosystem rupturing can take years and ample economic resources. Through their own resources and grand contributions from peoples of the world, governments mount relief efforts to care for those who lose their families, homes, and livelihoods. Such have been the recent cases in the 2004 tsunami-demolished regions of Indonesia and neighboring countries, in the regions of southeast United States ravished by the 2005 hurricane Katrina, and in the 2005 earthquake destroyed areas of Kashmir on the Indian subcontinent. Human trauma lingers after such events. However, the resiliency of survivors with tangible help and encouragement from their countrymen and co-religionists hastens recovery. With the passage of time, intruded ecosystems within hazard areas undergo self-healing and renew functioning habitats.

## Ecosystem Resources – Are They Sustainable?

The exploitation of natural resources need not irrevocably harm an environment if protocols adhere to environmental laws in all phases of a project. Laws are voted and passed to protect environments during preparation of sites for harvesting or extraction, during processing and/or refining, during manufacturing and distribution, and after use and disposal of products and spent materials. With human intervention such as a controlled use of fertilizer in agriculture, exploitation of most commodities necessary to maintain a good quality of life can result in sustainable yield. Among these are products from land-based agriculture (crops and food animals), fisheries, forestry (fiber and wood), and energy (hydroelectric, solar, wind). A regulated exploitation *modus operandi* leads to "development that meets the needs of present (global populations) without compromising the ability of future generations to meet their own needs (The Brundtland Commission, 1987)."

Sustainable development is based on equilibrium or positive changes in commodities being evaluated. That is, as much or more is produced as is used. Despite environmental regulations and human intervention (e.g., use of agricultural chemicals), some natural resources exploitation is not sustainable. Extraction of mineral and energy resources is a negative draw. The practice of conservation serves to prolong the time extractable resources are economically readily obtainable. To assure availability of non-renewable extracted commodities, pricing must change. For example, with 2005/2006 oil prices at >$60 a barrel, large scale extraction of oil from tar sands in Alberta, Canada and the Orinoco Basin, Venezuela became more economically attractive and production increased. At a May 2008 move to >$130 a barrel, the extraction of oil from tar sands, organic-rich olive and black shales, and coal received an incentive for more investment and development. Similarly, higher prices for critical metals will support environmentally sound mining and processing of lower grade ores on land, and the ocean mining of seafloor massive sulfide and manganese (Mn) nodule deposits for an assemblage of metals (e.g., copper [Cu], nickel [Ni], gold [Au], silver [Ag], Mn) in the not too distant future.

Loss of soils and soil quality, loss of land and water-based biomass, and degradation of water resources and water quality diminishes natural resource stocks. This is a bad portent for populations and their future. Good management with the purpose and plans to implement the "know how" for maintaining environmental equilibrium counters these losses. Another factor that affects sustainability is loss of capacity of environments to assimilate wastes. This endangers ecosystems and must be carefully assessed to protect their long-term viability.

The concept of optimal development is more realistic than sustainable development for many sectors. Optimal development necessitates a measured and efficient use of available resources. It requires investment in research that is innovative and focused on finding alternatives for diminishing supplies of critical extracted commodities, or the creation and manufacture of substitutes for them. Only in this way can the human populations on Earth achieve the goal of "generation to generation pass through of environmental quality and natural resources and their inherent social and economic benefits (Koopmans, 1965; Dasgupta, 1994)."

## *Now and the Future*

The basic needs of at least one-third of the global population are not being met. As an example, each year $1\frac{1}{2}$ to 2 million children die and hundreds of millions of others suffer gastrointestinal sicknesses from lack of safe water for drinking and hygiene, and water to carry wastes away for safe sanitation. How then can we propose to meet the needs of a population half again or more in number by the year 2050?

Although there is enough flowing water (surface and aquifer) on earth to service the needs of the growing global population, the water is geographically dispersed and not available to all who need it. Where it is plentiful, water may be naturally pure and potable. Conversely, water may be contaminated naturally or from human activities by harmful chemicals and bacteria that render it unusable. The latter is due in part to a lack of environmental legislation or its enforcement that can alleviate or prevent contamination. Many countries are able to provide their populations with reasonably priced clean water because of investments in systems to collect and treat tainted waters and then distribute safe water to consumers. Many developing nations lack capital or use available funds for priorities they put ahead of investments in water collection, treatment, and distribution facilities for non-serviced urban and rural areas.

# Socio-Economic Keys to Development

Societies have tangible needs in addition to clean air, safe water, untainted comestibles, and living areas safe from physical hazards to support socio-political aims and economic development. People must have jobs, medical care, and accessibility to goods and services. Their children need ready access to education, whether academic or apprenticeship for a trade. Filling these needs will open opportunities to improve peoples' quality of life and future prospects for their children.

Limitations to fulfilling the needs that create a generally satisfied society exist in many countries and regions. The limitations are primarily financial because governments do not have the incomes or do not use a nation's treasure to carry out programs to better the way of life for their citizens. It is possible to borrow funds from international financial institutions for development (Table P.1) or from commercial banks. Another limitation can be the lack of an experienced cadre of human resources, especially professional, technical, and managerial personnel.

## *Economic*

Some institutional lenders can impose restrictions on loans that can cause societal unrest. One may be currency devaluation. This can cascade into runs on banks or suspension of bank withdrawals. There can be restrictions on banking services such as money transfers. Without assent of depositors, a government may dictate conversion of devalued currency deposits into national bonds due a decade in the future. Devaluation diminishes purchasing power and can initiate an inflationary spiral of price increases for food, medicines, healthcare, and transportation. Retiree payments and benefits, often at subsistence levels in borrower nations, effectively lose purchasing power. Other lending institution requirements for a loan to be made include higher charges for electricity, water, cooking fuels, and telephone service, and cutbacks in the number of public employees. Together, these and other lender demands increase societal anxieties. To alleviate a population's stress, such policies, if absolutely necessary, should be put into place gradually and with sensitivity to the cultures involved. This can defuse conditions that catalyze civil unrest that can bring about changes in government via the "transparent" voting box on candidates or referenda, or by people power demonstrations, or otherwise.

Another brake on economic development and recovery in borrower countries is the high percent of government income that has to be paid to service the debts for existing loans. A consequence is that funds are not available for aiding distressed populations. During July 2005, the G-8 nations addressed this problem by a debt forgiveness program for 18 of the poorest countries worldwide. The majority of these are in Africa. The world will now wait to see if the freed up funds will be used for the good of these nations' populations.

## *Human Resources and Cultural Sensitivity*

In addition to funding, it is necessary to have a trained, educated cadre of professionals, craftspersons, workers and tradespersons to carry out projects and programs that will improve a people's way of life. In some developing countries, after supporting the education of this class of cadre, a country has not offered meaningful employment opportunities. This causes an emigration of brainpower to countries where educated and skilled people have these opportunities. National policies have to change to retain the people who are necessary for a country's economic development. Given competent and motivated human resources, development programs in many regions can progress only when company managers are sensitive to and overcome cultural barriers to change without offending a people's foundations of belief. This is done with education and pilot projects that show the success that can be achieved with operational and other modifications that are acceptable within cultural or societal norms.

### *Safety and the Physical Environment*

The purpose of this book is to focus attention on the importance of earth surface/near-surface chemistry to population sustenance and health, and to economic development. This is discussed within the framework of respect for environmental laws that guide new project planning and changes in existing projects to bring them into compliance with the laws. This also includes guidance for remediation/reclamation programs to reestablish usability of formerly contaminated areas. Economic development planning must be done with the understanding that finding sites safe from natural hazards is paramount for a population's living and working locations. Chapter 3 on Population Needs for Well-Being gives a brief general discussion of physical hazards. Project evaluation teams cannot overlook natural and anthropogenic-caused hazards in development planning as the numbers of people grow thereby increasing "safe" space needs.

## Afterword

The following chapter treats rates of population increase worldwide and in selected countries and regions, population demographics, and geographic situations with respect to resources. It assesses projections of what a stable global population will be and considers population shrinkage and what this means to a country. It is essential to take these factors and others into account when weighing social, economic, and political strategies for contemporary and future development.

# Chapter 2
# Populations: Growth, Braking, Contraction

A growing human population with needs to serve for its survival puts “ecosystem earth” and its inhabitants in a life or death struggle for natural resources that sustain life. There is competition for safe and adequate supplies of water, uncontaminated food (chemically and/or biologically), and other essential resources. In the past as at present, the competition for basic commodities leads to greatly disparate “have” and “have not” segments of societies. This is most pronounced in regions of Africa, Asia, Latin America and the Middle East. There is disease and famine where water, food, and medical services to support healthy populations are not available or affordable. There is a lack of education to prepare children for a place in our world. Where education does prepare graduates for work, employment opportunities are often lacking. The combination of governmental failures to provide the staples, services, and opportunities cited above, and respect for human rights, tears at the very fabric of societies. This leads to despair, desperation and frustration, social and cultural unrest, and war and destruction as evidenced today by populations in countries in Africa, the Middle East, and Asia.

The portent for the future is dismaying. Only changes in national public policy and international politics can address and alter the root causes of disillusionment experienced by people in developing nations. An equilibration in the availability and distribution of basic necessities and services, plus availability of gainful and meaningful employment can bring a good quality of life to distressed populations. This is achievable by realistic reforms in politically as well as culturally rigid systems that favor the concept of flexibility in order to attract investors for development projects. In addition, financial transparency in operations must be honored. Together, and with careful planning, investment can improve the economic status of many nations and well being of their citizens.

## Population Increase

Population increase is a two-faceted problem. There is the actual numerical increase in populations by country and globally. There is also an increasing demographic trend of population movement from rural areas to urban centers. The latter and its ramifications are discussed first.

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## *Agglomerations*

Expanding urban populations evolve into agglomerations comprised of a central city and neighboring communities (edge cities) linked to it by continuous built-up areas or by many short- to long-distance commuters. Some agglomerations, like Osaka, Japan, have more than one central city (Kobe and Kyoto). Today 75% of the population in developed (industrialized) countries and 38% of the population in less developed countries live and work in urban centers. This puts a great strain on the socio-economic resources of the cities and the state/federal governments that have the charge of providing safe, healthy, and productive environments for their inhabitants. Table 2.1 lists metropolitan areas with populations greater than 10 million people. In 1991, 11 city agglomerations had populations that exceeded 10 million people. By 2004, 25 urban areas had more than 10 million inhabitants, populations greater than those of 125 countries. They are true "city-states" with all of the

**Table 2.1** City agglomerations with populations greater than 10 million people and their city proper populations (in millions). After The World Gazetteer, 2008

| Location | City Agglomerations | City Proper |
|---|---|---|
| Tokyo | 37.2 | 8.3 |
| New York City | 22.9 | 8.1 |
| Mexico City | 22.9 | 8.6 |
| Seoul | 22.2 | 9.7 |
| Mumbai (Bombay) | 20.8 | 3.7 |
| Sao Paulo | 20.2 | **10.3** |
| Manila | 19.1 | **11.0** |
| Jakarta | 18.5 | 8.5 |
| Dilli (New Dehli) | 18.3 | **11.9** |
| Los Angeles | 18.2 | 3.9 |
| Osaka | 17.6 | 2.5 |
| + Kobe + Kyoto | + 1.5 | + 1.4 |
| Shanghai | 16.9 | **15.5** |
| al-Qahira (Cairo) | 16.0 | 8.1 |
| Kolcata (Calcutta) | 15.1 | 5.0 |
| Moskva (Moscow) | 14.7 | **10.5** |
| Buenos Aires | 14.1 | **12.1** |
| Dhaka | 13.2 | **10.0** |
| Teheran | 12.6 | 6.8 |
| London | 12.5 | 7.7 |
| Lagos | 12.5 | 9.3 |
| Istanbul | 12.4 | **10.4** |
| Karachi | 12.4 | **12.4** |
| Rio de Janeiro | 11.9 | 6.2 |
| Beijing | 11.9 | 7.7 |
| Paris | 11.8 | 2.1 |
| Bagdad | 10.6 | 5.7 |

Note: There were more than 280 cities in the world with populations greater than 1 million people by 04/2004.

benefits they offer as well as problems created by the number of inhabitants, population density, and demand for commodities and services people need to live.

## *Global/National Population Increases*

The expanding population is a key factor that works against achieving a balance between life-sustaining commodities, the capacity to provide them, and an enhanced quality of life for peoples of the world. As this manuscript is being prepared, the Earth's human population has passed 6.6 billion inhabitants. When this author began teaching environmental geology in 1972 and geological hazards in land-use planning in 1974, it was 3.8 billion people. At an average rate of population increase of 1.4% since the mid-1970s for about 50 years, the number of inhabitants of the Earth could more than double by 2025 to a projected 7.9 billion people. Because the rate of population growth is declining, statisticians estimate that a 9.2+ billion persons stabilization figure will be reached in 2050. The rate of growth is determined by the relation between the number of births and number of deaths in a population. For nations, this is modified by immigration and emigration during a year.

## *The Fertility Influence*

Fertility rate or the number of births per woman is the strongest influence on the percent rate of population increase. The goal of achieving a stable number of inhabitants (perhaps more than 9.2 billion people) will be reached when the fertility rate is 2.1 children per woman. Since 1970 to the present the fertility rate has dropped by 1.7 births per woman to a 2007 global fertility rate of 2.6 children per woman. The rate of population increase has dropped steadily from 2.1% in the 1960s to 1.6% in 1995 to the 2003 rate of 1.3% annually, paralleling the fertility rate drop. Projections of the world growth and fertility show continued trends to lower rates. Fig. 2.1 extrapolates a growth rate of 0.5% for the year 2043 while Fig. 2.2 predicts a below replacement fertility rate of <2.1 children per woman for 2043.

This global tendency of a decreasing rate of population increase and a decreasing fertility rate is the cumulative result of several factors. These are family planning counseling worldwide (for men as well as women), empowerment of women through education and economic advances (joining the work force), effective and available contraception techniques, change in cultural attitudes (albeit slow), and economic realities in developing societies. Better educational and career opportunities, health services, and the general welfare can be afforded to a lesser number of offspring in a family but would be less so for a larger number of children. Ultimately, couples balance their decision on family size against personal, social, and religious mores. In China there is no choice because the government mandates a one child per family policy. For families who have more than one child, there are

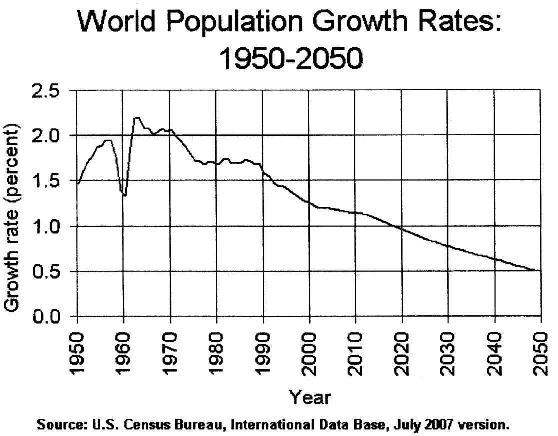


**Fig. 2.1** World population growth rate: 1950 projected to 2050 (after U.S. Census Bureau, April 2004 International Data Base)

social and economic penalties unless official permission is granted to have a second child. This has been enforceable to a good degree in cities but not so in rural areas. Population figures reported by the Chinese government are likely lower than reality.

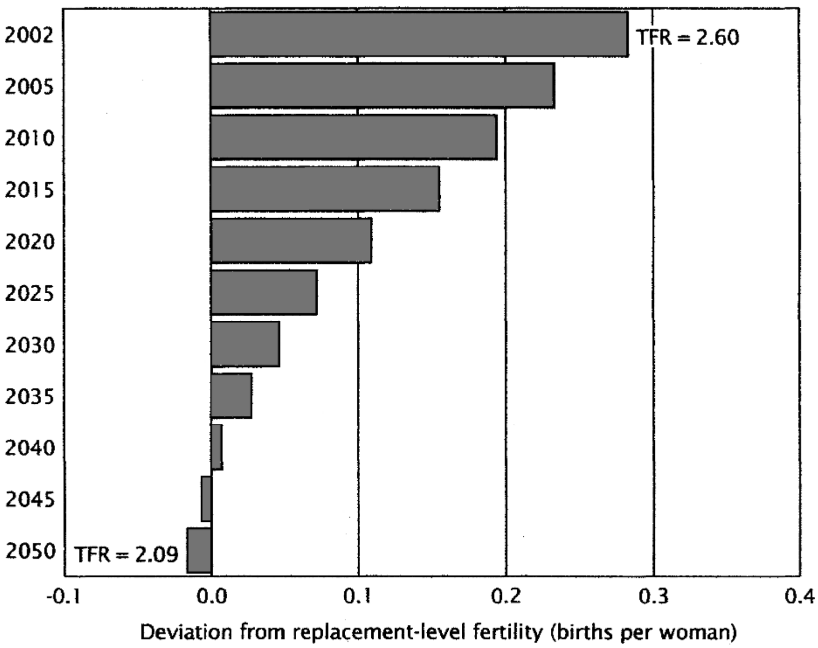


**Fig. 2.2** Global fertility levels relative to replacement level: 2002 projected to 2050 (after U.S. Census Bureau, International Programs Center, 2004 International Data Base). The level is projected to drop below replacement by mid-century

## Contraction/Depopulation

In some countries or regions, the fertility rate is below the replacement rate of 2.1 children per woman. For example, in Japan, the rate is 1.3 children per woman and in Europe the rate is 1.4 births per woman. The below replacement rates in many industrialized nations, and in Eastern Europe, Russia and the 11 states created from the Soviet Union, and China means that these countries are in a population braking mode and for some, eventual depopulation. For example, demographers expect that by 2050 Bulgaria's population will decrease 38% and that of Russia will decrease by 17%. In some developed nations, when a braking of growth is coupled with increased longevity because of better nutrition, health care and life style (e.g., more exercise, less smoking), there are shrinking and aging populations. In Japan and Europe, for example, the proportion of the population over 60 years old will soon exceed the number of children under 15 years old. Aging and depopulation mean work force shortfalls and fewer workers to support social and medical services or pension funds for retirees. There will not be enough "home grown" workers in some developed countries to provide or who want to provide the range of services needed by societies. This problem will intensify in several industrialized societies (e.g., Japan, Western Europe, Scandinavia) if they sustain less than replacement fertility rates for the long-term.

When depopulation is coupled with a lesser number of educated, technically prepared, and skilled persons coming out of universities and technical schools, it hurts a country's ability to maintain or advance its economic development status. This is sometimes exacerbated by emigration.

### *Consequences of Aging and Depopulation*

Some countries allow immigration as a matter of necessity to fill less desirable jobs. These include harvesting crops, working in food services, working in slaughter houses, collecting garbage, cleaning streets, cleaning homes, office buildings and factories, doing garden and tree work, and caring for the aged. Aging and shrinking populations mean that the number of immigrants allowed to enter developed countries to meet their labor needs will have to increase to help sustain economic growth and retain a good quality of life for their citizens. However, immigration of workers from different cultures can cause social problems such as have occurred in Germany and France in recent years and is now a potential problem in the United States and other countries that have substantial numbers of guest workers. When educated immigrants from less developed European Union nations begin fillings jobs at lesser salaries than nationals in developed countries so as to create unemployment or under employment, social unease will surely increase. These problems have disrupting effects on political evolution based on having a suitable work force to support growing economies.

## *Avoiding/Easing Immigration Problems*

In an effort to avoid or severely limit immigration and maintain cultural uniqueness, Japan is developing life-like robots in the image of Japanese. The female- and male-looking automatons are programmed to respond to inquiries through a 500 word working vocabulary. They can answer common questions and carry out verbal commands. This poses the possibility that robots could fill many service needs such as receptionists, security guards, office cleaners, and factory workers. The initial results on the effectiveness of cybernauts in these positions have been satisfactory, but the human "touch" is lost. The realization that the use of robots will not begin to solve Japan's aging-shrinking population needs, has forced the Japanese government to rethink and perhaps revise their strict regulations on immigration.

A long-term alternative to being an aging and depopulated nation dependent on automatons is to reverse the causes that led to lower fertility rates. There are many factors that determine family size. These include limited space apartments (those economically accessible to young families), long hours demanded on the job, extended travel times between home and work, limited access to child care, delays in

**Table 2.2** Examples of government incentives to increase fertility rates which are below replacement rates. Incentives include cash, tax credits, state run daycare, all to make it easy to balance careers and family

| |
|---|
| France - 16 weeks paid maternity leave for first child guaranteed job security; 26 weeks for third child and a monthly stipend of 1000 euros for a year; up to 26 months of parental leave; child care is subsidized |
| Norway - 10 months full salary or a full year of salary at 80%; father must take 4 weeks leave - subsidized by taxes |
| Sweden - Each parent receives 18 months leave (paid by the government); public daycare is heavily subsidized; parents have flexible work schedules; women with pre-school are children can reduce their working hours |
| UK - New mothers get 6 months paid leave plus option of 6 more months for 6 weeks at 90% salary and next 20 weeks at £102.80 per week; father gets 2 weeks paid leave at £102.80 per week |
| Netherlands - 16 weeks maternity leave at full pay with 4–6 weeks before the birth and the rest after; if pregnancy or childbirth give rise to incapacity to work, the woman can receive 100% of former pay for a year; if the woman gets sick as a result of the pregnancy before the period of maternity leave, she can receive an allowance of 100% of her wages |
| Germany - Up to 1800 euros a month for stay at home parents; more daycare centers |
| Spain - 2500 euro bonus for every baby born; 16 weeks paid leave |
| Italy - 1000 euros for second chid; will pay not to have abortions |
| Poland - 258 euros for each child |
| South Korea - $3000 help for in vitro fertilization |
| Singapore - sponsors a state matchmaking program for university graduates and government relationship advice |
| Russia - a day of conception was given off for sex with prizes such as cash, an SUV, and others to be awarded if 9 months later a baby is born; tested in Ulyanovsk Province and gave a 4.5% increase in births which was much the same as was normal for the province |

access to health care, high costs of education including preparation of students for exams, and loss of promise of job security. If governments address these and other problems, resolve or greatly reduce them, families in Japan and Europe, for example, could, in time, reach the replacement fertility rate of 2.1 children per woman. Many countries provide other incentives for married couples to have babies and increase the number of births such as cash, tax credits, excellent maternity leaves, state subsidized daycare, thus making it easier to balance careers and family (Table 2.2). France and Norway have had the best results in recent years and have raised their fertility rates to 1.9 and 1.81, respectively, vs the replacement rate of 2.1. Germany, Italy, Spain, and Greece have fertility rates less than 1.4.

## Current and Projected Population Figures

There is a great imbalance in the rate of population increase between richer and poorer nations and regions. This division is related to the level of development (e.g., in industries, agriculture, and service) and to some degree climate. The rate of population increase is less in the northern hemisphere nations (e.g., in northern and eastern Europe, Canada), and Japan, and greater in southern hemiphere nations (e.g., in Africa, the Indian Sub-Continent, and Southeast Asia).

Table 2.3 illustrates the annual percentages of population increase for regional groups of nations. If these rates continue, many countries in regions that now have grave problems with clean water, adequate food supplies, education and health care, will have exacerbated problems in the future. For example, Eastern Africa with 294 million inhabitants in 2007 is estimated to have a 48 + % increase in population to 438 million people in 2025. Indeed, Sub-Saharan Africa is expected to be the primary geographic region of population increase from 2002-2050, adding more than 800 million people (e.g., from Nigeria, the Congo [Kinshasa], Uganda). To put the regional increase in perspective, the Sub-Saharan Africa population was one-third the size of China in 1950, one-half the size of China in 2002, and has the potential to surpass that of China by 2050.

The disparity in the rate of population increase between economically advantaged and disadvantaged nations is reflected in an average rate of 0.1% for more developed (industrialized) nations and 1.6% for nations in development (1.9% if China is excluded). This translates to a global doubling time of about 54 years overall, 44 years for the developing world (37 years with China excluded), and >500 years for the developed world. In Africa, 29 countries have doubling times <35 years with the shortest in Liberia at <15 years and Uganda, Burundi, and Congo (Kinshasa) at 20 years. Uganda, for example, will have to deal with 130 million people in 20 years instead of the 65 million in the country today. Doubling time is calculated by dividing 70 by the rate % increase.

The annual rate of global population growth declined from a maximum of 2.1% during the 1960s to 1.6% in 1995 to the present 1.3% (Fig. 2.1). However, the percent of the population under 15 years of age (coming into child-bearing age)

**Table 2.3** The annual % of natural increase in population growth by geographic region (Population Reference Bureau, 2007.)

| | Population mid-2007 (millions) | Natural Increase (annual, %) | Doubling Time (years) | Fertility Rate | Projected Population Change (%) 2007–2050 |
|---|---|---|---|---|---|
| Northern Africa | 195 | 1.9 | 37 | 3.6 | +59 |
| Western Africa | 283 | 2.7 | 26 | 5.8 | +118 |
| Eastern Africa | 294 | 2.5 | 28 | 5.6 | +121 |
| Middle Africa | 118 | 2.8 | 25 | 6.4 | +167 |
| Southern Africa | 55 | 0.8 | 88 | 3.0 | +13 |
| North America | 335 | 0.6 | 116 | **2.0** | +38 |
| Central America | 148 | 1.8 | 39 | 3.0 | +39 |
| Caribbean | 40 | 1.0 | 70 | 2.7 | +27 |
| South America | 381 | 1.5 | 47 | 2.5 | +38 |
| Oceania | 35 | 1.0 | 70 | 2.4 | +41 |
| Western Asia | 223 | 2.0 | 35 | 3.8 | +65 |
| South Central Asia | 1662 | 1.7 | 41 | 3.3 | +56 |
| Southeast Asia | 574 | 1.4 | 50 | 2.7 | +35 |
| East Asia | 1550 | 0.5 | 140 | **1.7** | +5 |
| Northern Europe | 98 | 0.2 | 350 | **1.6** | +11 |
| Western Europe | 187 | 0.1 | >500 | **1.6** | **0** |
| Eastern Europe | 295 | −0.4 | – | **1.2** | **–22** |
| Southern Europe | 153 | 0.1 | >500 | **1.3** | **–5** |

**Bold values:** fertility rate is less then replacement rate population stable or lost between 2007 and 2050

averages about 33% for less developed nations (36% with China excluded) and 18% for developed nations. The U.S. Population Reference Bureau calculates that the growth rate will continue to fall, especially in developing nations. However, even if it fell to replacement rate immediately, growth momentum will move the global population higher until it stabilizes by 2050. The Population Reference Bureau estimates that the Earth will have 7.9+ billion inhabitants by the year 2025 (1.6 billion greater than in 2004) and may stabilize at about 9.2–11 billion people by the middle of this 21st century.

In addition to natural deaths, 5–6 million humans die annually from disease, famine, unsafe water, natural and anthropogenic disasters and war. HIV/AIDS is ravaging populations, especially in Africa where anti-viral therapies may not yet be accessible to poorer patients. In Africa, about 57% of HIV-infected adults are women as compared to 25% for the United States and 1.2% for the world. In 2005, two million people in Africa and 500,000 in Asia are reported to have died from AIDS. The total number of deaths worldwide is far outweighed by the more than 70 million newborns added annually during the past decade. The number of newborns annually too will decline by the middle of the century and in the longer term will move towards a contracting world population as death rates rise and birth rates fall.

## Trends in Economic Parameters vs Population Growth

As illustrated in Fig. 2.3, during 43 years from the 1950s to the 1990s, the Earth's human population increased 2.2 times. At the same time, food production increased by 2.7 times (with grain production growing 3 times) and energy consumption more than quadrupled by 4.4 times. Opportunities for employment increased as the global economy more than quintupled by 5.1 (Raskin et al., 1995). In grand part, these figures were highest for developed nations and lowest for developing nations.

If these trends continue, or more likely increase as in the case of energy consumption by emerging economies (e.g., China, India), there will be changes in numbers but growth will persist. Figure 2.3 shows the comparative changes in population increase and in agricultural and energy sectors, and total economic growth predicted for the period 1995 to 2050. Population will increase 1.6 times. This will be exceeded by a 1.8 times improvement in agricultural output to satisfy consumer demands. Energy use will increase by at least 2.4 times and the global economy will improve 4.3 times (Raskin et al., 1995). While this will be good for some segments of populations worldwide, only changes that will alleviate social inequities can benefit needy, disadvantaged people. Social economists and international organizations (e.g., the World Bank and regional development banks) should make their

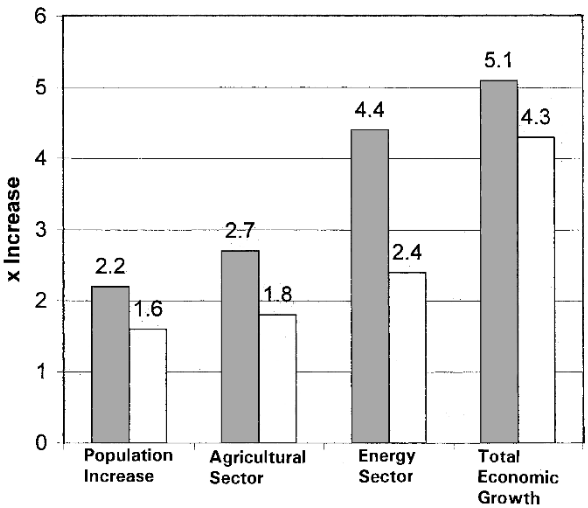


**Fig. 2.3** Comparison between population increase 1950s–1990s (*shaded*) and 1995–2050 (*white*) and agricultural and energy sectors and total economic growth (after data in Raskin et al., 1995)

loans conditional so that borrower governments with expanding economies have to invest a specified significant portion of the new found treasure to the benefit of their citizens (e.g., in healthcare, housing, education, job training, and job creation).

Although a global outlook based on the numbers shown in Figure 2.3 is positive for food supplies and economies growing at rates greater than that of population increase, they are misleading. The reality is that there are great discrepancies within and among nations and regions in the availability and distribution of food (and water), and energy, and the economic assets to acquire them. A result is that large and small populations worldwide do not have access to and lack basic needs.

Economies have expanded in many developing countries. (e.g., China, India, Mexico) because of cheap labor and lack of or lack of enforcement of laws that protect the environment and health of the workers. This comes at the expense of job loss in some developed countries (e.g., the United States and Japan). Jobs have been lost as well to automation in manufacturing industries (e.g., automobiles). This breeds the seed of unease in populations where there has been job loss. There can be unrest as well in less developed countries with growing economies where small segments of populations benefit but where there are limited trickle down effects to low income groups and little bettering of the socio-economic conditions for the great majority of their citizens.

## Age-Gender Distributions: Population Pyramids

A population pyramid is a graphic representation that defines the structure of a nation by age and gender. The graphs are constructed for each country with data submitted to an International Data Base. Governments use population distribution data to plan what will be necessary to serve the needs of future generations. This includes life-sustaining water and food, natural resources such as energy and raw materials, housing and infrastructure, medical services, and education for specific careers. Some male/female age distributions are triangular in form and by common usage have been called population pyramids. Other distributions approach a cylindrical form and still others a mushroom form. These age-gender representations provide a window to a country's future needs.

### *Examples of Population Pyramids*

Each distribution connotes something specific about where a population is now in terms of size and age/gender apportionment and where it can be expected to be in the future. The distributions will vary with time as new data reflect changes in percent rate of population increase and in fertility rates.

## *Population Stabilization Structures*

Figure 2.4 compares global population pyramids for the year 2002 with one projected for 2050. The 2050 cylindrical form extending from its base and moving up well into late child bearing ages (34–39) indicates the move towards population stabilization. Figure 2.5 shows a similar structure projected for India. The population pyramids for Egypt for 2000, 2025 and 2050 (Fig. 2.6) show the evolution of this class of age-gender structure. Among the 20 most populous countries, Pakistan, Mexico and the Philippines have age-gender structures similar to that of Egypt.

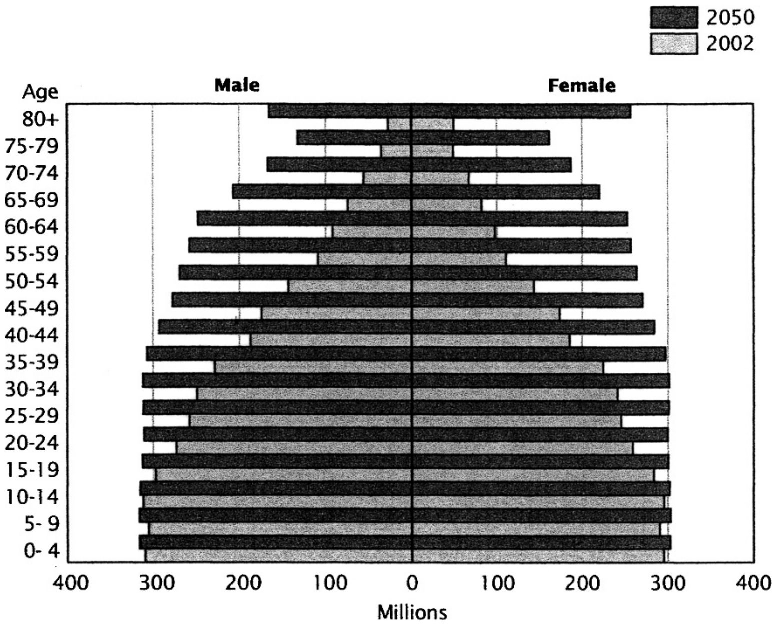


**Fig. 2.4** Pyramids of global population: 2002 projected to 2050 (after U.S. Census Bureau, International Programs Center, International Data Base, updated 08-24-2006)

## *Slowing But Growing Population Structures*

A structure with a broad base for 2002 that extrapolates to a lesser broad base for 2050 (e.g., Fig. 2.5, Sub-Saharan Africa) suggests that there is a population-braking trend but that the population is likely to grow because there are large numbers of young people coming into or already in childbearing years. Figure 2.5 shows a similar relation for the Near East and North Africa.

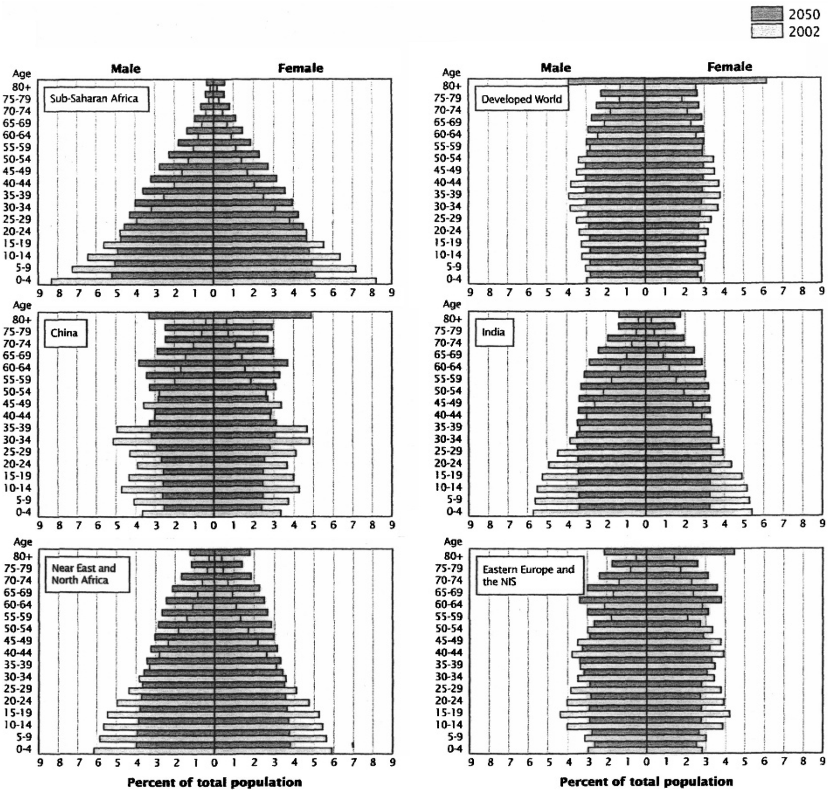


**Fig. 2.5** Population pyramids for regions and selected countries: 2002 projected to 2050 (after U.S. Census Bureau, International Programs Center, International Data Base, updated 08-24-2006)

## *Contracting and Aging Population Structures*

A structure for 2002 that is pinched at the bottom and into childbearing ages and that shows a stronger pinch for 2050, suggests a population moving towards contraction (Fig. 2.5, Developed World, Eastern Europe and the NIS, China). If the structure broadens towards the top or adds another age class, the population is aging. Figure 2.7 for the United Kingdom shows interim detail by age-gender distribution plots for 2000, 2025 and 2050 that signals real population contraction by an increasingly pinched base and aging by the addition of age/gender categories of 90-99 and 100+. Among the 20 most populated nations, Indonesia, Brazil, Turkey, Iran and Thailand have population distributions similar to those of the United Kingdom.

## *Population Realities*

Population expansion will be the greatest in less developed nations for two reasons: (1) the gender numbers <15 years of age (coming into the childbearing age) and

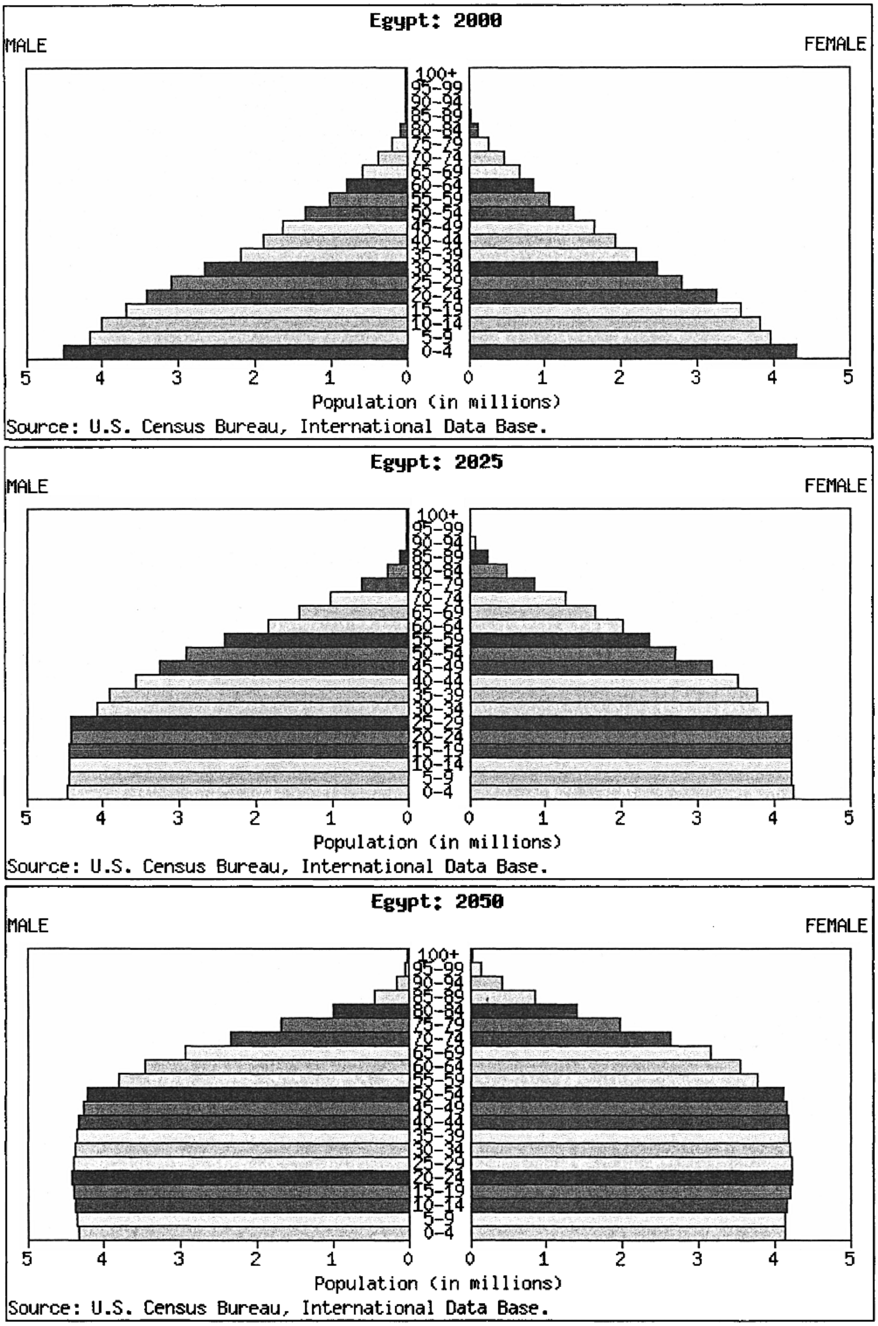


**Fig. 2.6** Population pyramid summary for Egypt: 2000 projected to 2025 and 2050 (extracted data from online aggregation, International Data Base, updated 08-24-2006)

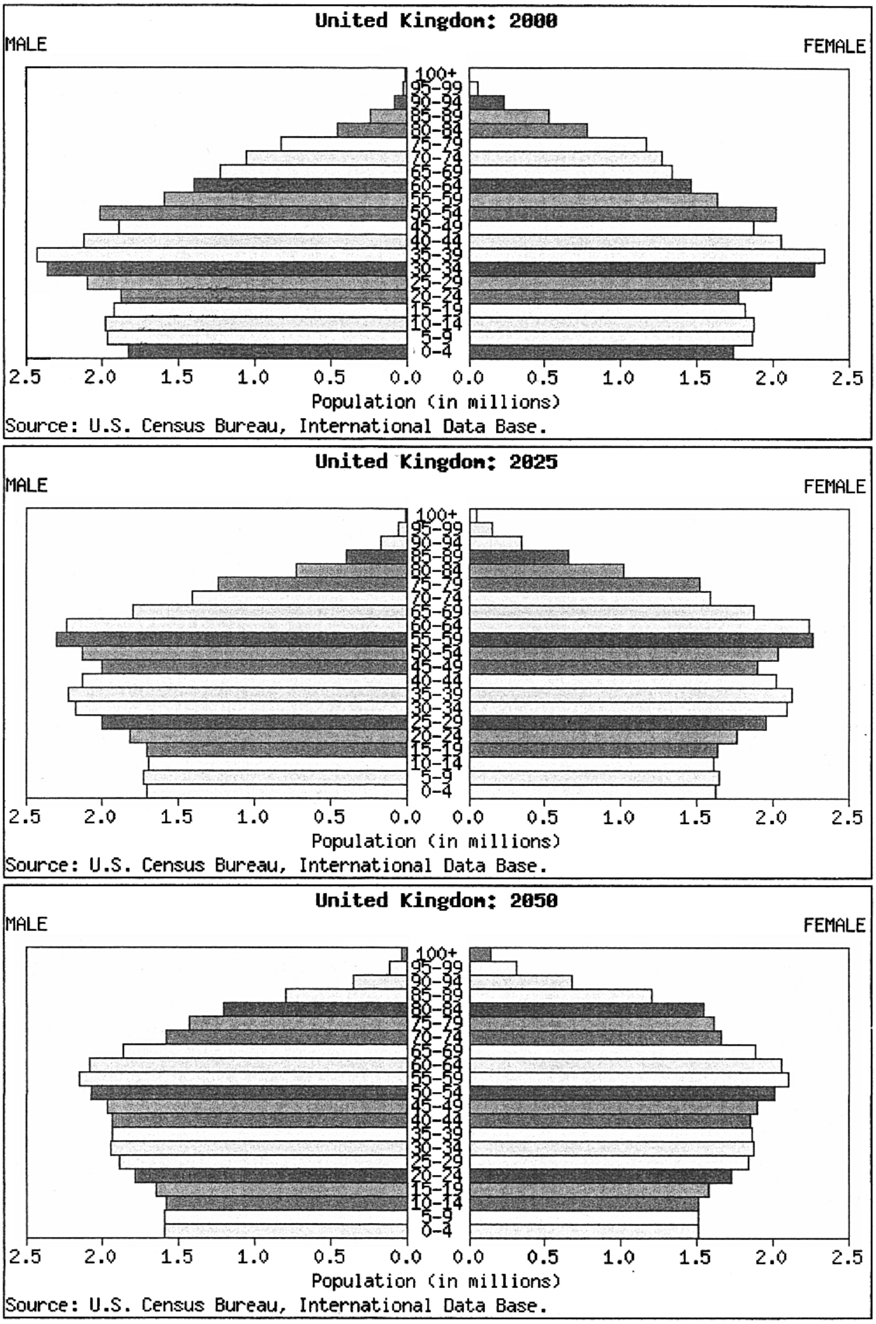


**Fig. 2.7** Population pyramid summary for the United Kingdom: 2000 projected to 2025 and 2050 (extracted data from online aggregation, International Data Base, updated 08-24-2006)

between 15 and 49 years of age (the childbearing period; Fig. 2.5); and (2) fertility rates (Table 2.3). However, a “pinch” at the bottom of developing nations structures (decreasing number for the $<$15 years of age class) suggest that there will be a slowing of the rate of increase. This will result in fewer people in the 15-49 years of age class that promises a continuing decrease in rate of growth and a longer span of time before the population doubles. The hope is that the world will achieve a “replacement” rate of growth perhaps by 2050 as suggested in Fig. 2.1. Even after reaching a replacement rate, population momentum will cause continued growth until stabilization. Will this be 9.2+ billion people, 11 million people? We can estimate figures statistically, but they may not reflect what the actual number is likely to be.

A major problem for global societies is that the median age in developing nations is approaching 20 whereas in industrialized nations it is nearing 60. Young populations can fulfill their hopes and aspirations in stable social situations when they have access to proper nutrition, health services, education, and then jobs for which they prepared via education and training. These goals are attainable via focused financial and technical assistance from industrialized countries and development banks (Table 1.1) to governments that offer transparency as to where, for what purposes, to whom, and in what amounts development assistance funds are being dispersed.

If the trend towards decreasing rate of population growth and decreasing fertility rate continues, the world population will reach a point of real contraction. A new stabilization figure will be reached. Will it be 9 billion people, 6 billion people? One can only make an educated guess. If the population contracts from 2050 to 2100 at a rate at which it is extrapolated to expand from the present to 2050 and then equilibrates, the 22nd century should mark stabilization, perhaps at 6-8 billion people. But this is only speculation. A “new” steady population will likely represent a “real” technologically-assisted carrying capacity of the earth and its many and varying environments and ecosystems. In theory, such technological assistance will make basic necessities available and distributed easily and promptly among the people in locations that require them.

## *Planned Population Growth - Social Stability or Disruption*

A few countries such as Saudi Arabia continue a policy of population growth (Fig. 2.8) whether for political (power base), economic (expanding markets), cultural or religious reasons. Nigeria and Bangladesh are very populated nations that do not encourage population growth as does Saudi Arabia, but they have age-gender pyramids similar to those of Saudi Arabia. This is ominous for existing and future generations in those countries. The only stabilization planned for Saudi Arabia is no growth in the number of male and female population under 14 between the years 2025 and 2050. No contraction is envisioned.

Compared with Nigeria and Bangladesh, Saudi Arabia is the least populated with more than 29 million people (in 2007) including ~5.6 million foreign workers. The population increase rate is 2.1% (doubling time of ~33 years) with a fertility rate of

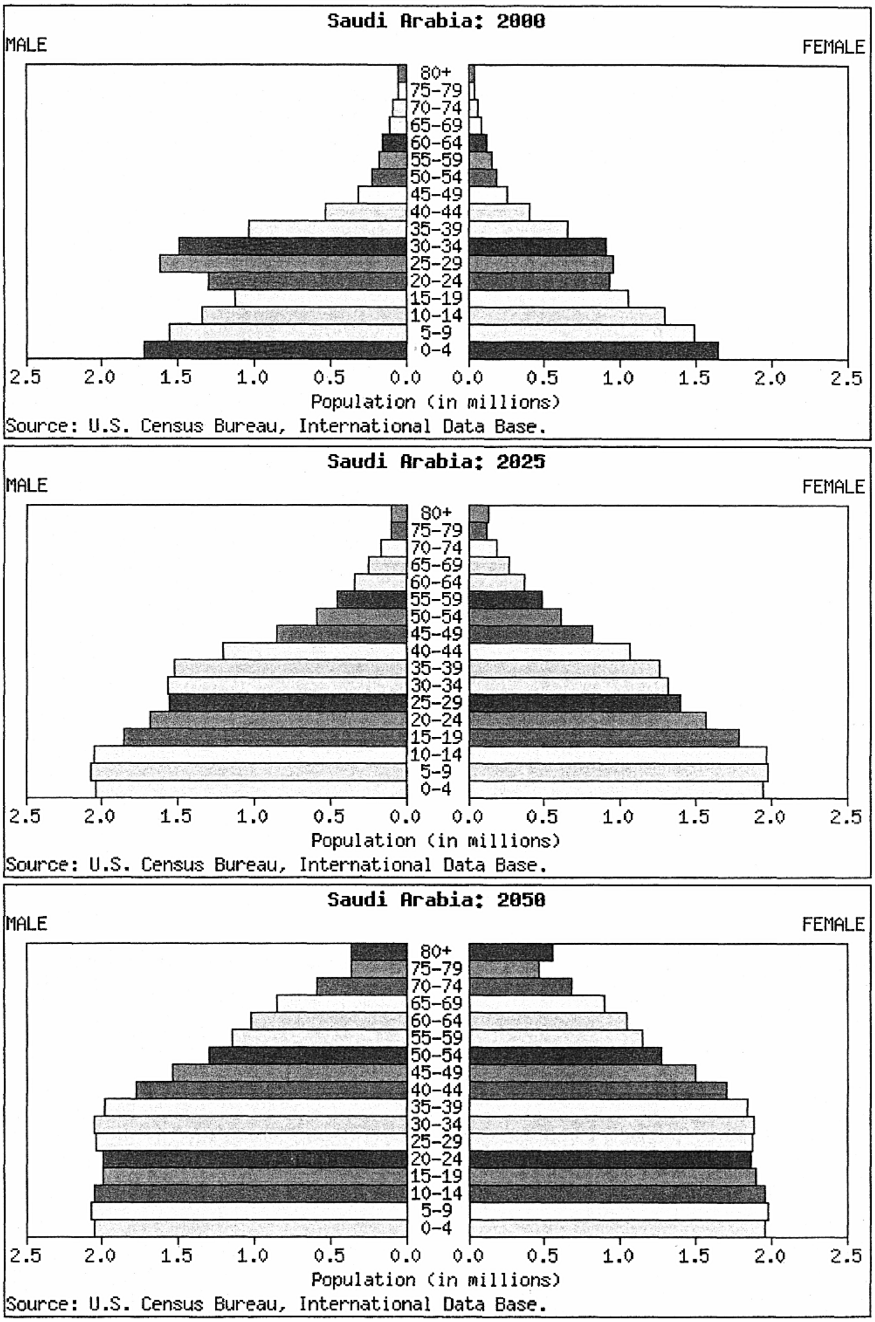


**Fig. 2.8** Population pyramid summary for Saudi Arabia: 2000 projected to 2025 and 2050 (extracted data from online aggregation, International Data Base, updated 08-24-2006)

3.9. There is a high rate of unemployment. At present about 38.3% of the population is less than 14 years of age and 60% is under 21 years of age. Fifty-seven percent females and 65% males are enrolled in secondary schools. This does not bode well for the students graduating from schools and universities (343,000 in 1999). Their employment prospects and economic futures are in question. There have not been enough meaningful jobs being created by the government or private investors to employ the growing and educated young population. This leads to frustration for the young people and a call for social and political change. Without change there is futility and desperation that ultimately leads to desperate acts and violence to bring about change.

A targeted population of $>46$ million people for Saudi Arabia cannot be sustained by an oil economy alone in a desert environment with an arable area of 0.6% of the country. Unlike Nigeria or Bangladesh, Saudi Arabia cannot feed itself and today needs desalination plants to supply potable water to 20% of its 29 million people ($\sim$5.8 million). Oil wealth provides these life-sustaining commodities. From mid-2005-2008, high oil prices increased oil revenue dramatically. However, this can change rapidly if there are technological advances in the transportation and energy generation sectors and if demand for oil declines or global supply increases at a rate greater than demand. For example, per capita income in Saudi Arabia in constant 1997 dollars was $19000 in 1981 but plummeted to $7300 in 1997 as oil revenue decreased from $227 billion to less than $60 billion in constant 2000 dollars. Saudi Arabia's wealth fluctuates with oil prices and can strain socio-political equilibrium. Many governments with oil and trade surpluses are alert to changes that could affect their economies and at least 15 have created mega-funds to buy assets around the world to protect their ability to provide for their populations in the future. For example, from oil revenue, the UAE has assets estimated at $875 billion, Norway at $350 billion, Kuwait at $213 billion. From trade surpluses, China has assets at $200 billion, Australia at $40 billion, and Korea at $20 billion. Saudi Arabia does not appear on the listing of countries that have created mega-funds.

## *Planning*

If experience is the key to planning global populations' futures, and humans have learned from it, the path is clear. Populations must be stabilized. Availability of life-sustaining commodities must be be equally distributed within and among populations even when they are geographically separated. Poverty has to be alleviated and then continually lessened so that people have hope for their futures and those of their children. As emphasized earlier, educational opportunities have to be available and accessible and vital environments must be maintained, or if tainted, reclaimed through remediation. Healthy environments and people who respect them will avoid population crashes that can originate, germinate, and spread from natural biological and/or chemical seeds or may be the result of anthropogenic activities. For a society to be stable, vibrant, and successful, property rights must be codified and human rights respected and honored.

## Afterword

The human population on earth is growing and will reach replacement rate (no growth) when there are likely to be more than half again as many people as there are today. Today, major segments of populations in many developing and some developed countries are absent the basic essentials of a good life. This is an international problem now being addressed by economically advantaged developed nations. The next chapter deals with concerns of meeting current and future population needs.

# Chapter 3
# Population Needs for Well-Being

Population needs have been described as the gap between what is and what should be in light of the growing imbalance between the world's expanding population and the resources that support human life (Pimentel et al., 1994). This assessment has to be complemented by a population's safety from physical hazards. The needs were alluded to briefly in the previous chapter and will be discussed further here. A good start is with the life sustainers. Humans must have clean air to breathe, and sufficient supplies of safe water for drinking, cooking and hygiene. Clean water is also necessary for agriculture (field crops and animal husbandry) to grow food from fertile soils containing essential macro- and micronutrients. These assure healthy biological functions and promote a continuum of well-being for organisms in a food web and the symbiotic relations that exist there. In addition, populations need water for sanitation (sewage disposal) and safe sites for disposal of wastes other than sewage. A long-term failure to secure one or more of these necessities will degrade an environment and can lead to an ecosystem crash.

In the past, many population requirements were met based on immediate socio-economic factors. Proximity to water for waterpower, and for transportation to move people and goods inland or across seas and oceans was important to early settlements. This meant choosing sites for urban development close to major rivers, great lakes and/or coastal areas where rivers discharged into the sea. Subsequently, closeness to water was essential to founding industries and expansion of existing ones. Thus, safe water, security of an untainted and expanded food supply (fisheries), and proximity to other natural resources (wood, stone, coal) had an influence on the selection of the physical locations of urban, agricultural and industrial development projects. Because of the lack of experience with some natural hazards (e.g., earthquakes, volcanic activity, flooding, and landslides), early planners did not always allow for the potential impact of hazards on growing populations and their economic bases. When possible, socio-economic planning to meet population needs must be done in a physical setting with safe living and working space.

F.R. Siegel, *Demands of Expanding Populations and Development Planning*,

## Biological/Chemical Needs

Life-sustaining biological and chemical needs of hundreds of millions of people in many parts of the world, especially Africa, are not now met. The global challenge is to meet them for what may be a stabilized population of at least 9.2+ billion in 2050.

### *Clean Air*

Clean air is essential for respiring organisms. Citizens in many countries suffer health problems from airborne toxic gaseous and particle contaminants. Populations at high risk from bad air live downwind of coal-burning power plants and downwind of sulfide ore smelters. The metal toxicants volatilized by combustion of fossil fuels at these plants are released though tall chimneys into the atmosphere together with toxic gases and particles. Millions of tons discharge into the atmosphere annually. The metals include mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As). The dominant toxic gas is sulfur dioxide ($SO_2$). Sulfur dioxide reacts with water in the atmosphere to form sulfuric acid ($H_2SO_4$), the most damaging component of acid rain. Ingestion by respiration of "dirty air" emissions (inhaled particles and chemical toxicants) over long periods of time has resulted in human health problems.

Medical studies on humans have related the long-term ingestion of contaminants (via atmosphere and/or atmosphere to water to soil to food chain and food web) to brain damage (Pb), nervous system degeneration (Hg), kidney disfunction (Cd), cancer (As), and lung damage (mineral particles and $H_2SO_4$). Forested areas, other vegetation, and aquatic life in some intruded lakes and rivers have suffered severely from acid rain.

There are operational changes and technologies to reduce the discharge of dangerous pollutants to the atmosphere and thus limit the amounts that can access ecosystems and their food webs. One change is to use low sulfur coal or sulfur stripped oil for combustion. Another is to use natural gas. These fuels provide combustion energy but greatly diminish $SO_2$ in chimney emissions. Solid phase capture equipment can remove major masses of particles from chimney emissions. Chemical scrubbers do the same for volatile metals and gaseous pollutants before emissions discharge into the atmosphere. The installation of these technologies in new industrial facilities or retrofitting them into existing ones is costly. Pollution control has the added costs of system maintenance and the treatment and disposal of captured contaminants. This aspect of cleansing emissions is discussed further in Chapter 9 which examines remediation and reclamation options. Added benefits of stripping emissions of heavy metals and toxicant gases are improvement in downwind ecosystems in water quality, agricultural production, and husbandry of food animals. The long-term economic benefits of controlling emissions outweigh the initial and long-term operational costs.

## *Safe Water*

There is enough flowing fresh water (surface and aquifer) on earth to service the drinking, cooking, hygiene and sanitation needs of a growing global population and provide for agricultural production. The populations with access to fresh water are now using about one-half of the obtainable fresh water. In theory then, the other half is available for people lacking sufficient water supplies. However, there are practical problems in providing water to populations in short supply. First, water is unevenly distributed geographically. Second, less developed nations often have little capability of getting water from where it is plentiful to where it needed.

Water may be naturally pure, untainted by potentially harmful bacteria or chemicals. Contaminated water may reach consumers as safe water because of wastewater collection and treatment plants that cleanse polluted water before distributing it. In many areas, especially in less developed nations, the water for domestic and personal use is biologically and/or chemically contaminated. This is responsible for the death of $1\frac{1}{2}$ to 2 million young children worldwide annually, and for hundreds of millions of temporary incapacitating intestinal illnesses. The reasons for this tragedy are mainly twofold. First is a lack of legislated regulations or little or no enforcement of laws on sewage and industrial effluents disposal that can prevent contamination. Second is a lack of capital for investment in wastewater collection and treatment facilities and in systems that can distribute cleansed water to where it is lacking. In some cases, government investment for such systems benefit a few economically-advantaged and politically-connected people, and the military. This leaves major populations at risk of debilitating diseases because they lack access to safe water.

## *Untainted Food*

Modern field and fruit tree cropping, foul and animal husbandry, plus natural and aquaculture fisheries can, in theory, yield the food to nourish the projected 2050 world population. However, unless organic farming is the *modus operandi* so that these foods can be grown clean, soils need the application of manufactured fertilizers and biocides to sustain long-term production. In this case, care must be taken to use the amounts of agricultural chemicals that allow optimal growth yet avoid chemical buildup in the growth environments and the possibility of contaminated runoff or seepage into aqueous ecosystems.

Organic farming contributes to our food bank. This agriculture uses natural fertilizers and pest control by predators that do not threaten crops or ecosystem inhabitants. However, there is the question of whether organic farming can produce large enough quantities of food to feed a significant portion of the 2050 world population. Plant hybridization can develop species that are pest-resistant and that discriminate against uptake of toxic levels of contaminants. This will be increasingly important for farming in the future. Hybridization and other approaches can be used to bypass the application of biocides and maximize "clean" food crop yields without resort to genetically engineered crops. Chapter 8 discusses methods of increasing the global food supply in some detail.

As is the case for water, food distribution can pose a barrier to feeding populations in some regions or countries. Foods have to be moved from where they are grown in abundance and processed, to distribution terminals. Then they must be transported to locations to feed people, often times malnourished and starving. In the contemporary world, three problems deter the delivery of foods to famine stricken populations. First, a national government may not allow entry of donated food from other countries or NGOs (e.g., Zimbabwe, 2006 and earlier) or government agents may steal the food to sell to desperate people. Second, there is a lack of infrastructure to transport food from a port of entry to a country's interior. Third, opposing armed factions within a region or country can prevent movement of food to where it is needed or can hijack food shipments for their own use or to sell at exorbitant prices. The first problem can be dealt with only through a change in government attitude driven by international sanctions such as cut off from sources of capital, cut back in commercial access, or transportation bans. The latter two problems have solutions. The second, supportable by low or no interest loans from the World Bank and/or regional development banks (Table 1.1), can be solved by government investment in infrastructure. The third can be resolved through agreements between politico-military factions or via an intervention of internationally sanctioned armed contingents that can assure free passage of foodstuffs to where they are needed.

### *Secure Waste Disposal*

Life forms cannot survive in their own wastes. Thus, the capture and disposal or containment and isolation of human and other organism biologic wastes, and of inorganic wastes from human activities (e.g., heavy metals, toxic chemicals from agricultural, industrial, mining and domestic sources) are essential. Proper disposal of toxic wastes safeguards human health and that of other organisms. Investment in research and development on disposal, containment, and isolation of wastes can improve methodologies that will ensure clean water and clean food. Wastes can be treated and used (e.g., solids from organisms for energy generation, or treated for use as natural fertilizer), recycled after capture and reprocessing (e.g., liquid wastes, glass, metals, plastics), or disposed of safely and securely in a long-term containment situation (e.g., toxic chemicals, radioactive wastes). The isolation of non-recycled wastes will help preserve ecosystems for future generations.

## Socio-Economic Needs

A population's satisfaction level and its contribution to productivity and economic progress are founded on accessibility to and delivery of tangible items and on respect for intangible qualities that underpin a society. The tangibles mirror to some degree the needs of ecosystems: clean air, safe water, and untainted fertile soils. In addition, populations need the natural resources tangibles that ecosystems yield (e.g., fibers, wood, industrial minerals, ores, and energy sources) and which are necessary to the functioning of various development sectors. Governments responsive to safeguarding these tangibles by preserving the vitality of the ecosystems make environmental security that prevents ecosystem pollution a national priority.

Governments are also vested in meeting the social needs of their citizens by delivering service tangibles to them. These are quality services for healthcare, education, and when necessary, welfare. Healthcare for the young is especially important because young people who are sound of body will be sound of mind and respond to education with a grand desire and ability to learn. They will build upon that learning through their innate curiosity and intelligence. Their education, coupled with training and experience, is basic to employment whether in professional and technical fields or in the trades. Success in delivering the tangible needs to citizenry creates a solid social foundation for economic advancement.

Intangibles are no less important as contributors to progressive societies. These include living in a lawful society where justice is equal for all, where there is respect for human rights and property rights, and where there is freedom to express one's self politically and the right to follow one's religious beliefs.

Investors evaluate various factors when appraising the possibility of locating development projects in competing sites. Among these is presence of a firm basis for social stability provided by the intangibles and tangibles available to or provided to populations as described above. Another is an existent, prepared and experienced pool of human resources. A readied cadre has a positive influence on investor decision-making.

If a project is approved, its presence and output will add to a municipality's and a nation's economic growth. Development enterprises give employment opportunities to people with expertise and skills in different fields. An employed workforce gives economic stability to a society from general taxes on incomes, taxes on supplies and services delivered to the enterprises, taxes on sales from domestic purchasing power, and taxes on imports and exports. The taxes provide the finances for sustaining conditions that have led to socio-economic progress.

## *Barriers to Meeting Population Needs*

There are limitations to fulfilling the needs that allow citizens a good quality of life. An economic barrier sometimes abetted by a political barrier slows solutions to physical, chemical and biological environmental problems, and sources of social disillusion and unrest in many countries. Governments may not have the tax base to attack these issues. Even if financially able, governments often give low priority to the cleansing and preservation of environments and their resources. They fail to initiate or carry through on development projects that give their constituents economic opportunities and thus contribute to a nation's future.

## *Economic*

There are multiple economic barriers to meeting population needs. One is in the political culture prevalent in a country. A second is in the financial policies of a country with respect to both its currency valuation regulations and its revenue collection system. A third is in availability of funds for projects that benefit a country's people and national development, and the conditions under which funding is accepted.

With respect to the first economic barrier, in some political cultures corruption is an accepted way of life. It drains financial resources that otherwise could improve the standard of living for poorer segments of populations. Government officials may accept bribes from politically connected individuals, businesses large and small, and industries, to permit tax avoidance on income, sales, exports, and imports. Skimming money from designated projects for use on non-priority programs or for personal use by government officials are other ways donated or borrowed financial resources can be misused. These problems can be corrected by enforcing laws against such illegal activities. Enforcement allows for meting out harsh penalties to offending individuals or responsible agencies.

A second economic barrier that can hurt a government's financial condition is an overvalued currency. This undermines investment and makes the costs of exported goods overly expensive and less competitive in world markets. Overvalued currencies also discourage tourism, a major source of income for a number of countries. This barrier to producing income can be lowered by a realistic valuation of a country's currency.

In the international scheme of finances, some countries seek to maintain an undervalued currency in order to export more and attract tourism. Unfortunately, the added income from these sources has not often trickled down to the lower income people who need it most. This has been the case for China in recent years where perhaps one-fifth of the Chinese population has benefited greatly from a booming economy but the rest of the people have not, especially in rural areas and in interior parts of the country. International economic assessors have encouraged China to move to a realistic valuation of its currency in order to maintain a global economic balance. The Chinese government has been regularly reevaluating its currency position versus potential trade barriers (higher tariffs) on exported goods by importer nations if it does not do so.

If there are no investment funds available internally to provide for a country's population, they may be obtainable via loans or grants. A country with a good credit history, realistically valued currency, an efficient tax collection system, and enforced anti-corruption laws, can borrow funds from international financial institutions, commercial banks, or international funding groups. When economic resources become available, government offices that control their disbursal and use must assure transparency via documentation that prove that the funds are being spent for special projects as designated. If transparency is not the norm, development loans or international donor funds will not be forthcoming or will be greatly reduced because of the potential for corruption that bleeds the economic resources from the uses for which they were specified.

Becoming party to a loan, sometimes pushed by lenders (e.g., the International Monetary Fund and commercial banks during the 1980's), creates responsibility for repayment with interest. A country should accept loans only at interest rates that it can pay without severely draining its real income. Where this has not been the case the results have proved damning because of the high proportion of a government income that has to be paid to service the debt. This leaves little extra to invest in "needs" projects. Borrower countries have sometimes defaulted on repayment and have not been able to secure additional loans until an arrangement has been reached with a lender for repayment of part or all of the defaulted loans.

## *Politico-Cultural*

A political limitation to filling a population's needs is often tied into a government's economic capacity or will to invest in infrastructure that facilitates commodity movement. Nonetheless, governments have the moral responsibility for the free flow of essential goods to needy populations and the provision of basic services to them. Physical barriers to underserved people include no pipe and pump systems to move clean water to where it is needed. There may be no roads, poorly maintained and seasonally impassible roads, bridges in disrepair, or irregularly functioning railroads to move food, medicines, and other basic goods from sites of origin to storage areas to regions where they are absolute necessities. These problems can be overcome by political decisions to focus investment on building or repairing the infrastructure barriers.

It is important to deal sensitively with cultural resistance to change when planning to provide for population needs. Economic development that leads to social benefits may clash with a people's religious beliefs, social structure, law, politics, and other inherited cultural norms that pass from generation to generation. In some societies change can be brought about through education and "show me" programs. These can demonstrate the successes that can be achieved when cultural barriers are flexible enough to embrace changes that do not offend a society's moral/intellectual foundations. This, and support for change by the general population, can overcome cultural restraints.

In addition, unfettered societal progress is based on having an educated, trained cadre of professionals, tradespersons, and workers who can evaluate, cope with, and solve existing problems concerning needs of populations. Together, politically responsible and culturally sensitive project planning teams, and a good cadre of personnel can devise strategies to overcome barriers to satisfying a population's basic necessities and otherwise service people at risk. Finally the planners must move beyond this stage by presenting citizens with opportunities that put their hopes and aspirations and those for their children within reach.

## *Human Rights*

Populations can be healthy and have access to good education and opportunities for employment that fulfill economic and intellectual needs. But this is not enough for societal stability if human rights are not respected. Human rights protect individuals and groups from intrusion into their lives by hooligans, organized groups, or governments. Human rights mean that they are free to speak out against injustices and to petition their governments for redress. They convey a right to habeas corpus, assure that there is security for people to practice their religion, and that they have ready access to the basic essentials to a good life. Human rights mean that all are treated with dignity and property rights are respected. This is achieved through governmental legislation and an enforcement arm that makes no exceptions to the defense of human rights because of place in society, economic resources, or political influence. Governments and societies respectful of these rights, can flourish. Those that repress them will, in time, collapse.

## Consequences of not Meeting Population Needs

The consequences of not meeting the organic, social, and physical needs of populations are in evidence worldwide. They are pronounced in less developed nations in Africa, Asia and the Middle East but are experienced in some developed nations as well, often by undereducated, underemployed immigrant groups.

The consequences manifest themselves on a personal level by sickness from bad water and malnutrition. Poverty from lack of education and employment opportunities affects groups and leaves them with little hope of escaping poverty and with poor perspectives for the future of their children. This brings distressed and desperate people together in group responses and complaints against government policies and calls for changes. On a group level, the consequences of not responding to the basic needs of people that give rise to a satisfying life are expressed by civil unrest. The unrest can grow, intensify, become heated, and boil over and evolve from a peaceful to a violent rebellion aimed at bringing about changes in government attitudes and policies or in governments themselves. In the worst cases, political responses to demands for redress to provide societal needs is met by the abrogation of personal freedoms and rights of complainants, by repression and unwarranted beating, maiming and killing by government police or military units. There can be attempts as ethnic displacement that evolves into internecine fighting or war between nations.

Only reforms that respond to valid citizenry demands for redress and the promise for better futures for all levels of society can resolve the problems given above. These reforms and a satisfied citizenry would surely build investor confidence and attract development projects.

## Proposal to Alleviate Tangible Needs Problems

Kates (2000) presents a "7–8**S**" guide or template for action to reduce consumption thus alleviating impacts on an environment and slowing down the rate of natural resources depletion. This breaks down into three fields. First and foremost is to **SLOW and STABILIZE** population growth. Second is to **SATISFY** population needs (e.g., energy, materials) more with renewable commodities that the earth yields, **SATIATE** needs with what is plentiful, renewable if possible, and readily available, and **SUBLIMATE** urges for greater than basic consumption of commodities for the good of the overall population with the aim of reducing the consumption per person. Third is to **SHIFT** use to less harmful consumption, **SHRINK** the demand for energy and materials derived from natural resources, and **SUBSTITUTE** information technology. This leads populations to alternate energy and natural materials sources with the purpose of alleviating environmental degradation and diminishing the rate of depletion of natural resources. In equation form this would be represented as:

| IMPACTS | = | POPULATION | × | CONSUMPTION/PERSON | × | IMPACTS/CONSUMPTION |
|---|---|---|---|---|---|---|
| | | slow | | satisfy | | shift |
| | | stabilize | | satiate | | shrink |
| | | | | sublimate | | substitute |

### *Additional Consideration: Technology Factor*

In a report published during the same month as that of Kates (2000), Guillebaud (2000) also emphasizes that it is necessary to curb population growth so as not to exceed the carrying capacity of the Earth's ecosystems. He cites three factors (after Ehrlich and Ehrlich, 1990) that affect the anthropogenic impact on an environment and gives them in the equation $\mathbf{I} = \mathbf{P} \times \mathbf{A} \times \mathbf{T}$. The **I** is the impact, **P** is the number in a population, **A** is the per capita economic capacity (linked to resource use and waste), and **T** is the per capita technology component. Guillebaud (2000) states that an increase in consumption and pollution that results from advances in industrial and manufacturing technology contributes to the value of **T**, the impact of technology. He considers that the **T** can be lowered with greener technologies such the use of more renewable energy, but writes that "the **T** factor is never going to make a really dramatic impact."

Clearly, expanding populations (**P**) coupled with improving economies and acquisitive power increases the consumption/waste factor **A**. The escalating draw on natural resources, more waste from product manufacture, and a greater waste disposal problem threaten ecosystem vitality. There is a question, however, on Guillebaud's evaluation of the importance of the **T** factor that can lessen the **P/A** environmental impact. An example of a dramatic impact of **T** is the slowing of the degradation of the ozone layer by a global ban on the use of chlorofluorocarbons (CFCs) in sprayer propellants. The substitution of other propellants such as nitrous oxides for the CFCs is arresting the thinning of the ozone layer and the widening of the holes in it thus allowing a long-term but real repair process to begin. The reestablishing of the natural ozone layer will cut back on the added exposure of humans of dangerous UV radiation and the skin cancer it can cause. Efforts to heal the ozone layer will be discussed further in the following chapter.

There is no doubt that utilization of green technologies in recycling is reducing per capita resource use and waste. In many countries, there is a diminished per capita use of fossil fuel combustion for power generation, transportation, and heating because of advances in combustion technology, increased efficiency, and higher fuel prices. This is complemented by the application of best available technologies for capture, containment, and either use or isolation of captured pollutants. The growing use of alternate energy sources is also reducing per capita contaminant gaseous and particle emissions. In the long-term, as more countries adopt these changes and technological advances, there will be a major improvement to ecosystems' living conditions and the environments that contain them.

## *Space Needs - Physical Security*

A principal goal of this text is to highlight how chemistries of the earth surface/near-surface materials air, water and soil impact populations, ecosystems, and development now and in the long-term. However, the siting of centers of human activity with respect to physical hazards and their short-term impacts is important as well and merits inclusion in this chapter. This is especially true in light of expanding and shifting of populations to urban centers described in the last chapter.

The location of homes, workplace structures, and infrastructure in zones at low risk from natural hazards is basic to planning for growing populations and changing demographics. To find such locations is ever more difficult. As noted in the previous chapter, 75% of the populations in developed countries and about 38% in less developed countries live and work in agglomerations comprised of large cities and their suburbs or edge cities.

Planners and community leaders in early civilizations did not have the benefit of contemporary geological knowledge about an area's risk from natural physical hazards such as earthquakes, volcanic eruptions, floods, and others. They chose locations for urban centers to serve the needs of societies without adequately assessing the potential for havoc the hazards could wreak on people, property, and infrastructure.

They did not envision population growth as a future problem and could not anticipate the rapid expansion of industrialization in the future. Decision makers favored locations that were close to safe water for drinking and agriculture and that had nearby sources of wood and rock to build homes, other structures, and attendant infrastructure. Some sites had harbors suitable for ports. All had access to inland transportation routes and were close to energy sources (flowing water, fairly steady winds, firewood, and coal). A defensible position against malicious incursions was important in choosing many sites. These factors influenced the locations of population centers in the new world as well.

## *Hazards Triggered by Human Settlement*

Floods and landslides have become more common with human settlement. For example, when locating population centers at the mouths of drainage basins, early planners often did not envision habitation and exploitation upstream as a threat to downstream urban-suburban zones. However, areas exploited for housing, agriculture, and timbering upstream resulted in increased and more rapid rainwater and melt water runoff in some basins. This caused greater erosion, increased landslide potential, and flooding downstream. Subsequently, protection for downstream populations required the use of flood control methods (e.g., dams, levees, and straightening, widening and/or deepening channels) and the installation of flood warning systems and evacuation protocols. Landslide control or land stabilization was by exclusion (e.g., divert water from landslide-prone slopes) or stabilization techniques (e.g., construct bulwarks at or beneath the land surface; vegetate exposed terrain). The vegetation helps control erosion as well. Water that infiltrates a slope does two things that can lead to landslides. It adds weight to the slope and lubricates soils and underlying rocks decreasing friction that holds a hillside together. This can destabilize a slope and cause landslides. A landslide control technique used extensively in Japan is to direct drainage away from slopes susceptible to mass movement and to seal terrain (e.g., with shotcrete) to prevent seepage into slopes and to strength them.

Environmental geologists identify sites to avoid during the land-use planning phase of development studies especially if at risk locations have no previously installed monitoring and warning systems for hazards known to have impacted these locations in the past. These include active fault zones, the flanks of active volcanoes and contiguous valleys, flood plains, low-lying marine coasts along tropical storm tracks, and areas threatened by secondary events a primary hazard can trigger (Siegel, 1996). Geologists target these risk zones following the axiom, "a knowledge and understanding of the anatomy, areas affected, and damage done during and after past and contemporary natural physical hazards are the keys to planning to protect life and property against future hazards."

## *Population Density and Hazard Planning*

Logically, densely populated locations suffer most from natural (and anthropogenic) hazards. This is an international concern. The risk to people from a hazard increases as more people settle at a locale. The people density/hazard impact problem affects pre-development construction decisions on where urbanization can expand or where future cities can be safely sited. Many cities founded during ancient, historical, and recent eras now have populations in the millions. Two hundred and fifty cities globally (150 in China) have more than one million inhabitants. As noted in the previous chapter, over 20 of them worldwide have grown into urban agglomerations with more than 10 million people. Many of these have suffered the onslaught of hazards in the past and continue to be at high risk from them today (e.g., Mexico City, Los Angeles, Tokyo, Osaka-Kobe, Istanbul).

The magnitudes and reaches of natural hazards are such that they can be threats to life and property at some distance from where they strike. Here, populations may not be concentrated but dangerously located with respect to a hazard event and secondary events they may trigger. From December 2004 to December 2005, four hazards shocked the world with the deaths, injuries, displacement of populations, and general destruction they caused. The Indian Ocean tsunami cited previously was triggered by an under sea earthquake off the Sumatran coast (December, 2004). The tsunami killed 200,000 coastal zone inhabitants mainly in Indonesia, Sri Lanka, Thailand and India. During September 2005, the Category 4/5 hurricane Katrina struck the U.S. southeastern coast. The force of winds and water pressure breached protective levees causing devastating floods in much of the city of New Orleans. Winds ripped buildings apart in Louisiana, Mississippi and Alabama coastal regions. At least 1000 people died and more than 2 million people evacuated flooded and destroyed areas and found refuge in other cities. In October 2005, collapsing structures, landslides and rock falls during an earthquake killed more than 77,000 people mainly in the Pakistani governed part of Kashmir. A like number were severely injured. At least 3 million people were made homeless. Several tens of thousands were isolated in Himalayan villages accessible only by helicopter because earthquake triggered landslides obliterated the few roads leading to them. Disaster responders from various countries assisted Pakistani and Indian responders and had a hard time reaching the isolated villages. A lack of food, clean water, and shelter presaged many deaths from freezing, starvation and sickness. However, international aid did reach most of them and supply the necessities that carried many villages through the winter. At almost the same time, flooding and mudslides in Guatemala from continuous heavy rains killed almost 1000 people with entire villages buried beneath meters of mud that were declared mass graves by the government.

Because of knowledge gained from research and the technology developed from it, there are ways that can be used today to combat the dangers to people and property from physical hazards. For example, technological advances offer control and warning systems for floods and warning systems for tsunamis. Similarly, better construction materials and methods for structures (new or retrofitted) in earthquake prone areas minimize loss of life, injury, and loss of property where they are properly installed, used, and maintained.

Unfortunately, many less developed nations and their industries have not adopted proven technologies to minimize risk to people from natural or anthropogenic hazards. Their citizens continue to suffer from them. This may be from the lack of funds but may also be due to a political decision to use national treasures for other purposes. Countries have passed zoning laws and have building codes to protect citizens from hazards. However, some do not enforce them.

The plans communities have put into effect to safeguard people against the onslaught of natural hazards have to be continually reviewed and revised in light of population increases, demographics, and technological improvements. Governments have to install or update monitoring networks and warning methods. They have to provide for orderly evacuation protocols that include pre-provisioned centers to house people, and personnel to care for their medical, food, and water needs.

## *Planning for Future Population Changes*

The Earth's population will grow from the 2006 6.6 billion people by at least another $2\frac{1}{2}$ to 3 billion or more humans by the middle of the 21st century. Existing and expanded agglomerations, and new ones will be more densely populated than at present. The probability that primary and secondary physical events will hit population centers can be high or low depending on the geology of an area and climatologic shifts driven by global warming. Thus, population centers near active earthquake zones or volcanic activity (and the triggered secondary events) have to be critically evaluated before selecting sites for additional or new living and working locations. The same can be said for areas susceptible to flooding or mass movement. Land-use planning and the implementation of political policy (e.g., zoning, and strict, enforced building codes), economic methods (e.g., mortgage and insurance restrictions) and social means (e.g., education) to direct planning can protect against settling people and property in high risk hazardous locations. If citizens have to live and work in these locations, planners can use technological, engineering, and warning systems to alleviate the impacts of a hazard event and secondary events it can generate (Siegel, 1996).

## *Preparedness*

Today's scientists, engineers, architects, and risk analysts study detailed observations and measurements from hazards that occurred during ancient and modern times and those from contemporary events as they happen. Hazard evaluation teams use these data to determine where and why injury, death, damage, and destruction were severe, moderate, or light during and after an event occurred. Their analysis yields information that focuses on problems in preparedness that communities can address in order to mitigate the effects of future hazards. Some of this preparedness uses political assets such as control of the issuance of building permits and setting and enforcing zoning restrictions (avoidance of high risk areas). Some follows political/engineering tracks by revising building codes to require adherence to state-of-the-art engineering norms and the use of new materials where warranted. Economic controls cited previously such as the refusal of lenders to offer mortgages and insurers to issue policies can deter rebuilding and re-occupation in high-risk locations.

Where appropriate, civil authorities have to implement the use of hazard monitoring technologies coupled with real-time warning and evacuation strategies. This has been successful for tropical storms that can evolve into hurricanes (typhoons, monsoons), for flood-prone areas, and for volcanic eruptions. Tsunami monitoring buoys and real-time warning signals were active for the Pacific Ocean but lacking elsewhere. A tsunami monitoring and warning network was installed for the Indian Ocean during the latter half of 2006. This was a reaction to the December 2004 tsunami that killed and injured hundreds of thousands of citizens and devastated coastal populations in four countries.

As yet there are no reliable predictive methods for earthquakes. Scientific groups in government agencies and universities are investigating observations and measurements of various factors that have the potential to predict where, and perhaps in the future when (in days or weeks), and in what magnitude range earthquakes will occur. They are also investigating techniques that can reduce the force of natural physical hazards. For example, it may be possible to release stress that builds up in the earth along active faults by inducing low energy earthquakes. Geophysicists, geologists, and geological engineers have been experimenting with fluid injections into relatively shallow faults and with controlled explosions in shallow fault zones to achieve this. Their research extends to evaluating secondary hazards that can be triggered by any primary event and identifying the high-risk zones. This is the basis for insurance companies to assign costs for the purchase of protection against physical hazards.

## A Growing Societal Threat

For the great majority of scientists worldwide, the foremost anthropogenic threat to populations may be global warming, its effect on climate change, and the impact of the change on the water and food needs of the world's expanding population. The Intergovernmental Panel on Climate Change (IPCC) has studied this problem for several years. In the IPCC 2007 report, the panel of scientists presents projections on the short- and long-term effects of global warming geographically. Governmental and international experts in land-use planning, economics, epidemiology, sociology, and other fields will use the IPCC report as they assess future needs of local, regional, national, and global populations.

### *The Need to Cope with Global Warming/Climate Change*

Global warming is a physical change that originates in great part from chemical change to the atmosphere. It is the result of the build up of greenhouse gases from human activity (mainly carbon dioxide [$CO_2$]) that have been adding to the natural contents of the atmosphere. The $CO_2$ is emitted to the atmosphere through fossil fuel combustion (e.g., for electricity generation, for transportation, for heating). Before the revving up of the industrial revolution, the mass of $CO_2$ released from wood and coal burning and from respiration was balanced by the use of $CO_2$ in the photosynthesis reaction of vegetation to form chlorophyll and emit oxygen ($O_2$), and by the absorption of $CO_2$ in oceans and other water bodies where it is used by organisms to build their shells and skeletons. Since the industrial revolution, about 200 years ago, the amount of $CO_2$ in the atmosphere has increased whereas major tracts of forests and other vegetation that take up $CO_2$ have been reduced dramatically worldwide by timbering (e.g., Brazil, Borneo, Africa), land clearing for settlements, towns, and cities worldwide, agriculture (e.g., Brazil), and for the production of charcoal for stoves (e.g., Africa). Scientists have measured increasing contents of $CO_2$ in the atmosphere and correlated them with lesser heat transfer away from the earth that brings about global warming.

Warming trends parallel the $CO_2$ build up. The rate of warming quickened with increasing industrialization in developed nations in the decades after WWII. Warming has intensified during the past few decades. This has been related in grand part to rapid industrial growth in emerging economies in China, India, Brazil, and other countries.

A warming global environment is singularly important as a real and increasing danger to island nations and to coastal and near-shore inland regions in other countries. Melting of ice caps, glaciers, and icebergs calved from them releases water to ocean basins that supports sea level rise. Inundation of coastal areas, more coastal erosion, and intensified effects of tsunamis, result from higher sea level. Warming ocean water increases its volume and more warm ocean water over a larger area increases evaporation. Greater water loading into the atmosphere likely contributes in part to a higher number of damaging tropical storms and hurricanes (typhoons, monsoons). If the high energy, storms driven by high velocity winds reach land, storm surges will have a reach farther inland. Their precipitation can cause higher flood levels over extensive inland areas. Finally, cold glacial and ice cap melt water discharging into the North Atlantic Ocean over time can interfere with the weather-regulating warm Gulf Stream current flow. A displacement of the warm current to lower latitudes can cause marked climate changes for North America and Europe in the foreseeable future unless global warming slows and ultimately stops. The climate changes and shifting climates will affect agriculture, water availability, and species survival worldwide with some regions suffering their effects more than others.

In the book “An Inconvenient Truth”, Gore (2006) synthesizes observations and measurements made by scientists worldwide that make a strong scientifically based case for global warming. A movie based on the book popularized the global warming problem and raised public, private, and political awareness about it, nationally and internationally. Nonetheless, there are a small number of scientists who believe that the emission of greenhouse gases to the atmosphere is not the cause of global warming (e.g., Robinson, et al. 2007). Industry has been aware of the problem for some time and many of the multinational corporations that depend on the use of fossil fuels invested significant funding to support the work of scientists and groups with that belief. After the publication of the book, viewing of the movie worldwide, and public response to them, the Exxon-Mobil Corporation withdrew its long time funding for scientists and groups cited above and acceded to the concept that global warming and climate change were real threats to the way of life on Earth. Other energy companies can be expected to do the same. One think-tank group still interested in disclaiming the anthropogenic influence on global warming after the Gore (2006) publication and film, offered $10,000 to academics who published papers to that end in refereed journals. There will likely be few takers. In 2007, ConocoPhillips joined the U.S. Climate Action Partnership, a business-environmental leadership group dedicated to the quick enactment of strong national legislation to require significant reduction of greenhouse gas emissions. These actions coincide with those adopted by the European Union nations to reduce greenhouse gas emission to 20% below 1990 emissions by 2020 and to 50% by 2050.

Important to this text is that global warming affects the chemistries of surface/near-surface ecosystems and the well being of their inhabitants. Slowing and ultimately stopping global warming is now a highly prioritized need for protecting the Earth's expanding populations. This will be discussed in Chapter 8 on proactive planning to benefit expanding populations.

## Afterword

Population statistics predict that that 67 million people will be added to the 2006 United States population of 296.5 million people by 2030-2035, a generation away. This will come from natural population increase and immigration (legal and illegal/undocumented). Where will they locate? Can one million people each be added to cities such as Boston, New York, Philadelphia, Baltimore, Washington, D.C., Atlanta, New Orleans, Miami, Chicago, Detroit, Milwaukee, Minneapolis-St. Paul, Cleveland, Cincinnati, St. Louis, Kansas City, Houston, Dallas, San Antonio, Tulsa, Denver, Albuquerque, Salt Lake City, Phoenix, Las Vegas, San Diego, Los Angeles, San Francisco/Oakland, Portland, Seattle, Honolulu? If possible, this would accommodate 31 of the projected 67 million "spaces" needed. The other 36 million people can be be settled away from urban agglomerations in less populated areas determined to be capable of employing, housing, and providing them with basic services. But then, this is likely to create additional agglomerations in what are now relatively small and stable southern and western cities, for example in California, Texas, Alabama, Tennessee, Florida, Wyoming, and Montana.

How about the rest of the world in which 2 to 3 billion or more people will be added by 2050? Most of this increased population will be in already stressed ecosystems in developing countries (e.g., in Africa, Asia and the Middle East). Many nations in these regions exist now with strained social, economic and political systems. Planning for greatly expanded populations does not seem to be a "now" priority although "now" is less than 45 years in the future. This is a problem in search of solutions.

The chemistry of the atmosphere, the hydrosphere, and soils and rocks from which they originate will have a determining influence on the quality of life and the future for the earth's expanding populations. The next chapter deals with the atmosphere's natural chemistry and the effects of human-generated pollutants in the atmosphere on the living environment. It examines the past and present atmospheric chemical statuses and their impacts on populations in ecosystems. It considers how continued changes in atmospheric chemistry might affect the future for life on earth.

# Chapter 4
# The Surface/Near-Surface Atmosphere

## Part I

### Air Quality

We cannot avoid breathing the air around us. Living things avoid polluted water and shy away from tainted food. Humans may use bacterially dangerous water after boiling it, or after cleansing it of bacteria and/or potentially toxic metals chemically *in-situ* or at treatment plants. Similarly, contaminated food may be avoided in favor of "clean" foods, those cooked thoroughly to kill bacteria. Food may be treated chemically or with radioactivity during processing to make it safe to eat. However, all terrestrial creatures must breathe the atmosphere.

Nitrogen (∼78% $N_2$), oxygen (∼21% $O_2$) and minor amounts of argon (>0.9% Ar) and carbon dioxide (>0.03% $CO_2$) dominate the composition of the air we breathe. The air may carry higher than natural concentrations of gases (sulfur oxides [$SO_x$], carbon oxides [$CO_x$], and methane [$CH_4$]), volatilized metals, aerosols and particles such as soot (black carbon) and biological matter (dioxin, bacteria, viruses). If the air is continuously polluted in an area, such as downwind of a smelter or coal-burning power plant, ecosystem health is at risk from acid rain and bio-magnification of airborne pollutants (e.g., mercury) that can enter a food web and bio-accumulate at all trophic levels. Ingestion of airborne pollutants over time causes sickness (or death) in humans and other organisms. The same is true but restricted in reach when industrial or manufacturing operations pollute workplace atmospheres with releases of gases, aerosols, and particles. Similarly, the burning of fuel such as coal, wood, dung, or biomass briquettes for indoor cooking and heating in poorly ventilated dwellings contaminates the air. Over time, this can be responsible for bronchial illnesses.

There is no escaping bad air. Hundreds of millions of tons of pollutants emit to the global atmosphere annually. In some sectors the mass emitted is decreasing because of enforcement of environmental legislation that mandates emissions controls by the use of best available technology and real-time monitoring of chimney emissions. Figure 4.1 illustrates the decrease in European emissions of Cd, Pb, and Zn from the 1950s to the 1990s. This represents trends for many other emitted

F.R. Siegel, *Demands of Expanding Populations and Development Planning*,

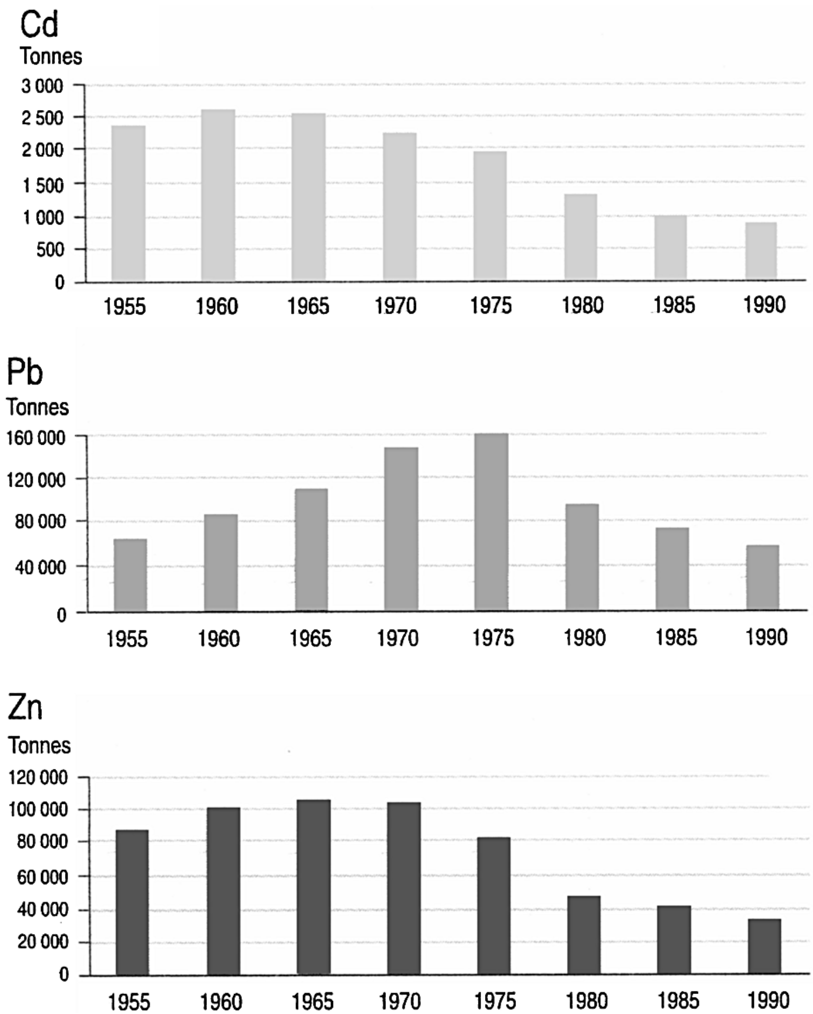


**Fig. 4.1** Changes in European atmospheric emissions of the heavy metals cadmium (Cd), lead (Pb) and zinc (Zn) from the 1950s to the 1990s (after Olendrzynski et al., 1995). Source: http://www.amap.no/assess/soaer7.htm

contaminants as well. However, in some global areas such as the Asian region, the trend is towards increased emissions of airborne pollutants. This is the result of one or a combination of factors: (1) the industrialization surge in Asia in the 1990s is continuing; (2) there are fewer regulations and/or controls on contaminant release to the atmosphere; or (3) there is a lack of enforcement of laws limiting pollutant emissions into the atmosphere. An exception to this in Asia is the decrease in atmospheric Pb because of the use of unleaded gasoline.

More nations with larger populations are greatly expanding their industrial bases (e.g., China, India, Brazil). Even with environmental protection laws nominally in place, their industries discharge larger masses volatile metals, gases and particles into the atmosphere because of lack of enforcement. In contrast, in many industrialized nations there has been a decrease or stabilization in emissions. Thus, the quantity and types of atmospheric contaminants added from activities of increasing populations and/or rapidly growing economies (e.g., in China and India) is canceling out and overriding any decreases achieved by developed nations. Much of this contamination (e.g., $SO_2$, Hg) is from the global combustion of greater amounts of coal and oil.

A polluted atmosphere can originate naturally. Pollutant input to the atmosphere from human activity may be inadvertent when it is unperceived by managers of an offending source. This is in contrast to the release of toxic contaminants to the atmosphere by rogue plant or factory managers who are aware of the health risks to life forms.

In the case of natural pollution, the effect on an atmosphere may be short-term and intense (e.g., from an explosive volcanic eruption). Conversely, anthropogenic input of pollutants to an atmosphere (e.g., $SO_2$, As, Cd, Hg, selenium [Se]) from fossil fuel combustion at smelters, electricity-generating plant or other industrial facilities creates long-term problems. Anthropogenic pollution of the atmosphere is an insidious process that harms all organisms living and feeding in areas surrounding the sources. A short-term anthropogenic event with long-term health effects for living populations was the explosion at the Chernobyl nuclear power plant. As noted in the last chapter, the explosion released vast quantities of radioactive gases and particles to the atmosphere. The immediate area of radioactive fallout killed people and other living things. The fallout in areas at farther downwind put large populations at risk of developing radiation sickness. It continues to be responsible for pain, suffering, and death, and has rendered large tracts of farmland in Ukraine and Belarus uninhabitable and unworkable.

## Meteorological Dispersion of Atmospheric Pollutants

### *Climatologic Factors*

Several climatologic factors influence the direction in which natural and anthropogenic gaseous, aerosol, and particle emissions to the atmosphere will be carried, the distances they are transported, and the size of particles that can be moved before being deposited by gravity and with precipitation. The obvious factors are the direction of prevailing winds, wind velocity, the duration of a wind event, topography, and precipitation. In addition, temperature, humidity, and barometric pressure change seasonally and affect the dispersion and deposition of emission components.

## *Dry Deposition - Particles*

Dry precipitates from gravitational settling of particles through the atmosphere after emission from volcanoes or from industrial chimneys can interact with the ecosystem in several ways. The particles are respired by humans and other life forms, sorbed onto vegetation (e.g., lichen), incorporated into soils, and deposited in water bodies. In addition, toxic components deposited from the atmosphere can access an ecosystem's food chain through their incorporation in water and soil. Over time they can cause health problems for organisms because of bioaccumulation that damages vital organs.

## *Wet Precipitation - Dissolved and Solid Loads*

Precipitation incorporates gases, volatile elements, aerosols, and particles released into the atmosphere naturally or through human activities. Gases such as $CO_2$ and $SO_2$ react with rainwater to give acid rain (e.g., $CO_2$ to $H_2CO_3$ [carbonic acid] and $SO_2$ to $H_2SO_4$ [sulfuric acid]). Additionally, gases and aerosols in the atmosphere may carry volatilized heavy metals (e.g., Hg, As, Pb). Precipitation deposits these, dissolved or as particles, on high latitude/high altitude snows and ice masses, on land, in rivers and lakes, in estuaries and oceans, and in juxtaposed wetlands.

The precipitation infiltrates soils, runs off into flowing waters, and seeps into aquifers. An acid rain input can damage soils. Acid water in runoff can disrupt ecosystems in ponds, lakes and rivers and displace or kill fish and other organisms that cannot tolerate strong acidity (pH). Figure 4.2 illustrates the effect of acidity of riverine waters on organisms. Fathead minnow, clams, and snails are least tolerant of weakly acidic waters (pH = 6) whereas brook trout, yellow perch, bullfrogs and the American toad are tolerant of stronger acidic water (pH = 5). In the example shown, the wood frog is most tolerant of the strongest acidic water (pH = 4.5).

As noted before, precipitation deposits heavy metals in soils and waters. The metals can be taken up from soils by vegetation and enter a food chain. In water, precipitated particles may dissolve or desorb and add heavy metals loading. Potentially toxic metals in precipitation and runoff intrude rivers, lakes, estuaries and oceans and can enter their food chains at lower trophic levels. In this way, metals can translocate to predators at higher trophic levels in water environments and to birds and land animals that feed on aqueous prey. For example, at the top of a food chain, humans can bio-accumulate Hg by consumption of certain large food fish that themselves have bio-accumulated the toxin. The Hg is a neurotoxin that can affect motor control as it builds up in consumers. At the top of the arctic food chain, polar bears bioaccumulate Hg from their main prey, the bearded seal. Research suggests that this may interfere with polar bear reproduction.

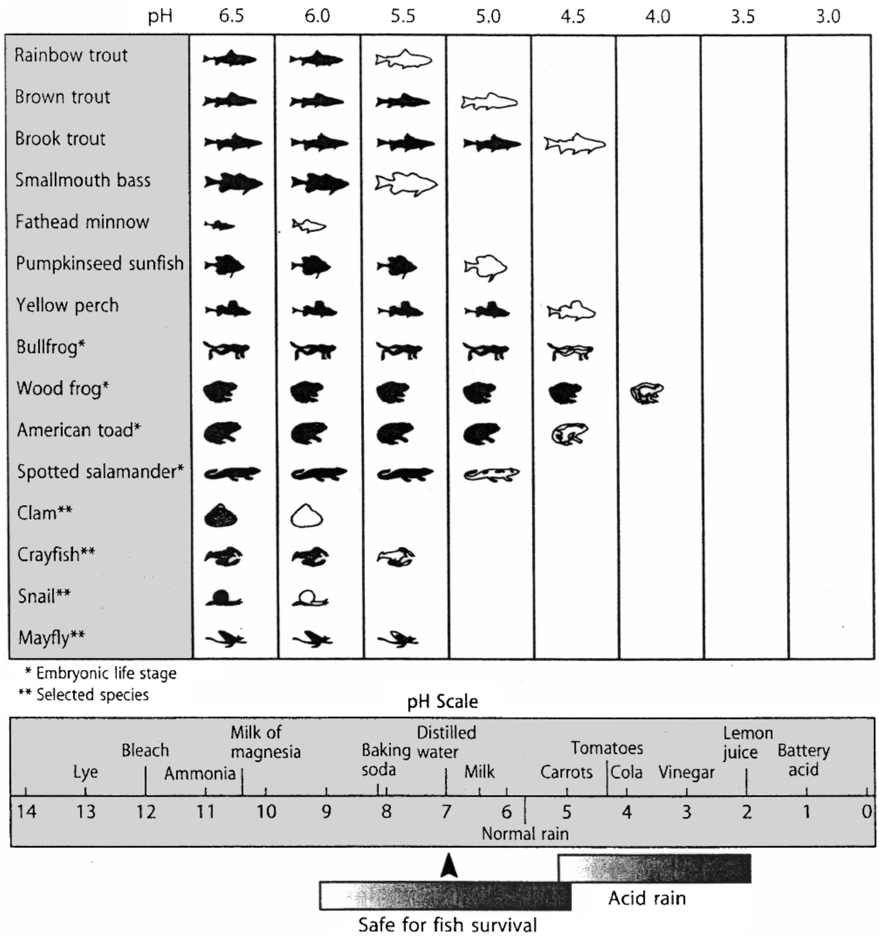


**Fig. 4.2** The result of pH changes of riverine water on the survivability of some organisms. The pH scale gives a comparison of the range of water pH considered safe for fish survival and the pH of acid rain. The approximate pH at which an organism will die with extended exposure is given in the organism pattern in white (after Christensen, 1991, from U.S. Department of the Interior, Fish and Wildlife Service)

## Natural Input to Atmospheric Composition

Evidence indicates that human-like species controlled fire date from about 1.5 million years ago in South Africa. A species like *Homo erectus* migrated from Africa to Europe and Asia and possibly mastered fire 790,000-690,000 years ago in northern Israel (Goren-Inbar et al., 2004). With the development of systematic and widespread smelting during the Bronze Age (3100 B.C.-700 B.C.) and Iron Age (700 B.C.-300 A.D.), the invasion of the Earth's atmosphere by anthropogenic emissions of pollutants started. With the industrial revolution and an increasing use

**Table 4.1** A comparison of estimated global anthropogenic emissions of selected potentially toxic metals in the mid-1990s (Pacyna and Pacyna, 2001) with emissions from natural sources (Nriagu, 1989) in $10^3$ metric tons/year. The parenthetical figures show the values estimated by Pacyna and Pacyna for the year 1983

| Global | As | Cd | Hg | Pb | Zn |
|---|---|---|---|---|---|
| Anthropogenic | 5.0<br>(20.7) | 3.0<br>(8.3) | 2.2<br>(3.9) | 119.3<br>(366.3) | 57.0<br>(145.2) |
| Natural | 12.0<br>(8.6) | 1.3<br>(1.1) | 2.5<br>(6.6) | 12.0<br>(20.9) | 45.0<br>(4.4) |

of coal, pollution from chimney emissions began a steady and unrelenting assault on the Earth's ecosystems and their inhabitants that continues today, more than two hundred years later. The realization that anthropogenic discharge into the atmosphere of some components exceeded natural emissions, damaged ecosystems they intruded, and harmed humans, forged a union between legal means and technology that would work to reduce anthropogenic emissions to acceptable levels.

The effect of such measures is illustrated in Table 4.1 that compares natural and anthropogenic global emissions of As, Cd, Hg, Pb and Zn to the atmosphere in 1983 with those in the mid-1990s. By the mid-1990s, the loading of emissions from human activities into the atmosphere had dropped from 1983 values for all the metals but Hg. The drop was likely due to the passage and enforcement of laws to lessen anthropogenic pollutant discharge and of the use of improved technology to capture pollutants in chimney updrafts. The higher Hg emissions for the middle 1990s was the result two factors: (1) a rush to industrialization in Asian emerging economies (e.g., China, see Table 4.4); and (2) an increased use of coal and the lack of installation or failure to use best available technology for Hg capture. The mass of Hg emitted to the atmosphere from natural sources is still greater than that from human activities. The following sections will examine sources of natural emissions of chemical elements and compounds that enter the Earth's atmosphere.

## *Volcanoes, Fumaroles, Thermal Vents, Hot Springs*

The earth's atmosphere originated largely from degassing from volcanoes. Gases discharged in short or extended pulses during explosive eruptions, and as continuous flow from quiescent volcanic activity, fumaroles, thermal vents, and hot springs. The emissions that contributed to a proto-earth atmosphere consisted of mixtures of $CH_4$, ammonia ($NH_3$), hydrogen ($H_2$), hydrogen sulfide ($H_2S$), hydrogen chloride (HCl), hydrogen fluoride (HF), $CO_2$, carbon monoxide (CO), and $SO_2$. In addition, they contained volatile heavy metals such as Hg, As, Se and antimony (Sb), and particles (volcanic ash) carrying an array of chemical elements. Sublimates of sulfur deposited around orifices where liquid and gases emanated at the surface contained many potentially toxic metals. The atmosphere evolved during geologic time and began to charge with oxygen when oxygenic photosynthesis bacteria, alga, and plants appeared some 2.7-3 billion years ago or about 1.8-1.5 billion years after the formation of the planet. The dominant gas emitted by volcanoes today is steam (∼98% $H_2O$). The mass of metals discharging annually into today's atmosphere from quiescent volcanic activity is known in terms of order of magnitude but the values given by different researchers vary. Hinkley et al. (1999) published a detailed record of metals released from the slowly degassing volcano Kilauea (Hawaii). These scientists combined the emissions record with data from other volcanic areas for sulfur normalization (e.g., the Indonesian arc and Mt. Etna) to estimate the global rate of discharge of metals to the atmosphere. The upper limit of the annual emitted mass reported by Hinkley et al. (1999) is about 10,000 tons of metals. The proportions of metals used by these authors differ from those used by Nriagu (1989) who calculated an annual emitted mass of 23,000 tons of metals.

The same sources and processes that formed the Earth's proto-atmosphere and subsequently modified it during geologic time are active today. However, much volcanic activity is non-cataclysmic and comparatively short-lived compared to those during the early evolution of the Earth's atmosphere. Over geologic time, a chemical equilibrium evolved between atmospheric components and the hydrosphere, biosphere and lithosphere. This is a "source-sink" balance. For example, in the case of $CO_2$, large pulsed volumes of gas in the atmosphere from volcanic eruptions or from major forest fires equilibrated with the environment in part through $CO_2$ respiration by vegetation (with the photosynthesis product $O_2$ released). Seas, oceans and other water bodies absorbed excess $CO_2$, which as noted earlier was used in part to grow animal carapaces. The added $CO_2$ reacted to form a more concentrated $H_2CO_3$ in rainwater that abetted the dissolution of rock matter. As industrial activities accelerated globally, they generated more $CO_2$ than could be absorbed by these sinks and processes, and $CO_2$ has built up in the atmosphere. This is considered to be a major cause of global warming (IPCC, 2007).

Volcanic ash deposited from the atmosphere can damage environments by causing fires, by burying farmlands and animal forage, and by releasing heavy metal contaminants to waters in which it settles. Respired ash will clog lung alveoli and asphyxiate living things. More than 30 people died from asphyxiation when they were caught in the Mount St. Helens massive eruption in 1986. History records similar deaths and destruction from volcanic ash by burial and asphyxiation through time such as at Pompeii in 79 A.D. In 1906, 30,000 people died when a pyroclastic flow in the form of a nueé ardente (a glowing cloud of hot ash) from the eruption of Mt. Peleé, rolled over the city of St. Vincent's on Martinique consuming all the atmospheric oxygen, asphyxiating, burning, and burying the city population.

Seemingly dormant volcanic systems can cause death by poisoning an at-surface atmosphere without erupting. Early one morning in 1986, a cloud of $CO_2$ gas erupted from the Lake Nyos crater in Cameroon. The $CO_2$ cloud rose over the rim of the crater lake and followed topographic lows rolling through villages to as far as 23 km away. The $CO_2$ is heavier than air and displaced it asphyxiating more than 1750 persons as they slept, and 8300 head of livestock. The gas, probably from subsurface quiescent volcanic activity and decay of organisms on the lake bottom (see following section), accumulated "capped" under increasing pressure, trapped in the stratified crater lake because there had been no water overturn. An overturn breaks the stratification seasonally and releases the gas. This prevents a dangerous gas accumulation. When a natural event such as seismic movement triggered a landslide at one side of the lake, the stratification cap was ruptured and the $CO_2$ that built up high concentrations under extreme pressure in the lake's bottom waters escaped.

## *Gases of Biological Origin - Fauna and Flora*

Gases from normal organism functions (faunal flatulent activity) add masses of $CH_4$ and $H_2S$ to the atmosphere. Decaying organic matter adds $CO_2$. Methane and $CO_2$ gases also enter the atmosphere from the reaction of animal urine with water (hydrolysis). Methane is 20 times more effective as a greenhouse gas than $CO_2$ and contributes to global warming. Likewise, insects contribute large quantities of gases to the atmosphere (e.g., termites emit $CH_4$). Flora releases volatiles such as terpenes and also life-sustaining $O_2$ to the atmosphere.

## *Emanations from Mineral Deposits/Soils/Rocks*

The analysis of soil gases or gases captured at the air-soil interface is used in prospecting for mineral deposits. For example, areas with high concentrations of $H_2S$ gas in surface/near-surface gases can indicate release by sulfide mineral ores (e.g., of Cu, Pb, Zn, Hg, Au) in the subsurface. Similarly, high contents of radon (Rn) and helium (He) gases can indicate radioactive minerals. Other gases (e.g., COS, $CO_2$, $CS_2$, $SO_2$) and volatile metals emanate from buried mineral deposits and contribute to natural atmospheric chemistry. In the search for oil and natural gas accumulations, "sniffers" (transportable real-time gas-detecting equipment) and soil air analyses can highlight exploration targets by anomalous high concentrations of $CH_4$, ethane ($C_2H_6$), propane ($C_3H_8$) and butane ($C_4H_{10}$) that escape from the hydrocarbon deposits rise to the surface and discharge into the atmosphere.

Natural loading of volatiles and gases in the atmosphere from mineral and hydrocarbon deposits has been an ongoing process through time. Although the process is continuous, it is not constant. It varies with environmental conditions such as barometric pressure, the air-surface temperature differential, season, wind conditions, humidity, precipitation, and cracks, fissures and faults in subsurface rocks.

## *Evasion from Sea Water*

Conditions at the air-water interface in oceans, seas and other water masses influence the evasion of volatile elements to the atmosphere or their dissolution in water.

Mercury is a volatile metal that moves from the air-water interface into the atmosphere whereas $CO_2$ gas moves from the atmosphere into the water. Volatiles and gases move in the direction that will drive the coupled environments towards chemical equilibrium in accordance with atmospheric pressure, air-water temperatures, and air-water chemical concentrations.

### *A Methane Threat*

Methane gas is released as small bubbles from deep seafloor seep blowouts from gas- and oil-producing zones, sometimes activated by minor volcanic activity. Most of the $CH_4$ dissolves in seawater during its ascent to the surface and has little effect on global warming. However, recent observations and videotaping by scientists from the University of California at Santa Barbara, revealed that large bursts of $CH_4$ gas bubbles rose as a cloud from a 60 foot deep continental shelf seabed (Leifer et al., 2006). There was little time for dissolution of the $CH_4$ in seawater. The gas originated from the decomposition of methane hydrate also known as clathrate hydrate that is buried beneath extensive areas of the continental shelf as ice-crystals. Leifer et al. (2006) estimated that the volume of the release was 5000 $ft^3$ or that of the bottom floor of a two-bedroom home. This had not been measured before.

Computer modeling suggests that blowouts of gas from deeper continental shelf seafloors could release massive amounts of $CH_4$ into the atmosphere. This possibility was supported by a blowout off Norway at a depth of 750 ft (upper continental slope) that released 89% of the trapped seabed methane. Because $CH_4$ is 20 times more efficient as a greenhouse gas than $CO_2$, this source of $CH_4$ is of great concern to scientists. They caution that global warming is increasing ocean water temperature, and that this could initiate seep blowouts from the continental shelf (to 660 foot depth) and beyond. Massive releases of $CH_4$ would further global warming and climate changes.

## Wind-Lifted, Wind-Driven, Wind-Deposited Particles

Strong winds blowing across terrain covered by loosely bound particles and little significant vegetation can move fine-size matter and lift it into the atmosphere. Soils on parched land and fine-size sands in deserts are very susceptible to wind erosion, transportation, and deposition. Winds can transport fine-size sediment hundreds to thousands of miles from their source areas. Inorganic and organic pollutants associated with wind-eroded materials (e.g., from mineralized areas, from farm fields, from open dumps, from piles of mine wastes or tailings) and moving as airborne particles can be respired by humans and cause sickness. During the 1989 Northridge earthquake in California, movement energy propelled bacterial/viral-bearing fine-size particles from farmlands into the atmosphere. People who inhaled the contaminated atmosphere suffered from bronchial problems.

## Anthropogenic Intrusions to Air Quality

Major sources of atmospheric anthropogenic pollutants include fossil fuel combustion to generate electricity (e.g., $SO_2$ and Hg from coal and As from oil) and for transportation (e.g., Pb and vanadium [V]). Pollutants are discharged into the atmosphere from smelters for Cu-Ni [nickel] production, from the smelting of other sulfide ores (e.g., $SO_2$, As, Cd, Ni and Sb), and from steel and iron manufacture (e.g., chromium [Cr], Mn and Zn). Table 4.2 gives examples of the contributions to global emissions of several heavy metals in the mid-1990s from the principal emissions sources. The table shows that coal combustion is the major source of Hg, whereas the main one for As, Cd, Cu and Zn is the non-ferrous metals industry. Table 4.3 gives the emissions by continent. During the mid-1990s Asia was the major global source of metal emissions (As $\approx$ 48%, Cd $\approx$ 49%, Cu $\approx$ 50%, Hg $\approx$ 50%, Ni $\approx$ 43%, Pb $\approx$ 43%, Zn $\approx$ 61%). In Asia, China is by far the principal emitter of metal pollutants to the atmosphere. The phasing out of Pb as an anti-knock agent in gasoline for internal combustion engines in most countries (first in 1974 in the United States) has greatly reduced the amount of Pb in the world's atmosphere (Fig. 4.1).

**Table 4.2** Worldwide emissions in tons/year of heavy metals to the atmosphere from major human activities in the mid-1990's (modified from Pacyna and Pacyna, 2001)

| Sources | As | Cd | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|
| Stationary fossil fuel combustion | 809 | 691 | 7081 | 1475 | 86110 | 11690 | 9417 |
| Vehicular traffic | | | | | | 88739 | |
| Non-ferrous metal production | 3457 | 2171 | 18071 | 164 | 8878 | 14815 | 40872 |
| Iron and steel production | 353 | 64 | 142 | 29 | 36 | 2926 | 2118 |
| Cement production | 268 | 17 | – | 133 | 134 | 268 | 2670 |
| Waste disposal | 124 | 40 | 621 | 109 | 129 | 821 | 1933 |
| Other | | | | 325* | | | |
| Total | 5011 | 2983 | 25915 | 2235 | 95287 | 119259 | 57010 |
| 1983 Emission** | 18820 | 7570 | 35370 | 3560 | 55650 | 332350 | 131880 |

* Emission of Hg from gold (Au) production
** From Nriagu and Pacyna, (1988)

**Table 4.3** Global emissions in tons/year of heavy metals to the atmosphere from major anthropogenic categories in the mid-1990's, by continent (modified from Pacyna and Pacyna, 2001)

| Metal | As | Cd | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|
| Europe | 607 | 362 | 2245 | 313 | 20417 | 28091 | 7689 |
| Africa | 324 | 172 | 2031 | 380 | 10690 | 11349 | 2353 |
| Asia | 2416 | 1463 | 12979 | 1121 | 41228 | 51212 | 34886 |
| North America | 658 | 482 | 2841 | 215 | 11236 | 17015 | 5859 |
| South America | 925 | 452 | 5453 | 84 | 11092 | 9118 | 5353 |
| Austrialia & Oceania | 81 | 52 | 366 | 113 | 624 | 2474 | 870 |

## *Combustion of Fossil Fuels*

Coal burning in power plants produces more than 46% of the electrical power in the United States and a higher percentage in many other countries. Emissions from coal-burning power plants introduce huge tonnages of various products into the atmosphere. These include $CO_2$ that is linked to global warming, $SO_2$ that is linked to acid rain, and an assemblage of heavy metals that are linked to human illnesses and declining ecosystem vitality. The metals are similar to those emitted from natural contaminant sources (e.g., Cu, Pb, Zn, Cd, As, Sb, bismuth [Bi], Hg, Se, molybdenum [Mo], Ag, iron [Fe] and others). These metals have an affinity for sulfur (S) and form minerals with the sulfide anion in a chemical reducing environment (one lacking oxygen or having electron donors). Coal forms under reducing conditions and incorporates these elements. As reiterated in reports by various groups (e.g., the WHO, the EEC, the Arctic Monitoring and Assessment Program), their release during combustion poisons the atmosphere. In addition to gases and volatilized metals, particle matter (soot or black carbon, organic compounds) also discharges into the atmosphere. As noted earlier in the text, respiration of particles and their bioaccumulation in lungs over time can cause bronchial problems and other illnesses.

With increases in global population, the use of coal to generate electricity will increase (Fig. 4.3). During 1937, the world used approximately 1800 million tons of coal. By the mid-1970s this had increased to about 2600 million tons year. The world population in the mid-1970s was about 3.8 billion people and was 6.1 billion in 2001. If the use of coal grew proportionately to the population during this period, the mass used should have been about 4200 million tons. Instead, coal use in 2001 was about 6000 million tons. This is the result of expanded industrialization in emerging economies and the need for greater power generation capacity to meet demands by a growing world population and the rush to industrialize. China, for example, plans to expand and build 199 coal-burning power plants in the next 10 years to service its rapid industrial and manufacturing growth. Emission controls (not known if they are best available technologies) are being installed in these new facilities, but as has been the case in some functioning facilities, managers may not be using them in order to maximize profits. The burden is then on government agents to assure their use and maintenance. When the world's population reaches a projected 9.2+ billion people (or more) in 2050, the combustion of coal is estimated to reach 7500 million tons, somewhat less than a proportional increase in population from 2001 to 2050. This latter relation reflects a slowing rate of global population increase during the last decade of the 20th century. A decreasing use of coal for combustion in the future will be stimulated in part by greater electricity generating capacity in many countries from newly built nuclear-fueled power plants. There is a real possibility that coal production will increase as the price of petroleum rises to levels that make it attractive for countries with abundant coal reserves to use coal to produce oil.

Petroleum crude contains sulfur (S) and heavy metals such as V, Ni and Cu that are natural components in the soft parts of creatures from which petroleum forms. The refining process that produces heating oil, gasoline, diesel fuel, jet fuel, and other petroleum products extracts these contaminants. Thus, oil burning in all

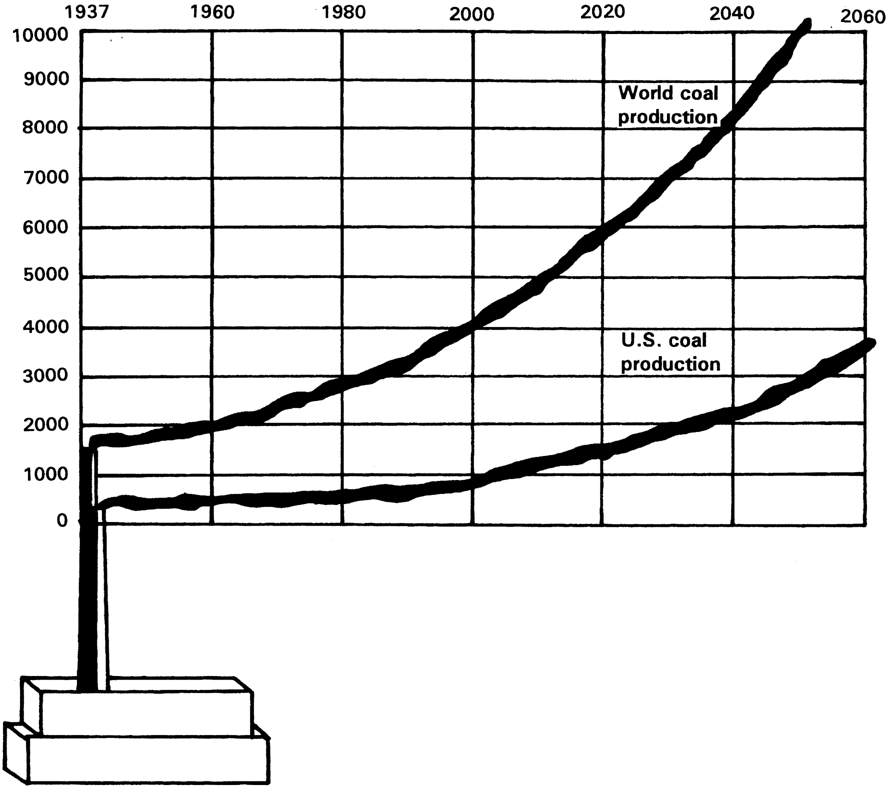


**Fig. 4.3** U.S. and world production of coal (in millions of metric tons) from 1937 to the present. Combustion is projected to increase at a faster rate in the future (after Gabbard, 1994). Source: http://www.ornl.gov/ORNLReview/rev26-34/text/colmain.html

sectors discharges massive quantities of $CO_2$ into the atmosphere but little of the heavy metal contaminants. Natural gas is the cleanest of hydrocarbon fossil fuels and yields mainly $CO_2$ to the atmosphere after combustion for power, and for functions in industrial plants.

In many large regions in Africa, Southeast Asia, and Latin America, people use wood, charcoal, dried dung, and dried vegetation or crop residue wastes for cooking and heating. This adds $CO_2$ to the atmosphere together with $SO_2$ and volatile heavy metals in the biomass. Biomass used raw or as briquettes for fuel indoors without good ventilation pollutes a domestic atmosphere and endangers the long-term health of a dwelling's inhabitants.

## *Smelters*

Smelting sulfide mineral ores releases millions of tons of $SO_2$ into the atmosphere annually. Together with this are hundreds of thousands of tons of potentially toxic metals such as As, Ni, Cu, Pb, Zn, Cd, Hg and others. Humans and other organisms living close to a smelter and downwind of it respire these pollutants and suffer chronic lung problems and other maladies.

In northwest China's Gansu province, almost every family from the villages of Xinsi and Moba in Hui County had high levels of Pb in their blood. Lead poisoning damages the nervous system and can cause convulsions and even death. It is especially threatening to children because bio-accumulated Pb can affect their mental and physical development. The Beijing Daily Messenger (2006) reported that 879 people had been affected but other sources put the figure in the thousands. The Pb poisoning was attributed to air pollution from a nearby smelter. China's push to rapid industrial expansion has knowingly or inadvertently compromised public health and aroused environmental awareness about the dangers of poorly controlled smelter emissions. The Pb smelting plant was closed down, but too late for the families suffering the Pb poisoning. This is but one of the many cases that could be cited of poisoning of humans by ingestion of metal pollutants emitted from smelters. The ingestion is via respiration, drinking and cooking with tainted waters, and eating contaminated foods grown or raised close to and downwind of smelters.

Norilsk, in Siberia, Russia, is an industrial city of 200,000 people which has an economy based on mining and smelting ores for Ni-Cu and platinum group elements. Until the beginning of the 21st century with the installation of modern equipment, the smelter complex spewed huge masses of pollutants into the atmosphere annually from equipment that was put into operation in 1934. The poisoned atmosphere caused a high incidence of respiratory and other illnesses in the Norilsk population. The pollutant load, deposited as particles or in precipitation, killed off lichen and other vegetation in what was an important reindeer grazing ground close to and downwind of Norilsk (Fig. 4.4). This subverted local economic development in the agricultural-animal husbandry sector. The area of maximum pollution extended about 70 km to the SSE of the smelter complex and is about 40 km wide. The severe pollution extended an additional 50 km to the SSE and adds 20 km to the width of the maximally affected area. Air quality in Norilsk is now greatly improved.

## *Mineral Extraction Other Than Smelting*

The extraction of fine size gold from fluvial placer deposits is based on the ability of Hg to separate the Au from stream or river sediment by amalgamation. In areas not covered by environmental regulations or where they are not enforced, refiners have recovered the Au by burning off the Hg. The volatilized Hg poisons the local atmosphere whether the burning is done outdoors or indoors. This method was used in the Brazilian Amazon and put workers who regularly inhaled the volatilized Hg at risk of future neural disorders.

Mining Hg ores (the mineral HgS, cinnabar; native Hg) underground in the past has caused nervous system problems for miners working in poorly ventilated shafts where a high concentration of volatile Hg was a natural component of a mine atmosphere. In the past, miners worked in such shafts without personal protection

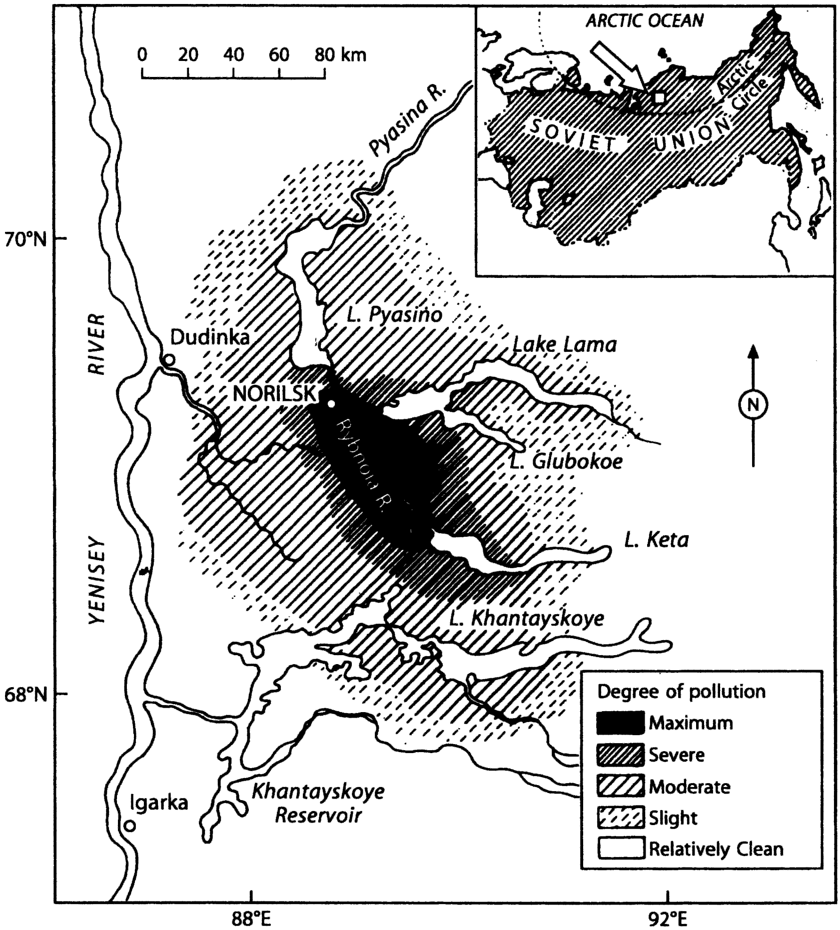


**Fig. 4.4** The meteorological influence (wind and other factors) on the dispersion of atmospheric pollutants emitted through chimneys from the Norilsk industrial complex smelters and their damaging effects on lichens and other vegetation after atmospheric deposition (after Klein and Vlasova, 1992)

ventilators. Depending on the mine, shaft atmospheres carry airborne particles of asbestos, silicon, coal dust, and radioactive matter. Inhalation of these particles by miners has caused black lung disease, silicosis, and lung cancer.

## *Industrial/Manufacturing Production*

Iron and steel fabrication releases large masses of gases, volatilized metals, aerosols, and particles into the atmosphere through factory chimneys. These emissions have high amounts of Cr, Mn and Zn (>75%). They also carry significant amounts of Se, Sb and Cd (>20%) and lesser amounts of Ni, V, As, and Pb. These suites of heavy metals are much the same as those from other sources of anthropogenic emissions (e.g., coal-burning, smelters). Ingestion of an individual metal or more than one can harm breathing organisms and the vitality of ecosystems affected by atmospheric deposition of pollutants into water and onto soil. The impact is mainly local. However, combined emissions from centers of iron and steel production, such as the Kola Peninsula, can affect regional air quality and the cleanliness of atmospheric-linked agricultural farmland.

The manufacture of many commodities can introduce harmful waste products into the atmosphere. These include biocides, computer components, electrical components, paints, pigments, plastics, rubber products, wood with preservative, and others. Toxic chemicals can be added to the wastes. High temperature incineration is a costly but effective way to destroy the toxic chemicals but it must be coupled with technology that captures the emission products for disposal at secure sites.

## Reduction of Regional Air Pollution

The annual emissions of potentially toxic metals (100s of thousands of metric tons) pales when compared with the 100s of millions of metric tons of $SO_x$, nitrogen oxides [$NO_x$] and $CO_2$ gases discharged into the atmosphere from all human activities. Smith et al. (2001) estimate that of the 1990 global emissions of these gases from combustion, 56% were from coal, 24% from oil, 15% from industrial processes, and 3% from biomass.

There was an encouraging change in a regional discharge of $SO_2$ emissions during the 15 years from 1980 to 1995. In 1980, 60% of the global emissions were from the North Atlantic basin region. By 1995, this region accounted for less than 40% of the global discharge of $SO_2$. Asia is the major contributor to atmospheric $SO_2$. China is the principal global producer with 25.5 million metric tons of $SO_2$ spewed into the atmosphere during 2005, mainly from coal-burning power plants and industrial and manufacturing factories. This is up 27% from 2000. The 1997 figures for $SO_2$ indicated that the rate of discharge for Asia had slowed. However, increased industrialization, the rush of construction of coal-burning power plants, and the 2005 data from China negate this trend.

If Asia is to reestablish a trend towards lower $SO_2$ emissions, three major tactics can be followed: (1) enforce existing laws or pass and enforce new laws for reductions in permissible mass for emissions; (2) use of low sulfur (higher quality) coal and oil products for combustion; and (3) reduce industrial coal use (Streets et al., 2000). The reduction can be achieved by increased use of renewable energy (e.g., hydroelectric, solar, geothermal, wind) and nuclear energy. This is unlikely to take place in the near future because of the combustion of increasing tonnages coal as new or expanded power plants in China come on line at a rate of one every two or three weeks. Nonetheless, a decrease in $SO_2$ discharge is achievable if two things are done in addition to the tactics given above. First, existing coal-fired installations (and sulfide ore smelters) can be retrofitted with state-of-the-art chemical pollution control equipment. This will be discussed in Chap. 9 (Remediation). Second, the capture technology built into new coal-fired operations must be used and maintained according to manufacturer's specifications.

## *Hg: Atmospheric Reduction - Success and Failure*

Anthropogenic sources account for $\approx$ 40% of the Hg emitted to the atmosphere in addition to high percentages of other heavy metals (e.g., $\approx$ 30% of As, $\approx$ 70% of Cd, $\approx$ 91% of Pb, and $\approx$ 97% of Zn [Table 4.2]). During 1995, more than 80% of the anthropogenic Hg was from coal combustion, cement production, and incineration of solid wastes. Lesser amounts were from smelters, iron-steel plants, chlor-alkali plants, chemical production and other industrial/manufacturing facilities (Pirrone et al., 2001; Pacyna and Pacyna, 2002).

European sources contributed about 13% (estimated at 342 metric tons) to global anthropogenic Hg emissions during 1995 (Pacyna et al., 2001). This represented a major decrease of 45% (about 280 metric tons) compared to the 1990 emissions. By 2000 the decrease reached 46%. Natural emissions in the region are 250-300 metric tons annually. Pacyna et al. (2001) caution that estimates of anthropogenic Hg emissions for Europe are considered to be 25-50% accurate. This likely reflects the accuracy of data worldwide. Adherence of industries to environmental regulations on Hg emissions in the United States resulted in a 40% reduction in Hg discharge into the atmosphere, mainly from coal-fired power plants. The major decreases of Hg emissions in Europe and the United States were the results of two factors. First, new regulations set protocols on useable coal composition. Second, this was coupled with the mandated installation of best available technology controls in industrial operations, especially for chlor-alkali production using the Hg-cell process.

**Table 4.4** The ten largest emitter countries for Hg in tons from stationary fossil fuel combustion (mainly coal) in 1995. (after Pacyna and Pacyna, 2001)

| | |
|---|---|
| China | 495 |
| India | 117 |
| Australia | 97 |
| Zaire | 90 |
| United States | 77 |
| South Africa | 76 |
| Russia | 54 |
| Japan | 45 |
| Korea (Rep. Dem.) | 44 |
| Kazakhstan | 36 |

During 1995, China was by far the largest emitter of Hg into the atmosphere, mainly from coal combustion (Table 4.4). The Hg released into the atmosphere from China has been increasing 5% or more annually (Science News, July 29, 2000) thus negating the decreases attained in Europe and the United States and the lesser input to water, soils, and ecosystem life. When properly installed, used, and maintained, the best available technologies for coal-burning facilities can capture $>75\%$ of Hg, plus other volatile toxic metals and particles from their emissions.

### *Summary of Industrial Anthropogenic Pollution Sources*

Table 4.5 highlights the potentially toxic metals that are generated as emissions and effluents by various industries. Their capture in chimneys or by effluent treatment systems benefits water bodies, soils, vegetation, and organisms.

## Industrial Accidents - Slugs with Short- and Long-Term Effects

### *Chemical*

Industrial accidents can poison local atmospheres temporarily and have immediate short-term life and death health impacts and long-term genetically influenced illnesses. They can halt development projects in specific sectors. In Bhopal, India, just after midnight on December 3, 1984, a toxic cloud of methyl isocyanate ($C_2H_3NO$) escaped from pesticide plant tank. The mass of gas drifted slowly in the night air over hundreds of dwellings. Inhabitants awoke, coughing, choking and rubbing painfully stinging eyes. They suffered acute inhalation exposure to this toxic gas that attacks respiratory tissues and then blocks air passageways. There were 3800 deaths. The toxicant disabled another 11,000 people (40 totally, 2680 partial permanent), and sickened several thousands of inhabitants in close by areas. The likely cause for most of the deaths was pulmonary edema but many were from secondary respiratory infections such as bronchitis and bronchial pneumonia. Women survivors suffered reproductive effects such as leukorrhea, pelvic inflammatory disease, excessive menstrual bleeding, and suppression of lactation. There were increases in the number of stillbirths and spontaneous abortions (Browning 1993).

Regulations were in place for the safe handling of methyl isocyanate but they were useless against sabotage. An angry employee trying to spoil 21 tons of methyl isocyanate stored in a tank added thousands of gallons of water to the tank. A chemical reaction created the deadly gas and a build up of heat and pressure that caused the tank to rupture and release the gas. This was a signal event that alerted development planners to include psychological evaluations of employees on a regular basis (each year, every other year) to protect industrial sites from a like disaster.

**Table 4.5** Pollutant priority listing of natural and anthropogenic sources of trace metals in wastes via emissions and effluents (modified from Sparks, 2005)

| | Ag | As | Be | Cd | Cr | Cu | Hg | Ni | Pb | Sb | Se | Tl | Zn | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mining and smelting | • | • | | • | | • | • | • | • | • | • | | • | |
| Mine drainage | | | | | | • | | | | • | | | | |
| Spoil heaps/tailings | • | | | | • | • | | | • | • | | | | |
| Pyrometallurgical industry | | • | | | • | • | | | | | | • | • | |
| Electrolysis industry | | | | | | | • | | | | | | | |
| Metal finishing | | | | • | • | • | | • | | | • | | • | |
| Metal scrapheaps | | | | • | | | | | | | | | • | |
| Fossil fuel combustion | | • | | • | | | • | • | • | • | • | | • | • |
| Refineries | | | | | • | | | | • | | | | | |
| Iron and steel industry | | | | | | | | • | • | | | | | |
| Paint/pigment industry | | • | | • | • | • | | • | • | • | • | | • | |
| Nuclear industry | | | • | • | | | | | | | | | | |
| Electronics industry | | | • | | | | | | | | | | | |
| Microelectonics | | | | • | | • | | • | • | | | • | • | |
| Plastic industry | | | | • | • | | • | • | | | | | • | |
| Pulp/paper industry | | | | | • | • | • | • | • | | | | | |

**Table 4.5** (continued)

| | Ag | As | Be | Cd | Cr | Cu | Hg | Ni | Pb | Sb | Se | Tl | Zn | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cement industry | | | | | | | | | | | | • | | |
| Photographic industry | • | | | | | | | | | | | | | |
| Textile and tanning | | • | | | • | • | | | | | | | • | |
| Landfills/refuse disposal | | • | | • | • | • | • | | • | | | | • | |
| Battery manufacture | | | | • | | | | • | • | | | | | |
| Plumbing | | | | | | | | | • | | | | | |
| Phosphate fertilizer | | | | • | | | | | | | | | | |
| Pesticides | | • | | | | • | | | • | | | | • | |
| Fungicides | | | | | • | | | | | | | | | |
| Wood preserving/treatment | | • | | | • | • | | | | | | | | |
| Sewage sludge | | | | • | | | | | • | | | | • | |
| Poultry manure | | • | | | | | | | | | | | | |
| Swine manure | | | | | | • | | | | | | | | |
| Irrigation waters | | | | | | | | | | • | | | | |
| Automobile exhaust | | | | | | | | | • | | | | | • |

Note: Most nations use unleaded gasoline and Pb-free paint.

## Nuclear

### *During Plant Operation*

The controlled uranium fission at nuclear power facilities is the cleanest source of electrical energy because the process does not generate $CO_2$, $SO_2$, heavy metals or particles for release into the atmosphere. The cleanliness of the process is not disputed. However, there are two major concerns. First is the possibility of an accident that releases deadly radioactive gases, liquids and solids to the atmosphere and their subsequent fallout over surrounding and distant areas. Second is the grave problem of disposal of radioactive wastes so that they will be isolated and contained for a minimum of 500 to a 1000 years.

In the extraordinary accident at the Chernobyl nuclear power facility in the Ukraine in 1986, prevailing winds carried clouds of radioactive gases and particles initially to the north and then to the west. Radioactive nuclides deposited over large areas of the former Soviet Union (now Ukraine and Belarus) poisoning people and their environments. Two towns and 184 villages with populations totaling more than 180,000 people were evacuated from about 4300 $km^2$, but only 36 hours after the explosion and ejection of radioactive matter into the atmosphere. Because of this delay and a lack of emergency management and evacuation planning, inhabitants of the radioactivity fallout area suffered harmful dosages of radiation through respiration and from body exposure. Vast tracts of productive farmland were abandoned and there was no hope for agricultural use in the short-term because of high levels of soil radioactivity.

According to the Ukrainian ambassador, about 70% of the radioactive fallout was in Belarus where more than 14,000 $km^2$ were highly contaminated. Ten years after the explosion, babies were born in Belarus without arms, without eyes, and with only stumps for legs, probably as the result of radiation-induced genetic mutations. In Gomel, Belarus, about 115 km north of Chernobyl, the rate of thyroid cancer in children under 15 years old was more than 200 times higher in 1991-1994, the second 4 year period after the blast than in pre-blast times. This is a frightening increase from the 21 times higher the pre-blast rate in the first four years (1986-1990) following the initial exposure to airborne and atmospheric deposited iodine-131 ($I^{131}$). This attests to the long-term health risk to populations well after an exposure to high-level radioactivity. The cancer rate is high in children because their thyroid glands are small so that a dose of $I^{131}$ is more harmful for a child than for an adult.

Radiation-laden clouds were driven by prevailing winds over Scandinavia (mainly Sweden and Norway), and northern Europe (especially Poland). In some zones, atmospheric deposition lightly contaminated extensive areas of productive farmland. Levels of strontium-90 ($Sr^{90}$) were so high in some food products (e.g., milk and milk derivatives) that they could not be used. The $Sr^{90}$ translocated from the atmosphere to water, soil, and forage, and then to dairy cows.

"Lesser" accidents have occurred at other nations nuclear power facilities but have been contained. In some cases, exposure to and respiration of escaped radiation inside nuclear facilities caused radiation sickness and death of personnel.

### *During Radioactive Waste Storage*

There have been nuclear reactions and subsequent explosions and emissions of radioactive matter to the atmosphere at radioactive wastes storage sites in Russia. These contaminated the atmosphere with radioactive gases and particles, killed technical staff and support workers, and caused others to fall to radiation sickness. Agricultural fields have been quarantined where wet and dry precipitation deposited radioactive pollutants.

It is difficult to locate geologically suitable sites for the safe disposal of highly radioactive wastes. Most of these wastes are being stored on site at nuclear power plants. About 90% of radioactive wastes are from nuclear weapons manufacture and are stored mainly on site.

Some storage schemes for radioactive wastes can poison sensitive environments. Multiple naval (nuclear) reactors, many with unspent nuclear fuel, are "stored" in decommissioned submarines tied up in the port of Murmansk, Russia. The submarines are rusting at docks because of corrosion by seawater. Some may be leaking radioactivity into arctic waters and possibly into the atmosphere. Northern European populations are at direct risk from this "storage".

During earlier decades, the former Soviet Union "disposed" of naval reactors (16), some still loaded with nuclear fuel, by scuttling submarine sections containing them in deep troughs in the Arctic Kara Sea. However, these reactors were reportedly encased in furfurol, a resin that is supposed to protect them from corrosion by seawater for 500 years. Some of the radioactive elements in the reactors have long half-lives and will be dangerous to the ecosystem for more than 500 years. If radioactive gases escape from the reactors and are not adsorbed by seafloor sediment, they will rise through the water column and evade into the atmosphere.

## Indoor Air Pollution

Indoor air pollution affects millions of people in their homes worldwide, in office building where they work, and at industrial and manufacturing workplaces. Gases, aerosols, and particles in indoor air come from different sources. They may be from construction materials vapors (insulation, paints, solvents [VOCs]) and from accessories (carpets and other floor coverings) brought into a structure. They may come from cooking and heating in a poorly ventilated dwelling such as happens in less developed countries. Table 4.6 lists some common indoor air pollutants in homes and office buildings, their probable sources, and health problems that can arise from regularly inhaling them (Niu and Burnett, 2001). Niu and Burnett (2001) proposed

**Table 4.6** Indoor air pollutants, sources, health effects (modified from Niu and Burnett (2001)

| Pollutant | Source(s) | Health Effects |
|---|---|---|
| Radon (Rn) | Seepage into structure from underlying soil or rock<br>Emitted from earth-derived building materials such as concrete and brick | Lung cancer – pronounced for smokers |
| Carbon monoxide | Incomplete combustion of coal or biomass in simple stoves | Dizziness, weakness, death |
| Heavy metals (e.g., Hg, As, Cd) and particulates | Combustion of coal or biomass in simple stoves | Loss of motor control, cancer, kidney problems, others |
| Asbestos fibers | Fire-proofing materials | Lung disease: asbestosis, cancer |
| Formaldehyde | Particle-board and plywood | Membrane irritation, suspected carcinogen |
| VOCs* | Adhesives, sealants, and architectural coatings, paintings<br>Carpet, resilient flooring, and wall covering | Species-dependent, likely causes of SBS** |
| VOCs* and particulates | Insulation, acoustical ceiling tile, furniture | |

*Variety of volatile organic compounds
**Sick building syndrome

emission standards that should be met, and methods to combat and limit domestic and workplace air pollution.

The main causes of indoor air pollution are ventilation systems that are unable to adequately remove pollutants from the air. Over time, respiration of hazardous substances or contact with them in an indoor atmosphere can cause health problems. Some people are more sensitized and suffer allergic reactions when exposed to specific air pollutants while others living or working in the same environment are not affected. The sources of indoor bad air problems have to be greatly reduced or eliminated to protect people's health and thus sustain productivity at indoor facilities.

## *In-Home Atmospheres*

Domestic air pollution increases the risks of pulmonary disease and respiratory infections, the principal causes of death of children less than five years of age (Bruce et al., 2000). Bruce (2000) reports that bad in home air may also be responsible for low birth weight, increased infant and perinatal mortality, pulmonary tuberculosis, mouth and throat cancers, cataract growth, and lung cancer.

## *Carbon Monoxide and Volatile Heavy Metals*

Burning coal, charcoal, wood, dried dung, and crop residues for cooking or heating in inefficient stoves and with poor venting of emissions is common for about half the world's population. The indoor air can accumulate carbon monoxide (CO), an odorless and colorless gas, and heavy metals. Inhalation of CO sickens and can kill humans and other organisms that are unknowingly engulfed by it. Bad domestic air is especially dangerous to women, young children, and the aged who are exposed to high levels of air pollution daily (Bruce et al., 2000).

Combustion of biomass can also release volatile heavy metals into a home atmosphere. Long-term inhalation of these metals or pollutant-bearing particles can result in a bioaccumulation in organs (e.g., brain, liver, kidneys, lungs). This can interfere with their functions and cause illness or organ shut down and death.

## *Radon*

Radon (Rn) is a gaseous radioactive decay product of uranium minerals. It is odorless, colorless and tasteless. As Rn continually leaks into an outdoor atmosphere, it disperses rapidly and poses no health concern. However, Rn can be a cause of lung cancer if high concentrations are inhaled over an extended period of time. Radon has been linked to the high incidence of lung cancer in miners who worked underground extracting uranium ores during the 1930s to 1950s. It has likewise been linked to lung cancer in occupants of well-defined pockets of housing. If a home is underlain by soil and/or rock that contain wee amounts of uranium minerals, Rn will insidiously seep into the home through imperceptible cracks in the foundation. In homes that have been tightly insulated to improve energy efficiency, this carcinogenic gas accumulates, mainly in basements and ground floor rooms, and becomes a danger to its occupants. Epidemiologists linked the high incidence of cancer in some neighborhoods in the United States to the fact that high Rn levels were measured at locations where homes were built tightly insulated after the 1973/1974 OPEC oil embargo, on soils and rocks containing small amounts of uranium minerals. There is lesser chance of Rn accumulation in older homes because they were not built tight and allow for a slow but steady exchange of inside air with outside air.

Testing can identify areas underlain by soils and/or rocks that emit higher than permissible concentrations of Rn. Avoidance of these areas for home sites can eliminate a community's future health problems. If this is not feasible, proper venting can resolve the Rn build up problem. Chapter 7 discusses municipal responses to this problem.

### *Workplace Bad Air Problems*

Hazardous substances are found in all workplaces. They include those used directly in work activities (e.g., cleaning agents, paints, glues), and substances generated during work activities (e.g., fumes from soldering and welding). Additionally, hazardous substances in building materials (e.g., formaldehyde from particle board, VOCs from carpeting) and natural substances (e.g., bacteria, blood, grain dust) release into workplace atmospheres. Table 4.7 shows the relationship between hazardous substances in workplace air and diseases their inhalation can cause. Table 4.8 gives the maximum permissible concentrations for selected indoor workplace air pollutants.

## Part II

## Assessing Atmospheric Chemistry Problems and Solutions

Two global atmospheric problems plus those of transnational, regional, and local reaches are the result of changes in atmospheric chemistry. These are targets for corrective actions to mitigate physical and health threats to the Earth's populations. One global problem that is being resolved is the degradation of the Earth's ozone layer. Global warming/climate change is a problem that is not being solved but in fact is worsening. A transnational-regional problem is acid rain. Locally, there are

**Table 4.7** Examples of health effects in the workplace from long-term respiration of a polluted atmosphere, from absorbtion of atmospheric pollutants through skin, and damage to skin from pollutant contact if there is poor ventilation of volatile and fumes and capture and exhaust of particles (adapted from text in Watterson, 1998)

| Pollutant | Health issues | Workplace for exposure |
|---|---|---|
| As | Human carcinogen (lung, skin) | Pesticides |
| | Cirrhosis, angiosarcoma, heptocellular carcinoma | Pesticides, wood, vinters, smelters |
| | Fetotoxic, teratogen, transplacental carcinogen | Agriculture, wood preserving |
| | Peripheral neuropathy | Metal production, pesticides |
| | Skin cancer (via absorption) | Agriculture, lead workers, dyers, copper smelters, brass makers, chemicals, textiles, painters, pesticide users |
| | Myocardial injury | |
| | Aplastic anaemia | Glass, paints, enamels, pesticides, tanning agents |
| Be | Granulomatous disease | Ceramics |
| Cd | Nephrotoxicity | Welding, engineering |
| | Spontaneous abortions, impaired implantation, teratogen | Engineering, chemicals, batteries, paints, smelting, mining |
| | Hypertension | |
| Cr | Lung cancer | Metals, welders |
| | Teratogen | Chemicals, engineering |
| | Allergic contact dermititus | Metals and engineering workers |
| | Percutaneous absorption | Engineering and chemcials |
| Hg | Nephrotoxicity | Chemical, paints |
| | Fetotoxic, teratorgen, menstrual disorders | Chemical, pesticides |
| | Tremor, weakness, ataxia from chronic exposure, mental impairment | Chemicals, pharmaceuticals, dentistry, plastics, paper |

**Table 4.7** (continued)

| Pollutant | Health issues | Workplace for exposure |
|---|---|---|
| | Cranial nerve palsies | Chemicals |
| Mn | Decreased fertility, impaired implantation | Various |
| | Encephalopathy, ataxia, Parkinson disease-like symptoms, acute psychosis | Engineering, aircraft industry, steel, aluminum, magnesium and cast iron productions |
| Ni | Lung, nose cancer | Metals, smelters, engineering |
| | Headache | Engineering |
| | Hypersensitivity | Metals engineering |
| | Allergic contact dermititus | Metals, engineering |
| Pb | Nephrotoxicity | Chemicals, paint, batteries |
| | Decreased fertility, fetotoxic impaired implantation, teratogen, sperm damage, hormonal alterations | Various |
| | Spontaneous abortions | Triethyl lead |
| | Encephalopathy and peripheral neuropathy | General |
| | Optical neuropathy | Foundry industry |
| | Myocardial injury, hypertension | |
| | Red blood cells, porphyria | General |

**Table 4.8** USEPA National Ambient Air Quality Standards given as an averaging period of concentrations exposures per unit of time

| Pollutant | Averaging period | Primary standard | Standard |
|---|---|---|---|
| Ozone | 1 hr | 125 ppb | Not at or above 125 ppb more than 3 days over 3 years |
| | 8 hrs | 85 ppb | The 4th highest daily 8 hrs maximum over 3 year period not to be at or above 85 ppb |
| Carbon Monoxide | 1 hr | 35.5 ppm | Can be at or above 35.5 ppm only once per calendar year |
| | 8 hrs | 9.5 ppm | Same as above |
| Sulfur Dioxide | 3 hrs | 550 ppb | Can be at or above this level only once per calendar year |
| | 24 hrs | 145 ppb | Same as above |
| | Annual | 25 ppb | Not to be above 35 ppb |
| Nitrogen Dioxide | Annual | 54 ppb | Not to be at or above 54 ppb |
| Lead | Quarter | 1.55 $\mu g/m^3$ | Not to be at or above 1.55 $\mu g/m^3$ |
| Respirable | 24 hrs | 66 $\mu g/m^3$ | Not at or above 66 $\mu g/m^3$ as Particulates a 3 yr average of the annual 98th percentile for monitor within a populated area |
| 2.5 $\mu m$ or less | Annual | 15.1 $\mu g/m^3$ | 3 yr average level of annual arithmetic mean for one or more monitors in community areas not to be at or exceed 15.1 $\mu g/m^3$ |
| Respirable Particulates 10 $\mu m$ or less | 24 hrs | 155 $\mu g/m^3$ | Not at or above 155 $\mu g/m^3$ for a 3 yr average of the annual 99th percentile for monitor in a populated area |
| | Annual | 51 $\mu g/m^3$ | 3 yr average level of annual arithmetic mean for one or more monitors in community areas not to be at or exceed 51 $\mu g/m^3$ |
| Sulfates* | 24 hrs | 25 $\mu g/m^3$ | |
| Hydrogen* Sulfide | 1 hr | 0.03 ppm 42 $\mu g/m^3$ | |

* California Standards - No Federal Standards

heavy metals and fine-size particles in emissions to the atmosphere that are inhaled and cause chronic illnesses and death. Smog as a localized toxicant can do the same.

## *Global Atmospheric Problems*

### Ozone Layer: Holes and Thinning

The Earth's ozone layer is at altitudes ranging from about 15 to 35 km. It protects life from harmful solar radiation by absorbing dangerous wavelengths of ultraviolet (UV) radiation. UV-C that would be very harmful to humans is entirely filtered out by ozone at the 35 km altitude. UV-B is the main cause of sunburn and is responsible for a genetic change that can cause skin cancer. The ozone layer filters it out effectively but some does reach the surface. Most UV-A reaches the surface but is less dangerous to humans. Holes in the ozone layer and thinning of the layer allows passage of dangerous UV wavelengths which medical experts believe are responsible for a high incidence of skin cancer in the southern hemisphere, especially in Australia.

Research proved that the ozone layer is depleted by interaction of man-made chorofluorocarbons (CFCs) and to some degree by bromofluorocarbons (BFCs), and by naturally occurring nitric oxide, hydroxyl, chlorine and bromine radicals in the atmosphere. The CFCs were used as propellants in spray cans and in fire extinguishers, and as refrigerants in air conditioners for automobiles, for homes and workplaces, and in refrigerators. Collaborative global restrictions on the production and use of CFCs have lessened ozone depletion and are discussed in a later chapter. Investigations indicate that a slow healing of the ozone-depleted layer encircling the Earth has started.

## *Global Warming/Climate Change*

Mitigation of the global warming threat is possible. If achieved, it will ease future natural hazards problems associated with sea level rise and more moisture in the atmosphere. The hazards driven by global warming were identified in an earlier chapter and include inundation of land, higher storm surges with greater sea water reach inland, and more severe flooding from intense, excessive rainfall inland. Reining in the rate of global warming will moderate these effects and those brought on by climatic shifts such as changes in lengths of growing seasons in farming zones.

A slow down in the rate of global warming and ultimately the stabilization of the warming trend requires first that there be a major decrease in the anthropogenic input of $CO_2$ into the atmosphere sooner rather than later. As reiterated in this chapter, $CO_2$ is mainly from fossil fuel combustion for power generation, from vehicular transport, and from other industrial and manufacturing processes. Emissions of other greenhouse gases from human activities (e.g., $CH_4$, $N_2O$, and CO) plus total suspended solids should be reduced as well. Secondly, to help decelerate the increase of $CO_2$ in the atmosphere and slow global warming, forests must be restored and their area coverage extended to increase vegetation sinks that will absorb $CO_2$ from the air for photosynthesis. Meijer (2001) believes that sink enhancement for $CO_2$ such as afforestation is at best a temporary solution. He emphasizes that source/sink characterization in good detail can give focus to long-term solutions to retard the increase in atmospheric $CO_2$. This starts with less use of hydrocarbon fuels, capture of $CO_2$ where it is generated, and disposal where it will not issue back into the atmosphere.

Carbon dioxide sinks have been and continue to be sacrificed for perceived human needs and for economic benefits. Extensive areas of forests have been cut down for timber. They have been cleared for farming "money crops" (e.g., soybeans in Brazil) and for raising livestock in areas of the Amazon (especially in Brazil) and Southeast Asia. Clearing is often done by burning which in some areas accounts for about 30% of $CO_2$ added annually to the atmosphere. This human activity both destroys important sinks for $CO_2$ and adds significant amounts of $CO_2$ to the atmosphere until a burn is completed. Cutting old forests for valuable wood such as teak and mahogany for export continues. Clearing forests for farming and livestock ventures continues. In 2007, the World Bank proposed to pay governments to preserve forested areas for the $CO_2$ sinks they provide.

A political solution aimed at reducing the input of $CO_2$ to the atmosphere was initiated with the 2004 ratification of the Kyoto Protocol Treaty by all but a few nations. The protocol sets as goals that signatory nations bring their $CO_2$ emissions to 1990 levels. Unhappily, of the EU and other industrial signatory nations, only the United Kingdom and Germany may near this goal by 2012. In light of this, the 27 nations that now comprise the European Union resolved in January 2007, to cut $CO_2$ emission by 20% of the 1990 levels by 2020. In a more ambitious proposal, the G-8 nations set a goal in 2007 to cut $CO_2$ emissions by 50% of 1990 levels by 2050.

The United States, the principal global emitter of $CO_2$, is a non-signatory to the treaty. The reasons for this are political and economic. China, India, Brazil and other countries designated as developing nations have no $CO_2$ emission limits under the treaty. However, because of rapid economic growth and industrialization, China is now second to the United States in $CO_2$ emissions with other developed and developing countries far behind (Table 4.9). The International Energy Agency predicts that China's $CO_2$ emissions will pass the United States by 2010 if not sooner. The United States and other industrial nations are working to rein in $CO_2$ emissions using their own regulations. These include requiring higher per gallon mileage on automobile fleets, tax advantages for buyers of gas-electric hybrid vehicles, providing stimulus packages for development and use of renewable energy sources where geographically possible, economically viable and efficient. With respect to the higher per gallon mileage, it is interesting to note that the United States has legislation pending a vote that sets a standard of 35 miles per gallon by 2020 for passenger vehicles. This effort pales somewhat when fuel efficiency standards for France, Germany, Italy and the United Kingdom have been set at 48.9 miles per gallon by 2012, and for Japan the figure is 46.9 miles per gallon by 2015. The populations in the EU nations cited above have been driving smaller, lighter cars with high mileage performance so that they are more easily able to set improved mileage standards. This is due in part to high gasoline prices, a high degree of urbanization that presents parking problems, and an excellent rail and bus system for intercity and international travel.

An example of what a change to gas-hybrid vehicles can do to benefit the environment is found in a comparison of the annual emission of $CO_2$ from a vehicle with an internal combustion engine and the same vehicle as a gas-electric hybrid unit.

**Table 4.9** Countries with power-generating sectors that create the highest emissions of $CO_2$ (after CARMA/Center for Global Development, 2007) compared with total $CO_2$ emissions from fossil fuel combustion (after UN Environmental Indicators Update 2007). Values are in millions of tonnes. Data from 2004. Source: http://www.unstats.un.org/unsd/environment/air_co2_emissions.htm

| Country | Power generating sector $CO_2$ mass | Total fossil fuel combustion $CO_2$ mass |
|---|---|---|
| United States | 2,790 | 5,987 |
| China | 2,680 | 5,010 |
| Russia | 661 | 1,617 |
| India | 583 | 1,342 |
| Japan | 400 | 1,285 |
| Germany | 356 | 885 |
| South Africa | 222 | 437 |
| Britain | 212 | 562 |
| South Korea | 186 | 465 |

The USEPA reported that a 2007 Honda Civic driven 12000 miles during a year emits 8177 pounds of $CO_2$. The same vehicle as a gas-electric hybrid emits 5451 pounds of $CO_2$, or 33% less. There are 232 million passenger cars in the United States and they emit 332 million tons of $CO_2$ annually that represents 20% of U.S. emissions. More gas-electric hybrids on the road can contribute to the reduction of the U.S. $CO_2$ emissions footprint. The percent savings in $CO_2$ emissions is greater if a driver of a non-hybrid takes public transportation. In this case if a person drives to work 5000 miles annually, the vehicle output of $CO_2$ would be 5000 pounds annually. If the person uses public transportation (bus or rail) his/her contribution to $CO_2$ emissions would be 2850 pounds annually or a saving of 43%.

It is noteworthy that California, USA, with the sixth largest economy in the world, and several other states mandated the reduction of $CO_2$ emissions from energy-generating, industrial/manufacturing, and transportation sources. This was done in spite of the lack of enforcement of USEPA to that end because of administration political consideration. Federal government courts have ruled that the USEPA must enforce standing legislation on $CO_2$ emissions throughout the country.

Unless national attitudes change worldwide, cutbacks in $CO_2$ in developed nations will soon be balanced and surpassed by unrestricted emissions from China, India, and other surging economies in developing nations. Global warming will continue its damaging effects on ecosystems and human activities related to climate.

To confront the continuing problem of global warming, the United Nations convened a forum in December 2007 of all signatories to the failed Kyoto Treaty. The outcome of the forum was an agreement of industrialized nations to negotiate a proposal to reduce their greenhouse gas emissions (principally $CO_2$) beginning in 2012. It is to be finalized in 2009. The rapidly developing nations (e.g., China, Brazil) agreed to commit to do the same if the developed nations pledged to provide them with technological expertise to that end, and also to aid the poorer developed nations economically to cope with changes brought on by global warming. The industrialized, rapidly developing, and developing nations have good intentions to meet goals set by the UN plan. The success of the plan is in the social, economic, and political interests of all nations. It remains to be seen whether the international negotiators can reach an agreement by the end of 2009 target date and then follow the norms of the pact with the positive actions that would allow each signatory nation to achieve its reduced emission quotas. For the most part, the Kyoto Treaty did not bring about a reduction of emissions. However, the real present and future dangers posed to all societies by global warming and climate change suggest that there will be a focused and serious effort to meet the negotiated greenhouse gases emissions reduction goals.

## *In-Line Capture of $CO_2$: An Overlooked Opportunity?*

The thrust of solutions to the reduction of anthropogenic $CO_2$ emitted to the atmosphere is to reduce the use of fossil fuels as a combustion energy source mainly in power plants, in the transportation sector, and in industrial/manufacturing facilities. However, the reality of being able to capture $CO_2$ with in line technology at many of these sources is being passed over, perhaps because of the cost of retrofitting systems to do so. The cost of not doing so, in combination with increased burning of fossil fuels, will be greater in the long-term.

A meaningful drop in $CO_2$ emissions is achievable using existing technology. Carbon dioxide gas has been captured from large point sources for almost 100 years. It has been injected underground as one of the petroleum industry's secondary oil recovery methods for more than 30 years. This same technology for an industrial inline capture of $CO_2$ can be used at most major sources before $CO_2$ emits to the atmosphere.

The captured $CO_2$ can then be contained and isolated through engineering and chemical, physical, and biological interventions (Friedmann, 2007). To be successful, this requires a thorough understanding of the geological characteristics of rocks in the deep subsurface that can retain and immobilize $CO_2$. The $CO_2$ can be injected into porous, permeable rock formations overlain and underlain by impermeable rocks. These geological environments are found in depleted oil and gas fields, deep coal seams, or brine-bearing formations at depth of $>800$ meters. The pressure at this depth will liquidize $CO_2$ gas. A large volume of $CO_2$ gas once in a liquid state, can be injected into a limited pore volume space. Detailed geological analysis is necessary to locate subsurface rock systems that can contain and lock in liquidized $CO_2$. Monitoring of these disposal sites would be necessary to reveal any leakage that may occur so that it can be stopped and the integrity of an isolation project assured.

## *Liquidize In-Line*

The technical feasibility of in-line capture and pressure liquefication of $CO_2$ and its transport to a deep geological formation for injection as a storage/disposal method will be tested in a prototype 275MWe coal-fired power plant called the FutureGen

Plant to be constructed in Mattoon, Illinois. The U.S. Department of Energy will fund 74% of the $1.2 billion and be supported by 26% from an alliance of 12 of the largest international coal companies and electric utilities in the world (The Future-Gen Alliance). The goals set by the USDOE in collaboration with the Alliance are: (1) removal of 90% of $CO_2$ from emissions of 1-2 million metric tons annually; (2) sulfur removal at >99%; (3) Hg removal at >90%; $NO_x$ emissions at <0.05 pound (∼22 gm) per million BTU; and particle emissions at <0.005 pound (∼2.2 gm) per million BTU (Futuregen, 2007).

Basically, coal will burn (with $O_2$) in a gasifier unit to yield syngas of $H_2O$ and CO. The syngas will be reacted with steam to give $H_2$ and $CO_2$. The $CO_2$ is separated from the $H_2$ and fed to a unit that liquefies it under pressure for transport to a deep geological formation for injection and storage/disposal. The $H_2$ powers a combustion turbine that generates electricity. Steam heated from the turbine exhaust drives a second turbine to give additional electricity. At Mattoon, the liquefied $CO_2$ will be transported to a depth of more than 6500′ where it will be injected into porous, permeable sandstone, 1400′ thick. The sandstone is sealed above by an impermeable shale, 550′ thick, and below by a granite. Recovery of marketable byproducts during the operation such as slag/ash, sulfur, and $H_2$ will enter into decisions of the economic benefits or limitations of the project.

## *Solidification*

Research is also proceeding on the capture and pressure solidification of $CO_2$ from emissions and even from the atmosphere itself to control atmospheric loading of $CO_2$. A recent proposal involves pumping $CO_2$ gas into the ocean to depths of >3000 m (1.86 miles) and injecting it below the sea floor (Schiermeier, 2006). Here the high pressure and low temperature would turn the gas into a liquid denser than the seawater. Ice-like compounds would form from the liquefied $CO_2$ ensuring that it remains in the sediment even during strong seafloor earthquakes.

This all considered, a reality of the global warming threat to mankind is that even if the global release of $CO_2$ emissions could be stemmed now, lag time before it takes effect would result in a warming by 1.4°C or more during this century. If nothing is done to decrease $CO_2$ input to the atmosphere, an average temperature rise up to 5.8°C can be anticipated (IPCC, 2007).

## *Regional: Acid Rain*

The emission of $SO_2$, mainly from coal-fired utilities and industrial plants including sulfide ore smelters is responsible for regional and local environmental intrusions by acid rain. Acid rain runoff can lower the pH of aqueous ecosystems to values that can harm life there (Fig. 4.2). Acid rain that damaged vegetation, lakes, and rivers in northeastern United States and southeastern Canada, originated with $SO_2$ from coal combustion at power plants in east-central United States. The $SO_2$ was moved by prevailing winds and reacted to photochemical energy to form $SO_3$ that combined with water to give $H_2SO_4$ in acid rain. Similarly, acid rain originating with $SO_2$ emissions from coal-fired industries and utilities in Norway and Sweden literally killed thousands of lakes. Acid rain that originated with coal-burning utilities and industries in eastern Germany precipitated on southwestern Germany's Schwarzwald (the Black Forest). By the early 1990s the acid rain ravaged 50% of the forest. In cases such as these, alleviation of the problem requires that mitigation efforts focus first on the closure of the heaviest polluting emitters that cannot be economically rehabilitated. Cleansing the $SO_2$ from chimney updrafts requires one or more of the following: the use of low-sulfur coal, improving or engineering new technologies that extract sulfur and heavy metals associated with sulfur (e.g., pyrite [$FeS_2$]) from this solid fossil fuel previous to its use, and the installation of the most efficient pollution control equipment that strip the $SO_2$ from the emissions. This has been successful where put into operation (e.g., the United States, the European Union, Canada). As a result, the threat to ecosystems from harmful acid rain is far less than it was a decade or two ago. This is not the case in China. In 2007, one third of the country suffered from acid rain fueled by rapid industrial growth. This is a threat to soil fertility and reliable food sources for the Chinese population.

## *Increasing Electrical Energy from Non-Fossil Fuel Sources*

Another way to alleviate air pollution from $CO_2$ and $H_2SO_4$ is to improve efficiency of combustion systems in order to decrease the amount of fossil fuel used. A greater use of operational alternate energy sources (e.g., hydroelectric, wind, solar, geothermal) can further decrease dependence on fossil fuels. Climatic and geological conditions for greatly increasing hydroelectric energy output are favorable in Africa, Southeast Asia, and Latin America. Investments in wind farms are accelerating in Europe and the United States. Germany is planning to satisfy 10% of its electrical needs from wind farms. The development of new alternate energy sources (e.g., ocean tidal energy, ocean or deep lake thermal energy exchange) that can power domestic users, industrial activity, and a meaningful percentage of transportation needs will further help to decrease the amounts of fossil fuels combusted in the future. When these steps are coupled with higher electricity transmission efficiency, air contamination from fossil fuel burning facilities will decrease.

## *Regional/Local: Heavy Metals and Particles*

Smelters spew out large masses of potentially toxic metals and particles into the atmosphere, and in the case of sulfide ores, $SO_2$. These contaminants intrude ecosystems close to and downwind of the emissions and most often affect local air, waters, and soils. The use of "clean" coal combined with chimney installations that capture toxic metals and trap particles can resolve this local environmental problem.

What remains to be reclaimed after the atmosphere is cleared and waters renewed are the lands contaminated by precipitated pollutants and pollutant-bearing particles.

## *Local: Smog*

Smog is a noxious mixture of gases comprised of various chemicals and particles that can accumulate in the near-surface atmosphere. Smog can be life threatening to human populations. It is considered in some detail here because incidences of severe smog are increasingly affecting more urban centers worldwide. The major chemical in smog is ground-level ozone. Ozone forms when nitrogen oxides, VOCs, and particles are exposed to sunlight photochemical reactions. An increase in the presence of "raw materials" for producing smog correlates with three main factors: (1) population growth; (2) increased transportation needs which leads to more vehicle exhaust, the major source of smog components; and (3) emissions from industries that locate close to urban centers. Changing demographics as urban centers grow at the expense of rural areas gives a higher population density that contributes to smog and exposes a greater number of people to smog conditions.

Smog worsens when there is a thermal inversion so that denser cold air near the ground resists rising through a layer of warm air above it. Its accumulation is especially efficient on hot (at least 18°C) summer days. Nonetheless, some of the worst instances of death and severe smog conditions have occurred during the late autumn. Dangerous smog commonly appears as a brown haze and takes several hours to form after component chemicals accumulate in the near-surface air. This scenario most often occurs in a valley, but can accumulate in a lowland area surrounded by highlands, or even in lowlands when winds are calm. Climate and topography have a great influence on smog formation and the length of time this dangerous atmospheric hazard lingers in an area. Many high population and densely populated cities are at risk from smog. Mexico City and Los Angeles are cities well known to periodically suffer from smog that is harmful to human health. Others include London, New York, Beijing, Athens, Hong Kong, and Toronto.

Respiratory illnesses from this mixture of noxious gases and particles are on the rise globally. Severe smog lying in an area for days has caused deaths. Two signal events focused public attention on the problem. First, in Donora, Pennsylvania, smog lay in a valley from Oct. 26-31, 1948, killed 20 people by asphyxiation, and sent more than 7000 people to hospitals with respiratory illnesses. In London, UK, a center of high pressure stalled over the city and caused a temperature inversion from Dec. 4-7, 1952. A smog layer formed and killed 4000 people from respiratory and cardiac stress. During the following weeks and months 8000 more Londoners died from its effects. Plans to deal with smog days in major urban centers will be discussed in Chap. 7 on environmental legislation.

Some population centers where smog could envelop them did not plan for a smog event and have suffered the consequences. For example, a report released by the director of Teheran's clean air committee during January 2007 estimated that in

Iran, 9900 people died during the period March 2005 to March 2006. Most of the deaths were from heart attacks and respiratory illnesses brought on by smog. There were 3600 deaths during October alone. These numbers are calculated from World Bank data that extrapolates mortality rates based on specific levels of air pollution.

## Emissions Controls - Costs/Benefits to Society and Ecosystems

Costs to control emissions from power plant and smelter chimneys, vehicular and air transportation modes, from industrial and manufacturing facilities, and other anthropogenic sources are high. Dollar figures on investment in best available technology vary between projects because each has its own specifications according to contaminants generated and legislated emission standards. The composition of emissions is dependent on the fuel used for energy generation, on the stock being used in industrial or manufacturing plants, and on vapors from liquid and solid manufactured products. Utilization of state-of-the-art technologies for emissions control during manufacturing processes, and reformulation of some products to reduce vapors they release, will improve air quality thereby benefiting people and their environments. With reduced pollutants in the air, less can access humans directly through respiration, and via an indirect path to humans through water and soil ecosystems to a food web. Better air quality means better health for communities with the social benefit of lower medical costs and the economic benefit of higher productivity from healthy work forces.

Table 4.10 describes the generalized benefits and costs to pollution emitting facilities of installing, using, and maintaining best available emissions capture/control equipment. It compares them with the benefits and costs of not using the equipment and the probable short-term/long-term implications to societal economic/social/political benefits/costs.

## Perspectives for Managing/Mitigating Air Pollution

There is no doubt that chemical and particle pollution in the atmosphere is being abated to a greater or lesser degree. This is dependent on adherence (or not) to environmental laws governing emissions, on the economic constraints to achieve abatement, and on the moral response of owners of pollution sources. The lessening of chemical air pollution on any scale reduces chemical intrusions on linked ecosystem waters and soils.

Air pollution management has had successes globally, regionally and locally in combating different classes of pollutants. These have been discussed earlier in this chapter. They include the global agreement (Montreal Protocol) by 191 of 197 countries to phase out and stop manufacture of chemicals that have contributed to the thinning and hole formation in the ozone layer.

**Table 4.10** Generalizations on benefits/costs relations that can be expected if planned industrial or manufacturing facilities or those that could be retrofitted took the decision to use advanced available emissions control/capture equipment. The contrast of benefits/costs relations if a decision is made not to use the best equipment available is also presented

| | |
|---|---|
| A. Using Best Advanced Emissions Control/Capture Systems Gives: | |
| Benefits: | A healthy work force means more productivity; |
| | An economically stable social environment means stronger tax base and better community services |
| | A well-funded educational system means children better prepared for higher education and subsequent entry to a higher level labor market which translates to a strong socio-economic situation |
| | The knowledge base of existing workers can be improved with the expectation that it will translate to ideas and an increasingly more productive work force |
| | A stable political environment |
| | In many cases emissions products captured by advanced emissions control technologies can be recycled or sold to serve as stock for other industries or manufacturers and thus contribute to the amortization of the equipment |
| | Long-term profitability |
| Costs: | Installation and maintenance of the most advanced emissions controls technologies designed to accept changes as improvements come on line |
| | Disposal of captured emissions products at a secure, monitored site unless saleable (see above) |
| | In this scenario **BENEFITS** >> **COSTS** |
| B. Not Using Best Available Emissions Control Systems Gives | |
| Benefits: | Short-term profits good |
| Costs: | Poisoned environment around and downwind of emissions pollution means non-productive land for farming or grazing, sickness in the population, damaged ecosystems, less food production |
| | Sick employees means less productivity or absenteeism and no productivity |
| | Sick families means inattention to work, errors on a production line/process, and decreased productivity |
| | Less take home pay means discontent, an unhappy work force, social unrest, less of a tax base to support services such as bettering education and health clinics |
| | Discontentment means political upheaval |
| | Long-term profits for industry or manufacturer not good |
| | In this scenario **COSTS** >> **BENEFITS** |

A partial success in control of air pollution has been attained by passing and enforcing legislation so that the best available $SO_2$ capture and control equipment had to be installed at emission sources. This reduced the damaging acid rain that degraded forested areas and water bodies and allowed their rehabilitation. However, the same has not been true in parts of Asia where control of $SO_2$ emissions has been lacking, especially at coal-fired power plants and other industrial facilities in China. The result is a degradation of agricultural terrain and water bodies by acid rain that poses a real threat to sustaining national sources of food supplies. The perspective for lessening ecosystem intrusion by acid rain is good where authorities establish stringent limits on $SO_2$ emissions, monitor them, and bring enforcement to the fore when needed.

There has been success in managing $SO_2$ and heavy metals emissions at smelters worldwide where state-of-the-art pollution control units strip out $SO_2$, heavy metals, and particles from chimney emissions. Where this has not been done, for lack of monitoring and/or enforcement of existing laws because of political or economic reasons, people living downwind of them continue to suffer serious health problems. When the health problems are revealed and widely publicized by today's rapid communications capabilities, public pressure often prompts governments to act and shut polluting smelters down. However, this generally happens after the fact that populations and ecosystems have been harmed. Smelter emissions controls have improved greatly in most nations where they had been ineffective. The perspectives for controlling smelter emissions where damage to environments has been an ongoing problem are improving for two reasons: (1) because ready communications as cited above make the damage known and the citizenry demands change; and (2) because multinational mining/smelting companies have acted with environmental responsibility, pushed or not by government mining regulations.

The genesis of smog is known. The smog problem can be managed and its effects mitigated so as to protect citizens from sicknesses it can cause. When weather experts predict that a temperature inversion is likely to occur, responsible government officials issue orders that greatly reduce vehicular traffic and cut back on emissions from fixed sources of airborne chemicals that combine to form ground level ozone, the major component of smog. As an adjunct to the measures given above, a warning system must be in place to advise citizens of the smog condition. In many cities that are susceptible to the physical and chemical conditions that favor smog formation, municipalities are prepared to deal with the problem and their perspectives are good. The perspective for others that do not prepare for the problem is that they will be hurt once, and then, under public pressure, set up a smog preparation and response action plan.

The perspective is questionable that all the nations of the world will work together to curb the discharge of $CO_2$ and other greenhouse gases into the atmosphere to slow the rate of global warming and the climate changes it can cause. National interests in emerging economies have overridden the overall worldwide need to reduce $CO_2$ discharge into the atmosphere. The efforts to curb $CO_2$ emissions have been spotty at best. Developed nations are striving to cut back greenhouse gases emissions, especially $CO_2$, following goals set out in the Kyoto Treaty. They have good intentions but there has been little success. Developing countries are not beholden to the Treaty and their $CO_2$ emissions more than make up for the $CO_2$ reductions achieved by industrial countries. The perspective for positive change will be defined by the results of the two year negotiation period that follows he previously discussed UN forum agreements. If both developed and developing countries in concert and without exception become parties to the UN forum negotiated agreements reduce $CO_2$ emissions will be reduced globally, the threat to Earth from global warming will ease and the seed planted by the Kyoto Treaty will have germinated.

## Afterword

The atmosphere and water are coupled in a hydrologic cycle that is put into motion when water evaporates from oceans and other water bodies into the atmosphere. Moisture accumulates in clouds that are moved by winds. When a saturation point is reached, precipitation takes place and may fall back to water bodies to reenter the start cycle or fall on land to continue the cycle. Precipitation on land, whether "clean" or carrying atmospheric contaminants, follows multiple courses before it returns to the ocean. It may flow in rivulets and streams into rivers, and in rivers into estuaries and oceans and seas. Water may be taken up and used by vegetation before transpiration and evaporation return it to the atmosphere. Water may infiltrate into and recharge aquifers from which it can be extracted and used, ultimately to make its way back to the sea. Water interacts with soils and outcropping rock, with vegetation and animal life, and with aquifer rock along these flow paths. Water chemistry changes. These changes have a direct influence on the quality of life for humans and plans for development projects that affect social, economic and political status of nations. They are the focus of the next chapter.

# Chapter 5
# Water: An Essential, Limited, Renewable Resource

## Part I

### Clean and Available Water = Health, Development, Prosperity

Water sustains life on Earth. Humans can survive without food for about 40 days by living on their stored body fat. They can live for only about 4 days without water. Other life forms are equally dependent on water. Water is a special natural resource because it is self-cleansing over time and renewable. However, the volume of useable (fresh) water for terrestrial life is finite.

### *Water Quality*

Quality determines water's usefulness for drinking, hygiene, irrigation of food, fodder and feed crops, food animals, aquaculture, and industrial production (e.g., pharmaceutical, chemical) and manufacturing (e.g., semi-conductors). Different water qualities (and properties) are required for varying applications. Failure to meet water quality standards for specific uses can have serious consequences such as sickness in humans and other organisms. Poor water quality can lead to reduced yield or non-marketable products in agricultural sectors, and faulty or defective products in manufacturing sectors.

In general, water quality is categorized on the basis of chemical composition, salinity (salt content), bacterial (coliform) content, color, odor, taste and turbidity. The main chemicals that define water quality include alkaline elements potassium (K) + sodium (Na) and alkaline earth elements calcium (Ca) + magnesium (Mg), the anionic complexes bicarbonate ($HCO_3^-$), sulfate ($SO_4^{2-}$), and chloride ($Cl^-$), and heavy metals (e.g., As, Cd, Fe, Hg, Pb), and organic compounds.

## *Safe Water Standards*

Safe drinking water supports the health of humans and other organisms. National, regional and international health groups such as the USEPA, the EEC, the WHO, and others have established standards for safe drinking water (Table 5.1). In addition to the chemicals listed in Table 5.1, the USEPA sets standards for 87 potential contaminants in five categories: microorganisms (7), disinfectants and disinfecting products (7), inorganic chemicals (16), organic chemicals (53) and radioactivity (4). Other organizations have their own detailed listings. State and provincial governments and local municipalities have modified federal maximum allowable concentrations in

**Table 5.1** Safe drinking water standards for some chemicals as established by the World Health Organization and regional and national agencies

| Inorganics mg/l-ppm | WHO | PAHO | EEC | USEPA | China | Taiwan | S. Africa | Canada |
|---|---|---|---|---|---|---|---|---|
| Ammonia | 1.5 | | 0.5 | | | | 1.5 | |
| Bromate | 25 | | 0.01 | | | | 0.025 | 0.01 |
| Chloride | 250 | | 250 | 250 | | 250 | | 250 |
| Fluoride | 1.5 | | 1.5 | 4 | 1 | 0.8 | 1 | 1.5 |
| Nitrate | 50 | | 50 | 10 | 20 | 10 | 10 | 45 |
| Sulfate | 250 | | 250 | 250 | | 250 | 200 | 500 |
| **Metals mg/l = ppm** | | | | | | | | |
| Aluminum | 0.2 | | 0.2 | 0.2 | | | 0.2 | 0.2 |
| Antimony | 0.005 | | 0.005 | 0.006 | | | 0.005 | 0.006 |
| Arsenic | 0.01 | | 0.01 | 0.01 | 0.05 | 0.05 | 0.01 | 0.01 |
| Barium | 0.7 | | | 2 | | | 0.7 | 1 |
| Beryllium | | | | 0.004 | | | | |
| Boron | 0.3 | | 1 | | | | 0.3 | 5 |
| Cadmium | 0.003 | | 0.005 | 0.005 | 0.01 | 0.01 | 0.01 | 0.005 |
| Chromium | 0.05 | | 0.05 | 0.1 | | 0.05 | 0.05 | 0.05 |
| Copper | 1.0 | | 2 | 1.3 | | 1 | 0.5 | 1 |
| Iron | 0.3 | | 0.2 | 0.3 | | 0.3 | 0.2 | 0.3 |
| Lead | 0.01 | | 0.01 | 0.015 | 0.05 | 0.05 | 0.05 | 0.01 |
| Manganese | 0.1 | | 0.05 | 0.05 | | 0.05 | 0.05 | 0.05 |
| Mercury (Total) | 0.001 | | 0.001 | 0.002 | 0.001 | 0.002 | 0.005 | 0.001 |
| Molybdenum | 0.07 | | | | | | 0.07 | |
| Nickel | 0.02 | | 0.02 | 0.1 | | | 0.02 | |
| Selenium | 0.01 | | 0.01 | 0.05 | | 0.01 | 0.02 | 0.01 |
| Sodium | 200 | | 200 | | | | 100 | 200 |
| Zinc | 3 | | | 5 | | 5 | 1 | 5 |
| **Radiological** | | | | | | | | |
| Gross α activity | 0.1 Bq/L | | | 15 pCi/L | | | | |

**Table 5.2** Some parameters used to set quality standards for irrigation waters

1. Total concentration of soluble salts (electrical conductivity should be less than 700 microsiemens/cm)
   - A. High salt concentration can build up in soils, cake roots which cannot then absorb water and crop wilts
   - B. Saline soils can reduce potential crop yield
2. Relative proportion of sodium (Na) to other cations
   - A. A high Na/Ca + Mg (>18) brings Na to soil particles altering the physical structure of high clay soil by allowing it to harden and compact and relatively impervious to water infiltration
3. Bicarbonate concentration as related to the concentrations of calcium (Ca) and magnesium (Mg) (should not exceed 339 mg/l)
   - A. Can limit uptake and metabloism of nutrients by crops harming planned mineral nutrition
4. Sulfate ($SO_4^-$) concentration
   - A. Can disturb the cation balance in crops by limiting uptake of Ca and Mg and increasing uptake of Na and K
5. Total suspended solids (should not exceed 75 mg/l)
   - A. Can clog pores in soils, diminishing permeability and water infiltration
6. Concentrations of ions, trace elements and compounds
   - A. High potassium (K) concentrations can cause magnesium (Mg) deficiency and iron chlorosis
   - B. Imbalances in crops can cause toxic symptoms to develop
7. pH between 6.5 and 9

water according to their evaluation of health risks. Similarly, agricultural departments have established water quality standards for food crop and animal feed production via irrigation (Table 5.2). Industrial and manufacturing groups set standards for their operations according to how water quality affects the fabrication and performance of individual products.

## Hydrologic Cycle

Water follows a renewal/cleansing model called the hydrological cycle (Fig. 5.1). Evaporation from oceans and seas can be taken as a starting phase in the cycle. Evaporation takes place from other water bodies as well and from water stored as pack snow and glacial ice. The vaporized phases accumulate in the atmosphere and condense in clouds that can precipitate their loads (rain, snow, hail) over water or be moved by winds over land to precipitate there.

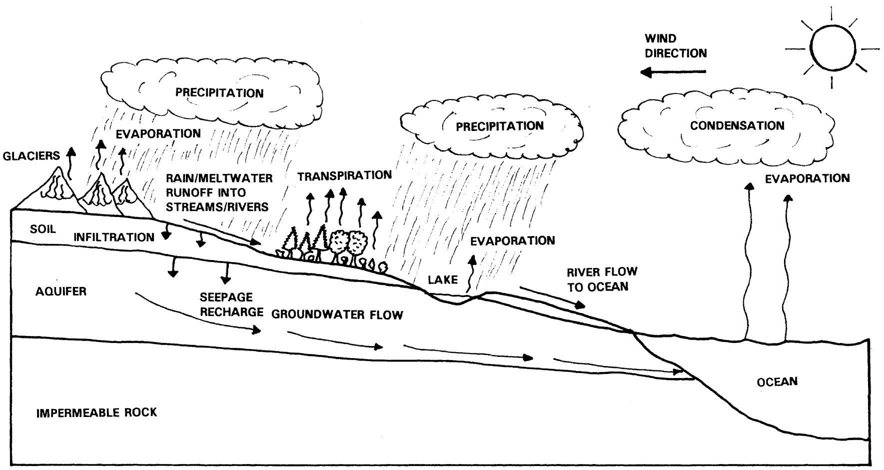


**Fig. 5.1** The hydrogeological cycle

The rain that falls on land follows multiple paths (Fig. 5.1). Ten percent (10%) of the rainwater is stored in soils as moisture and as water that infiltrates through soils into rocks to feed aquifers. The aquifers in turn may feed streams by outflow and can issue at the surface as springs. Twenty percent (20%) of the rainfall flows over the surface into stream and river channels and may be stored temporarily in lakes and ponds before rejoining a river watershed flow to the oceans. River waters often flow to oceans through estuaries or fjords. During the flow, streams and rivers may recharge aquifers by inflow. Of the remaining 70% of the precipitation, most infiltrates soil and is taken up by vegetation roots. The water can evaporate from soils and transpire through plant leaves to the atmosphere. A small portion of the 70% evaporates during rainfall and when rain hits a surface.

Water can move through the cycle fairly quickly with respect to a human time frame. Some estimates have 35% of the water flowing in stream and river channels for about 12 weeks until it discharges into an ocean. Another 56% of the water remains in soils for about 10 weeks. Aquifers store 6% of the precipitation for 200 to 10,000 years and about 3% is in lakes for up to 100 years. Small volumes of water continually circulate from glaciers that calve into water bodies and melt, and as evaporation from pack snow, glaciers, and salt lakes. Other estimates give somewhat different cycling times for the categories of inventoried water (Table 5.3).

The cycle should properly be called the hydrogeologic cycle because water reacts with geologic materials. In this way water acquires a natural chemistry with imprints of the chemistry of the rocks and soils over which or through which it flows. Rivers continually discharge dissolved salts and sediments into the marine environment. This is responsible for the 3.5% salt content of seawater. The salt content is called salinity ($S^{\circ}/_{oo}$) that is given as 35 parts per thousand. Although river discharge is an ongoing process, ocean salt content has not increased over hundreds of millions of years. A chemical equilibrium was reached in the geologic past between the mass

**Table 5.3** General estimates of periods for water cycles in the Earth's hydrological reservoirs. (after UNESCO Water Day, 2000)

| Reservoir | Cycle time for complete recharge |
|---|---|
| Ocean | 2500 yrs |
| Ground Water | 1400 yrs |
| Lakes | 17 yrs |
| Bogs | 5 yrs |
| Soil Moisture | 1 yr |
| Fluvial Water | 16 days |
| Atmospheric Moisture | 8 days |
| Biological Water | Several hours |
| Mountain Glaciers | 1600 yrs |
| Polar Ice | 9700 yrs |
| Permafrost Ice | 10000 yrs |

of chemical components added to the oceans mainly by rivers and the mass being removed from the oceans (e.g., to sustain ocean life and to form shells, skeletons and new minerals). Calving glaciers, melting ice, undersea volcanoes, sea bottom vents (black and white smokers), and offshore springs contribute some cycled water and chemicals to the oceans.

If contaminants do not enter the hydrogeologic cycle, all the recharged water, fresh, brackish and marine, is useable by life forms that have adapted to the different aqueous ecosystems. When natural contaminants access the cycle (e.g., from disintegration and decomposition of mineral deposits or volcanic emissions), water may be temporarily unsafe to use until contaminants are stripped out during the cycle. The removal may be by adsorption onto or absorption into clay and Fe/Mn oxy/hydroxide mineral phases and by vegetation and bacteria that act as water filters in soils and wetlands. To limit or stop discharge of anthropogenic pollutants and their build up in waters requires technological intervention bolstered by public awareness and political pressure on legislators to pass explicit, loop-hole free water protection laws.

## The Earth's $H_2O$: Where, How Much, How Used?

### *$H_2O$ Reservoirs: Oceans, Ice Caps and Glaciers, Aquifers, Lakes, Rivers, Moisture*

Most of the Earth's $H_2O$ (96.5%) is in the oceans (Table 5.4). The 3.5% dissolved salt content (salinity) makes ocean water unsuitable for human consumption and irrigation.

Another 1.74% of the Earth's $H_2O$ is held in icecaps, glaciers, and snow. Locally, a small number of inhabitants living at high latitudes melt and use the

**Table 5.4** Estimated inventory of $H_2O$ on the earth as water bodies and ice and snow, and in the earth as ground water and moisture (modified from Gleick, 1996)

| | Surface Area ($10^3$ km$^2$) | Volume ($10^6$ km$^3$) | Percent of Total |
|---|---|---|---|
| Subsurface (aquifer) waters | 125,000 | | |
| Ground water | | | |
| Freshwater | | 10.53 | 0.76 |
| Shallow (< 750 m) | | 4.66 | 0.34 |
| Deep (> 750 M) | | 5.87 | 0.42 |
| Saline | | 12.87 | 0.94 |
| Soil moisture | | 0.0165 | 0.001 |
| Ground ice and permafrost | | 0.3 | 0.022 |
| Surface waters | | | |
| Freshwater lakes | 825 | 0.091 | 0.007 |
| Saline lakes and inland seas | 675 | 0.0854 | 0.006 |
| Rivers and streams | | 0.00212 | 0.0002 |
| Swamp water | | 0.01147 | 0.0008 |
| Biological water | | 0.00112 | 0.0001 |
| Atmosphere | | 0.0129 | 0.001 |
| Icecaps, glaciers, permanent snow | 17,240 | 24.06 | 1.74 |
| The oceans | 348,750 | 1338 | 96.5 |
| Total $H_2O$ for Earth | | 1386 | 100.0 |

snow and glacial ice as their water source. Seasonal melting of glaciers is a major feeder for fluvial and lake waters and is an important water source for aquifer recharge and for generating hydroelectric power. Another 0.94% is in saline water aquifers.

The remaining 0.82% of the water on earth maintains most terrestrial life. The great part of this (0.76%) is found in shallow (<750 m) and deep (>750 m) freshwater aquifers whereas 0.007% is in freshwater lakes, and only 0.0002% is in rivers and streams (Table 5.4). This water, together with recycled, treated water, desalinated water, soil moisture, and air humidity, provides water for drinking, hygiene, sanitation, industrial processes, and growth and irrigation of crops (which yield 40% of the world's food supply).

New water is being added to the earth's aqueous inventory at the expense of icecaps and glaciers. Global warming is likely responsible in great part to the observed and measured accelerated calving, melting and recession of icecaps and of mountain (alpine) glaciers at high latitudes and high altitudes worldwide. This adds water to ocean basins increasing seawater volume. Warming of seawater also increases its volume. These sources are responsible for the rise in sea level given in the IPCC (2007) report. There is a consequent creeping inundation of land and expansion of ocean surface area.

The greater ocean surface area and warmer sea water favors increased evaporation that puts more moisture into the oceanic atmosphere and results in more rainfall over land. This has been reported for several coastal regions. In some areas, this increases the amount of water delivered to streams and rivers. More water flowing on land and infiltrating unconfined and confined aquifers makes more water accessible to growing populations, but at what expense?

There are negative aspects to this situation. Greater rainfall on land increases the probability of more frequent and higher flood levels with a broader reach out of existing floodplains than has been recorded historically for regions. The flooding will have more potential to damage the environment because of more rapid flow rates. In addition, increased moisture in the atmosphere appears to have intensified the severity of tropical storm damage in coastal areas and will likely continue to do so because of farther reaches of storm surges inland. The surges have three principal effects. First, they add to destructive flooding inland. Second, inundation of coastal regions by salt water damages inland coastal brackish and fresh water ecosystems by instantly changing the aqueous chemistry. Third, the seawater surges salinize inshore farmland soils.

Another negative aspect to a continuing thinning and contraction of mountain (alpine) glaciers means that in some drainage basins, water supplies will fall below what is necessary to sustain the basic needs of populations. A water deficit will stunt the activities that support peoples' livelihoods and the vitality of ecosystems with their natural resources that depend on a reliable water supply. Large populations in Asia, Europe, South America, and North America are dependent on water from rivers and aquifers fed, respectively, by melt waters from the Himalayas (Tibetan Plateau), the Alps, the Andes, and the Sierra Nevada and Rocky Mountains. An additional consequence of shrinking glaciers is that there is less melt water to feed rivers with hydroelectric installations and thus can affect regional power supplies.

Economists assess the future viability of programs for development in agricultural and other sectors based in large part on econometric analyses. They assess how much and where growing seasons will be shortened or extended with climate changes, probable changes in water availability for irrigation of food crops, drinking, hygiene, sanitation, industrial, and other needs.

## *Some Domestic and Other Sector Water Uses*

The per capita daily home use of water in industrialized nations averages about 70 gallons ($\sim 100\,m^3$ annually) but can range to hundreds of gallons depending on life styles and perceived needs of affluent sectors of society. On the other hand, the per capita daily home use of water in Sub-Saharan Africa may be less than $\sim 10\,m^3$ annually ($\sim 7$ gallons daily). This is enough to subsist on but not enough for a people to thrive. In some regions the water problem is compounded because there is an inequality of water availability between socially/economically disparate segments of societies. This imbalance has to be minimized in order to improve health, social conditions, and economic possibilities of lower income groups especially in less developed nations. The answer is to find more water where it is needed, or where possible, to invest in infrastructure that can bring this essential resource from water-rich to water-deficient regions.

Much water goes into food production. Table 5.5 illustrates the volumes of water used to produce some foodstuff, fiber, and industrial products plus water used in some domestic endeavors. During the past 30 or so years water volumes for the irrigation of field crops have been reduced considerably by using more efficient protocols (e.g., drip irrigation) and otherwise conserving water. This is due in some part to

**Table 5.5** Some general water requirements for domestic use, for growing agricultural sector products, and for manufactured goods from the industrial sector. One gallon = 3.875 liters. Water use for crop yields are general and do not reflect the range that exists from growing area to growing area as a function of climate and soil type and conditions (modified from Cargo and Mallory, 1977)

| Use/Product | Water volume (in gallons) |
|---|---|
| **DOMESTIC** | |
| Per capita home use (industrialized nations) | 70 |
| Toilet flush | 2–3 |
| Shower per minute | 4–5 |
| Bath | 20–30 |
| Wash dishes | 10 |
| Dishwasher | 15 |
| Automatic washing machine | 30–55 |
| Water lawn one hour | 300 |
| **AGRICULTURE SECTOR** | |
| 1 ton of rice | 480,000 |
| 1 ton of wheat | 135,000 |
| 1 ton of corn | 85,000 |
| 1 ton of alfalfa | 200,000 |
| 1 ton of potatoes | 140,000 |
| 1 ton soybean | 160,000 |
| 1 ton oats | 140,000 |
| 1 ton sorghum | 75,000 |
| 1 ton sugarbeet | 95,000 |
| 1 ton of sugar | 250,000 |
| 1 gallon of milk | 16,000 |
| 1 hen's egg | 57 |
| 1 ton of beef | 7,500,000 |
| 1 ton of cotton | 2,500,000 |
| **INDUSTRIAL SECTOR** | |
| 1 ton of finished steel | 65,000 |
| 1 ton of synthetic rubber | 660,000 |
| 1 ton of nitrate fertilizer | 82,000 |
| 1 ton of paper | 120,000 |
| 1 ton of fine book paper | 184,000 |
| 1 ton of bricks | 250–500 |
| Refine 1 42 gallon barrel of crude oil | 468 |
| Refine 1 gallon of gasoline | 10 |

conservation efforts to extend an available water supply and in part on economics. If the cost of water increases, less can be used more efficiently to yield the same mass of product, thus keeping water costs down and maintaining or increasing profits.

For example, during the 1970s about 1,000,000 gallons of water, on the average, were used to produce one ton of rice. Today, as a result of research and conservation, this volume is less than 500,000 gallons. Australia is most efficient and uses less than 300,000 gallons of water to grow a ton of rice. The reduced use of water in rice agriculture is very important for Asia, where the population is large and increasing. In Asia, 36% of the world's water resources support 60% of the world's population. Rice is the staple food in Asia and more than half of the world's population will depend on it in the coming 30 years. The World Bank (1999) estimates that production will have to increase by more than 40% to avoid a rice shortage. Rice cultivation is the major economic engine in Asia where farmers cultivate about 90% of the world's rice areas and produce 90% of its harvest. Rice agriculture is the principal source of employment and income for the dominantly rural Asian populations. New techniques for growing rice such as wet seeding, intermittent irrigation, land leveling, improved weed management, and management of cracked soils are being evaluated. Implementation of these techniques promises up to 25% less water usage without lowering grain yields (World Bank, 1999). On the negative side, however, the use of these techniques can reduce the per hectare labor needs for establishing the crop. This would cause unemployment in areas with a limited diversified employment base. Unemployment means social stress, less domestic spending, and a slowdown in local and/or regional economies. This impact can be countered by attracting new ventures to otherwise agricultural regions. Government incentives such as tax benefits and the retraining of workers for venture needs can be used to attract investors to that end.

## *Geographic Realities of Water Availability*

The geographic "where" poses the basic problem to servicing the needs of people who are surviving on minimum rations where there is a scarcity of water. Populations are growing at an alarming rate especially in Africa and the Middle East (Chap. 2) where many nations now face a water deficit or where they are stressed by lack of water (Table 5.6). Growing populations will cause a further reduction in the per capita availability of renewable freshwater (Table 5.7). In Jordan, Libya, Saudi Arabia, Yemen, Ethiopia, Somalia, Afghanistan, Ghana, Nigeria, Tanzania and Uganda, for example, less than half the water available per capita during 1995 will be available in 2025 if population growth projections are realized. This will lead to social problems, affect economic development, and can ultimately undercut a nation's political stability. The competition for water sources has the potential of leading to wars.

Water quality and accessibility to safe water are other problems to deal with. Contaminated water causes sickness, debilitation, and death. Witness the $1\frac{1}{2}$–2 million

**Table 5.6** Nations with water deficiencies that constrain development (after World Resources Institute, 2005)

| |
|---|
| **Grave** with $<1000\,m^3$ per capita actual renewable freshwater resources; using 2004 population estimates |
| Sub-Saharan Africa: Burkina Faso, Burundi, Djibouti, Kenya, Rwanda |
| North Africa and Middle East: Algeria, Egypt, Israel, Jordan, Kuwait, Libya, Morocco, Oman, Saudi Arabia, Tunesia, United Arab Emirates, Yemen |
| Asia: Singapore, Turmenistan, Uzbekistan |
| Europe: Hungary |
| (21) |
| **Marginal** with $> 1000\,m^3$ but $< 2000\,m^3$ per capita of actual renewable freshwater resources; using 2000 population estimates |
| Sub-Saharan Africa: Eritrea, Ethiopia, Lethoso, Malawi, Somalia, South Africa, Sudan, Zimbabwe |
| North Africa and Middle East: Iran, Lebanon, Syria |
| Asia: India, Pakistan, Republic of Korea |
| Europe: Belgium, Czech Republic, Denmark, Germany, Poland |
| Caribbean: Haiti |
| (20) |

Note:
Since the 2000 World Resources Institute report, there have been significant changes in grave group and marginal group designations.
Ten countries leave the stressed and marginal groupings: Mauritania, Niger, Benin, Botswana, Chad, Ghana, Nigeria, Uganda, Azerbaijan, Ukraine
Four countries move from the grave group to the marginal group: Somalia, Eritrea, Syria, Pakistan
Two countries move from the marginal group to the grave group: Burkina Faso, Morocco
This happens because of a change in population data and/or a reinventory and remeasurement for 2004 that shows more actual renewable fresh water resources than inventoried in 2000.

infants who die annually where safe water is unavailable to families with average economic resources (for their country). The purchase of clean water from unscrupulous vendors at inflated costs may not be an option given other family needs. Figure 5.2 shows global areas where populations do not have access to safe drinking water. Table 5.8 gives World Health Organization estimates of water-related diseases in the early 1990s. There were 4 billion global morbidity episodes of people afflicted with these diseases. The mortality was 5.3 million deaths/year. Especially disconcerting are the billion people who suffer with diarrheal disease annually from ingestion of biologic-contaminated water and the 3.3 million who die annually from it. With clean water, these morbidity/mortality numbers can be reduced.

In some cases, a government's inability, indifference, or unwillingness to invest in infrastructure to pipe clean water from distant sources or from treatment plants to all its population causes serious problems. First is in human health (Table 5.8). Second is in agricultural development and the ability of a people to feed itself. Government authorities in some nations or municipalities have built infrastructures to bring clean water at fair costs to economically advantaged and politically connected populations but not to poor and non-influential ones. As a result of this failing,

**Table 5.7** Growing populations (in millions) and reduction of renewable freshwater availability per capita (in $m^3$) for selected countries. Countries go from water-sufficient to water-scarce or water-scarce to water-stressed or water-stressed to water-stressed intensified from 1995 projected to 2025 (modified from Gardner-Outlaw and Engleman, Population Action International, 1997

| Country | Population 1995 | Per capita Water 1995 | Population 2025 | Per capita Water 2025 |
|---|---|---|---|---|
| **Water Stress Intensified (Grave)** | | | | |
| Algeria | 28.1 | 527 | 47.3 | 313 |
| Egypt | 62.1 | 936 | 95.8 | 607 |
| Israel | 5.5 | 389 | 8.0 | 270 |
| Jordan | 5.4 | 318 | 11.9 | 144 |
| Libya | 5.4 | 111 | 12.9 | 47 |
| Saudi Arabia | 18.3 | 249 | 42.4 | 107 |
| Yemen | 15.0 | 346 | 39.6 | 131 |
| **Water Scarce to Water Stressed (Marginal)** | | | | |
| Ethiopia | 56.4 | 1950 | 136.3 | 807 |
| Iran | 68.4 | 1719 | 128.3 | 916 |
| Kenya | 27.2 | 1112 | 50.2 | 602 |
| Morocco | 26.5 | 1131 | 39.9 | 751 |
| Somalia | 9.5 | 1422 | 23.7 | 570 |
| **From Water Sufficient to Water Scarce** | | | | |
| Afghanistan | 19.7 | 2543 | 45.3 | 1105 |
| Ghana | 17.3 | 3068 | 36.3 | 1464 |
| India | 929 | 2244 | 1330.2 | 1567 |
| Nigeria | 111.7 | 2506 | 238.4 | 1175 |
| Tanzania | 30.7 | 2964 | 62.4 | 1425 |
| Uganda | 19.7 | 3352 | 45.0 | 1467 |

Source: http://www.populationaction.org/

low-income populations in many less developed economies do not receive safe water as a basic municipal service. They must purchase clean water from vendors at prices 4 to 100 times the prices paid by middle and upper class citizens for a piped supply from municipalities (World Bank, 1992). In Lima, Peru, for example, inhabitants of squatter settlements paid US$3 per cubic meter of clean water in 1990 to vendors while middle class households 8 km away paid US$0.30 for each cubic meter of piped, treated municipal water (World Bank, 1992). Such an unfair and immoral practice creates conditions for sickness caused by tainted water (Table 5.8) and mainly affects low-income populations.

## Dealing with Problems of Water Deficits

The earth's human population uses about half of the available freshwater from lakes, fluvial flow, aquifers and springs. Yet more than 1.3 billion persons are without adequate supplies of safe water for personal use and more than 2 billion

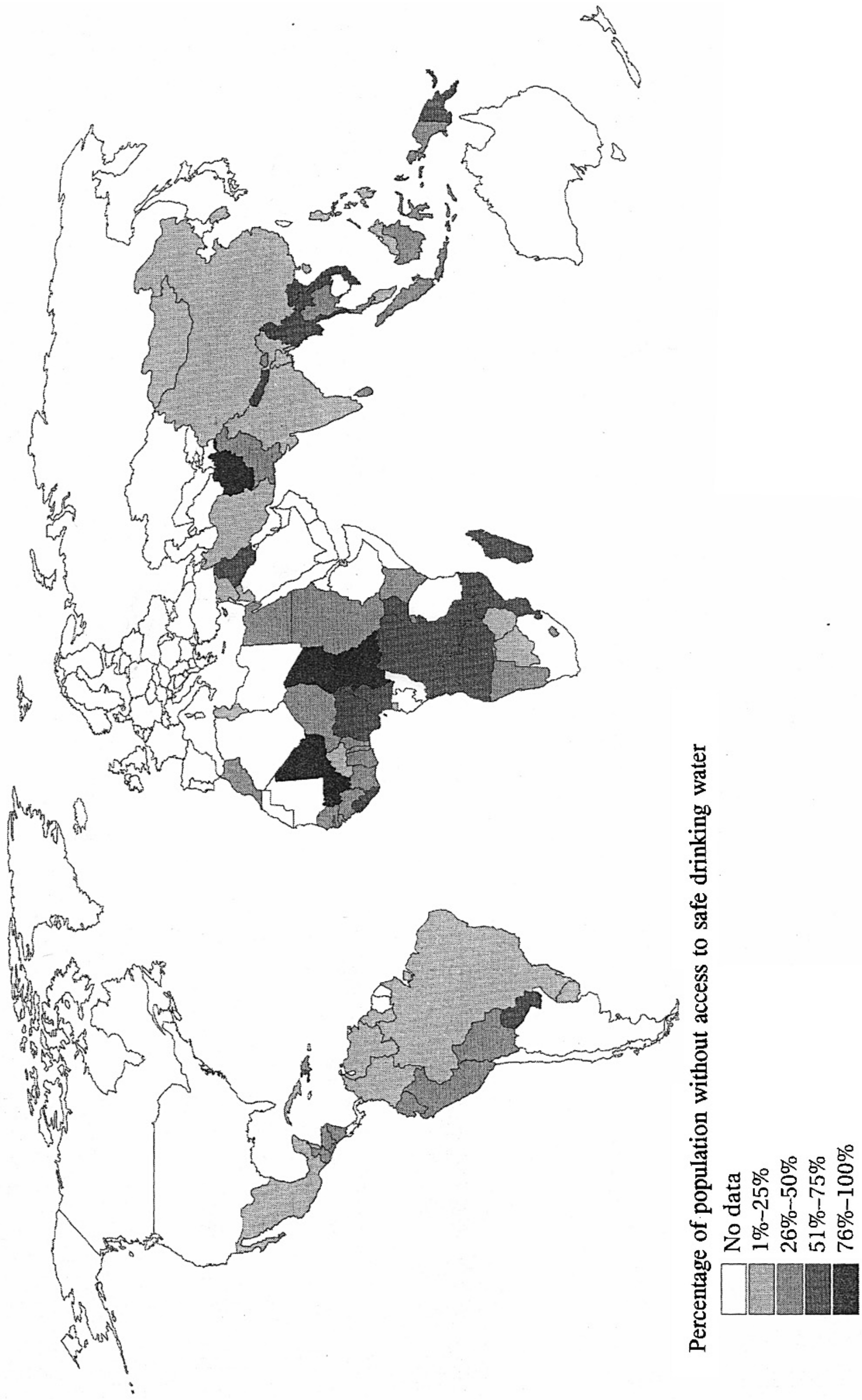


**Fig. 5.2** Populations without access to safe drinking water (after Gleick, 1998)

**Table 5.8** Estimates of global morbidity and mortality of water-related diseases (early 1990s) (after WHO, 1995)

| Disease | Morbidity (episodes/year or people infected) | Mortality (deaths/year) |
|---|---|---|
| Diarrheal disease | 1,000,000,000 | 3,300,000 |
| Intestinal Helminths | 1,500,000,000 (people infected) | 100,000 |
| Schistosomiasis | 200,000,000 (people infected) | 200,000 |
| Dracunculiasis | 150,000 (in 1996) | – |
| Trachoma | 150,000,000 (active cases) | |
| Malaria | 400,000,000 | 1,500,000 |
| Dengue fever | 1,750,000 | 20,000 |
| Poliomyelitis | 114,000 | – |
| Trypanosomiasis | 275,000 | 130,000 |
| Bancroftian filariasis | 72,800,000 (people infected) | – |
| Onchocerciasis | 17,700,000 (people infected; 270,000 blind) | 40,000 (mortality caused by blindness) |

people or one-third of the world population are without water for sanitation. As shown in Table 5.6, forty-one nations, especially those in Africa and the Middle East are stressed because of limited water supplies. Several others will surely fall into the scarce/stressed categories by 2025 as populations increase and the water supply remains unchanged (Table 5.7). There is insufficient water for agricultural expansion and industrial development in some regions where it would otherwise be possible.

This might be in the semi-arid areas bordering great deserts (e.g., the Sahara, the Kalahari, those in the Middle East, the Takla Makan and Gobi deserts in northwest and north-central China, and the Australian outback). The same is true for smaller deserts such as in southwest United States, north-central Mexico, northern Chile and southern Peru, and south-central Argentina. The semi-arid regions receive 10–20 inches of annual rainfall but lose much of it from high temperatures that cause high rates of evaporation. Together with arid regions ($<10$ inches of annual rainfall), they comprise almost one-third of our planet's land area (Fig. 5.3).

The Earth has safe water to service water-deficient regions but source locations are irregularly distributed geographically. Unless there is an infrastructure to move water from where it is available to where it is needed, large populations survive on water at subsistence levels.

## *Import via Aqueducts and Canals*

Where there were economic resources, progressive planning, and plan implementation with focus on societal and political progress as well as economic development,

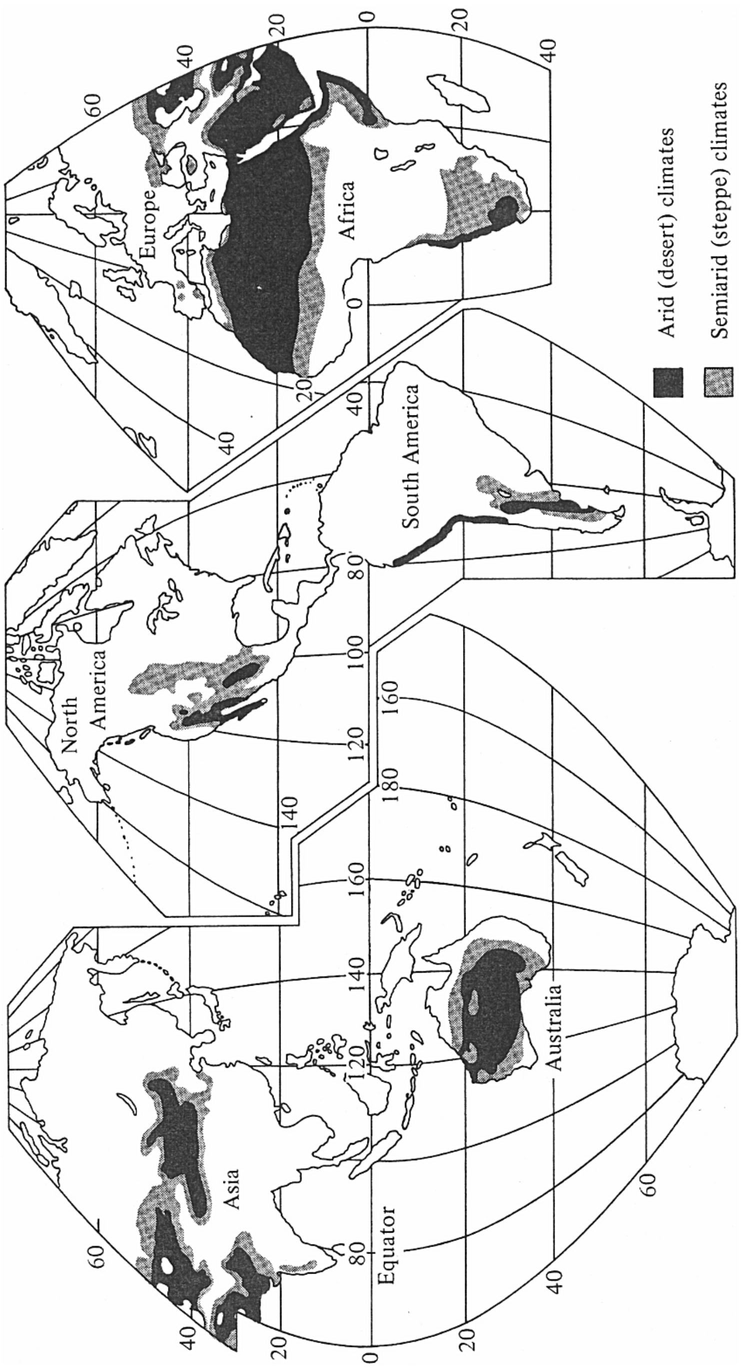


**Fig. 5.3** Arid and semi-arid climatic areas of the world (after Flint and Skinner, 1974)

infrastructure was built to move water from areas of surplus to areas of shortfall. This was done in the past with grand aqueducts throughout the Roman Empire thousands of years ago in Rome, the Middle East, Spain and France. In modern times, canals were built to sustain Los Angeles, California. This city of 14 million inhabitants imports water from rivers in northern California 400 miles ($\sim$640 km) away and from 300 miles ($\sim$480 km) to the east from the Colorado River. New York City brings water from the Catskill Mountains, 125 miles (200 km) to the north, through a series of large diameter aqueducts to service its more than 9 million citizens. This reduces the need to take water from industrially polluted rivers and send it through treatment facilities to make it safe to drink.

## *Desalination*

In some countries, potable water is made via desalination and sustains large segments of their populations. However, desalination first requires proximity to marine or brackish water environments (or access to saline water aquifers or to inland seas) as sources of feed water for the process. Second, a country must have economic resources to construct, operate, and maintain desalination plants. Saudi Arabia meets both criteria and extracts 20% of its national drinking water needs (to supply $\sim$6 million people) from the Red Sea by desalination. One hundred and twenty countries produce desalinated water. The largest production is in Saudi Arabia (>5.0 million $m^3$/day) followed by the United States with 2.8 million $m^3$/day, the United Arab Emirates with more than 2.1 million $m^3$/day and Kuwait with about 1.3 million $m^3$/day (Table 5.9). The world's installed capacity for desalination is expected to almost double by 2015.

Desalination is done using two general processes. A thermal process using a pressure-controlled system during heating to boiling to distill fresh water from saline water accounts for 55% of desalination. Membrane-based processes, electrodialysis or reverse osmosis uses the ability of specially manufactured membranes tailored to the feed water to selectively separate dissolved salts from it. Electrodialysis uses an electric field to drive the separation process whereas reverse osmosis uses a pressure driven system to effect the separation. Distillation and reverse osmosis are most effective for desalination of seawater whereas electro-dialysis is preferred for desalination of brackish water. Presently 71% of desalinated water is from seawater. In either case, spent feed water with concentrated salts, a brine, has to be periodically discharged in a controlled manner and properly disposed of so as not to pollute water bodies or terrestrial ecosystems. Disposal may be into a nearby sea, by injection into a saline aquifer, or by evaporation to precipitate salts to use as feedstock in chemical plants. In some cases dilution before disposal is used. The cost of disposal could greatly affect the costs/benefits economics of a proposed desalination facility. In general, it costs \$0.20–\$0.30 per $m^3$ to desalinate brackish water and \$1 per $m^3$ to desalinate seawater. The cleansing of industrial and manufacturing effluent to useable water ranges from \$0.30->\$1 per $m^3$.

**Table 5.9** Selected countries with desalination capacities greater than $125,000\,m^3/day$ on January 1, 1999 (after Pacific Institute, 2005). One $m^3$ is approximately $35.3\,ft^3$ or 264 gal

| Country | Total Capacity (cubic meters/day) | Country | Total Capacity (cubic meters/day) |
|---|---|---|---|
| Saudi Arabia | 5,006,194 | Bahrain | 282,955 |
| United States | 2,799,000 | Korea | 265,957 |
| United Arab Emirates | 2,134,233 | Netherlands Antilles | 210,905 |
| Kuwait | 1,284,327 | Algeria | 190,837 |
| Libya | 638,377 | Hong Kong | 183,079 |
| Japan | 637,900 | Oman | 180,621 |
| Spain | 492,824 | Kazakhstan | 167,379 |
| Italy | 483,668 | Malta | 145,031 |
| Iran | 423,427 | Singapore | 133,695 |
| Iraq | 324,476 | | |

Source: http://www.worldwater.org/data19981999/table16.html
The world desalination capacity is projected to almost double by 2015 at a capital cost of over $30.5 billion with operating costs of more than $6.6 billion.
Note: Presently, 55% is from thermal desalination; 45% is from membrane-based processes
2015 Projected: 59% will be from membrane-based processes (especially reverse osmosis); 41% will be from thermal desalination.

California, USA, has a growing population especially in the south part of the state. As noted previously, water is imported from northern California and from the Colorado River to service population and other sector needs. However, there will be decreased imported water supplies in the future because California is legally bound to share more of the Colorado River water with Nevada and Arizona, two bordering water-deficient states. To cope with the decrease in water from the Colorado River, the state government is planning the construction of several desalination plants along its southern coast to assure a water supply for its citizens and other needs.

## *Recycling with Chemical Treatment*

Recycling of water used in Japanese industries reduces the need for new water by 90%. In many developed economies, tainted water from rivers and domestic wastewater is recycled through collection and treatment facilities. Recycling extends water supplies but this demands large capital investment for the construction and maintenance of collection and treatment facilities and distribution networks.

## *Recycle Without Chemical Treatment: Nanofiltration*

A "low-cost capital investment" recycling plant that makes chemical treatment of some wastewaters unnecessary was put into operation at Val D'Oise, France. The plant uses nanofiltration in a full-size water treatment plant. The filtration captures anything down to a 10,000th of the thickness of a human hair such as bacteria, viruses and pesticides. Water is extracted from the Oise River, decants for two days and is filtered through sand and charcoal before being pressured through spiraling tubes of nanofilters at 8–15 bars. More than 3 million $ft^2$ of filter surface is used to produce 4 million $ft^3$ of water ($\sim$30 million gallons or $>$113,000 $m^3$) that is now servicing 300,000 households. The cost of production is about 10 cents more than conventional treatment but the capital investment for the plant was only $150,000 (Pigeot, 2000). Although the nanofiltration does not remove dissolved heavy metals, the technology offers a major advance in solving water availability problems for some areas.

## *Import via Sea-Towed Containers*

In still other situations, it may be plausible to import water from one country to another. Israel has examined the possibility of importing water from Turkey in towed sea containers but has not opted for this solution to help service its water needs. Nonetheless, this could be a partial solution to coping with drought, needs of a larger population, and increasing agricultural and industrial demands. The import of water using this option has to be within economic reach, necessitates an infrastructure for storage and distribution of the water, and the water source has to be reliable and thus removed from any political maneuvering. Water-deficient nations with seaports and relatively nearby extraterritorial water sources can consider this option as needed seasonally or in reserve for extended droughts.

## *Seasonal Supplies and Yearly Shortages*

Another aspect of water macro-problems is in regions with plentiful water seasonally, perhaps few months annually, but little or no water during the rest of a year. In such cases, plans to alleviate seasonal scarcity of water have to include storage of water (e.g., in surface reservoirs and/or underground facilities) in volumes large enough to sustain populations and their activities during dry periods (e.g., 3–6 months). If large enough volumes cannot be stored, a region's water supply must be rationed and/or supplemented from distant sources. Failing this, populations may migrate with the seasons or subsist as best they can under drought conditions.

## *Limitations to Coping With Water Supply and Quality*

The limitations to making safe and sufficient water available for people and their activities have already been emphasized. One major limitation is economic as developing countries do not have the financial resources to invest in projects to increase water supplies for existing populations much less growing populations. Financial aid that they receive from economically advantaged countries and/or international institutions can be designated for use only on developing safe water sources. Initially, hydrogeologists set out to identify sites where there may be aquifers. Once geologically favorable sites are located, funds are used for drilling wells to prove out an aquifer, determine its water quality, and the amount of water that can be withdrawn long-term that will be in balance with the amount of recharge to the aquifer. This will prevent over pumping and an excessive draw down of the water table that could be detrimental to the aquifer. Once the aquifer is proven out as a reliable supply, funding can be sought to build an infrastructure to distribute the water equitably to where it is needed. Depending on the water yield, funding may be used to develop a system to transport excess water to water-poor areas farther away. Alternatively, extra water capacity can be the basis for economic development in sectors such as light industry or agriculture. Where safe water aquifers or other water sources are limited in what they can supply long-term, funding, if available, can be used to invest in the infrastructure for a waste water collection, treatment, and distribution network for clean water. In this way governments can provide healthy living environments for their citizens. Perhaps the gravest limitation to solving water supply and quality problems lies with governments and their priorities which may misdirect available capital for purposes that are not related to economic, social, and political development (e.g., for military use). Problems such as this can be overcome and populations' water needs serviced with well-defined water projects and transparency in the use of loans or grant-allocated funds.

# Part II

## Water Chemistry and Pollutant Inventory

### *Natural Controls on Water Chemistry*

The pristine chemical content of water depends mainly on the solubility of mineral and organic components of the earth materials over which and through which it flows. Table 5.10 illustrates the chemical compositions of waters in soils formed from different rock types.

Solubility of earth materials depends on several physical, chemical, and biological parameters. The rate and volume of water flow during rock decomposition are important factors that affect the rates of mineral solution and the crystallization of secondary minerals.

The pH of waters affects the solubility of chemical elements and species. For heavy metals, solubility or mobility generally increases as pH becomes more acidic (values $< 7$) but this also depends on the reduction-oxidation potential (Eh). The Eh

**Table 5.10** Chemical composition of water associated with soil formed on some different rock types (modified from Langmuir, 1997). Values are in ppm except for pH

| | Ca | Mg | Na | K | $HCO_3$ | $SO_4$ | Cl | pH | Na + Ca |
|---|---|---|---|---|---|---|---|---|---|
| On Wissahickon schist, MD, USA | 4.2 | 3.3 | 5.4 | 4.9 | – | – | | 5.4 | 0.57 |
| On Woodstock granite, MD, USA | 5.8 | 15 | 4.9 | 0.9 | 80 | 11.6 | 0.8 | 8.4 | 0.46 |
| On granite Sierra Nevada Mtns, CA, USA | 7.0 | 0.3 | 3.9 | 1.0 | 34 | 0 | 0.4 | 6.9 | 0.36 |
| On basalt Kauai HI, USA | 0.9 | 1.9 | 6.3 | 0.6 | 6 | 4 | 9.1 | 5.1 | 0.88 |
| Limestone Central Florida | 34 | 5.6 | 3.2 | 0.5 | 124 | 2.4 | 4.5 | 8.0 | 0.09 |
| Limestone Central Pennsylvania | 83 | 17 | 8.5 | 6.3 | 279 | 27 | 17 | 7.4 | 0.09 |

Expect calcium and bicarbonate to be high in limestones.
Higher calcium and bicarbonate values plus lower pH in Pennsylvania indicate water in equilibrium with high $P_{CO2}$ Higher sulfate, chloride, potassium and sodium + high nitrate 0.01 in Florida vs 38 in Pennsylvania suggest anthropogenic contamination derived from sewage, fertilizer and road salting during winter.

determines if chemical elements or species in an ecosystem will gain or lose electrons. Oxygen in water or in air is a dominant oxidizing agent in most surface/near-surface environments. The chemical elements change their ionic charge (valence state) and alter to chemical species that will be more soluble or less soluble in water environments. For example, iron in an oxidizing environment will lose electrons and form iron oxide/hydroxide (rust). Changes in one or both of these parameters under ambient aqueous conditions increases or decreases chemical mobility and makes components of earth materials more able or less able to intrude ecosystems.

Figure 5.4 illustrates the coupled influence of pH and Eh on the solubility or mobility of some potentially toxic metals in different environments. For example, under acidic pH and low Eh (reducing = gain electrons) water conditions, As is mobile as the arsenite species, its most toxic form. Drinking arsenite-bearing water over time, cooking with it, or consuming crops irrigated with it results in As bioaccumulation in humans. This has caused grave health problems in parts of India and neighboring Bangladesh. Other examples of mobility conditions for potential toxic heavy metals are evident in Table 5.4. For example, the neurotoxin Hg is mobilized under oxidizing conditions in a slightly acidic environment, and Cr, which can give a false diabetes signal if it enters a food chain and bio-accumulates in humans, is mobilized under oxidizing but basic conditions.

Ambient temperature also affects earth materials solubility. In general, solubility increases with rising temperature. When temperature falls and/or there is a chemical reaction within a solution or between a solution and adjacent rock or soil, precipitation may take place. Precipitation removes an element or compound from the liquid phase.

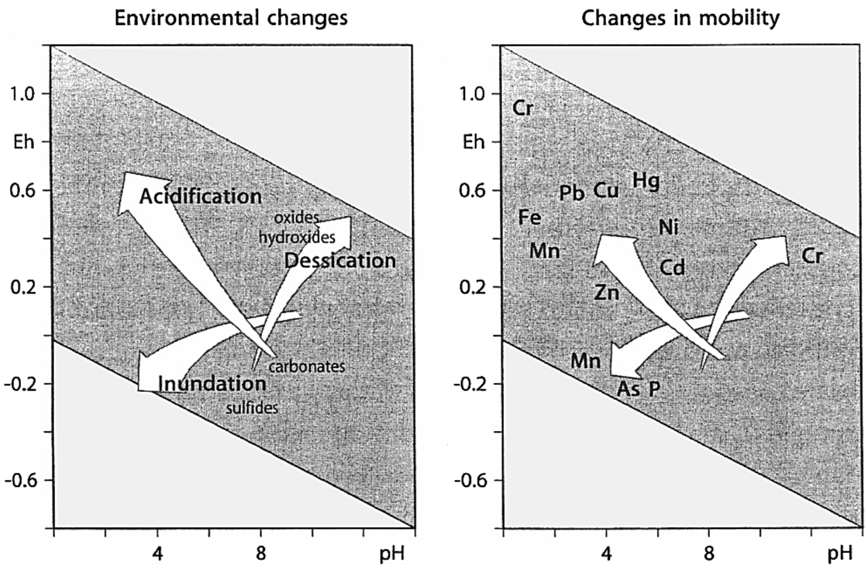


**Fig. 5.4** pH-Eh diagrams showing the coupled influence of acidity and oxidation-reduction potential on environments and on the main mineral classes controlling the solubilities of potentially toxic heavy metals and the resulting trends of increasing or decreasing mobilities (after Siegel, 1998; modified from Förstner, 1987 and Bourg, 1995)

Another important factor in mobility assessments is the saturation state of water with respect to a chemical element or compound. If water is under saturated with respect to an element, it is likely that a mineral containing the element in contact with water will slowly go into solution. This moves the system towards chemical balance. Conversely, water that is over saturated with respect to an element will precipitate it to reach chemical equilibrium.

## Sources of Water Pollutants

### *Natural*

As noted in the previous chapter, volcanoes, fumaroles, thermal vents, and hot springs are natural sources of atmospheric pollution. They also are direct or indirect sources of pollutants in water from volcanic ash and fluid emanations that reach water bodies. In the main, however, the decomposition of rocks and their component minerals and of ore bodies releases the greater natural chemical loads to surface and subsurface waters. This includes rock-forming elements Ca, K, Mg and Na as essential macronutrients, plus aluminum (Al) and silicon (Si). Heavy metals derive from ore minerals and some rock types (e.g., black shales). Some heavy metals are essential micronutrients. However, at higher concentrations, these and other non-essential heavy metals dissolved in waters are potentially toxic elements.

## *Ore Minerals*

Many common ores are found as sulfide minerals such as the copper mineral chalcopyrite ($CuFeS_2$), lead as galena (PbS), and zinc as sphalerite (ZnS). Several toxic metals such as As and Hg form their own sulfide mineral such as arsenopyrite (FeAsS) and cinnabar (HgS). Others may substitute in part for another heavy metal in its mineral such as Cd for Zn in sphalerite (Zn[Cd]S), or As for Fe in pyrite ($Fe[As]S_2$). Large amounts of the mineral pyrite ($FeS_2$) are omnipresent in most ore deposits.

Under ambient atmospheric conditions (oxidizing) and in contact with water, sulfide ores decompose and their metals mobilize naturally into waters and pollute ecosystems. The decomposition reactions, especially for pyrite, also release $SO_2$ that reacts with air and water to give $H_2SO_4$. Sulfuric acid is the principal component in acid mine drainage and acid rock drainage, aided somewhat by acid solutions from the decomposition of other sulfide ore minerals.

When soil scientists consider metals solubility and mobilization by waters moving through soils, they determine the phases in which metals are found and categorize the metals as being easily soluble, exchangeable, associated with iron-manganese (Fe-Mn) oxy/hydroxides, bound to organic matter, and residual (Fig. 5.5). As evident from Fig. 5.5, a greater proportion of cadmium (Cd) in a soil is easily soluble and exchangeable so that more mobilizes readily into solution than other metals represented in the figure. Conversely, chromium (Cr) is strongly bonded in residual minerals and is least soluble among the metals studied.

## *Anthropogenic Sources*

Human activities discharge inorganic and organic chemical contaminants into natural waters and degrade their quality. This input is generally more concentrated than that from natural sources. However, anthropogenic intrusion of ecosystem waters is manageable and controllable. Ideally, this would be through the education of polluters so that they voluntarily reduce pollution from their plants or factories by using available technology to clean wastewater before effluent discharge. Realistically, controls on water pollution have to be set through legislation that punishes polluters when they do not comply with laws until they agree to reduce the pollutant load from their facilities. This reduction can be accomplished by retrofitting up-to-date contaminant control technology at polluting sources so that effluents are clean when they discharge into ecosystems.

The use of contaminated water for humans' drinking water and hygiene, and for agriculture (field crops and animal husbandry) and aquaculture compromises an ecosystem's organisms even when waters do not contain action level concentrations.

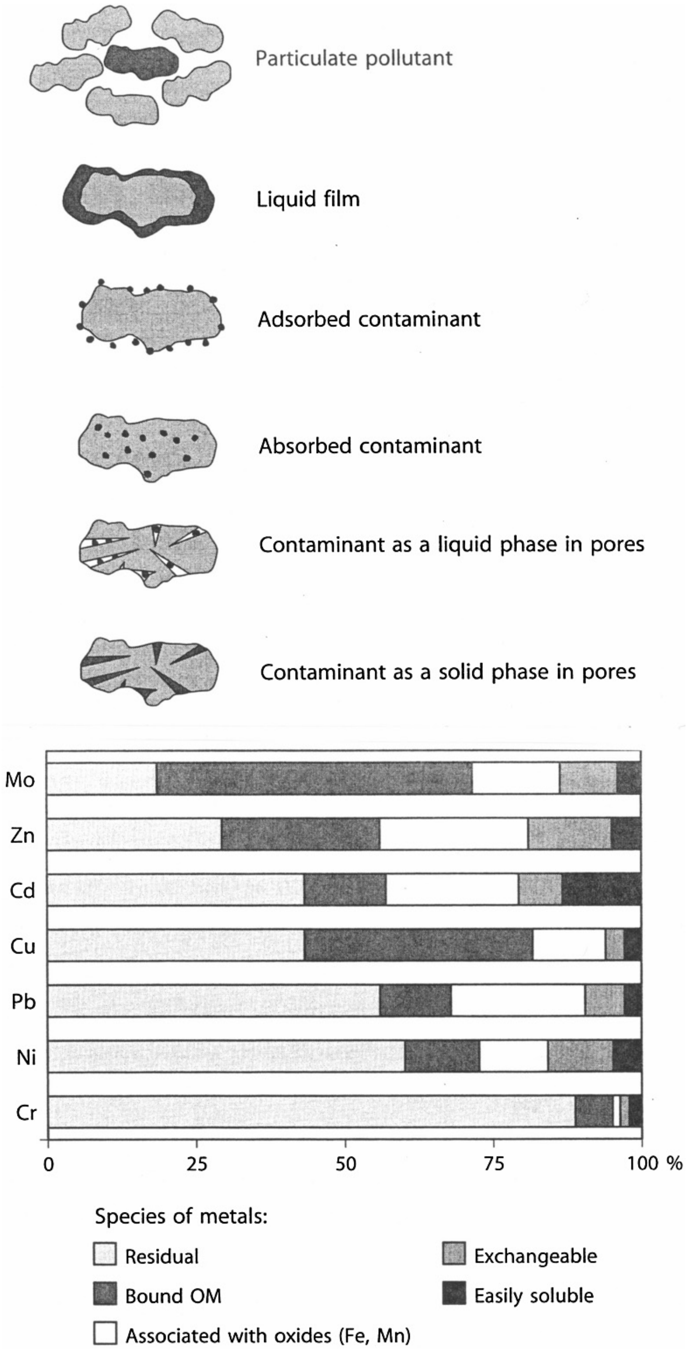


**Fig. 5.5** *Top*. Physical states of contaminants in soils and sediments. These affect the chemical reactivity, mobility and bioavailability of potentially toxic (inorganic and organic) chemicals (after Rulkens et al., 1995). *Bottom*. Extractability of some potentially toxic metals bound differently to solid phases of soils in Poland (after Kabata-Pendias, 1993). Distributions in sediments are similar

As already noted, this happens when organisms along a food chain or food web bioaccumulate one or more potentially harmful elements or compounds to toxic levels over extended periods of consumption. Humans, plants, animals, foul and fish, and other ecosystem life forms can fall sick, lose physical condition, be incapacitated, or die. If tainted waters are inadvertently used in industrial processes, they can cause defects in manufactured products (e.g., computer chips, chemicals, pharmaceuticals) or impart damaging or dangerous properties to them.

Chemical pollutants in waters and those in the atmosphere can issue from the same anthropogenic sources, but as effluents instead of emissions. Each source sector (industrial, manufacturing, agricultural, mining, domestic and business) has multiple sub-sources with their individual chemical fingerprints. As a result, pollutants in waters and their concentrations can vary greatly.

## *Industry and Manufacturing*

Industrial effluents carry toxicant metals and other inorganic and organic chemical wastes. They are major sources of surface water pollution that can pollute aquifers as well. Table 4.3 listed heavy metal contaminants that are commonly found in effluents (and emissions) from representative industrial operations. For example, pulp and paper factories have discharged Cr, Cu, Hg, Ni and Pb in their wastewaters. The Hg discharged from a pulp and paper factory into Minamata Bay, Japan, bioaccumulated in food fish, a staple for inhabitants of villages on the bay. Daily consumption of the fish and Hg bioaccumulation in humans was responsible for death and disability among the village populations. This was an early (1950s) environmental warning that alerted governmental health authorities and factory managers about sicknesses and deaths that contaminated effluents could cause. It was a poignant signal that industrial and manufacturing operations had to have pollution control equipment in line to remove contaminants from waste fluids before effluent discharge into water bodies and waterways. This can be done voluntarily or can be mandated by legislation.

## *Agriculture*

Farm and field runoff of dissolved inorganic and organic agricultural chemicals from fields treated with excess amounts of pesticides, herbicides, rodenticides and fertilizers invade surface waters directly. Runoff from fields that have been spread with animal wastes (e.g., chicken manure, cattle dung) is an important source of nutrient-rich water that adds to the fertilizer (nutrient) runoff. The nutrient-loaded water fuels blooms of algae and planktonic organisms (e.g., dinoflagellates) in water bodies. Dinoflagellates release a neurotoxin (brevetoxin) to ocean waters that cause great fish kills called the “red tide”. This has also killed marine mammals of the Florida coast and has cost the New England shellfish industry millions of dollars. At the end of their life cycles, dead algae, plankton, and other organisms fall to bottom waters where they decay using available oxygen. If the mass of decaying organic matter is large, it can create a biological oxygen demand that exceeds oxygen in the water. This will harm an aqueous ecosystem by eutrophication. Without oxygen in the bottom water, most organisms there either die or migrate to hospitable waters.

## *Waste Disposal Sites*

Wastes generated by human activities have to be properly disposed of to prevent contaminants they carry from damaging ecosystems and/or harming human health. Some wastes are inert (e.g., wood, brick, concrete from construction sites). Other wastes, inorganic and organic, contain potentially toxic metals and chemical compounds. If not checked, contaminants from disposal sites, mobilized in fluids (mainly rainwater), as windborne particles, and as bacterial or viral infectors carried by animal or insect vectors, can invade and harm ecosystems and their inhabitants.

Waste disposal sites are mainly at the earth's surface and are known as landfills or more commonly as dumps. In the special case of radioactive wastes, there are no true disposal sites but rather storage sites many of which are specially prepared underground bunkers. Wastes from coastal populations centers are often disposed of in the ocean. This can create problems for marine ecosystem and is discussed further in a later chapter.

Disposal sites are subject to leaching of chemical components from waste matter when rainwater seeps through a waste pile and runoff water moves through the base of a pile. Leachate loads vary with the waste material from which they originate from rather harmless if released into an environment or highly toxic if they intrude an ecosystem. Disposal sites are classified as secure or non-secure. Secure waste disposal sites are engineered to collect and trap leachates *in situ* in specially designed receptacles that prevent the escape of their toxic inorganic and organic components from a site. The leachates can subsequently be recovered for treatment and if necessary secure disposal. At non-secure disposal sites, contaminant-bearing leachates in seepage or runoff moves away from a site and pollute surface waters and aquifers (and soils) they reach.

Piles of mine tailings are sources of heavy metals pollutants and acid mine drainage in climatic zones where they are exposed to rainfall and aqueous runoff. They do not lend themselves readily to leachate control and mitigation of pollutant runoff. Abandoned mines close to the tailings piles add to heavy metal loading and acid mine drainage (AMD) into ecosystems. Continuous runoff from these sites endangers life forms and disrupts what otherwise were productive ecosystems. A solution to such problem sites is to divert runoff from them to treatment ponds. The ponds are prepared with liners to prevent seepage. In the ponds, contaminants are neutralized by precipitation of heavy metals and acid waters pH is raised to acceptable levels by reaction with bases. The cleansed waters can then be released into the environment.

## Pollutant-Bearing Precipitation

The previous chapter emphasized the fact that atmospheric precipitation can deposit a variety of contaminants from industrial emissions into water bodies. These include the familiar suite of heavy metals such as As, Hg, Cd, Pb, Sb and Se, fine particles, as well as $SO_2$, the precursor to $H_2SO_4$. Atmospheric contaminants can contribute significant masses to fluvial and lacustrine pollutant loads that may subsequently intrude aquifers.

In addition to contaminating surface waters, pollutant-bearing precipitation on land can combine with runoff and effluent discharge and seep into soils. The soils may strip pollutants from infiltrating waters under some physical/chemical conditions. Under other physical/chemical conditions, soils may release contaminants to infiltrating waters. The latter situation is a common pathway through which contaminants access and degrade aquifer water supplies and limit the usefulness of the groundwater.

## Inadvertent Water Pollution from Human Activities

Sources of water pollution are generally known and polluters are often aware that their activities release effluents that can harm environments. However, some industrialists may not be aware of the degree of environmental damage being done. This is plausible because of the long-term cumulative effect of a regular or an irregular feed of pollutants to an ecosystem. Once made aware of the hazards, some owners may install alleviation and abatement technologies into their operations so that waste effluent chemical element concentrations conform with or are less than permissible levels set by governmental regulations. Others industrialists may choose to ignore pollutant releases into ecosystems from their operations. They react to correct a pollution problem only when there is enforcement of environmental laws under penalty of substantial fines or closure.

## Example from the Sub-Continent

Arsenic poisoning in West Bengal, India and East Bangladesh is a good example of inadvertent water pollution. During the 1980s, the "green revolution" drove agricultural development in the two countries in a planned effort to improve food production for growing populations. The "new" agriculture required that additional wells be drilled in known aquifers to service greatly increased the number of hectares of new farmlands. Farmers dug and exploited 20,000 tube wells in an area where pre-development pumping from a relatively few wells satisfied the needs of municipalities and existing farms. High volume pumping of the 20,000 wells during growing seasons lowered the water table seasonally and exposed aquifer strata to aeration and oxidation.

Agricultural planners and their consultants did not assess the mineralogical and chemical compositions of the aquifers before digging the 20,000 tube wells. Thus, they were unaware of the presence in the aquifer strata of the mineral pyrite ($FeS_2$) that contained As that substitutes for part of the iron ($Fe[As]S_2$). Oxidation during seasonal aeration triggered the decomposition of the pyrite and released As to aquifer water as the very toxic arsenite species (Fig. 5.4). Bioaccumulation of As in humans over several years from drinking and cooking with arsenite-laced water and eating food grown under irrigation with the water resulted in As poisoning of at least 200,000 people. Many people were seriously ill and at risk for cancer and other sicknesses. Medical personnel and epidemiologists estimated that several million people could be at risk from As poisoning (Dipankar et al., 1996, Bagla and Kaiser, 1996, Salopek, 1997, Voight et al., 1996). Clearly, planners did not foresee the impact of high seasonal pumping on water quality from a changed subsurface chemical environment.

The As poisoning was a signal event which had two effects. First, economic planners learned that they had to evaluate any consequences of natural system changes on minerals comprising aquifer rocks from seasonal heavy extraction of water. Planning teams have to thoroughly assess models of changes that can be expected over time in strata and aquifer waters and the environmental impacts of such changes on populations. Second, if analysis predicts a release of a toxicant from over pumping (such as arsenite in the India-Bangladesh case), the planned development for which well water is essential has to be modified. Project plans must include proposals for implementing methodologies to capture a contaminant at the wellhead or prevent its release from aquifer minerals into waters. Only this will allow development to proceed safely. Signal events in the past, such as this one, alert development consultants to potential problems from contaminated water so that project design and engineering can avert them.

The fact that the As poisoning resulted from bioaccumulation by ingestion of low concentrations over time led health organizations worldwide to reconsider the safe water standard values. The WHO and EEC lowered the maximum permissible concentration for As in drinking water to 0.01 ppm. This lead was followed by the USEPA and health agencies in many countries.

## Alleviating/Eliminating Water Problems

The preceding sections of this chapter considered human actions or inactions that degraded water, affected how water could be used, and limited its availability as a commodity necessary to sustain life. Only a convergence of political, social, and economic wills can solve problems of water quality, water supply and distribution, costs for safe water, and management of anthropogenic activities that can pollute waters.

## Political Strategy

The political approach to keep water safe for humans and for uses such as crop irrigation is legislative. Politicians draft bills that mandate that owners of polluting sources reduce contaminant levels in effluents to concentrations that meet water quality standards. Similarly, legislators draft proposals that would force municipalities to consider the construction of water supply and distribution networks especially in light of serving the needs of expanding populations. Political staffs study and modify most aspects of clean water legislation to benefit their constituencies (e.g., domestic, commercial, agricultural, industrial). They send the modified proposals to legislatures with the expectation that they will become laws. As with any environmental protection law, the key to compliance is enforcement. A first stage in the enforcement of clean water laws is the threat of the imposition of fines. The expectation is that this will convince the owners of polluting facilities to install, use, and maintain treatment systems so that their contaminated wastewaters meet clean water requirements before discharge into the environment. If fines do not bring a source into compliance with the law, government representatives can shut it down until there is compliance. Governments may opt to keep a facility operational to protect jobs and a tax base, or for national security. In this case, the government takes responsibility for installing technologies that clean polluted waters before release into an environment and charge the costs to the owners of the facility for doing so.

In still other situations, government authorities have sought to amend some legal regulations in favor of polluting industries. However, in countries where government officials are elected, the voting public has brought its political pressure on elected representatives to maintain the regulations that keep waters safe. For example, in the United States, lobbyists for water treatment facilities and some municipal governments wanted USEPA drinking water standards for As kept at 0.05 ppm, five times the 0.01 ppm standard set by the WHO and the EEC. This was a politico-economic decision aimed at keeping costs down for As removal from drinking water. The industry friendly U.S. administration in 2002 favored the economic argument. However, health professionals' pressure and people pressure (influence of votes in the 2002 congressional elections) brought about a change of political attitude. As of January 2006, the revised As standard in drinking water for the United States was 0.01 ppm.

## Social Strategy

The voting issue is political action grounded in social awareness and responsibility. Education supports changes that work to prevent water pollution along two main tracks. One track focuses on water quality, availability, and use. Education emphasizes how society can help preserve safe water by following good hygiene and sanitation habits, by using only the amount necessary for a task, and by using secure waste disposal sites. The importance of water conservation and its role in water availability is basic to development programs. Education is necessary to show how responsible water allocations for competing sectors of an economy will allow steady development. This follows a humanistic hierarchy of priorities with domestic use first, agricultural use second, and industrial or manufacturing use last.

Lack of water conservation in the rapidly growing Chinese economy presents a threat to large populations. Industries, manufacturers, agriculture, service providers, and newly economically advantaged urban populations are demanding more and more water. Demand exceeds supply. An inadequately planned water diversion projects to increase a water supply for economic growth in urban areas of China is causing water shortages and uncommonly dry conditions in rural and other areas. The resulting reduction in water supply affects 400 million rural and urban poor at risk, especially peasant farmers who contribute greatly to China's food needs. The shortfall of water for irrigation or imposing higher prices for the delivery of this precious commodity puts farm agricultural productivity at risk. If such decisions on the distribution and use of water continue, the hard won achievement of China being able to feed its populace would be threatened and China would become an importer of food. Clearly, the Chinese government did not learn from the environmental disaster that nearly destroyed the Aral Sea, when in order to support cotton farming, the former Soviet Union diverted water that fed the Sea.

In many developed countries farmers pay less for irrigation water than do urban populations for their water. If supply goes down, or remains stable but with farmers paying a higher price for water, food costs would increase to levels people might not be able to afford. The same is true for other farming regions worldwide whether in less developed or developed nations. Inaccessibility to food because of cost will lead to social unrest and is to be avoided.

A future Chinese water supply problem and those in other countries can be alleviated using several tactics cited before: (1) conservation in agricultural projects by using directed irrigation (e.g., drip irrigation); (2) recycling by industry such as in Japan where 90% of water used is recycled; (3) and investment in wastewater collection, treatment and cleansed water distribution systems. The Chinese Environmental Protection Administration is strongly supporting these and other efforts to more efficiently use water supplies. The Chinese EPA has taken this stand in spite of the less than enthusiastic backing of Beijing officials who are reluctant to take steps that could slow down the growth rate of the country's economy. Nonetheless, these steps will have to be taken, sooner rather than later, to preserve social stability and a climate that invites investment in projects that drive development.

A second track focuses on social pressure that can bring about a change in attitude and responsibility of water polluting entities. Initially, educated individuals or respected organizations work to gather unequivocal evidence to show polluters the environmental problems they cause. Next, this is coupled with the presentation of sound technical advice to polluters on how they can improve their operations so that they discharge clean water. A final step in education emphasizes the importance of voting power and how to work as political action groups to bring pressure on politicians. Positive pressure brings about better responses than negative pressure. Positive pressure means contributing to, campaigning for, and voting for politicians who support legislation that mandates and enforces the clean up of water-polluting sources.

### *Economic Strategy*

Investment in infrastructure to make safe water available and accessible to urban, suburban, and rural populations in cities and villages where it is necessary follows two tracks. First, the *modus operandi* in many nations has been well-funded engineering projects that meant laying networks of pipes to draw contaminated waters from rivers and lakes, and in special cases sewage, move it to a treatment plant to clean it physically, chemically and biologically, and then distribute the safe water to consumers. Second is to build up an infrastructure to move safe water (regionally) from where it is plentiful to where it is lacking. In both situations, the cost of water has to be in line with a country's economic condition and the general population income. A country has to prepare for its future with the realization that safe water and healthy populations are critical to social, economic, and political progress. Some less developed countries with rapidly expanding populations do not have nationwide or even citywide functioning safe water programs to prevent onslaughts of water-borne diseases. Only economic assistance from richer nations and no-cost or low-cost loans from international and regional lending agencies can supply funds to bring safe water to what have been disenfranchised populations.

Social-economic action can give rise to boycotts of goods produced at facilities that pollute clean water environments irrespective of lack of laws that prohibit pollution. Boycotts have brought enough economic pressure on some polluters to force them to treat contaminated effluents in their facilities before discharging them into an environment. As described previously, voting brought enough pressure on the United States congress and administration in 2002 to lower maximum permissible concentration limits for As in drinking water based on best available global health data. This cut profits for water supply companies but upgraded public health. A threat of fines or take over of pollutant sources imposed by laws are convincing reasons for managers to control pollutant contents in effluents at offending facilities.

## Afterword

Water and air, complemented by organisms, interact to disintegrate and decompose rocks during the formation of soils. Clean water and clean air interact with soils that provide humans and other living organisms with food…grains, vegetables, fruits, nuts, fodder, food animals, and other natural resources. Uncontaminated soils yield safe food products. Pollutants from soils intruded by contaminated air and water can translocate into field or tree crops and to food animals that consume them.

They may hurt crop yield or quality and diminish food supplies. The pollutants can bio-magnify in food crops and food animals to concentrations dangerous to the health of consumer populations. In the following chapter we will examine the chemical contents of soils and their importance in growing food supplies for expanding populations.

# Chapter 6
# Soil Formation, Quality, Sustainability

## Soil: Generic Definition

Soil is an upper layer of unconsolidated material at the earth's surface that can be plowed or dug into. It contains varying amounts of sand-, silt- and clay-size particles, and ever changing contents of fresh and decomposed organic matter. Soil chemistry is derived in part from the parent rock from which it forms and in part from environment conditions where it evolves. The nutrients and other chemical elements and compounds in soil are important factors that determine its productivity.

A soil promotes vegetation growth when it contains sufficient contents of 16 essential plant nutrients (Table 6.1) and retains moisture at or close to the surface environment. Without sufficient essential macro- and micronutrients and moisture to sustain plant life, soil loses fertility. A plant deprived of any one of the essential elements in a growth environment will fail.

Sustainable productivity is predicated on multiple management strategies. One is to conserve the physical soil against loss by erosion. A second is to replace soil nutrients in amounts equal to that being used by crops and other vegetation. Another is to protect soils against an intrusion of pollutants that can damage a harvest. Chemical pollutants that intrude soils from natural or anthropogenic sources can cause a decrease in the quality and yield of cultivated products depending on the uptake and response of a crop to a pollutant. Lastly, it is necessary to protect a soil environment against other degradation factors such as salination or water logging. A healthy soil will sustain continuous vital activity of organisms (bacteria, worms, plant roots and others) which themselves work to promote growth of a diversity of plant life. This in turn bolsters animal life and agricultural activity.

## Societal Need: Productive Soils

Soil stores water that carries macro- and micronutrients, and essential trace metals and moderates their release to plants. The chemical elements and compounds translocate through the food web to supply essential nutrients for humans (Table 6.2).

**Table 6.1** Nutrients essential for plant growth (Tucker, 1999)

Nutrients from air and water:
Carbon (C), Hydrogen (H), Oxygen (O)

Nutrients from soil (also from lime and commercial fertilizers):

| Primary Nutrients | Secondary Nutrients | Micronutrients |
|---|---|---|
| Nitrogen (N) | Calcium (Ca) | Boron (B) |
| Phosphorus (P) | Magnesium (Mg) | Chlorine (Cl) |
| Potassium (K) | Sulfur (S) | Copper (Cu) |
| | | Iron (Fe) |
| | | Manganese (Mn) |
| | | Molybdnum (Mo) |
| | | Zinc (Zn) |

A plant deprived of any one of these elements will cease to exist
Primary = used in largest amounts by crops
Secondary = required in much smaller amounts by crops than primary nutrients
Micronutrients = required in even smaller amounts by crops than secondary nutrients

**Table 6.2** Essential nutrients for humans (after Crounse and others, 1983, Fergusson, 1990, Merian, 1991)

Essential macronutrients (100 mg/day or more)
Calcium (Ca), Chlorine (Cl), Magnesium (Mg), Phosphorus (P), Potassium (K), Sodium (Na), Sulfur (S)
Essential micronutrients (no more than a few mg/day)
Arsenic (As), Chromium (Cr), Cobalt (Co), Copper (Cu), Fluorine (F), Iodine (I), Iron (Fe), Manganese (Mn), Selenium (Se), Silicon (Si), Vanadium (V), Zinc (Zn)
Possible essential micronutrients
Nickel (Ni), Tin (Sn)
Harmful metal trace pollutants that have been ingested and have bioaccumulated to the level that they have caused grave illnesses in human populations
Aluminum (Al), Arsenic (As), Cadmium (Cd), Lead (Pb), Mercury (Hg)
Others
Antimony (Sb), Barium (Ba), Beryllium (Be), Boron (B), Bromine (Br), Lithium (Li), Rubidium (Rb), Silver (Ag), Strontium (Sr), Titanium (Ti)

Nutrient-sufficient soils and availability of water are the foundations for productive agriculture and a sustainable food supply. They are the growth medium for 90% of all human food, livestock feed, fibers, and fuel wood. Unfortunately, the geographic distribution of good soil and favorable growing conditions are lacking in many areas leaving many populations food-deficient. This is particularly true for areas of Africa and Asia where a problem of food (nutrition) scarcity will intensify where there are high rates of population growth. The distribution problem also exists for water (Chap. 5). However, when economic resources are available, water can be moved from water-rich to water-deficient areas by aqueducts and canals or by pipelines and pumps. Soils cannot be moved, but their ability to support growth and maintain productivity can be improved.

In addition to nourishing life, soils provide other benefits to ecosystems. They partition rainwater, melt water, and irrigation water among infiltration into earth surface materials and underlying aquifers, and runoff into streams, rivers, and lakes. Soils can adsorb and immobilize many waterborne potentially toxic chemical elements and compounds and other manufactured contaminants. This prevents a contaminant release to growing vegetation and to surface and subsurface sources that supply water for human consumption and for cropland irrigation. Other pollutants that do not adsorb onto soils can move from soil to crops, be passed on to humans and food animals that feed on contaminated crops, or pass from food animals to humans. Soil amendments selected to inhibit chemical mobility in a growth environment can reduce or arrest pollutant transfer. This is discussed later in the chapter.

Soils deteriorate from erosion, other physical processes, depleted nutrient reservoirs, salination, and intrusion by pollutants. When productive soils fail from such degradation or insufficient water supplies, populations disperse and civilizations fall apart. This has been suggested as one of the causes of the scattering of the peoples of the Mayan civilization. In modern societies, the economic impact of soil degradation is severe for countries with economies dependent on agriculture and forestry. To sustain food production in developing countries, a myriad of farmers worldwide clear forests and cultivate small parcels of land, some initially marginal. This activity is endemic in regions and countries with large and/or rapidly expanding populations (e.g., in Africa, Asia, and Brazil). Many of these farmers use agricultural practices that deplete soil nutrients and physically disrupt soils to put them at high risk of erosion by moving water and wind. After short periods of time, poor farming practices result in low crop yields that do not meet societal needs.

Fertile soil assures continued existence of life on Earth. Without it there is little human settlement. In the minds of futuristic thinkers, *in-situ* generated soils are the keys to human colonization of other planets. Mars?

Chemical characteristics of soils will affect proposed agricultural development projects. Thus, soil chemistry has to be thoroughly evaluated. Project assessment should also include the physical nature of soils and their engineering properties. These factors will affect the responses of a soil to natural events such as earthquake shaking, jarring and rolling motions, high intensity rains, water infiltration, and a changing water table. A knowledge and consideration of such factors and other civil engineering and geotechnical data will determine the land use and construction norms for project sites.

## Soil Formation

Soils develop slowly through the physical disintegration and biologically assisted chemical decomposition of rock materials in the process called weathering. An understanding of the physical, chemical, and biological parameters that affect soil formation is essential for planning long-term agricultural programs. Also important to the planning is an appreciation that soils are sensitive, fragile systems that will deteriorate if not shielded against degradation processes. These may be natural (e.g., erosion), from bad farming practices, or from intrusion by anthropogenic or natural chemical pollutants.

## *Disintegration + Decomposition = Weathering*

Disintegration is the physical break up of rocks. As a lone process it does not yield soils. When disintegration is coupled with decomposition by chemical and biological activity, soils are created. Disintegration creates small pieces of rock from large ones and increases surface areas many fold to permit a more efficient chemical attack that promotes decomposition. For example, a cube 10 cm on a side exposes 600 $cm^2$ of surface area to chemical attack. If this cube is divided into 8 equal parts, 5 cm on an edge, the volume (1000 $cm^3$) will be the same as in the first example but 1200 $cm^2$ of surface area are exposed to chemical reactants. Continuing the division of the same volume to 32 equal parts, 2.5 cm on an edge will expose 2400 $cm^2$ of surface area to chemical weathering and markedly increases the rate of soil formation.

Disintegration acts in one or a combination of ways. At high altitudes and high latitudes, water seeps into hairline fractures in rocks during the day. If the water turns to ice during freezing nights, the expansion of ice exerts a force that further widens and deepens fractures. New fractures will likely open. When frost wedging loosens large pieces of rocks and gravity pulls them free, they tumble from higher altitudes to lower altitudes smashing into the rocks beneath giving rise to further disintegration. Different coefficients of expansion of minerals comprising rock faces cause them to fall apart as well. This happens when there are marked diurnal changes in temperatures. The repetitive differential expansion and contraction over long periods of time ultimately causes separation to take place between minerals, weakening the rock with inter-crystalline fractures. This leads to a flaking breakup of rock called exfoliation. Exfoliation can be abetted by frost wedging after water seeps into fractures during the day and turns to ice during freezing nights, and by plant root growth in fractures with nascent soils.

During decomposition, carbonic acid ($H_2CO_3$) attacks rock matter. Chapter 4 showed that the union between $CO_2$ and water in the atmosphere produces $H_2CO_3$. Additional $CO_2$ in soils from decaying organic matter and from micro-biota (bacteria, nematodes) reacts with moisture during weathering to increase $H_2CO_3$ activity. Organic acids generated from decomposing organic matter (e.g., humic acids) in weathering environments augment the chemical attack on exposed rock surfaces.

Other internal factors besides acidity affect rock decomposition and chemical element (nutrients, metals) mobility in a soil-forming environment. Porosity and permeability of earth materials control the volume and rate of water flow (hydraulic conductivity) in soil and rock. Water flow and temperature affect decomposition intensity or effectiveness of various other physical/chemical parameters (e.g., pH, reduction-oxidation potential [Eh]) that relate to soil formation. To a great degree, these factors control chemical element mobility and sorption activity between chemical elements, soil minerals, and water (adsorption, desorption, absorption), and the activities of ecosystem dwellers (microbes, bacteria). Clearly, multiple parameters influence solubility of minerals comprising rocks and determine whether elements are dissolved from them to break down a rock framework.

## *Factors That Play Roles in Weathering and Soil Formation*

Physical, chemical, and biological processes acting together disintegrate and decompose rock matter. They reorganize decomposed rock mineral and chemical components into earth material that sustains vegetation growth: a soil. The character of a soil that forms and its fertility depend on six interrelated factors: rock type, topography, climate, vegetation, drainage, and time.

## *Rock Type*

Soils inherit the chemical imprints of their parent rocks. This is true of macronutrients such as K, Na, Ca and Mg, and micronutrients such as Fe, Cu and Zn. A parent rock containing ore metals minerals will leave its metals chemical imprints in soils that form from it. Naturally contaminated soils can have high concentrations of potentially toxic metals such as As, Cd, Hg and Pb from (sulphide) ore minerals in rocks or from parent rocks without ore minerals but with natural high concentrations of potentially harmful metals (e.g., Cr, Ni and Co (cobalt) in peridotite or serpentine). In these cases, soils contain contaminants that may translocate to food crops. Other parent rocks lack some essential nutrients and soils that form from them carry the deficiency.

There are optimal concentrations of chemical elements that support the growth of "safe to consume" vegetation in a soil. Too little of macro- or micronutrients (including essential heavy metals) in soil can lower crop quality and yield and pass the deficiency on to consumers. Over an extended period of time, this deficiency can harm the well-being of populations that depend on crops for nutrition, especially children. For example, in 1980, a link was found between very low concentrations of the metalloid selenium in the rocks, soils, and waters of an area in China (Chen et al., 1980). This gave rise to a deficiency of Se in the food web. The Se deficiency in diets of children originated a cardiomyopathy condition (Keshan disease) and was responsible for a great number of deaths before the causal relationship was established. A weekly supplement of Se of 0.5-1.0 mg (dose is determined by age) by pill eliminated the incidence of Keshan disease in China (Yin et al., 1983). This was a signal event to alert other world areas where Keshan disease has been diagnosed and prevalent to the probable cause of and therapy for this medical malady. Gupta and Gupta (2000) wrote that livestock can suffer diseases from Se deficiency. They reported that feed crops containing more that 0.1 mg Se per kg (0.1 ppm) protects livestock from Se deficiency disorders. These include muscle disease in calves, sheep, and goats, and heart disease in pigs, all important food animals.

Although excess concentrations of potentially toxic metals in soils can be taken up by vegetation and harm crop quality and yield, some vegetation or crops absorb pollutant metals without harmful effects. Consumers of pollutant-enriched edibles can bio-accumulate the metals to health-threatening toxic levels. For example, rice grown in soils formed on a uraniferrous black shale containing 6.3 ppm Cd in the Deog-Pyoung area of Korea contains a high content of 0.6 ppm Cd (Kim and Thornton, 1993). The average daily intake of 574 gm/day of rice translates to an ingestion of 344 μg/day of Cd, a concentration that caused osteomalacia ("itai-itai" disease - degradation of bone to cartilage-like consistency). The "itai-itai" affliction had a high incidence of occurrence in areas of Japan where rice had been contaminated with Cd that originated from mine drainage into river waters. The rice was irrigated with these waters and the populations drank and cooked with the waters (Kobayashi and Hagino, 1965). Ogawa et al. (2004) found that there was also a strong positive relation between Cd in rice and renal disfunction when they evaluated people who had lived in the same areas for 30 years and were at least 50 years old. The Korean dietary Cd load increases from eating leafy and other vegetables (e.g., lettuce, cabbage, red pepper) as well as from smoking tobacco grown in the Cd-rich soils. Tobacco contains an average of 14 ppm Cd in dry matter (to a maximum of 46 ppm). This means that each pack of cigarettes adds 42 μg to the ingested Cd load (Kim and Thornton, 1993). The population in the Deog-Pyoung area of Korea is at risk for osteomalacia and kidney disease from the ingestion and bioaccumulation of Cd (Nordberg et al., 1996).

## *Climate and Vegetation*

Climate and vegetation are arbitrarily coupled here as a single factor because an area's temperature, humidity, precipitation, and orientation with respect to the sun, determine the distribution of vegetation. In any region, there will be a transition from one climatic zone to another. There will be a like transition from one vegetation zone through mixed flora to another vegetation zone. As illustrated in Fig. 6.1, vegetation distribution by climate follows changes in latitude or altitude. Without water, rock decomposition (by chemical and biological attack) will be minimal and retard soil development. Without nutrient sufficient soil, flora cannot take root and grow.

Vegetation is an integral part of soil formation because acid at root tips contributes to rock/mineral decomposition and also mobilizes nutrients into plants (Fig. 6.2). In addition, plant roots growing in nascent soils in rock cracks functions as a wedge, slowly but continuously widening and deepening them. This increases rock surface area for chemical attack and speeds up the rate of chemical decomposition.

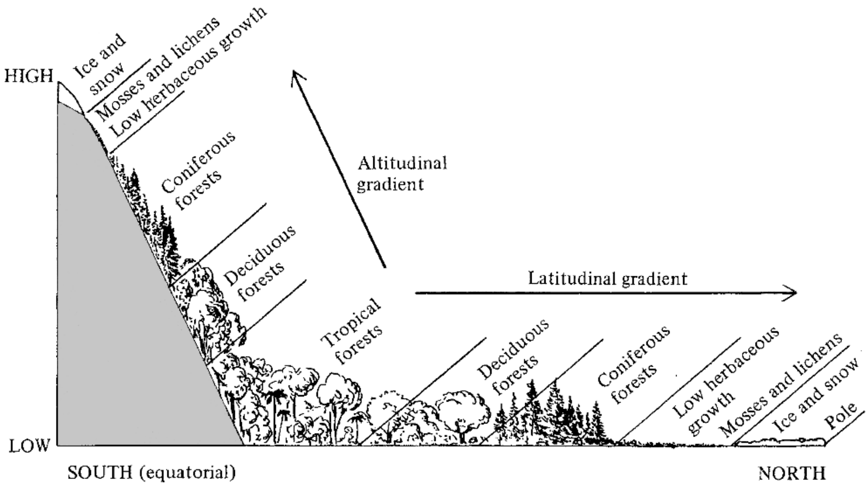


**Fig. 6.1** The parallel between the horizontal and vertical distributions of life zones (after Simpson et al., 1957)

## *Topography*

Topography affects soil erosion. Erosion takes place more readily in areas of steep topography where there is a faster runoff of precipitation than on flatter terrain where rainwater or melt water can seep into a soil-forming environment and abet weathering processes. Areas of steep topography are subject to mass movement where soils literally creep down slope under the influence of gravity. Soil creep is abetted by climate (precipitation or freeze-thaw cycles). Steep areas are also subject to landslides that displace soils, and to rock falls. These processes disrupt soil stability and favor erosion. There are variations in weathering environment microclimates with changing altitude that cause changes in biomes (organisms in an ecosystem). Topography is partly responsible for differences in a region's soils.

## *Drainage*

Drainage depends on topography and on the porosity and permeability properties of soils and rocks. Porosity is the capacity to store fluids. Permeability is the ability to transmit fluids. Thus, a loose or fractured soil comprised of sand-size particles allows precipitation to infiltrate readily and facilitates continued soil formation. Conversely, a poorly permeable tight soil comprised mainly of fine silt and clay allows less water infiltration. This results in more rain runoff, erosion, and less water for rock decomposition during soil evolution.

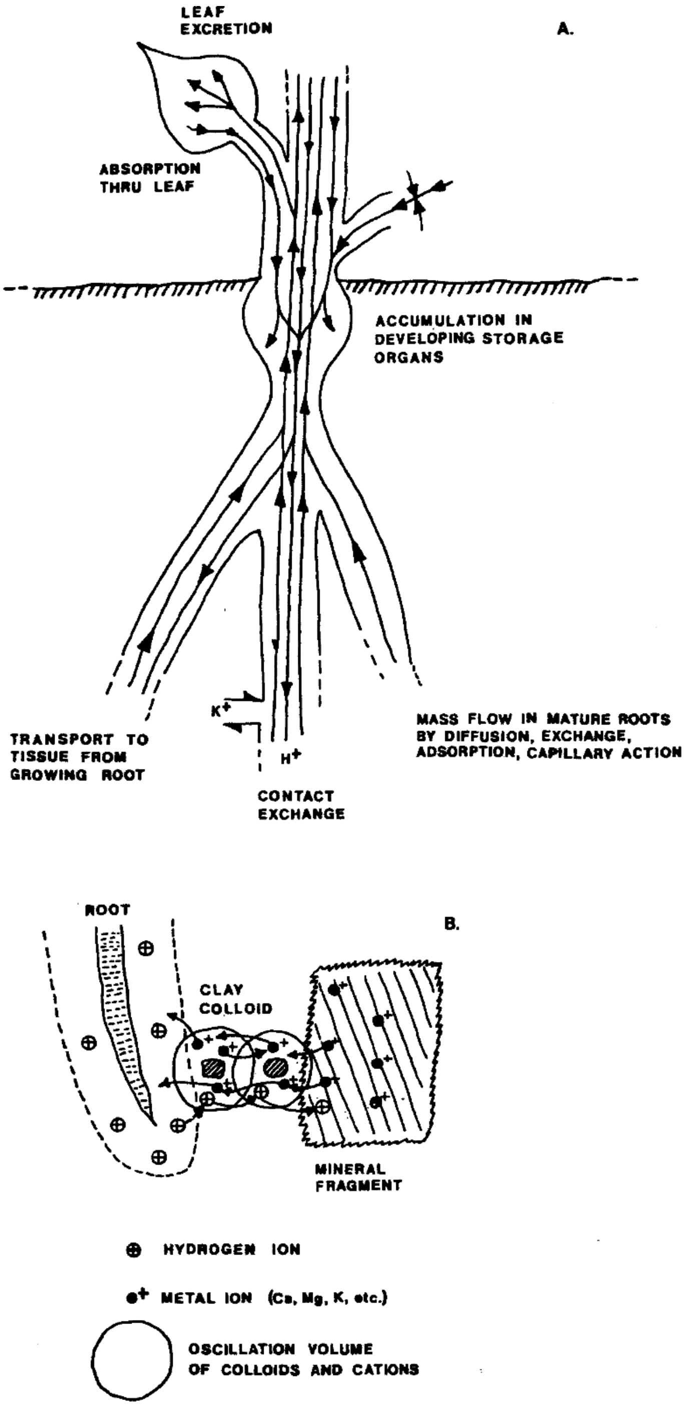


**Fig. 6.2** Graphic illustration of absorption and excretion processes in plants (*Top* after Sutcliffe, 1962; *bottom* after Keller and Frederickson, 1952)

### Time

It takes scores to hundreds to thousand of years for a soil to form from a parent rock. A soil exists when seeds can germinate, vegetation can root, and growth can proceed using the earth materials' store of nutrients. Soils may be thick or thin. They evolve continuously from underlying rock. Soil maturation is slower at high latitudes and high altitudes where it is cold and precipitation may be snow or water depending on the season, and where there may be permafrost. Soil forms faster in an area with good drainage where the climate is warm and humid.

### Products of Weathering

Weathering yields solids (detritus), dissolved nutrients, and other chemical elements and compounds. Minerals resistant to decomposition such as quartz, a major mineral in rocks, or accessory minerals apatite and zircon, can accumulates *in situ*. Part of the detritus can be eroded and transported out of the soil-forming environment by water or wind. Chemical elements released by decomposition go into solution or adsorb onto suspended matter. High concentrations of nutrients such as K, Na, Ca, and Mg, move in solution into surface waters and groundwater. Part of this dissolved load bonds with silica ($SiO_2$) and alumina ($Al_2O_3$) during the formation of soil to reorganize and recrystallize as new aluminosilicate forms called clay minerals. These mix with mineral detritus to provide a soil framework. The clay minerals contain nutrients essential to vegetation growth and are keystones to productive soils.

As noted earlier in this chapter, it can take hundreds to thousands of years for disintegrated, decomposed rock and incorporated organic matter to differentiate into nutrient-sufficient soils that sustain plant growth. In general, it takes a longer time for soils to develop in a glacial-periglacial region (colder, less flow through of precipitation and melt water) than in the humid tropics (warmer and greater flow through of infiltrating rain water).

## Soil Horizons - Soil Classification

### Horizons

A soil begins to form from the top down on a mass of rock. Over time, distinct layers called soil horizons become evident. By convention horizons are designated as A, B, and C, bounded above by an O layer (organic surface litter) and by parent rock (R) below (Fig. 6.3). Soil horizons are transitional one to another. They are defined by diagnostic criteria such as mineral and chemical contents, and by qualities such as texture (relative contents of sand, silt and clay), structure (granular, blocky, prismatic, platy), consistency (plasticity, stickiness), and color.

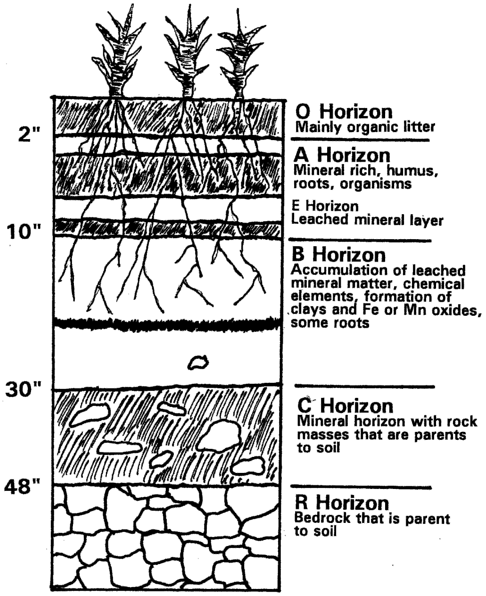


**Fig. 6.3** Master horizons of a soil profile (modified from U. S. Department of Agriculture)

**Table 6.3** Descriptions of master soil horizons including general estimates of water and gas in pores (modified from Food and Agricultural Organization of the United Nations, 1998)

| |
|---|
| H - mainly of undecomposed and partially decomposed organic debris and present where water saturates soil surface for long periods or where surface was saturated but has been artificially drained (wetlands) |
| O - layer mainly of undecomposed or partially decomposed organic litter (leaves, conifer needles, twigs, moss and lichens) accumulated on top of mineral or organic soils and not saturated with water for long periods of time; 25% organic matter and 75% gas |
| A - mineral rich formed at the surface or below an O horizon with no trace of an original rock structure with or without a mixing of humus with properties (e.g., morphology) resulting from surface-related processes that differ from underlying horizons; 5% organic matter, 15% gas, 30% water 50% mineral grains |
| E - mineral horizon that has suffered leaching and loss of silicate clay, Fe, Al, obliterating an original rock structure and leaving an accumulation of sand and silt; often lighter in color and coarser in texture than an underlying B horizon |
| B - accumulation of eluviated (leached) silicate clay, Fe, Al, humus, carbonates, gypsum (sulfate) or silica and residual concentration of sesquioxides (Fe and/or Mn oxy/hydroxides) especially as coating that make the horizon orangy/reddish versus the horizons above and below; the formation of clay and/or liberation of oxides can result in granular, blocky structure or prismatic structure if alterations include volume changes; may be brittle; trace organic matter, 10% gas, 20% water, 70% mineral grains |
| C - mineral horizon excluding bedrock that has not obviously been part of soil-forming processes; often the parent rock from which soil formed; 5% gas, 20% water, 75% mineral grains |
| R - bedrock (e.g., granite, basalt, limestone, sandstone, gneiss, dolomite) underlying a soil; 100% mineral grains |

Note: Horizons A and B make up what is designated as the solum.

Soils mature with time into sequences of horizons called soil profiles. Figure 6.3 is a representative horizon profile. Table 6.3 describes components of the master horizons or layers from surface to depth. Scientists also group soils into series. Soil series have similar profiles that develop from like parent materials under comparable geologic, climatic and vegetation conditions.

## *Classification*

Soils are classified into great mature zonal groups that are widely distributed and have common internal structural features. Underlying this is soil chemistry. For example, pedocals are soils found in relatively arid regions and have calcium carbonate layers (caliche) in the solum. Those called pedalfers are found in humid regions and have Al- and Fe-rich layers. Each soil group nurtures a characteristic vegetation cover in a climate defined by a range of temperature and precipitation conditions, and drainage (Fig. 6.4). As Fig. 6.4 illustrates, laterites are found in humid tropical climates in areas with good drainage. They represent earth materials that have been leached of essential nutrients rather completely and do not support significant plant growth. Laterites are not true soils.

Soils are also classified into major orders based on climates or environments where they occur such as bogs, deserts/edge deserts, and grasslands (Table 6.4).

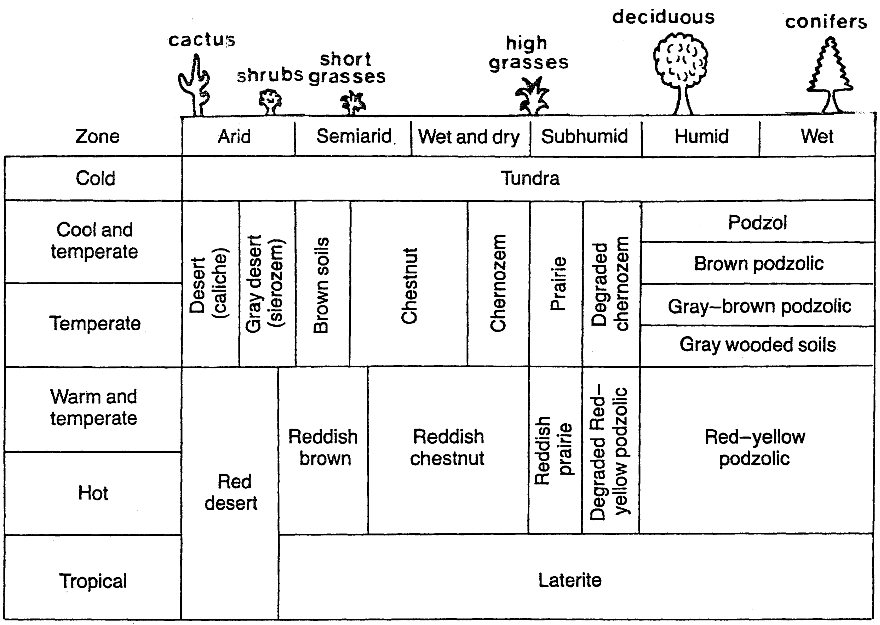


**Fig. 6.4** Soil classification based on the Great Soil Groups (modified from Rahn, 1986)

**Table 6.4** Soil orders (major categories) distinguished by the USDA (modified from Hunt, 1972)

| | |
|---|---|
| 1. Entisols | - soils without horizons except for a plowed layer |
| 2. Inceptisols | - very young soils with weakly developed soil horizons that have suffered little leaching or change in mineral composition |
| 3. Histosols | - bog-type soils |
| 4. Aridisols | - soils in arid and semi-arid environments, and related saline or alkaline soils; often with calcium carbonate (caliche) layer |
| 5. Mollisols | - grassland and steppe soils, developed on base- rich parent rock; have a thick organic matter rich A horizon and clay-rich B horizon with calcium and magnesium |
| 6. Spodosols | - soils with an acid leached A horizon, light ashy (podzols) gray in color, and a B horizon with organic matter and clay carried down from the A horizon |
| 7. Alfisols | - forest soils in humid/sub-humid climates; strongly acid-leached A horizons with clayey (often smectite clay) B horizons rich in nutrient base metals (calcium, magnesium, sodium and potassium) |
| 8. Ultisols | - deciduous forest soil; similar to alfisols but with chemical decomposition more advanced; includes some lateritic soils |
| 9. Oxisols | - still more strongly weathered that ultisols; includes most laterites |
| 10. Vertisols | - soils with inverted or mixed upper horizons caused by shrink-swell (smectite) clays; rich in exchangeable nutrient base metals (calcium, magnesium, sodium or potassium) |

The environments house biomes with wide distributions from low to high latitudes, along longitudes, and from low to high altitudes.

## Soil Quality: Indicators and Concerns

Soil quality is the capacity of a soil to sustain plants, and other organisms, and be productive in natural or managed ecosystems. It is assessed separately for individual soils in large and small areas using indicators that are sensitive to natural changes and to changes in soil management norms for different land-use planning programs. The indicators fall into biological, chemical and physical classes (Table 6.5). In the physical class, texture (sand to silt to clay relation) links soils. Texture affects a soil's plasticity, bulk density (increases with compaction), aggregate stability, structure, and water storage and retention capacity.

Soil properties and productive capacity can change for the worse with climatic aberrations such as an extended drought. They can also change for the better with sound management practices such as measured use of agricultural chemicals.

### *Quality Indicators*

Soil scientists use five characteristics to assess soil quality: organic matter, crusts, aggregate stability, infiltration, and pH (acidity/alkalinity relation).

**Table 6.5** Indicators of soil quality conditions (after Manaaki Whenua Press, 1999 and Landcare Research, 2001)

| | |
|---|---|
| Biological Indicators: | |
| | $CO_2$ production - a measure of microbial activity, organic matter mass inventory |
| | Microbial biomass - a measure of cycling of organic matter and nutrients |
| | Nitrogen content - soil supply of vegetation-available nitrogen |
| Chemical indicators: | |
| | Total carbon - organic matter inventory |
| | Total nitrogen - bioavailable nitrogen inventory |
| | Cation exchange capacity - buffering capacity and ability retain bioavailable nutrients |
| | Olsen phosphorus - vegetation available phosphate |
| | pH - acidity or basicity (alkalinity) of soil |
| Physical indicators: | |
| | bulk density - soil compaction, environment for rooting and soil organism support |
| | particle size - environment for rooting and soil organisms support, storage and release capacity of moisture and nutrients to support plant growth |
| | moisture release - water and air availability, water retention, drainage properties |
| | hydraulic conductivity - infiltration rate, drainage properties |

http://www.landcare.cri.nz/science/soilquality/index.shtml?mdsTable

## *Organic Matter*

Soil organic matter derives from decomposing remains of plants and animals. It generally comprises $<5\%$ of a soil volume. Decaying organic matter releases essential nutrients (e.g., $N_2$, P, S and C) into a soil. This maintains a good environment for soil organisms that in turn establish favorable conditions for plant growth. In addition, organic matter surfaces can adsorb and immobilize some potentially toxic metals, excess pesticides, and other chemical pollutants. This reduces pollutant interactions with a healthy soil ecosystem. Organic matter aids soil productivity because it resists compaction and keeps bulk density lower. This improves a soil's capacity to store water and air and makes it easier for germinated seedlings to emerge and plants to grow. Decomposing organic matter also binds soil particles together and provides a good foundation for plant rooting. The binding reduces erosion by water or wind. Non-decomposed organic detritus in topsoil makes it less cohesive and easier to work.

## *Aggregate Stability*

Soil aggregates are masses of particles that bind strongly to each other but not to adjacent particles. They are stable if they do not disaggregate by raindrop impact, flowing water, or wind. Soil aggregates impede erosion and keep pathways for water infiltration open. Aggregate porosity provides storage space for water, allows a ready exchange of $O_2$ and $N_2$ with the atmosphere, and provides space for plant root growth. Calcium in clay minerals improves the stability of aggregate as do concentrations of 5% iron oxides and the earlier cited higher contents of decomposing organic matter. Some microorganisms such as *Mycelia* exude organic matter that binds soil particles together to strengthen aggregates.

### *Crusts*

Soil crusts and desiccation cracks form when raindrops break up aggregates, move clay-size particles down into a soil, and evaporate leaving a sand/silt layer at the surface. Crusts also originate during freeze-thaw cycles when melt water carries clay particles down into a soil.

Soil crusts are mainly thin, 2.5–5 cm ($\approx$ 1–2″) and are underlain by loose soil. They destabilize surface materials by inhibiting water infiltration thereby causing increased runoff and erosion. Crusts restrict the exchange of air with the atmosphere and reduce oxygen diffusion to seeds. This inhibits germination. Crusts also create a physical barrier to the emergence of seedlings that do germinate. The potential impact of crusting on agricultural productivity can be countered by good management practices. This is done using a method appropriate to a problem area such as maintaining a plant or crop residue cover to reduce raindrop impact. Other methods involve increasing organic matter content in soils, amending soil to exchange Ca for Na, and keeping surfaces wet to reduce physical resistance to seedling emergence.

### *Water Infiltration*

Rainfall seeps easily into a soil with a stable granular, blocky, or prismatic structure and good permeability. Also, increased amounts of new plant cover and decomposing plant matter favor infiltration. Conversely, infiltration can be slowed or stopped in several ways. Pores can become clogged with fine-size detritus and pore space can be decreased by compaction from the use of heavy farm machines on wet soils. Clay-rich surface soils, soil crusts, frozen surfaces, or an impervious horizon below the surface also impede infiltration. This impermeability causes water logging of soils, ponding, and eventual runoff. Runoff can erode soils and transport harmful excess (unused) agricultural chemicals and potentially toxic metals in solution or adsorbed on sediment into aqueous ecosystems.

### *pH*

The previous chapter explained that pH measures acidity or alkalinity (basicity) of an environment. Strongly acidic soils have pH $<5.5$ with extremely acidic soils having a pH $<4.4$. Strongly alkaline (basic) soils have pH values $>8.5$. Commonly, essential plant nutrients are bio-available at soil pH values between 6 and 7. The acid/base condition of a soil is critical to plant growth because pH exerts an important control on the mobility and bio-available nature of essential macro- and micronutrients, including some essential heavy metals. It also influences the activity of micro-biota that decomposes organic matter and take part in other critical chemical reactions in a soil.

This can be a problem for crops if a contaminant metal is mobilized at the same pH conditions as essential nutrients. For example, at pH $<5.5$, several heavy metals are mobilized in soil moisture and can be taken up and bio-accumulated by vegetation. At the same pH, the availability of the nutrients Ca, Mg, and P (phosphorus) to plants is low. The pollutant metals problem is solvable in agricultural fields. Soils with a low acidic pH can be amended by the addition of finely ground limestone (calcium carbonate) to them. This is called liming. The correct amount of liming can bring soil pH to a preferred nutrient uptake range of 6–7. Microbial activity that yields $N_2$, S and P to a growth environment is favored by pH conditions between 6.6–7.3.

Soil amendments are matched by type and amount applied per hectare (or acre) to the needs of a specific soil. The effects of an amendment have to be monitored to assure that contaminants known from chemical analysis to be in a soil are not mobilized into sensitive ecosystems where they could access a food chain or inhibit absorption of essential nutrients by plants or other organisms.

If liming is the amendment used and an excess is applied it can raise the soil pH to $>7.8$. At this pH, most heavy metals are not mobile but the heavy metal Mo becomes mobile and bio-available. Agricultural planners have to be aware of this chemical fact because of the economic damage a bio-available metal can cause in farming areas. For example, if Mo bio-accumulates in cattle fodder, it will prevent the absorption of the essential micronutrient Cu in the same fodder by cattle or by other ruminants and cause hypocuprosis. In dairy cows, this is a disease that leads to weight loss, deterioration of condition, and decreased milk production. This hurts local economies dependent on dairy products.

A liming that brings a soil pH to $>8$ will restrict the availability of the essential macronutrient P and essential micronutrients such as Fe, Mn, Cu, Zn and boron (B) to crops. Land-use managers who know the chemical and mineral composition of a soil can work with agricultural consultants to control the application of liming or other soil amendments. A correct treatment can bring soil pH to an optimal level for crop nutrition without mobilizing those chemical elements or compounds that could harm crop quality and yield.

Soil pH also impacts pesticide effectiveness. Thus, soil conditions and crops must be carefully matched to pesticide type and amount used to maximize crop protection and minimize runoff that could degrade linked ecosystems.

It is clear that the mobilization and immobilization characteristics of soil components vary with pH. Soil pH can be adjusted to allow maximum crop uptake of macro- and micronutrients and fertilizers by food crops. The carefully fixed soil pH can also discriminate against the mobility and uptake of harmful metals and pesticides by crops.

Table 6.5 cited earlier summarizes the biological, chemical and physical indicators of soil quality conditions.

## Soil Degradation

The physical loss of soil, chemical damage to soil, and loss of soil fertility are gradual processes. They lower soil capacity as a growth medium to produce plants of suitable quantity and quality to satisfy the needs of existing and expanding populations. Soil degradation represents a loss of a natural environment for normal cropping and for food animal production. This differs from land degradation that affects development sectors such as transportation, raw material resources, and building

**Table 6.6** Reasons for soil degradation

| |
|---|
| **Physical degradation** - Erosion |
| Land clearing and overgrazing increases erosion by water and wind by destroying or decreasing a vegetative cover that functions to hold soils together and slow rainwater runoff |
| Compaction of soils by heavy equipment increases bulk density, increases resistance to rooting, affects soil structure and decreases porosity and permeability of soils and infiltration of rainwater or irrigation water causing greater runoff and water erosion |
| Crusting that resists water infiltration and prevents seedling emergence thus enhancing erosion by water runoff and wind |
| Eroded soil can move any pollutants present (heavy metals, fertilizers, biocides) into other media in an ecosystem |
| **Chemical degradation** - Nutrient and moisture loss, pollution |
| Depletion of soluble essential macro- and micro-nutrients by overcropping without refertilization and by removal, by leaching as water infiltrates through and moves out of soil system |
| Salination or precipitation of solutes from irrigation or rising water table and capillary action causes crusting on plant roots because of lack of an efficient drainage system or scheduled flushing to carry salts out of soil system |
| Pollution from sewage or industrial effluents and emissions containing harmful chemicals and/or potentially toxic metals and their adsorption by soil organic matter, clay minerals and Fe and Mn oxy/hydroxides; from overuse pesticides and fertilizers |
| Acidification from precipitation of acid rain and atmospheric deposition of pollutants |
| Laterization (decomposition of soil minerals with loss of cations and silica in solution leaving $Al_2O_3.nH_2O$ and Fe oxy/hydroxides as a hardened and dense surface crust), podzolization (strongly leached and bleached gray/white layer beneath the H and O horizons but above the B horizon), and large scale erosion. |
| The accumulation of potentially toxic metals can build up but is liable to be suddenly released and mobilized into an ecosystem (e.g., by a lowered pH) and is considered by some as a "chemical time bomb". A release may also be stimulated by a change in land use, decomposition, exposure to air or oxygen-bearing water, erosion and discharge into an ecosystem, and drought and ablation by wind. |
| **Biological degradation** - Loss of binding strength and nutrient- moisture storage and transfer capacity |
| Organic matter loss means loss of storage capacity of soil for nutrients and moisture and hence their availability to growing plants; loss of organic matter soil-binding function decreases the resistance of soil to water erosion |
| Pollutant intrusion or changes in physical-chemical conditions in soils lessen the activity of microbiota that affects the balance of growth conditions and decreases productivity of a soil |

construction. Soil degradation is qualified as being slight, moderate or severe when the productive capacity is reduced by 10%, 10–50% and >50%, respectively. Soils are characterized as being at high risk or very high risk. Table 6.6 describes physical, chemical and biological processes that cause soil deterioration.

It is essential to protect soils against natural degradation (e.g., erosion) that reduces their productive capacity. They must be shielded as well from anthropogenic intrusions by chemical contaminants that diminish soil quality and from human activities that promote soil loss (e.g., vegetation stripping).

## Global Extent and Causes

The extent of the soil degradation problem is evident from totaling the hectares (ha) affected. Approximately 1642 million ha, or ~86% of the more than 1900 million ha of cropland worldwide suffers some degree of loss of fertility and hence productivity (UNEP Geo-2000, 1999). In Asia, (including China) and the Pacific region alone, 550 million ha suffer from soil degradation that results in crop yields of inferior quality and in lesser quantity to feed hungry populations. Indeed, more than 600 million ha of productive cropland have been lost worldwide since the beginning of settled agriculture. Much of this is the consequence of poor agricultural practices, deforestation, and the loss of farmland to urban expansion. Figure 6.5 graphs some

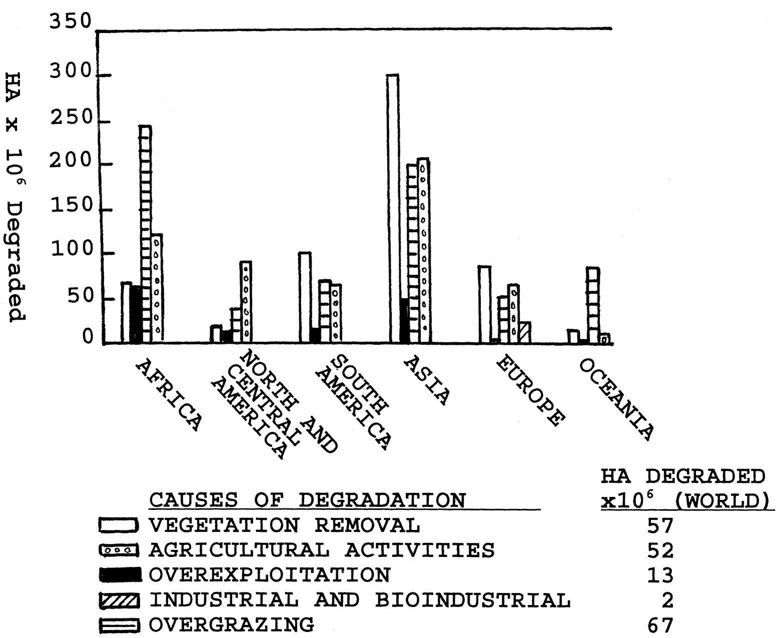


**Fig. 6.5** Regional areas affected by soil degradation caused by human activities from 1945 to late 1980s (after UNEP and UNDP, 1992)

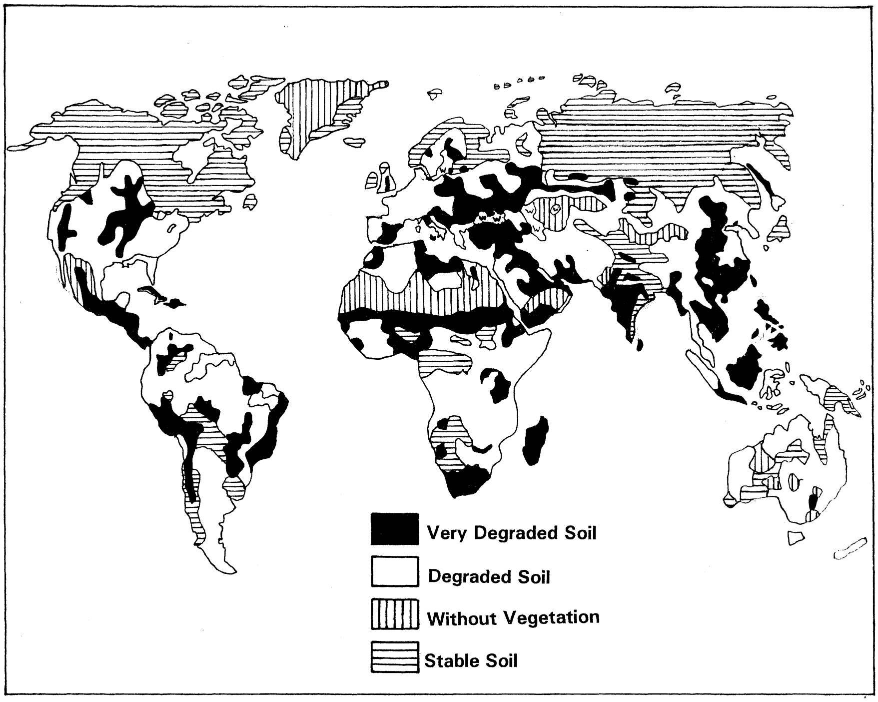


**Fig. 6.6** UNEP/GRID-ARENDAL, 1997. Degree of soil degradation worldwide. In Atlas of Desertification in the World, 2nd Ed. Arnold Publishers, London, Phillippe Rekacewicz, cartographer/designer
Source: http://maps.grida.no/go/graphic/global_soil_degradation

major human-induced damaging impacts on soils from 1945 to the late 1980s by world regions.

Figure 6.6 depicts global regions where soils are stable or have varying degrees of degradation, and regions without vegetation (UNEP/GRID-ARENDAL, 1997). The area of cropland affected by all types of soil deterioration from natural and anthropogenic activity has been increasing by 5–6 million ha annually. Mexico alone has suffered yearly losses of one million ha of cropland. This upsets the balance of nature among life forms by slowly destroying their habitats.

Widespread soil degradation from ill-advised, politically directed human activities in the People's Republic of China from 1957 to 1990, greatly reduced arable land. Deforestation and vegetation removal led to major erosion, especially in parts of southern and eastern China. The areas affected were equal to the total cropland in Denmark, France, Germany and the Netherlands (ESCAP, 1993). Subsequently, the Chinese government put policies in place that improved agricultural practices and land-use management. As previously noted, this allows China to feed its population which represents ∼20% of the world's population using 7% of the world's arable land and 7% of the world's useable water. During the past decade as China hurried its push towards greater industrial development and rapid economic growth, pollution has hit more than 10% of China's farmland and poses a real threat to the nation's ability to feed itself. This ability is at risk because of several factors: (1) the loss of soil to erosion; (2) air pollution (e.g., acid rain); (3) water pollution (e.g., heavy metals, runoff of agricultural chemicals applied in excess); (4) water diversion from agricultural regions to urban and industrial centers; and (5) inadequately controlled disposal of solid wastes.

Heavy metals alone contaminate 12 million metric tons of grain annually at an economic cost to China of $2 billion. On a smaller scale, the transference of heavy metals from the atmosphere to soils to vegetables harvested near and downwind of smelters is not only costly to the agricultural economy but harms consumers of the polluted produce. For example, at the largest Zn smelter in Asia in Huludao City, China, heavy metals have contaminated soils where farmers grow edible vegetables. The ore is sphalerite in which Cd proxies for Zn (Zn[Cd]S). Zheng et al. (2007) found that consumption of vegetables grown <500 m from the plant have the highest health risk for consumers and that the risk is especially acute for children from Cd and Pb. There is a high health risk for consumers of vegetables grown in the contaminated soils up to 1000 m from the smelter.

During the first 10 months of 2006, arable land in the country shrank by 306,800 ha (760,000 acres). China presently farms 121.8 million ha (30 million acres) and according to the Ministry of Land and Resources should not fall to less than 120 million ha (China's Xinhua news agency, 2007). At the 2006 rate of loss, there will be less than 120 million arable hectares in 2013 and this nation of 1.3+ billion citizens will become a food importer unless the government keeps its vow to clean up the country's heavily polluted environments (countryside, cities, waterways and coastlines).

The pollution problems cited in the previous paragraph not withstanding, China's planning in the past to bring about the capacity to feed its population can be used as a model to do the same in other countries subject to modification to fit the norms of other global communities. To reach the goal of food independence, a country's farmers must heed advice from agricultural experts and planners and receive political and economic support from their governments. International lenders and NGOs are able and willing to provide technical expertise and financial assistance to achieve success in self-sufficiency programs. Economically advantaged nations, defined in terms of financial reserves and not in terms of per capita income, plus the World Bank Group and regional development banks (Table 1.1) and NGOs are bound morally and by charter to tangibly encourage and assist countries in this effort.

A region of special concern is Africa where 325 million ha of fertile farmland have suffered soil degradation since 1950 (Oldeman, 1994). At the present rate of soil loss, African crop productivity could be halved by about 2030 as the region's population doubles (Scotney and Dijkhuis, 1990). Half as much food for twice as many people is as frightening a prospect as is half as much water for a doubled population cited in the last chapter. The soil deterioration of an additional 175 million ha of non-agricultural land damages African animal habitats. These figures do not project probable future changes in the hectares of arable land because of global warming and climate shifts.

Most agricultural zones undergo a broad range of slight to very severe loss of productivity. Erosion is the process that damages the most cropland globally. For example, erosion lowers agricultural production in Nigeria (with the largest population in Africa), Haiti, the Himalayan foothills, Southeast Asia and Central America. Once topsoil is lost to erosion, it can take scores to hundreds to thousand of years to reestablish it as a rooting and growth environment.

Three hundred million ha of agricultural land in Latin America have been degraded by erosion, nutrient depletion, deforestation, over grazing, and poor management. Erosion is the main process that damages 95 million ha in North America (UNEP/ISRIC, 1991).

Water erosion degrades 115 million ha of soil (52%) in greater Europe. Another 101 million ha suffer deterioration from wind erosion (42 million ha), compaction (33 million ha), pollution (19 million ha), salination (4 million ha), and nutrient loss (3 million ha). Acidification and water logging do little harm to European soils. In contrast to greater Europe, water erosion impacts 40% of the soils in the original EU-15 country group. (UNEP/ISIRC, 1991). This suggests that the original EU-15 countries follow better agricultural practices under regularly monitored land man-

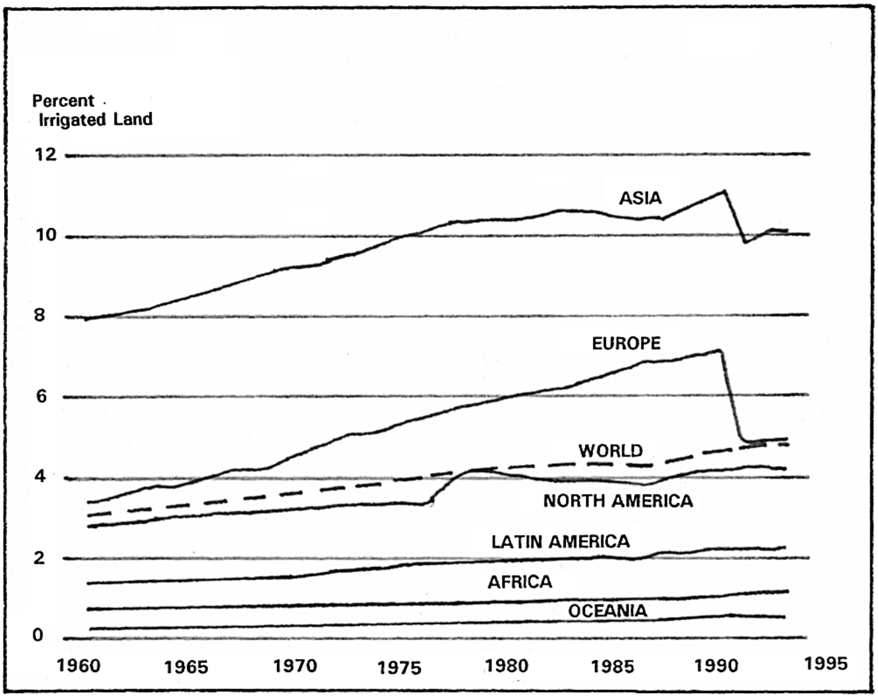


**Fig. 6.7** Increase of irrigated land as a percentage of agricultural land during the period 1961–1994 (After FAO, 1997, FAOSTAT Statistical Database, Rome)

agement controls. These practices are being adopted by the additional 12 nations that now comprise the EU.

Globally, two-thirds of food crops are grown under irrigation. The areas cultivated under irrigation have increased worldwide to meet the food needs of expanding populations (Fig. 6.7). Salination is a major problem for irrigated lands in the basins of the Indus, Tigris and Euphrates rivers, in northeast Thailand and China, in the Nile delta, in northern Mexico, and in the Andean highlands. Agricultural experts advise farmers in these regions of the need for good drainage and regular flushing of soils to avert salination and thus sustain normal crop yields.

Depletion of soil nutrients diminishes crop yields over large areas of Africa and many locations from the Caribbean to Myanmar. Indeed, nutrient depletion and loss of organic matter is responsible for 7% of the degraded soils in Africa and South America. Natural fertilizers or economically accessible man-made fertilizers can be used judiciously to alleviate a nutrient deficiency.

Causes of human-induced soil degradation listed in Table 6.6 affects areas worldwide. Figure 6.6 highlighted areas with very degraded soils and degraded soils. Loss of production in Africa from soil erosion alone is about 8% whereas the loss in Asia (and the Middle East) from all other damaging processes is about 20%. Nationally mandated and technical support for good soil renewal practices and maintenance by individual farmers and agribusiness farms can counter this threat to global agricultural output.

## Practices to Reduce Soil Degradation

Physical, chemical and biological processes degrade soils (Table 6.6). Poor agricultural practices, faulty land management, and inadequate land-use planning decisions do the same (Table 6.7). The amount and rate of soil degradation from processes and activities cited in Tables 6.6 and 6.7 has to be minimized and slowed in order to preserve soils as reliable sources of food supplies. A soil's capability to sustain cultivation can be restored and its fertility and farmland productivity assured if the degree of degradation requires it. Geologists, chemists, and biologists can work with agronomic engineers and planners to come up with the best ways to do this for specific soils in different climatic regimes. Where soils have been degraded to the point that they are no longer productive, agricultural experts and environmental engineers can offer advice on suitable methodologies for their remediation and reclamation given adequate economic resources. This is discussed in the final chapter.

### *Preparation, Planting*

Erosion of agricultural soils by running water or wind is a physical process that can be lessened by altering field preparation and planting strategies. Good field prepa-

**Table 6.7** Main causes of soil degradation

| |
|---|
| Poor agricultural practices |
| Tilling or plowing (mechanical) - can give compaction/crusting; ruptures natural surface and protective vegetation; opens terrain to erosion |
| Strip natural vegetation to bare soil for planting - leads to erosion and leaching of soluble components |
| Overgrazing - removes vegetation cover and leads to less moisture retention and more erosion |
| Row cropping - exposes soil between row crops to erosion |
| Monoculture - harvesting takes place all at same time; leaves field bare and open to erosion; disease can wipe out an entire crop |
| Repeated cropping without fallow periods or nutrient (fertilizer) replacement and continuous crop removal leads to depletion of nutrients and soil organic matter |
| Higher cropping densities and multiple cropping - can deplete soil nutrients and organic matter and result in progressively smaller crop yields |
| Over application pesticides and fertilizers - can kill beneficial soil microbiota; runoff contaminates soils and waterways |
| Poor land management on site and in watersheds affecting cropland |
| Deforestation - increases runoff and erosion |
| Development of hillside marginal lands - slopes are cleared via deforestation and are susceptible to erosion in areas of high rainfall leads to increasd erosion as does grading of slopes which breaks soil structure and lowers cohesiveness |
| Extended areas of irrigated lands |
| Poor water management on irrigated cropland can result in inadequate drainage - salination and waterlogging affects 10–15% of all irrigated land |
| Poor land-use planning decisions |
| Uncontrolled dumping of wastes |
| Atmospheric chemical pollutants and acid rain deposition |

ration uses no till cultivation with special machinery that slices and seeds a planting surface with minimum rupturing of topsoil. This reduces susceptibility of cropland to erosion. However, no till cultivation can lead to increases in weed and insect populations that farmers have to cope with. If tilling and plowing are the modes of farming, contour plowing at right angles to the slope of the land can reduce erosion by up to 50%. Plowing in the spring when cover comes in rapidly rather than in winter when the broken earth is open to erosion for long time periods also reduces the problem. Terrace farming limits erosion. However, to be effective, any breaches in terrace walls have to be repaired promptly.

Planting strategies to reduce erosion include strip farming that leaves a mainly intact ground cover. Planned polyvarietal cultivation will bring in harvests during different times thereby limiting a soil's physical exposure to erosion. The addition of organic matter to soils, or plowing crop residues into soils mentioned earlier, replenishes soil nutrients and favors chemical reactions to form polysaccharides, sticky products that bind soil particles firmly. This reduces erosion. Trees or other plant barriers bordering fields will slow runoff and decrease wind erosion. Crop rotation, the use of cover crops, intercropping, and agro-forestry help reduce conditions that favor erosion.

## *Nutrient Replenishment, Salination Control, Pollutant Extraction*

Depletion of soil nutrients from crop to crop or season to season will degrade a soil and its productivity. As such, nutrient replenishment has to be planned for to prevent failed cropping. The nutrient condition of a soil has to be monitored regularly by reviewing rates of crop growth and quality of the cultivar. At the first indications of nutrient depletion, chemical analyses can establish which nutrient or nutrients are deficient. A planned replenishment program will reverse the depletion and sustain soil fertility. Nutrient replenishment is done using natural products or man-made chemical fertilizers.

Salination is another process by which soils can be degraded. It affects large areas worldwide (Table 6.8). However, instead of having to add product to a soil to cope with the problem, as in the case of nutrients, salt has to be removed from it to prevent its build up to the point that salt encased roots prevent the uptake of nutrients from an otherwise fertile soil. Monitoring the salt condition of a soil is necessary unless there is a regular removal of salts from the root zone so that nutrients uptake by a plant is not affected. This salt removal is a planned remediation approach to maintain soil productivity.

Similarly, soils with heavy metals or toxic chemicals, including organics, have to undergo remediation if they are to be useful in the future as reclaimed farmland. In some cases, a mass of pollutant-bearing soil may have to be physically removed and either treated or disposed of. Whether this is feasible depends on the area extent of the soil pollution and the volume of the soil. In other cases, soils polluted by inorganic and/or organic chemical elements or compounds may lend themselves to an *in situ* chemical or bio- or phytoremediation extraction of pollutants to make the land is useful again. Where radioactivity fallout is the pollutant, the area is quarantined as a no-man's land.

**Table 6.8** Percent of salinated soils in worldwide regions (derived from the FAO UNESCO Soil Map of the World)

| Region | % Salinated soils |
|---|---|
| Australia | 84.7 |
| Africa | 69.5 |
| Latin America | 59.4 |
| Near and Middle East | 53.1 |
| Europe | 20.7 |
| Aasia and Far East | 19.5 |
| North America | 16 |

Chapter 9 considers various aspects of dealing with soil pollution problems in some detail and the necessary attention that has to be given to remediation plans.

## The Reality of Food Deficits

Political implications of a decreasing global food supply are major concerns to governments and international institutions involved in advancing social improvement programs as an important key to economic development. Food shortages already cause nutritional deficiencies in populations of Sub-Saharan Africa, south Asia, and other developing regions, specially for a population's very young and very old groups. This problem will worsen. FAO estimates that in 2010 11% of the populations in these areas or about 650 million people ($\sim$10% of the world population) will suffer chronic under-nutrition. The countries or regions that have food shortages now, and where shortages will be worse in the future, have common problems. These are high rates of population growth, greater urbanization, low crop yields, and high foreign debt. They have limited economic resources to purchase food from where it is in surplus.

### *Global Food Production: Increase Followed by Decrease?*

The stress that soil degradation and falling crop quality and yield will put on future generations is presently masked in some countries by an increase in global food production. The increase is from greater use of fertilizer and pesticides, extension of irrigated lands, higher cropping densities and multiple cropping. However, the crop yield increase is leveling off and the rate of increase will not likely keep pace with population growth. Production gains of crops and livestock in developing countries in 1994 were 5%, reached 5.2% in 1995, but dropped to 2.9% in 1996. Globally production growth was 2.6% in 1996.

The problem of soil degradation and crop yields is exacerbated by greater affluence of relatively small numbers of economically advantaged people in populations and their rising demand for protein-rich foods (e.g., beef) and derived products. To satisfy this demand and achieve higher economic returns, farmers are using productive land to grow fodder and feed crops for food animals. Recently, in a rush to ease dependence on imported oil, and with little evaluation, if any, on the effects on citizens' everyday lives, the U.S. administration encouraged the conversion of food crop farmlands to crops and other vegetation used in ethanol production. Lobbyists for agribusiness were influential in getting support for the administration's position from elected officials from non-agricultural states. This may ultimately save a few percent of the imported oil needs. However, as a result the U.S. public is suffering the effects in higher food prices (e.g., for dairy, meats, grains and derived products). This can drive inflation and is the direct result of farmers getting higher prices to grow crops (e.g., corn) for bio-fuel production. The result is that there is less acreage given to growing feed, lower feed supplies, and the same or greater demand for feed to produce food animals, grains, and products derived from them. Although this process for ethanol production has been successful in Brazil due to good planning, it is a inadequately thought through venture for the U.S. public.

On the basis of estimated crop yields from cultivated acreage and population growth, FAO finds that 64 of 117 developing countries face critical food crises. More frightening is the projection that 38 countries using traditional subsistence agriculture will not be able to feed even half of their future populations. Yet, according to FAO, only 760 million ha of 2500 million ha ($\sim$30%) in developing countries that could be under cultivation are being farmed. Additional cultivation in these countries is warranted to increase their food supplies to levels commensurate with or above their rates of population growth. This has to be done by following good farming practices under monitored land management with sustainability of fertile soils as the goal. International investment to this end will have a payback in human terms by eliminating starvation or near-starvation conditions which otherwise will ravage populations in many countries. The payback to these countries can be financial if enough food crops are produced to allow for export. Ideally, income from exports of food can be used to propagate and extend responsible farming and to improve health conditions and educational possibilities for a nation' people.

## Sustainability of Productive Soils

Good soil health sustains productivity and promises adequate food supplies for expanding populations in many countries. This is the goal of millions of independent farmers worldwide. They work from dawn to dusk to grow food crops and raise food animals in many cases under environmentally friendly and sustainable conditions. In this way farmers provide their families with a good quality of life, economic security, and fertile cropland to pass on to future generations.

Soils are sustainable but need human intervention to limit the loss of topsoil by water and wind erosion and soil degradation by nutrient depletion, pollution, and other physical and chemical processes. There is no question that nutrient replacement is necessary to maintain stores of essential macro- and micronutrients in soils to allow plant organs to function well during growth. Nutrients from natural rock decomposition, plowed in organic matter, and optimal amounts of chemical fertilizers fill the nutrient replenishment need. This requires that agriculturalists monitor soil pH and moisture to assure that nutrients will be readily mobilized to root systems in physically- and chemically conditioned soils. Soil minerals can act as filters that adsorb and immobilize heavy metals and other pollutants. Without such natural traps, pollutants might mobilize and bio-accumulate to dangerous levels in a food web or interfere with plant uptake of essential nutrients.

Soils give sustainable high productivity when worked with good agricultural practices, under well-executed land management policies, and with careful and detailed agricultural development planning. Effective planning assesses short- and long-term direct and indirect impacts of proposed projects on soil (and air and water) in linked ecosystems near and far. Environments benefit greatly when nutrient- and organic matter-rich, moisture-retaining "healthy" soils store and transfer essential products to terrestrial habitats to support a diversity of life.

The capability of soils to sustain high yield plant growth ensures world populations continued availability of natural resources in addition to food. These include resources for the manufacture of wood and paper products, fibers and other commodities derived from agriculture and forestry.

Sustainability of soils has a role that extends to the engineering realm and the physical well being of people. Soils must be able to sustain stress from the weight of buildings that house populations and provides their work places as well as infrastructure elements such as roads, bridges, water and electric utility systems, and dams. Soils used as foundations for such construction must be able to resist changes of state during shaking, jarring and rolling motions in earthquakes, and resist landslides and/or swelling/shrinking soils as rainwater or groundwater seeps into them. Geotechnical engineers can test to determine if soils at proposed development sites have the physical (and chemical) capabilities to be used for infrastructure, building construction, and other development projects.

## Afterword

This chapter and the two preceding ones focused on the risks to growing populations and economic threats to existing and proposed development projects from toxic chemicals and physical and biological problems in atmospheres, waters, and soils. Their texts recognized that a portion of the contaminant chemicals is natural as are physical disruptions in the environment. However, they emphasized that most of the pollution problems for people and projects originate from human activities that are unregulated by law, or if regulated, are neither monitored nor enforced by responsible agencies.

The following chapter reviews selected "green" legislation in place in some countries. It suggests how successful legislation in one country can serve as a model for other countries that wish to exert control on existing pollution problems to diminish their impacts on environments and their contained ecosystems. "Green" legislation has the ultimate aim of greatly limiting pollution or even eliminating it to preserve environments and their ecosystems and natural resources for future generations.

# Chapter 7
# "Green" Legislation: Now for the Future

The intent of sponsors of environmental or "green" legislation is to protect natural environments against public and private human activities which will impact and harm ecosystems. The harm may originate with emissions or effluents of (chemical) pollutants that contaminate essential natural resources (e.g., air, water, land [soil], wildlife, and vegetation). In this case, laws can be proactive and set limits on the concentrations of contaminants that can be released into ecosystems without diminishing their vitality and productivity. Thus preserved, healthy ecosystems can sustain projects that help maintain expanding populations and allow successful development.

Laws are also reactive by mandating the remediation and reclamation of degraded ecosystems under policies such as the "polluter pays" principle. In many countries, the reactive laws are proposed and passed in response to outcries for environmental justice from important voting blocks.

In the past, implementation of environmental laws has been wanting in developing and developed nations alike. Environments have been compromised. Today, enforcement of "green" laws has increased because governments realize that clean environments are necessary to attract and retain investment that contributes to sustainable development.

## Legislative Targets

"Green" laws have been legislated worldwide to deal with health threats from contaminated air and water. These are the clean air and clean water acts. There are few national clean soils acts per se but many countries have soil protection laws. Soil protection laws deal forcibly with degradation processes such as erosion, decline in organic matter, sealing because of urbanization, salination, and others (Chap. 6). Many of these protection laws incorporate statutes that are designed to counter pollution from inorganic and organic chemical elements and compounds. They have action levels that warn when remediation is called for and allowable levels of chemical concentrations that remediation must reach. There are many countries that do not have soil protection laws. For example, only nine of the

F.R. Siegel, *Demands of Expanding Populations and Development Planning*,

EU nations have them. However, states or provinces in a great number of countries have legislated clean soil regulations. They set soil remediation concentration targets for chemical pollutants and the quality and thickness of soil that must be used to replace polluted soil when excavation is the remediation technique used. These relate to clean air and clean water acts because of the links between soil chemistry and chemistries of atmospheres and surface and aquifer waters, and irrigated crops.

The aims of environmental pollution laws are to eliminate or at least greatly reduce pollutant input to ecosystems from anthropogenic sources over a reasonable period of time. They provide economic incentives such as tax benefits to owners of pollutant-generating facilities to entice them to this end. They further provide for grants to monitor the effectiveness of pollutant reduction on the recovery of vitality in ecosystems which have been directly impacted as well as those that have been secondarily affected in a pass through process. Another important task of environmental legislation is to require risk assessment analyses for local, national, regional and global environments. This is important if clean air, safe water, and untainted and fertile soil regulations are not in place or if they are in place and not enforced. The risk analysis should include the "immediate future" (in 25 years) and far future (to 50+ years) time frames.

## *Cornerstones of Environmental Regulations*

Environmental regulations carry several layers of requisites that must be considered for them to be applied effectively to ease or abate chemical pollution of ecosystems. First, environmental assessors need data from health researchers on element concentrations and on observed and measured conditions in an ecosystem (e.g., pH) that affect life forms that inhabit it. With this known, legislation can set standards for these parameters in ecosystem media. Second, the laws have to carry consultative provisions to determine whether chemical pollutants in an ecosystem originate from a point source or an array of sources, geographically local or distant. Third, the laws must stipulate abatement aims, procedures to achieve them, and deadlines to meet them. Fourth, legislation must carry economic incentives that will encourage polluters to deal effectively with their specific pollution problems. Economic incentives can be tax benefits above and beyond those for new equipment, low cost loans, or grants that pay for a portion of installed pollution control technology. Laws may also allow some costs to be passed on to the consumer. Polluters will generally respond to incentives such as those cited above to institute a feasible abatement plan. If a reasonable agreement cannot be reached, legislation must provide for punitive measures. Fifth, incarceration of responsible parties is also an option. Lastly, the legislation has to allow for the possibility of a government takeover if there is an imminent public health threat or national security risk, or as a last resort, for closure.

## Legislative Structures

Management of environmental problems is based on governmental legislative measures or treaties among nations that will protect ecosystems and their inhabitants from being subjected to contamination and physical hazards. The measures originate as protocols that are preliminary memoranda generally approved by diplomat negotiators. They form the basis for mandating strict adherence to codified regulations in a final covenant to correct wrongs affecting environments.

Protocols evolve into treaties or conventions, which are contracts in writing between nations by which they agree to work towards solutions of environmental problems. Nations' authorized representatives sign treaties or conventions. In most cases, these instruments have to be ratified by the lawmaking authority of each sovereign signatory (e.g., congress, parliament). Once ratified, each nation has the obligation to assure that its citizens obey the measures that will ease, and within a determined time, reduce pollutant intrusions of ecosystems to permissible levels as determined by environmental agencies.

In cases where there is persistent non-compliance with the dictates of a treaty/convention, sanctions could be instituted against non-complying signatories, mainly by trade measures. In truth, trade sanctions could be effective in bringing nations with transitional economies into compliance, but would likely not be as effective in negotiations with developing countries.

In contrast to treaties or conventions, national or other governmental legislation becomes established law and sets rules of conduct for environmental etiquette. These laws are written to safeguard environments and their vital ecosystems by mandating the mitigation or elimination of practices that could harm them. This safeguards ecosystem sustainability and productivity. Established law is invariable and binding on citizens. Unlike protocols, treaties, or conventions, established laws impose enforceable penalties such as fines, take over, closure of facilities, or incarceration of responsible parties if there is no compliance in a prescribed time.

## Limitations

As has been stressed in this text, legislation to protect the environment from intrusion by harmful amounts of chemical elements and compounds or biological contaminants is good only if laws are enforced. Laxity in enforcement is a major limitation to controls on toxicant emissions or discharges into the air, water bodies, or onto soils. Another limitation lies in the penalties applied when laws are ignored and how the polluter responds to them. Will fines be paid? Will the business close? Will the business be moved?

There is a socio-economic risk to a community if the owners of a polluting facility indicate that they might shut down unless environment protection rules are waived or eased. Closure means loss of jobs not only at a factory but also at suppliers of goods and services for the factory and workers. It means a loss of revenue to a municipality and the need to generate an alternate source of funding to provide interim financial aid for those who lose employment. Whether or not a factory will close down may depend on the cost of installing required pollution control equipment, using it, providing for its scheduled maintenance, and the long-term effects on profit margin. As already reiterated, federal or local government tax incentives or grants can help defray the cost of pollution control and thus influence a factory owner's decision to keep a facility operational. In some cases the decision depends on the economic rationale of moving a factory to foreign locations (e.g., from the United States to Mexico, or from Japan or Taiwan to China). The attraction of doing this is that labor costs are notably lower and pollution laws are not as stringent or not enforced because of emerging economies' politics or a societal blind eye to corruption.

## Clean Air Regulations - Progress, Advances, Successes

Clean air laws have developed more and broader criteria over time to contend with different impacts of atmospheric pollution on our planet's ecosystems. National regulations set norms for permissible concentrations of chemical elements and compounds in the atmosphere. However, state or provincial controls can override federal laws. These controls are generally more restrictive because of specific problems and histories associated with local or regional health conditions and development activities.

For example, in the U.S., in 2002, California, plus four other western states, one mid-western state, and 10 eastern states states, together representing more than half the U.S. population, enacted Clean Car Laws. These are designed to reduce greenhouse gases emissions from cars and light trucks by 30% by 2020. In California, for example, the law requires that gasoline-electric hybrid vehicles make up about 5% of in-state sales and that 30% of all new vehicles be equipped with cleaner conventional engines. This will also reduce airborne carcinogens and the smog contributor $NO_x$. Medical experts project that the clean car laws will reduce the cases of asthma attacks from smog and soot by thousands annually, and will prevent a large number of premature deaths. The states' standards are stricter than USEPA federal standards so that a waiver is needed to impose the laws. The waiver is routinely granted for tailpipe emissions laws but in these cases were refused. They were refused by the USEPA because of automakers opposition (20 companies including BMW, Daimler-Chrysler, Ford, General Motors, Honda, Renault, Toyota, and Volkswagen) and possibly by pressure from the former Halliburton Industry's CEO and sitting Vice President Cheney who favored forcing a suit. Mr. Cheney favored fighting the suit although several earlier state and federal court decisions supported the California Clean Car Law waiver and in spite of the fact that his legal and scientific advisors recommended against it as did the legal experts at the U.S. Department of Justice. California was joined by the other states in filing a suit against the

USEPA to force the waivers to be granted. The plaintiffs will prevail but the automakers will gain tiime before they have to comply with the clean car laws. This is at the expense of contributing to the slow down of global warming. Under its law, California emissions standards will reduce $CO_2$ emissions by more than 32 million tons in 2020 vs less than 19 million tons reduction by following federal standards. Cumulatively, California will keep 58 million tons of $CO_2$ from discharging into the atmosphere between 2009 and 2016 vs 20 million tons if federal standards are used. Upon winning the lawsuit, California and the other states that are co-plaintiffs will reduce 60% more greenhouse gases emissions when their laws are in place than if they followed federal laws.

California continues to be in the forefront of legislating to promote clean air and contribute to the reduction of $CO_2$, other gaseous contaminants, and particles in the atmosphere. Beginning January 1, 2006, California passed a law with the purpose of forcing coal-burning power plants in western states that sell power to the state to install best available technology to capture gaseous and particle emissions. If they do not, they will not be able to sell power to the most populous state (36 million people and growing) with the sixth largest economy in the world. Wyoming, Montana, Nevada, New Mexico, and Arizona are following the lead of California.

The effectiveness of clean air regulations is measured by the amount of reduction of pollutants in the atmosphere. Active monitoring programs during the past decades show that there have been marked reductions of many pollutants in the atmosphere. Implementation of clean air laws and compliance with them has resulted in healthier air, water, and soil in ecosystems in many locales worldwide. The reduction in airborne pollutants is an ongoing process. Atmospheric cleanliness has bright perspectives as air quality regulations and strict enforcement bring more pollution sources into compliance with national laws. The following section describes some of the legislation driven advances and successes in abatement of air pollution.

## *Global, Transnational, Regional, National, Local*

### Resolving the Ozone Problem

The principal cause of the depletion of the ozone layer and its consequent thinning and hole formation was the use of chlorofluorocarbons (CFCs). A success of clean air protocols is the global collaboration to bring about a healing of the Earth's ozone layer. A solution to the ozone problem was initiated when Sweden banned the use of CFCs in 1978. Only in 1987 did 24 nations sign The Montreal Protocol that called for a limit in production of CFCs and ultimate phase out of their use in 1996. Subsequently, after 5 revisions, the Protocol was signed by 191 nations. Substitutes with no known negative effect on the ozone layer were found for the CFCs. Some propellants now used are nitrous oxides, mixed isomers of propane and butane, and carbon dioxide. Hydro-chlorofluorocarbons (HCFCs) are the most widely used refrigerant substitutes, species R134A in automobiles air conditioning and species R410A for home/workplace air conditioning. By 2003 the ozone depletion slowed down and today the layer appears to be in recovery. The healing of the ozone layer to its pre-CFCs condition will take some time because CFCs have 50 to 100 year atmosphere lives and the HCFCs can damage the ozone layer although to a much lesser degree than CFCs.

The HCFCs present a greater problem as factors in the global warming scenario. They or byproducts from their manufacture, such as HFC-23 from HCFC-22, have been shown to be up to 10,000 times more potent as greenhouse gases than $CO_2$. When this became known, the 191 signatories to the Montreal Protocol which originally agreed to freeze and phase out the use of CFCs during the period 1987-1997, met in Montreal during September, 2007, to seek a solution HCFCs problem. The countries agreed to accelerate the treaty to freeze production and added consumption of HCFCs by 2013 by phasing out their uses as substitutes for CFCs as refrigerants or propellants. They agreed on a final phase out on the use of HCFCs in refrigerators, home and vehicle air conditioners, hair spray, and for other purposes by 2020 for developed nations and by 2030 for developing nations. This treaty accord will encourage the development of alternatives to HCFCs that have low or no global warming effect and do not pose a threat to the ozone layer.

Although the ozone layer is showing signs of healing over much of the Earth, the risk to humans from ozone depletion remains high over Europe. The depletion extends to the North Pole. Scientists found that this is because of a less than projected drop in chlorine concentration and a rise in bromine content in the atmosphere. The EU countries have passed a resolution pledging to collectively reduce chlorine, bromine, and greenhouse gas emissions in order to relieve and reverse ozone loss. Because of this collaborative effort, scientists anticipate a significant reconstitution of the ozone layer over Europe and the North Pole by 2010 (European Commission, PR, January 22, 2002).

## *Smog*

Ground-level ozone is created by photochemical reactions of a combination of chemical components and particles. It is the major component of smog (Chap. 4). The key to alleviating smog and the health problems it can cause is to reduce the mass of emitted chemicals from which it forms.

The London case described in Chap. 4 was a signal event that focused public health attention on the problem and highlighted the need to reduce sources of chemicals that cause smog. As an immediate response, the London city council passed a law in 1953 that restricted the combustion of "soft" or "brown" coal. Recently, the London city council assessed costly fees on vehicles that enter central London. Many municipalities and responsible federal agencies passed laws that mandate the monitoring of air quality. For example, the state of California requires that all vehicles undergo smog emissions tests biannually. Existing laws are reviewed regularly and suggestions for changes made to reflect the threat of smog to populations. The

USEPA has a limit of 84 parts per billion (ppb) of ground-level ozone as a smog alert level. The agency is trying to reduce this to 70–75 ppb but is finding resistance from manufacturers and vendors of products that contribute to the formation of ground-level ozone.

During a smog alert, the public is warned by police and fire departments and through radio and television announcements to remain indoors if possible and to delay intense outdoor activities until the smog clears. Some localities limit the number of automobiles from entering cities when smog conditions threaten. In Mexico City, cars with even and odd first number on a license plate are allowed into the city on alternate days. At risk municipalities encourage the use of public transportation in lieu of autos. Others, such as metropolitan Washington, D.C. provide free bus transportation during very bad air ("code red") days.

In addition to the danger it poses to humans, smog can damage plants and lead to crop failure. According to Environment Canada, agricultural losses caused by smog and its ground-level ozone component is estimated to be almost $70 million in Ontario and $9 million in the Lower Fraser Valley of British Columbia. On a worldwide extrapolation, agricultural losses for many countries can be staggering, not just in financial terms but also in loss of important sources of food. A drop in productivity (and hence income and profit) because of workdays lost when dangerous levels of smog blanket an area has not been quantified but has to be important.

Kleeman et al. (2001) evaluated smog from atmospheric pollutants in the South Coast Air Basin, California. They found many sources that together can create severe smog conditions and published three lists with a total of 90 measures that could mitigate smog formation. Some were more effective than others in decreasing the masses of four major pollutants that react to produce smog in southern California: $SO_x$, particle matter ($<10\,\mu m$ and $<2.5\,\mu m$ sizes), reactive organic gases (ROG = VOCs), and $NO_x$. Table 7.1 gives a selected list of emission sources, measures to cut their emissions, and anticipated reduction of air pollutants.

## *Volatile Organic Compounds - VOCs*

Volatile organic compounds originate mainly with vapors escaping from gasoline pumps and by evaporation from organic solvents (e.g., as used in paints, primers, automotive body products, marine paint, shellac and other products). They are major reactants in the formation of smog and contributors to indoor pollution. Thus, a control on their release into the near surface atmosphere and indoor atmospheres is essential. A combination of the existing legislated use of vapor capture cups at gasoline pumps and encouragement to manufacturers to rework their products to lessen evaporation of VOCs (before this is regulated by law) will help reduce the smog threat at susceptible locations as well as indoor workplace air pollution. Although this approach is a good first step in easing the smog problem, laws are needed which will prohibit specific amounts of certain VOCs in products.

**Table 7.1** A selection of specific emission control measures from 3 lists totaling 90 given by Kleeman et al. (2001) for primary particles and reactive gases that pollute the atmosphere in the South Coast Air Basin, CA. The effectiveness of the measures are given by the percent reduction of pollutants after application of control measures

| **$SO_X$ emissions** | | | |
|---|---|---|---|
| | $SO_x$ before controls tons/day | Percent $SO_x$ reduced | |
| On road mobile sources – reduce S content of fuel and use electric vehicles | 28.19 | 74% | |
| Ships at berth – use electrification | 23.42 | 8 12% | |
| **Particulate emissions** | | | |
| | $PM_{10}$ before controls tons/day | $PM_{2.5}$ before controls tons/day | Percent PM reduced |
| Agricultural operations – reduce hay grinding; treat unpaved roads | 29.5 | 3.69 | 47% |
| On road diesel engines – use new technology | 14.50 | 13.77 | 86% |
| Paved roads – treat unpaved access roads | 132.68 | 24.77 | 29% |
| Unpaved roads – treat, restrict speeds to 15 km/hr | 42.29 | 9.26 | 29% |
| Construction and demolition dust – use existing environmental protection rules | 126.77 | 27.75 | 74% |

**Table 7.1** (continued)

| **Reactive Organic Gases (ROG) and Nitrogen Oxides ($NO_X$)** | | | | |
|---|---|---|---|---|
| | ROG before control tons/day | $NO_x$ before control tons/day | Percent ROG reduced | Percent $NO_x$ reduced |
| On road vehicles – meet 2006 emission standards | 1067 | 604 | 87% | 51% |
| Lower emissions standards on new jet aircraft engines | 5.17 | 10.6 | 50% | 50% |
| Cement kilns – selective catalytic reduction; scrubbing | | 7.76 | | 85% |
| Curing and drying ovens – combustion modification; alternative fuels | | 4.18 | | 75% |
| Require fuel shutoff to prevent topping off | 4.66 | | 50% | |
| Control of pesticide formulation and use | 9.04 | | 40% | |

The USEPA and agencies in other nations are proposing legislation to give rankings to VOCs by determining their relative photochemical reactivity and potential to contribute to the formation of ground-level ozone. The VOCs with the highest reactivity/potential rankings will have to be removed from products or reduced in them to prescribed allowable concentrations. Others with a low relative reactivity ranking will be exempted from legislation. This will reduce the stock of chemicals that react to sunlight to form ground-level ozone and thus lessen the smog threat to topographic/climatologic areas with high population densities and high traffic volumes.

## *Particles*

The emission of fine-size particles to the atmosphere, especially from coal-burning plants, and their inhalation is a cause of bronchial and other respiratory problems. Clean air laws in many countries have addressed the particle pollution problem. The laws limit the mass of 10μm and 2.5μm particles in emissions from different industrial and manufacturing sources into outdoors or workplace atmospheres. The use of particle-capturing equipment in chimneys has been effective is keeping particle emission levels below maximum permissible number of particles per cubic meter of air. Reduction in particle emission also helps to reduce the formation of smog.

## *Acid Rain*

Rain is naturally acidic because of weak concentrations of carbonic acid. This natural acidity is not harmful to earth’s environments. However, the addition of sulfuric acid ($H_2SO_4$) to rain that originates from $SO_2$ emissions (e.g., from coal-burning power plants and from sulfide ore smelters) makes this a stronger acid rain that is damaging to the environments where it precipitates and infiltrates or runs off into soils and water bodies. In some local areas such as Los Angeles, $NO_x$ species emitted to the atmosphere from vehicle exhaust and power generation reacts to form nitric acid ($HNO_3$) that becomes an important contributor to acid rain. As noted above, the $NO_x$ is a principal raw material that also contributes to the formation of ground-level ozone, the main smog component.

As a result of observable and measurable widespread degradation of forested regions and of lakes and streams by anthropogenic-charged acid rain and runoff, economies based on tourism and environmentally sound timbering in many countries has suffered. There has been economic loss in agricultural regions where rainfall provided much of the water to cropped farmlands and fruit orchards. Populations suffered losses where their properties were damaged by acid rain.

Added to the impact of acid rain on agriculture, personal property loss, aquaculture, and tourism, is the increased incidence of bronchial disease and difficulty in deep breathing by people living near and downwind of $SO_2$ belching chimneys. This can be a greater concern to the affected public than is the problem of acid rain.

In response to citizen health concerns from acid rain, many governments passed clean air regulations requiring industries to upgrade existing emission control units in smokestacks or install best available emission control systems dedicated to removal of $SO_2$. When coupled with a regulation to burn low-sulfur coal, there is a great reduction in $SO_2$ discharge to the atmosphere. In most countries the law provides incentives such as long-term, low-cost loans and tax benefits to industries to advance air quality compliance. The laws have been successful where enforcement brought non-conforming operations into compliance or closed down facilities that could not or would not comply with it. The end result has been a great drop in $SO_2$ emissions globally and a major decrease in the acid rain threat to ecosystems and to human health worldwide (Chap. 4).

## *Pb, Hg and Other Heavy Metals in the Atmosphere*

The amount of Pb in the atmosphere has been reduced dramatically worldwide by more than 50% since 1974. This reduction was initiated by the United States in 1974 and then by other countries with legislation which phased out the use of Pb as an anti-knock agent in gasoline, a major source of atmospheric Pb. Lead contents in the air we breathe continue to decrease as more nations prohibit the use of leaded gasoline and as greater tonnages of smelter emissions of Pb (and other heavy metals) are captured on site.

Clean air laws have been drafted, revised, passed, and then implemented in many nations in part because of solid data provided by medical experts and epidemiologists. These laws required the use of chemical scrubbers and particle-capturing equipment to reduce heavy metals emissions (and $SO_2$) from coal and oil combustion operations and smelters. The result is a large tonnage decrease in the discharge of many pollutants into the atmosphere (Chap. 4). There is little doubt that this has reduced human health ills (e.g., respiratory, neural, renal) from ingestion of the metals via atmosphere to water to comestibles. The cleaner atmosphere has also eased the pollution burden for surface waters and soils thus benefiting the habitability and vitality of ecosystems.

One major exception to atmospheric abatement successes is Hg. Its bioaccumulation in large food fish such as swordfish, tuna, king mackerel and tilefish, and its transference to consumers who themselves bio-accumulate the toxic metal concerned health professionals and has been documented. As already noted, Hg ingestion over time can damage a nervous system and cause loss of motor functions. Medical research has demonstrated that the Hg passes from pregnant women to fetuses and harms their development.

In line with the WHO and other global, regional and national environmental agencies, the USEPA recognized the need to put more stringent restrictions on Hg emissions from coal-burning power plants. The agency made cost/benefit analyses of Hg-reducing equipment and maintenance against health expense savings. The benefits outweighed the costs. A Harvard University study found significantly greater health benefits from Hg emission controls than were estimated by the USEPA. These findings were the basis for a national law requiring that Hg emissions from coal-burning power plants be reduced by about 50% of 2005 emissions in stages over 15 years from the 48 million tons emitted annually to about 24 million tons in 2020. However good this law is, it can be improved. If equipment can be installed that will reduce Hg emissions to the atmosphere by 75%, why settle for a 50% reduction? And can the reduction goal be achieved before 2020? The setting of a 50% instead of a 75% reduction goal and perhaps a longer time frame to reach it may be interpreted as a political decision that eases the investment burden on industries that use coal combustion. For most observers public health concerns about Hg emissions and human health should be put ahead of added investment for industries in taking such a decision. This is short sighted because use of best available technology now means that funds will not have to be spent in the future to upgrade pollution control equipment. Citizens today and those to be born have the right to all the health benefits that clean air can bring them now.

## *Radiation*

To deal with the Rn problem discussed in Chap. 4, statutes (housing regulations) in many municipalities require in-ground Rn testing before building permits are issued. If critical (high) amounts of Rn emit from the soils and rocks tested at a proposed home site, it must be relocated to a site that is safe from Rn.

Three organizations give recommended values for assessing Rn concentrations at building sites or in homes and the times for intervention when indoor radioactivity is above the action levels (Table 7.2). The values by the USEPA are given in pCi/l (pico curies per liter of air), whereas those given by the EU and the WHO are in $Bg/m^3$ (Becquerels per cubic meter of air). A value of 4 pCi/l = 150 $Bg/m^3$.

**Table 7.2** Reference values to assess radon (Rn) hazards in homes or at building sites recommended by the USEPA, the EU, and the WHO

| Organization | Concentration | Recommendation |
|---|---|---|
| US Environmental Protection Agency | $<4$pCi/l | No action |
| | $\geq 4-20$ pCi/l | Reduce the level in years |
| | $\geq 20-200$pCi/l | Reduce the level in months |
| | $\geq 200$ pCi/l | Reduce the level in weeks or evacuate occupants |
| European Union | $>400\,Bg/m^3$ * (existing buildings) | Reduce the level |
| | $>400\,Bg/m^3$ * (new construction) | Reduce the level |
| World Health Organization | $>100\,Bg/m^3$ ** | Reduce the level |
| | $>400\,Bg/m^3$ ** | Take immediate action |

* Average annual concentration of radon (Rn) gas
** Annual average

For example, if measured Rn indoors is $<$4pCi/l no action is required. However if the measured value is $\geq$20 pCi/l (750 Bg/m$^3$), the level should be reduced in months. The EU sets an average annual concentration of Rn gas at $>$400 Bg/m$^3$ ($\sim$10.5 pCi/l) before remediation is necessary. At an annual average of $>$400 Bg/m$^{3,}$, the WHO recommends immediate action for the remediation of the Rn hazard.

Various methods are offered to prevent an indoor Rn build up. They may be costly such as designing and manufacturing a ventilation system specifically for that purpose. Depending on the Rn concentration and rate of Rn intrusion, an efficient and inexpensive option could be the installation of a window fan on a timer that exchanges the air in a basement or ground floor of a house with outside air.

## Industrial Catastrophes and Killer Air - Despite Regulations

### *Chemical*

The tragedy in Bhopal, India, described in an earlier chapter, killed thousands of people by respiration of methyl isocyanate gas and was not foreseen. Regulations were in place for the safe handling of the chemical methyl isocyanate. However, they were ineffective against a disgruntled employee who initiated a chemical reaction that created the killer gas and a buildup of heat and pressure that breached a holding tank and released the gas.

There is no doubt that in addition to having regulations in place, other safeguards may have to be legislated to lessen the chance of similar happenings at other industrial sites. For example, it is important to present annual or semi-annual educational programs for employees to alert them to the dangers from an industrial chemicals release to the environment. Annual psychological evaluations of employees might reveal employee mindsets that could evolve into destructive response. In many countries, this is the law. It is clear that legislation should require the installation of monitoring and alarm systems at facilities where toxic materials could be released by sabotage or an unexpected mechanical failure or human error. This must be coordinated with plans for rapid evacuation of populations at imminent risk. Both of these latter programs are operational at nuclear power plants. Sometimes, such as at Chernobyl, they fail.

### *Radioactivity - Despite Regulations Chernobyl Failed*

Regulations are in place to prevent a nuclear power plant accident or to minimize its effects. However, at Chernobyl human error and response to it by inadequately trained, drilled, and disciplined personnel contributed to the accident and its aftermath. Flawed reactor design because of the lack of a secondary containment structure worsened the results of the Chernobyl explosion and the extent of its impact.

Human error also caused accidents at other nuclear power facilities such as at Three Mile Island in Pennsylvania, USA but radiation was contained because of rapid response to warning systems, personnel trained and drilled to respond to the problem, and a secondary containment structure.

The short- and long-term human costs of the Chernobyl nuclear power station failure in 1985 were discussed in Chap. 4. Radiation exposure to nearby populations could have been mitigated if evacuation took place immediately when problems were detected and the explosion happened instead of 36 hours later. There was a lack of emergency management and evacuation planning. During those 36 hours citizens were exposed to dangerous levels of radiation from radioactive gases and particles in the atmosphere. In addition to deaths and radiation sickness suffered by thousands in Ukraine and Belarus, 200,000 people are estimated to be at risk for future health problems related to exposure to the Chernobyl radiation.

The costs of the accident have been and will continue to be enormous in terms of human life and long-term damage to human health, and for local and regional economies. National and international treasure has been and will continue to be spent in the maintenance and monitoring of the cement sarcophagus that now contains the failed but still "radiation hot" Chernobyl reactor, in yearly medical exams and care for exposed populations and their environments, and in clean up of the environments where feasible. Thousands of hectares are under quarantine and it is probable that radioactive decay of isotopes and time will be the *modus operandi* for the "clean up." Clearly, the excavation of radioactive soils, their disposal requirements, and the refilling of excavated areas with clean soil are not feasible physically or economically given the extent of the areas quarantined.

## Clean Water Regulations - Progress, Advances, Successes

Earlier, this text emphasized that safe drinking water and irrigation water, clean water for hygiene, and water for sanitation are essential to a population's well being. Together, they contribute to a good quality of life and productive societies. In the United States about one-half of potable water is drawn from river and lakes and the other half from aquifers. Contamination of these sources puts consumers at risk of debilitating illnesses (Chap. 5). Sufficient and contaminant-free water sources are important to national economies because clean water is necessary for many development sectors to function, offer employment, deliver goods and services, expand, and prosper.

Clean water legislation worldwide has multiple goals. The first is to preserve the natural purity and flow of a nation's rivers, lakes, canals, and aquifers by eliminating or controlling discharge of pollutants into natural waters. Where applicable, this extends to a nation's wetlands, estuaries, and marine coastal waters. Second, clean water legislation supports remediation programs to bring the quality levels of polluted waters to purity standards for potable water, and for water useable for irrigation, and for fishing and recreation. To do this, legislation provides funds for medical research to establish maximum permissible concentration in waters for contaminants from natural and/or anthropogenic sources. Legislation also funds research to improve existing technologies and develop new ones to clean polluted waters at input sources and bring levels below allowable concentrations. In addition, there are federal or state/province permitting laws that control the locations for discharge or disposal of different classes and volumes of treated and raw waste effluents.

States or provinces can override national legislation and set more stringent water quality standards specific to their particular situations. Through clean water acts, national governments provide funding to states, provinces, or individual communities to meet their water infrastructure needs (e.g., sewage collection systems, modern waste water treatment facilities, and distribution networks for safe water). Regulations ensure that economic development projects and other activities that could affect aqueous ecosystems are done in an environmentally sound way.

## *Effectiveness of an Enforced Clean Water Act*

The results of well-drafted, inclusive, and enforced environmental legislation for water protection can be outstanding. For example, in the United States, the Clean Water Act was passed in 1972. During the middle 1970s, sewage treatment plants served 85 million citizens in the U.S. (about half the population). Today, almost 200 million citizens (about two-thirds of the population) are served by modern wastewater collection and treatment facilities. In the middle 1970s, only one-third of U.S. waters were safe for fishing and swimming. Today, two-thirds of the waters are safe for these activities. During the same time period, wetland losses to development were estimated to be about 460,000 acres annually but this has been reduced to 70,000-90,000 annually. In addition, reclamation is restoring tens of thousands of acres of wetlands and renewing once devastated habitats.

Enforcement of the U.S. Clean Water Act will lead to the clean up of Onondaga Lake near Syracuse, New York, which was polluted during the course of a century with toxic chemicals (e.g., Hg) from industrial and municipal sources. This is one of three lakes listed as Superfund sites. After legal proceedings with the State, Honeywell Inc. committed to a settlement in 2006 with a $451 million nine-year cleanup plan to dredge up 2.65 million cubic yards of polluted sediment from the 5 mile long lake and to seal 579 acres of lake bottom with a cap of clean sediment. In addition, Onondaga County is complying with a court order by spending $500 million over a 15 year period to stop polluting the lake with sewage to make the lake safe for swimming and fishing by 2012.

Part of the U.S. Clean Water Act sets regulations that were designed to control agricultural runoff. This reduced farmland erosion from 2.25 billion tons of soil in the middle 1970s to one billion tons of soil today. The curtailing of erosion also diminished by like amounts the masses of phosphorus and nitrogen nutrients carried in waters and sediment (from farmland agricultural chemical runoff) into sensitive water bodies such as estuaries and marine coastal zones. The phosphorus and nitrogen issue from excess amounts of fertilizer applied to farmlands (Chap. 6). When agricultural runoff discharges in water habitats, nutrients it carries stimulate excessive algae growth that harms fish and shellfish productivity. Similar legislative advances against agricultural fields erosion and reduction in nutrient runoff are in effect for many nations.

## *Quality of Life*

Clean water coupled with clean air influence where people elect to live and ranked second of 41 parameters presented in a poll made in the United States. This likely reflects a global preference. Location has an economic impact on property values. Real estate professionals report that proximity to clean water increases the value of a home 22% compared to a like property without this benefit.

## *New Home Construction Limited by Safe Water Availability*

The quality of safe water notwithstanding, sufficiency of clean water supplies can dictate if development will take place. The State of California assessed its growing population and limited water supplies. This prompted its legislators to pass a law that regulates where developers can locate extensive and densely populated housing tracts to accommodate changing demographics. The law became effective in 2002 and requires that developers for proposed housing tracts with more than 500 units show detailed proof that ample water supplies exist. Also, they must document that the supplies can sustain populations during extended periods of drought and can be tapped for at least 20 years. If this is not assured, building permits are not issued. The law was written to restrict urban sprawl and reckless growth that has been a hallmark of growing populations in water-deficient areas of California. Developers may attempt to skirt the law by breaking their tracts into units of less than 500. Land-use planning officials who review and approve construction permits can thwart this ploy. They can factor in long-term clean water availability when determining whether or not to issue building permits. Other water-deficient areas of southwestern and western United States such as in Nevada and Arizona have similar population growth problems as people relocate to them from northeast and north central states. The population shift for retired persons is driven by the desire to avoid harsh winter seasons and by the availability of affordable housing. Other people move to these areas because of job opportunities. However, these states have not yet enacted laws to assure sufficient clean, long-term water supplies before large-scale housing development takes place.

## *Agriculture*

Globally, crops grown with irrigated water represent more than 40% of the value of all crops sold. In many countries this figure is significantly higher. Laws relate the quality of irrigation water that supports this source of food crops and other useful products. Animal husbandry for food animals (e.g., cattle, foul) and aquaculture, require clean water. The annual economic value of crops and food animals worldwide is $100s of billions.

### *Commerce*

Effective clean water acts help countries with important commercial fishing and/or shell fishing industries. The industries are dependent on clean water in estuaries and marine coastal wetlands, in lakes, and for the previously cited aquaculture, so that they can provide protein-rich, untainted products for consumers. Trillions of gallons of clean water are used by manufacturing sectors. For example, the soft drinks industry is global and uses billions of gallons of clean water to produce saleables valued at billions of dollars (or euros) annually.

### *Recreation and Tourism*

Recreation and tourism depend on clean water where trips are for swimming, fishing, boating or just relaxing around water destinations. In the United States, for example, 1.8 billion trips or 7 per person annually are made for water dependent activities. This brings billions of dollars into the U.S. economy and into global tourist-based economies (e.g., Mexico, the Caribbean, and Southeast Asia).

## Clean Soil Regulations - Environmental Status

Although clean air and clean water acts have been passed and enforced by many nations, there is little legislation globally that regulates clean soils. During the early 1980s, The UNEP and the UNFAO programs presented a world soils policy statement and a world soils charter, respectively. They focused most of their attention to redressing physical processes that degraded soils and damaged their sustainable productivity. They gave little heed to the harmful effects of soil contaminants on agricultural crop quality and yield. Given the state of environmental awareness about inorganic and organic pollution during that time, this is understandable. However, the Netherlands started instituting soil protection regulations in 1983. These were written to protect the functions of soils through conservation and restoration, to regulate pollution sources from traffic emissions to animal wastes, and made companies responsible for the cleanup costs of their own properties but not for outside properties. An update of the Dutch legislation in 1998 stated that pollutants be eliminated where possible, that pollutants in soils be reduced (decontaminated), and that pollutant spreading be prevented or reduced in a lasting way thus guarding juxtaposed soils or water bodies from harmful changes. In 2006, the Commission of the European Communities noted that only 9 of the 25 EU nations had soil protection laws but that even the 9 had no coherent protection framework. The Commission proposed a general strategy. First it calls for legislation for the protection and sustainable use of soil (in the EU), and second for an integration of soil protection in national and community policies. The third step calls for research on how to cope with problems now and in the future, and the fourth for a program to increase public awareness of the need to protect soils.

A major problem in drafting legislation to clean up polluted soils is understandable because there is no compositional norm for them. Atmospheric chemists know the composition of pristine air. Hydrogeologists know the natural chemical contents and concentration ranges of fresh water from surface bodies and aquifer reservoirs, and of brackish and ocean waters. As discussed in the last chapter, soils have quite different compositions because they take on the chemistry of rocks from which they form and these vary greatly in their chemistries. If they have high contents of potentially toxic metals, this is reflected in the soil chemistry. For example, soils that evolve from olive-colored to black shales, most of which contain an assemblage of heavy metals in high concentrations, will inherit this chemical imprint. The same is true for rock containing minerals bearing ore metals. As such, crops grown in metal-rich soils may bio-accumulate one pollutant or more than one and make crops grown in them unsuitable for long-term consumption. The great variations in soil chemistry of inorganic and organic chemical constituents makes it difficult to write generalized legislation that sets norms for what is considered a clean or a polluted soil. Each regulatory jurisdiction whether it is large or small has to determine its own norms based on chemical studies which detrmine natural baseline concentrations.

Some countries such as Japan have established what they call trigger levels in soils (e.g., As = 50 ppm, Cd = 9 ppm, Pb = 600 ppm, and total Hg = 3 ppm) which means that some action is recommended. Trigger action for containment or remediation is suggested when these concentrations are exceeded but such actions are not mandated by law. During 1999, Germany drafted a Federal Soil Protection Act and Denmark passed a Contaminated Soil Act both of which carry the authority of national legislation.

## *German Approach*

The German Federal Soil Protection Act draft has four requirements. First, soil polluters and landowners must stop putting soils at risk; second, landowners must protect soils on their land from risks such as leaking underground storage tanks or buried pipes; third, there must be assurance that no harmful changes in a soil arises in the future; and fourth, existing soil pollutants that threaten humans or the environment must be removed. In the latter case, the draft laws assign responsibility for clean-up planning and clean up measures to return a soil to economic use and establish a safe environment. In the case of soils derived from rocks with natural higher than permissible concentrations of contaminants, remediation to national standards allowable concentrations for cropping is not an option. The viable options are to grow a crop that discriminates against the uptake of pollutant metals from these soils or not to use the soil to grow foodstuffs but rather saleable garden trees, flowers, or vegetation that yields useful fibers.

### *Danish Approach*

The Danish Act has five objectives. The first is to keep soils clean and thus protect potable water resources. A second is to prevent health problems caused by the use of contaminated areas for food production. The third directs public attention to the need to avoid detrimental acts that result in soil contamination. The fourth is to prohibit the use of polluted soil and keep it *in-situ* to prevent further pollution of the environment. If a polluted soil is excavated, the remediation plan must provide for secure disposal at permitted sites. Lastly, as in the German draft, the Danish Act holds the polluter responsible for excavation or remediation that removes the health threat from contaminated soil. It requires the restoration of the environment to its natural state. If the natural soil state is a polluted one, the options, as given above for the German approach, are not to use it for cropping or to grow a discriminator crop or non-edible but commercially valuable vegetation.

### *State/Province Role*

When state and provincial governments determine that federal laws on clean air and clean water do not sufficiently protect the health and safety of their populations and ecosystems, they enact laws establishing more stringent clean air and clean water requirements. Similarly, lacking national regulations, state/provincial governments have passed laws that set remediation levels for contaminated soils if they are to be used again for agricultural or other contact purposes and do not present a danger to the vitality of ecosystems. The laws also set regulations for the disposal of excavated polluted soil at authorized and monitored sites.

## Revisiting Legislation: Closing Loopholes/Modifying Norms

Legislation pertaining to chemical pollutants in the environment are reviewed and revised regularly. When new medical evidence and epidemiological data indicate that maximum permissible concentrations set by law for air, water, or soil products harm humans and ecosystems, they are changed. Thus, overtime, the WHO, regional groups, and national health agencies have lowered allowable concentrations of pollutants in air, water, soil, and foodstuffs. Examples from previous chapters include

As and Cd in water, Hg and Pb in emissions to the atmosphere, As and Cd in soil, and Hg and Cd in foodstuffs.

Closing loopholes in legislation can be difficult to do especially when international treaties are involved or when political influences are dictating interests that are not to the benefit of a country’s citizenry. An example is in negotiations that resulted in the Kyoto Treaty. The Treaty was written with the purpose of reducing greenhouse gas emissions worldwide in order to slow the rate of global warming/climate change and ultimately stop the warming if not reverse it.

Negotiators for developing nations argued that they should have the freedom to achieve their economic goals without restrictive environmental regulations on greenhouse gas emissions. They reasoned that industrialized nations reached their development status without the constraints of environmental regulations. Why then should developing nations not have the same opportunities to move to rapid industrial development and the sustained economic growth it brings without constraints of stringent environmental regulations? The questions to be addressed are whether this argument is valid or invalid and whether citizens’ environmental rights worldwide can be knowingly ignored. At the time the Treaty was being debated and drafted, the emerging economies boom and push to rapid growth industrialization in countries with large and expanding populations was just starting. The influence of greenhouse gases emissions on global warming/climate change was not as well documented and accepted by as many then as it is today. Thus, it did not seem to be an imminent environmental issue for developing nations.

The negotiated Treaty set carbon limits (emissions of $CO_2$, $CH_4$, $N_2O$, sulfur hexafluoride [$SF_6$], and perfluorocarbons [PFCs]) on industrialized countries (e.g., 8% below 1990 levels imposed on the European Union nations and 7% on the United States). It exempted developing countries from such limits. The aim was to reduce collective emissions of greenhouse gases in 2012 by 52% of 1990 emission levels. Although work on the Treaty began in 1992, it was put up for signing in December 1997. It came into force during February 2005, signed by 169 nations that produced more than 61% of global greenhouse gas emissions. The United States, the leading producer of these gases, and Australia were not signatories. The United States did not sign the Treaty because the administration believed that imposed limits cited above would slow down the economy. This is the same rationale given by developing countries with hopes for strong economic growth as they argued for their exemption.

The reduction goal will not be reached because of the exemption, a loophole in the Treaty, and greatly increased greenhouse gas emissions from developing countries with economies growing at 8-10% annually such as China and India. For example, $CO_2$ emissions from China increased 4% annually from 1994-2004 and during 2005 and 2006 rose to 5%. In 2006, the United States $CO_2$ emissions decreased by 1.3% (due in part to a warmer than normal winter) compared with the all-time peak reached in 2005. In a few years (2009-2012), if not sooner, $CO_2$ emissions from China will exceed those of the United States and China will be the world’s top emitter (Table 4.9). The Treaty exemption from greenhouse gas emission limits for developing nations is preventing an effective attack on the global warming/climate change problem.

The Kyoto Treaty terminates in 2012 and its goals will not be met, even at a minimum level. The effects of global warming driven in great part by $CO_2$ emissions are harming ecosystem habitats. This is reflected in organism migration and increased pressures on endangered species as well as the abnormal melting of sea ice, icecaps and glaciers.

As stated in Chap. 4, the United Nations hosted a forum during December 2007, to refocus on the problem of global warming. After two weeks of intense discussion and debate, the delegates from more than 190 countries agreed to a working document designed to reduce the emissions of $CO_2$ and other greenhouse gases and lessen the rate of warming. The final pact is planned for presentation and ratification by the end of 2009. Unlike the Kyoto Treaty, the United States is a signatory to the framework proposal. The main points of the working document are first, that the amount of emissions reduction below 1990 levels for developed nations between 2012 and 2016 will be negotiated. This is a compromise of an initial proposal for a 25-40% reduction below 1990 emissions by the year 2020 by industrialized nations. The 25-40% was an IPCC (2007) estimate as the amount of reduction in emissions that would keep temperatures from rising 3.6°F ($\sim$1.6°C) above pre-industrialization levels and is viewed largely as being unattainable. Second, the rapidly developing nations (e.g., China and Brazil) waive their Kyoto Treaty exemptions and commit to measurable emissions reduction phases, verifiable by international monitoring on two conditions. First, industrialized (wealthier) countries must pledge to provide them with clean air technology. Second, the developed countries must help strengthen the less well nations with financial aid and technical assistance that will improve their ability to adapt to climate change. India resisted making the commitment but is expected to join in as the global warming emissions reduction pact is finalized. A welcome forum proposal for the 2009 pact is to provide tropical nations with financial compensation for preserving the rain forests.

Previous to the UN forum and the working document that resulted from it, Harvard University began a two-year project during the second quarter of 2007 to formulate a successor to the Kyoto Treaty. The Harvard document is planned to be "scientifically sound, economically rational, and politically pragmatic". The Harvard Project on International Climate Agreements will draw on the expertise and experience of academics, business and government leaders and give ear to environmental advocacy groups to develop a replacement for the Kyoto Treaty and will likely make substantial intellectual, economic, and political contributions to the planned UN pact.

## *Cap and Trade or Buy/Invest and Earn - Interim Tactics*

### Cap and Trade

Cap and trade legislation creates a financial incentive for reduction of polluting emissions. The legislation assigns a cost to those who pollute above pre-agreed levels and provides those who cut their emissions below pre-agreed levels with a saleable commodity, emission credits.

To set up a cap and trade program, a joint committee of government and industry representatives appoints an environmental regulator who establishes the cap that sets limits on emissions from a specific group of polluters. This might be 30% lower than current emissions of $SO_2$ and $NO_x$ for power plants or of $SO_2$ for smelters. Emissions allocations under the cap are meted out as individual (plant) permits (generally in one ton units) that give a facility the right to emit that amount. Each plant finds the lowest-cost way to reduce emissions. This might be by using low-sulfur coal, by changing fuel to natural gas, by changing the stock used in the industry, or by installing new best available technology to capture pollutants before they emit to the atmosphere. Companies that reduce their emissions at a reasonable cost below their allotted units can sell their extra permits to companies that would have high costs to reduce their emissions to the required limits and elect to buy permits. Companies thus have flexibility as to how they attain their emission limits so that specific environmental goals can be met (e.g., less $CO_2$ emitted, less acid rain). Taxes on emissions beyond set limits offer an alternative and cause a polluter financial pain. However, if the polluter chooses to pay the tax, there is no benefit to the environment.

The cap and trade scheme to lower industrial emissions was instituted in the United States by amendments to the 1990 Clean Air Act to reduce acid rain damage to the environment from anthropogenic added $SO_2$ in the atmosphere. It has been successful in reducing $SO_2$ emissions at costs far less than projected to the benefit of polluters and to ecosystems that have suffered from acid rain. This method was adopted by the European Union during 2005 for a cap and trade system to reduce $CO_2$ emissions and the EU contribution to global warming.

In the European Union, the targeted reductions in greenhouse gases using the cap and trade policy and regulations on the use of best available technologies for their capture in coal-burning power plants is 6% below 1990 levels by 2011 and 20% below those levels by 2020. For vehicles the target is 30% below their 1990 emissions by 2016. During the second quarter of 2007, the U.S. Congress initiated a review of a set of cap and trade proposals and air pollution control measures which would set specific emissions reductions to be achieved for six greenhouse gases at 50%-80% (depending on the greenhouse gas) below 1990 levels by 2050. The Congress is also considering a bill that would approximately stabilize U.S. emissions at the 2008 levels.

## Buy/Invest and Earn

Many signatory industrial nations to the Kyoto Treaty realize that their industries cannot achieve the reductions assigned to them by the Treaty for greenhouse gas emissions. They hope to resolve this problem by buying or "earning" emission credits internationally. For example, Japan, Canada, and rich Western European countries intend to buy credits from nations in Eastern Europe and Russia. These nations have a decreased industrial base today because of the reorganization of Eastern Europe and the then Soviet Union at the beginning of the 1990s. Thus, they have credits to sell until their industries revive and reach a 1990 emissions level.

In another scheme to move towards allowable emission tonnages, industrial nations propose to earn emission credits by investing in non-$CO_2$ emitting clean energy and renewable energy projects (e.g., hydroelectric power, wind turbine power, solar, geothermal) at suitable localities in less developed countries. Also, where investment is made to capture and use methane gas from old dumpsites, the "earn" effort helps lessen the impact of methane emissions on global warming. Canada proposes to invest in the capture of methane gas produced in Chile by 100,000 pigs and thus earn emission credits for its polluting industries as Canadian industries plan for the near future installation of emissions capture equipment.

This is good in principal, but without a promising future if a facility in a country working with earned credits continues to release the same amount or increased masses $CO_2$ and other greenhouse gases to the atmosphere. Greenhouse gas emissions masses worldwide must be reduced if global warming is to be at all mitigated. The investment in clean-energy projects in poor countries is a noble effort, but not one that will reduce the amounts of existing and future emissions of greenhouse gases that is necessary to cope with the problem of global warming and consequent climate changes. These emissions can be decreased by lowering fossil fuel consumption (e.g., in electricity generation, transportation) and by the use of best available technologies for emissions capture at sources. Only a reduction in greenhouse gas emissions has the power to slow down the rate of global warming. Only this can mitigate the mounting environmental threats worldwide posed by factors such as rate of sea level rise, insidious inundation of coastal zones, climate shifts, and intensity and extent of storm damage in coastal areas.

## *Limitations to Change - Opportunity for Change*

How far can industrial economics be stretched to reach optimal controls on contaminant release to the environment? Will stockholders stay with industries that propose to invest in methodologies to preserve or improve the living environment if this means less return on their short-term investment but promises of good long-term returns? Can management and workers from top to bottom accept less than hoped for salary increases now but with the prospect of good salary increases in the future in order to work with industries to stabilize or improve conditions that damage environments? The likely answers are not predictable although one would hope that reason comes up with "yes" answers. Environmental legislation is commonly presented in wordy "legalese" and complicated formats. It seems written so as to confuse enforcement authorities and the public rather than be transparent and unambiguous for environmental monitors. At the same time, legislators and their staffs may not have thoroughly vetted possible loopholes in the laws they write and pass. Lawyers acting in the interest of their (polluter) clients without regard for the

Earth's health find omissions in legislation that benefit a polluter. The loopholes in environmental laws have to be closed.

## *Government Legal Action to Curb Wetlands Destruction*

Loopholes can be closed by changes in the law. An example is found in a rule that was added to the U.S. Clean Water Act in 1993 to clarify that federal permits were required for any discharges associated with draining wetlands. Subsequently the law was revised so that "discharge of dredged material" covered most construction activities. However, there was a loophole that allowed developers to excavate, ditch or drain wetland areas as long as significant materials did not fall back and they did not dump soil on the site. Although challenged, the loophole was upheld in courts in 1997 and 1998.

Since that decision almost 20,000 acres of wetlands were destroyed and more than 150 miles of streams channeled without environmental review. Under the existing clean water act, developers could drain most of the wetlands in the United States. Wetlands have important function in our ecosystems. For example, wetlands filter and cleanse waters and provide pathways to aquifers, help to reduce strength of tropical storms and hurricanes, help to retain floodwaters, and provide havens for spawning and emerging young fish and shellfish. If wetlands are drained and destroyed, runoff and flooding can increase and harm neighboring environments, unfiltered drainage contaminants will cause stream and river pollution, and there will be a loss wildlife habitats. This flaw in the law had to be redressed. In April 2001, under the aegis of the USEPA and the US Corps of Engineers, legislators acted properly in spite of intense lobbying from homebuilders interests and the loophole was closed by an amendment to the Clean Water Act.

## *Government, Citizens' Legal Action to Curb Air Pollution*

In 1999, 8 states (mainly from the northeast United States), a dozen environmental groups, and the USEPA brought suit against the American Electric Power company for expanding 16 coal-fired power plants without installing new pollution control equipment as required by the Clean Air Act. The plants are located in Ohio, Indiana, Virginia, and West Virginia. The aim of the suit was to reduce acid rain pollution that damaged forests, rivers, and lakes in the northeast mountain ranges and national landmarks during the past quarter century. Acid rain and smog are linked to $SO_2$ and $NO_x$ gases emitted from coal-fired power plants. After eight years of legal maneuvering, and a six-week trial during 2007, the company acceded to a settlement for $4.6 billion that will be used for the installation of chemical scrubbers and other pollution control equipment. This is estimated to reduce emissions of $SO_2$ by 79% by 2018 and of $NO_x$ by 69% by 2016. Acid rain will be reduced by 69% in ten years. In addition, the company paid $15 million in civil fines and committed $60 million for cleanup and mitigation costs for remediation of parkland and waterways damaged by the pollution. Of the $60 million, $24 million is for projects to conserve energy and produce alternate energy, $21 million is to reduce emissions from barges and trucks in the Ohio River Valley, $10 million is for acquiring ecologically sensitive land in Appalachia, $3 million is to aid pollutant reduction in Chesapeake Bay, and $2 million is to reclaim damaged areas in Shenandoah National Park. This is a signal to polluters that legal action by governments and citizens' organizations to bring their facilities into compliance with environmental laws may be delayed by a polluter's attorneys but will ultimately come to trial and can have costly consequences.

The settlement may have been spurred by the 2005 USEPA Clean Air Interstate Rule that required phased-in reductions in air pollution in 28 states, mainly in eastern United States to curb air pollution from $SO_2$ and $NO_x$ emissions as well as particle (soot) emissions.

According to USEPA analysis, benefits realized from this ruling will result in as much as $100 billion dollars in annual health benefits in a decade by preventing at least 17,000 premature deaths, 1.7 million lost work days, 500,000 lost school days, 22,000 non-fatal heart attacks, and 12,300 hospital admissions annually. Economists estimate that $2 billion in visibility benefits will also accrue. In 2005, the cost to the power producing industry was estimated at $4 billion, but with the 2007 settlement of $4.6 billion by the American Electric Power Company, the estimate will be greater. Even at $8 billion cost to curb the air pollution, the benefit to cost ratio of $100 billion/$8 billion is better than 12.5 to 1.

## *Use Best Available or Best Affordable Technology*

As noted in the discussion on clean air acts, the problem of Hg emissions from the 450 coal-burning power plants in the United States was addressed by USEPA regulations in 2005 that require reduction of Hg emissions by 50% by 2020. The costs of equipment and installation and subsequent maintenance will be high. As with the Clean Air Interstate Rule on smog and soot emissions reduction (as well as $SO_2$ and $NO_x$), the long-term health benefits of Hg emissions reduction to populations and its effect on national economies will exceed the costs of the technologically best Hg capture equipment. A reduction of Hg emissions by 75% is achievable but more costly to coal-burning utilities. It has to be determined if the additional costs are outweighed by additional health benefits.

## *Paths to Compliance with Environmental Safeguards*

There are political, economic and legal paths to follow to influence active and potential polluters of air, water, and soil to engage in the effort to minimize or prevent pollution. Following one or a combination of paths will bring about attitude changes towards preserving the environment and its resources for future generations.

## Political

A political/economic path already cited is incentive-based. Tax incentives can be offered to polluters as a subsidy to retrofit existing systems to substantially reduce or essentially eliminate the discharge of contaminants into the environment. Low-cost loans or grants for the purchase and installation of pollution control equipment may be part of an incentive package. This is especially important at coal-burning power plants that discharge $SO_2$ (acid rain precursor), $NO_x$ gases (abet smog formation), particles, and volatile Hg (enters food web where it can bio-accumulate in food fish) and other heavy metals. Tax incentives, low cost loans, or grants that lead to a decrease of $CO_2$ emissions from coal, oil, and natural gas burning facilities would be good "investments" in the battle against global warming.

## Economic

An economic path to turn polluters and potential polluters into protectors of the environment is market-based. When active or potential polluters realize that the elimination of pollutant discharge and maintaining a healthy environment is economically beneficial in the short-term but more so in the long-term, their interests will be to eliminate contaminant discharge. This can be coupled with economic incentives and lay the basis for following clean air and clean water acts and the use of the most effective and efficient technologies to protect soils from pollution originating with the atmosphere or water. Clean soils yield saleable crops. In 1999, an Indiana group (IWLA) proposed that incentives be included to encourage composting various farm wastes to create enriched topsoil and maintain soil fertility in a yet-to-be-drafted National Fertile Soil Act. This is being used in today's organic farming.

## Legal

The third path to follow to bring polluters into compliance with clean air and clean water legislation is punitive-based and least desirable. Polluters can be fined. They may choose initially to pay fines and pass along the cost to consumers unless governments prohibit this or limit the percent of pass-along costs. A loss in profitability because of fines will lower investor confidence. This will force offending industries to invest in pollution control technology to come into legislated compliance and assure long-term operations and continuing profits. Finally, polluters are liable to individual civil or class-action suits that can bring verdicts for actual and punitive damages. These can be more costly than the installation and maintenance of pollution preventing technologies for various sector ventures.

## "Green" Precepts and Legislation

The quality of life for people in any nation is measured to a great degree by several "freedoms" and "rights". These include, freedom from want, the right to healthy living, freedom from fear, freedom of speech, freedom of religion, the right to education, the right to choose government leaders, and the right to assemble and pose grievances to political authorities.

Freedom from want and the right to healthy living depend on establishing and maintaining environments with clean air, safe and sufficient water, fertile and unpolluted soils, and uncontaminated aqueous environments. Member countries of global organizations such as the WHO and the UNEP have signed treaties and conventions directed towards these goals. Regional groups such as the European Union and the North American Free Trade Association have done the same. National governmental agencies such as the USEPA set environmental laws. Similar groups globally do the same (e.g., in Canada, Japan, Russia, China, Egypt, Australia, India, Brazil, and Scandinavia). This is true as well at state and provincial levels.

These environmental protection units have the legal obligation to continually evaluate concentrations of chemical and biological components in air, water, and soil that can be damaging to the inhabitants and natural resources of ecosystems. The damage may be from a strong "slug" input of a pollutant or from long-time exposure to it. With this determined, authorities propose legislation to governmental bodies that enables them to evaluate a problem and set standards for the amounts of natural and anthropogenic contaminants allowable in air, water, and foodstuffs. Politicians pass laws based on reliable agency data that define maximum permissible concentrations of harmful pollutants that their citizens breathe, drink, eat, and use. These concentrations change, most often to lower levels. The changes are a result of ongoing medical research that demonstrate with a high degree of confidence that long-term ingestion of contaminants or exposure to them at lower than allowable concentrations will degrade normal functioning of humans and other organisms. To shore up research on chemicals and health problems, the European Parliament, acting for EU governments, passed a law during the first quarter of 2007 to control the use of thousands of chemicals (some toxic) in industry. The law requires that industries test more than 30,000 chemicals used in products for safety by 2018 and replace hazardous chemicals with safer ones. The chemicals to be tested have been used without a full understanding of their short- or long-term effects on the normal functioning of ecosystems. Other governments are expected to follow this lead.

Environmental covenants also set goals to control biological disease-causing agents and changes in physical factors that can affect chemical element levels and mobility in ecosystems. The covenants support research to find out which chemical elements bio-accumulate, singly or in combination, through ingestion via food webs, inhalation, or epidermal contact, and evaluate their affect on life forms. The research measures parameters such as disease, death, gene mutation, physiological malfunctions (including in reproduction), physical deformations in organisms or their offspring, and behavioral anomalies.

The harsh realities of environmental intrusions that have passed a "tipping point", damaged sensitive ecosystems, and directly affected people's lives, have elevated public awareness of the dangers to the way of life in many countries. Responsible governments have passed environmental laws where they were lacking or changed existing ones to improve protection for ecosystems inhabitants and natural resources against further harm. For example, during the second quarter of 2007, Italy drafted a law approved by the Cabinet, establishing maximum penalties for crimes against the environment. The law is the result of awareness by the Italian government of the damage done during recent decades to forests, water supplies, and coastal zones. The maximum prison term would be 10 years with fines up to 250,000 euros. Examples in the draft legislation include the penalty for illegal waste disposal (or criminal trafficking in waste) as 1-5 years in prison and fines of 10,000 to 30,000 euros. Another example is 2-6 years in prison and fines of 50,000 to 250,000 euros for trafficking in nuclear or radioactive waste or abandoning this waste in the countryside. The law awaits parliamentary approval.

In extreme cases, and at the expense of economic progress, central governments have acceded to the enforcement of existing laws or to actions of local governments to halt pollution that harmed their populations. A case in point is that of Wuxi City in Jiangsu Province, eastern China.

Wuxi City has welcomed industries for almost three decades and has 5300 factories that employ half of the population. Wuxi has become China's sixth largest industrial city and in 2005 and 2006 its industries generated 2% and 1.58%, respectively, of China's GDP. The industrial base consists of machinery (25%), textiles and garments (24%), petrochemicals (13%), metallurgy (11%), electronics (8%) pharmaceuticals (6%), building materials (6%), and light industry (7%). Industrial development proceeded without stringent environmental controls by many factories that released effluent with a toxic mix of pollutants into a network of canals, lakes, and rivers in the industrial areas. If a factory was closed because of egregious pollution, it was often reopened shortly thereafter to provide jobs. Pollution continued to a tipping point when in May 2007, the toxic mix of contaminated waters and sludge overwhelmed Lake Tai that supplied drinking water for more than 5 million people. Life in the lake was lost and the lake became rancid with toxic sludge, mattes of living and decaying algae, and emitted a rotten smell. The water was untouchable and undrinkable. City officials acted and declared Wuxi to be a newly reformed green city. They closed or gave notice to close to 1340 polluting factories, with those on notice having to clean up by June 2008, or close down. The city officials were backed in these actions by the central government. The Chinese Environmental Protection Agency supported the officials on the orders of the central government and punished offending factories by denying them loans, and by directing utilities to raise fees for power in accordance with the amount of pollution. The governor of Jiangsu Province vowed to bring the polluted areas back to nature even if it cost a province/city GDP decrease of 15%. This would mean a decrease in China's GDP of about 0.2%. The Chinese central government acceded to this as the price of remediation and reclamation of an environment damaged by pollution from industries fueling its rapidly growing economy. It was also a signal that the attitude of sacrificing environments and people to pollution in favor of economic growth may be changing in China.

## Afterword

A knowledge and understanding of environmental laws governing the protection of the public's health and well being in is essential to planning for economic development. The development may be in one or more sectors such as agriculture, energy, transportation, and heavy or light industry. At the same time that developers assess projects within the framework of environmental regulations, they must factor in the influence of future changes in population growth, demographics and needs. The needs as discussed in Chap. 3 and amplified in Chaps. 4, 5, and 6, start with the air people breathe, the water they drink and use, and the soils (and waters) that yield their food. The next chapter deals with these parameters and others that have to be factored into proactive development planning.

# Chapter 8
# Proactive Planning in Industrial/Agricultural Development: Minimizing Chemical Pollution

## Economic Development Aims and Requirements

Assessments of the viability of proposals for economic development projects are made initially on the probability that they will turn long-term profits on investments. In addition to product sales potential in existing and emerging markets, investors weigh several factors to determine the expectancy of economic gain. Principal among these is the availability of human resources. Others include proximity to natural resources and transportation, sources of energy, waste treatment and disposal options, and intellectual support from (nearby) educational institutions. Experiences of like industries affect decision-making, especially in costs to meet environmental regulations and the impact on a project's costs/benefits relation.

Local, state or provincial, and federal governments work to attract projects that promise economic development. To do this they vote tax advantages for investors to offset costs to be incurred for placing a project with them. The tax benefits may include a tax-free period for corporate or real estate levies or reduced taxes for a fixed period of time. A principal requirement that these concessions carry is compliance with environmental laws. This may be to install the best available pollution control technologies or other methods that will limit pollutant intrusions into ecosystems. Governments may also provide grants to train personnel for employment opportunities related to development needs. This subsidization is proferred because of the income generated from the jobs created when implementing a project, those created in the project itself once it is operational, jobs produced in supplier and service industries, and increased employment in general businesses that serve a community. As emphasized in this book, preservation of the natural chemical composition and vitality of earth surface/near-surface environments is essential to the future of Earth populations and deserves support from government financial incentives.

Earlier chapters cited recent human experiences and historical documents that demonstrate the damage to organism health that releases of chemical pollutants into terrestrial and aqueous ecosystems can cause. In addition to harming humans, pollutants can lessen comestible yields of productive ecosystems on land, in fluvial and lacustrine systems, in wetlands and estuaries, and in oceans and seas.

Sources of natural pollutants that intrude ecosystems can be identified but are not often controllable. Environmentalists focus on anthropogenic sources of pollutants because they generally can be identified and controlled. Previous chapters stressed the fact that contaminants from human activities originate mainly as emissions or effluent discharges from utilities, industrial and manufacturing plants, and agriculture (field runoff and animal husbandry). Mobilization of metals or other toxins from discarded domestic wastes and business products or manufacturing materials at non-secure disposal sites adds to an ecosystem's toxic chemical load.

In the past, metals and other chemicals were discharged into ecosystems from industrial facilities without knowledge or attention to the fact that they were harming living environments. Similarly, runoff of unused (excess) farm chemicals applied on agricultural fields to control pests (e.g., DDT) and to stimulate growth (e.g., phosphate/nitrate/potassium fertilizers) released the unused amounts of organic chemicals and nutrients into surface/near-surface earth materials. These harmed vital environments and their natural resources. Contemporary awareness of the risks posed by anthropogenic pollutants to humans and other life forms forced legislative actions by many countries to significantly limit pollutant release into environments worldwide.

Protocol for development-planning teams requires that they perform risk analysis on proposed projects that could pose a threat to a pristine environment from emitted or discharged chemicals. Assessments of the risks produce realistic recommendations on how to deal with chemical pollution. As reiterated in earlier chapters, this can be by changing how chemicals are used (e.g., in farming), by changing the stock used (e.g., clean coal in utilities), by contaminant capture and treatment before release into an environment, by secure disposal of captured toxic matter, by recycling, or by the shut down of a polluting facility. Ultimately, pollution control benefits an economy. An important aspect of dealing with the chemical pollution problem is leachate capture and containment at waste disposal sites and/or directed runoff of leachates to treatment ponds. These methods and others that are in use alleviate or eliminate contaminant release and protect ecosystems, citizens, and long-term economic ventures. Planning for pollution control that may be needed at a development project is based initially on two main factors: (1) the average contents of chemical elements in natural samples in an area; and (2) the estimated output of the elements from a project.

## Identifying Pollution: Chemical Baselines

Natural materials (rocks, soils, waters, air, vegetation) have average contents of chemical elements called baselines or background levels. There is a range of ± deviations from baseline concentrations that account for normal variations in the chemistry of earth materials. Samples with chemical contents greater than baseline values and the + deviations suggests anomalously high contents (excesses) whereas those with chemical contents less than baseline values and the - deviations suggest anomalously low contents (deficiencies). Excesses and deficiencies of some chemicals can affect agricultural development. For example, deficiencies of essential macro- and micronutrients in soils and waters will cause diminished crop yield and quality.

Global averages are published for chemical elements and compounds in air, water, soils, and vegetation, as well as averages for regions (e.g., Europe, Scandinavia, Asia, and North America), and for nations. However, the chemical compositions of samples vary greatly from one region to another depending on four basic factors: (1) rock type from which soils form; (2) the presence of or proximity to metals mineral deposits; (3) the drainage system; and (4) the climate as it affects drainage and type and growth of vegetation. Each geological area, small or large, has unique natural baseline contents. Most development ventures encompass rather restricted areas. Because of this, it is a mistake to use the general global, regional, or national chemical baseline data in decision-making for areas targeted for investment. Baseline concentrations must be determined for each parcel and terrain proximate to it as an integral phase of project planning.

## *Baseline Values in Pristine Areas*

Sampling strategies differ according to pollutants that may emit or discharge from a source and with the samples in which they can accumulate (Siegel, 1994). Initially, scientists (preferably environmental geochemists) review a study area and calculate the number, locations, and type(s) of samples (e.g., air, water, soil, vegetation and other life forms) to be collected and analyzed. They base this on factors such as the size of a study area and disposition of potential samples in relation to geography and topography. In addition, the scientists factor in chemical mobility of probable pollutants, dominant wind direction, direction of surface water or groundwater flow, and density of vegetation species (hence availability for sampling) or distribution of other organisms. Together these evaluations define a sampling strategy.

## *Samples*

Most studies to establish chemical baseline values use bulk samples. However, sub-samples may better reflect pollution threats to an ecosystem. Sub-samples may be a soil horizon or a horizon size fraction. They may be leaves, twigs, or roots of vegetation. They may be of suspended matter in water, or of particles in air. Nonetheless, because of economic reasons or poor judgment and possibly limited experience of environmental teams, the separation of sub-samples is often not done. Because of this, important compositional data can be missed. For example, a fine-size soil fraction (less than 4 μm or clay) can show high contents of a pollutant if it is separated from a bulk soil sample and analyzed. If only a bulk soil sample is analyzed, the mass and composition of coarser size fractions can dilute and mask a chemical signal in the clay-size fraction and hide a pollution problem.

## *Analysis*

Chemical and geochemical consultants choose methods of analysis for samples that will generate accurate (actual values) and precise data (reproducible values). Accuracy is determined by comparing values published for international or national standards with those obtained on the standards by a consultant's analytical laboratory. Precision (or reproducibility) is calculated from the analysis of duplicate samples from 10-30% of the sampling sites. Both are critical for chemical data to be used with a high level of confidence during the planning of a development project and for monitoring chemical element output when a facility is operational. An accuracy or precision level of $\pm 2.5\%$ is considered good. The average concentration for a sample type can be used as a baseline value. However, there are other statistical options that should be considered when delimiting baseline contents. These depend on the geology, topography, and climatologic characteristics of an area.

## *Calculation*

Scientists calculate baseline levels from analytical data using mathematical techniques that yield other than the average content. For example, a chemical concentration at the 50 percentile of a cumulative frequency plot on a probability graph gives a reliable baseline concentration.

In the case of large areas with changing geology, the analytical values for a suite of samples (e.g., waters, soils, vegetation) may represent a mix of two or more sample populations. Each one has its own baseline value and range. Average contents and the range in contents for sub-populations can be extracted statistically from the total sample population as described by Siegel (2001) following the method of Sinclair (1976). It may be more accurate to consider the range of values in a sample suite when assessing the pollution status of a study area. A three-point moving average can also generate baseline concentrations where sample contents change from site to site because of changing geology (underlying rock types). Trend surface analysis is another statistical technique that is used to give moving averages where there are changes in geology. This analysis also highlights sample sites or zones with anomalously high values (pollution?) or low values (deficiencies?) for the chemical species being investigated.

Environmental consultants have a good idea of probable contaminants that can discharge into the atmosphere or hydrosphere from specific sources (Table 4.3). They also have a good estimation of the masses of pollutants that would be released from these sources by the use of available pollution control methods. Once natural baseline contents are known, environmental engineers and economists can estimate the added investment that has to be made in contaminant abatement technologies when planning a development enterprise. They also assess the costs for a regularly scheduled monitoring program for emissions and effluents and periodically for ecosystem media to measure pollution control effectiveness.

### *Baseline Levels for Contaminated Areas*

It is a challenge to assign chemical baseline contents for earth materials in contaminated areas. Yet this is necessary in order to recommend realistic economic and time-frame remediation possibilities for their reclamation if they are to be once again suitable for development. Environmental scientists agree that there are ways to approximate baseline contents for the polluted areas.

One approach involves identifying a geographically related pristine area with geology and physical/chemical/biological conditions that are the same or close to those at a contaminated site. Sample media from the former can be analyzed and their values used to assign likely natural baseline levels for the polluted area. Similarly, data from more distant areas but those with similar geologic, climatologic, latitudinal, altitudinal, and sun exposure conditions can be used to approximate natural baseline contents for a contaminated area. The values thus determined are useful in setting acceptable provisional concentration targets for remediation projects.

Natural baseline levels are more readily determined in floodplains that contain agricultural fields that were uncontaminated and productive in the past but are now poorly productive because of pollution. Scientists take cores in the floodplain that reach sediments deposited before the onset of contamination. Analyses of the deep sediments can yield chemical baseline contents that are acceptable targets in planning soil remediation programs.

## Development Planning/Monitoring to Detect Chemical Pollution

As underscored in earlier chapters, environmental scientists have identified inorganic and organic pollutants associated with various specific industrial, manufacturing, mining and agricultural subsectors that drive economic engines. Using this knowledge, planners and consultants can predict which pollutants are likely to originate from a proposed project. Table 4.3 identified selected industrial and manufacturing categories that generate heavy metals laden emissions or effluents (e.g., As, Cd, Hg, Pb). In the past, these pollutants were not captured or inadequately captured and released into the environment as untreated or as inadequately treated phases. This practice is detrimental to local and regional populations but continues in some less developed or developing nations.

Similarly, various pesticides (e.g., organochlorines, organophosphates, carbamates) and fertilizer chemicals (e.g., nitrates, phosphates) used in agriculture can be dangerous. An environmental threat exists when residue excesses of these chemicals remain in ecosystems or move to other ecosystems after application and use, especially if their degradation is slow. For example, DDT has been a banned pesticide in most countries for more than 30 years. DDT has a half life of 14 years so that a metric ton (1000 kg) of excess left on fields in 1960 would theoretically be present today as a mass of more than 100 kg. In addition, there can be threats to the environment from decomposition products (e.g., DDE from DDT) which themselves may be harmful to organisms when contacted, inhaled, or otherwise ingested.

Environmental engineers are aware of the problems that can issue from new enterprises. Thus, they include capture, containment, treatment, and/or isolation technologies appropriate to a project that eliminate or minimize pollutant release into ecosystems. Good engineering design allows for in-line modular additions of more efficient and effective technologies as they evolve. Emission and effluent control systems have to be specific to each source because each can have very different chemical compositions or similar compositions but with markedly different proportions.

Comparisons of geochemical data from samples of air, surface waters, soils, groundwater, vegetation, or other organisms with baseline data after a project is operational is the monitoring mode. Comparative data allow environmental analysts to determine if pollution control systems at emitting or discharging facilities are functioning efficiently in the capture of contaminants, thereby safeguarding ecosystems. If this is not the case, pollution control methods have to be upgraded.

## Biocide/Fertilizer Application Controls

Biocide is a general term for chemicals used to control pests harmful to sustainable and efficient farmland cropping Biocides work by either killing or repelling pests. There are more than 1400 of these chemicals. Several major groups of biocides are known generically as herbicides, insecticides, fungicides and rodenticides (Table 8.1). Each group has subgroups many of which are "designer" compounds used to target specific pests or groups of pests.

The dangers posed by the use of man-made chemicals for pest control are based on several facts. For example, there is not enough knowledge of which life forms may be susceptible to attack by a biocide in addition to those each chemical is designed to control. There is the question of whether their use disrupts a link in the food chain. Another factor being investigated is the potential for transference of biocide chemicals from crops they protect (e.g., vegetables and fruits) to humans even when the products are washed or peeled before consumption. In addition, there is a

**Table 8.1** Major groups of biocides: a compendium of common names

| | | |
|---|---|---|
| Acarticides | Algicides | Antifeedants |
| Avicides | Bactericides | Bird repellants |
| Chemosterilants | Fungicides | Herbicide safeners |
| Herbicides | Insect attractants | Insect repellants |
| Insecticides | Mammal repellants | Mating disrupters |
| Molluscicides | Nematicides | Plant activators |
| Plant growth regulators | Rodenticides | Synergists |
| Virucides | | Chemical classes |

(source: http://www.hclrss.demon.co.uk/class_pesticides.html) question of how long these chemicals will persist in an ecosystem after application. Another unknown is how readily biocides can be mobilized into other ecosystems during irrigation, by precipitation and subsequent runoff into surface waters, and by infiltration into aquifers.

Fertilizers present their own set of problems when applied in excess of actual need. Nitrates and phosphates in runoff stimulate excessive growths or blooms of harmful algae. These blooms have caused massive fish kills (aka ”red tide”). The nutrients may also originate as runoff from fields that have been purposely fertilized with solid animal wastes from livestock production, or from terrain that has been used indiscriminately for disposal of animal wastes. Nutrients from these fields can seep into aquifers and degrade water quality.

### *Easing Ecosystem Problems from Biocides and Fertilizers*

There are ways to reduce, significantly alleviate, and even eliminate ecosystem problems that have been caused by an overuse of biocides and fertilizers. For example, research done at agricultural institutes can determine an optimal mass/volume application per acre or hectare of fertilizer or biocide(s) for specific crops or pests, respectively, under different soil and/or climatologic conditions. An information technology exchange of these data and their use in the agricultural sector has already resulted in planning for maximum protection and yield for crops with the minimum application of manufactured chemicals. This is an economic plus because farmers spend less on agricultural chemicals. Localized delivery of biocides and fertilizers via a system similar to that used for drip irrigation can further reduce the amounts of chemicals used in crop production. To use this latter approach, there has to be an initial investment in the delivery system and there will be maintenance costs. However, use of this method lessens overall long-term costs for chemicals while increasing financial benefits from higher yields of good quality crops. The use of optimum amounts of agricultural chemicals for a crop to be grown in a soil/climatologic zone and its focused delivery onto crops or to roots benefits ecosystems because of minimal contaminants in runoff to surface waters or in seepage into groundwater.

## Planning for an Improved Food Supply: Yield, Quality, Minimum Use of Chemicals

Populations in many parts of the world go hungry. The lack of adequate nutrition makes them susceptible to sickness and death. Where this exists, especially in regions of Africa, life expectancy is low. With a population half again as large by mid-century, if not sooner, the problem of food supply will become further exacerbated if production and distribution of food does not improve markedly from what it is today. This can lead to social unrest, political upheaval, and internecine and international conflicts.

The options to increasing the food supply where needed most, sustaining quality and nutritional value of the food, and doing this while minimizing the use of synthetic chemicals, and perhaps natural ones, lie in multiple tracks. One is the use of genetic engineering (GE) that yields transgenic (genetically modified [GM]) food crops with favorable traits taken from one species and spliced into another species. Another lies in conventional hybridization within a plant species or in the recent advances in the plant genome based marker-assisted selection that directs traditional hybridization. These biological approaches to improving agriculture can increase the yield of food crops and their nutritional values. They can reduce the use of synthetic and perhaps "natural" pesticides by breeding disease resistance and pest repellent properties into seed stocks. A third lies in organic agriculture. Finally there is seawater farming in an integrated natural system that yields field crops as well as aquaculture products.

Nutrient replenishment to sustain and increase crop yield is done in conventional farming using synthetic chemicals. In organic agriculture and seawater farming, natural nutrient replacement is used to maintain the soil capacity for sustainable farming.

## *Genetic Engineering: Manipulation of Interspecies Properties*

Life science companies such as Monsanto, Bayer, Syngenta, and Pioneer Hi-Bred International support genetic engineering and the production of GM food crops. Their scientists take a gene from one species and splice it into a different species to give transgenic cultivars. Company scientists believe that this change in agriculture is an efficient and cheap way to feed the growing global population, especially in less developed nations where all the land that could be used for agriculture is not under cultivation. The gene splicing most used now imparts one or more desirable traits to plants to give transgenic field crops with strengthened resistance to pests and compatibility with herbicides. Ongoing research in gene splicing is focused on creating seed stocks with resistance to disease, to pests, to drought, and with improved yields and nutrition values for GM crops.

## *Health Concerns: Present and Future*

Health experts, biologic consultants, and the public are uncertain about the possible short- or long-term effects of the ingestion of genetically altered crops by human or food animals. The uncertainty lies in the question of whether there can be a crop gene transfer from seed to product to humans or a fodder gene transfer to cattle or chickens or other livestock to humans. Health problems that may be caused by genetically engineered crops are not thoroughly evaluated because of the relatively short time they have been used as feed for food animals and in prepared foods consumed by humans.

However, there have been human health problems and food animal health problems from consumption of GM crop prepared foods or feed, and human sickness that occurs seemingly after inhalation of or contact with airborne pollutants during flowering of GM corn.

In the former case, transgenic corn that was supposed to be used only for animal feed was supplied "by mistake" to a franchised food chain in the United States and used to make tacos. People who ate the tacos suffered discomforting stomach sickness. Products made with the genetically altered corn stock were recalled and destroyed. The supplier was sued and came to financial settlements with the food outlet company for lost business and with individuals whose health was compromised by eating the product that made them sick.

In the latter case, a five acre field on Mindanao Island, Philippines, was planted with Bt maize seed (Dekalb818YG with Cry!Ab from the soil bacterium *Bacillus thuringiensis*). During July 2003, villagers living at Sitio Kalyong within 100 m of the field suffered unexplained sickness with fever, respiratory distress, and intestinal and skin ailments. The onset of symptoms and illnesses corresponded with the maize flowering time. Fifty-one people suffered with the symptoms. Subsequently, a total of 96 people got sick, with 5 unexplained deaths. Nine horses, 4 water buffalo and 37 chickens died soon after feeding on GM maize. In October, 2003, blood samples from 38 villagers who still had bad symptoms were analyzed and showed antibodies to the Bt toxin Cry!AB expressed in the GM maize. The Philippine government did not investigate the health problems and attributed them to influenza. However, this was not an isolated case. More illnesses developed in July 2004, when GM maize came into flower near 4 villages farther south. Here, 32 people fell ill with headaches, stomach aches, dizziness, diarrhea, vomiting and difficulty breathing. There did seem to be a relation between the flowering of the Bt maize, inhalation and/or contact with airborne contaminants, and the ailments suffered by nearby populations (SANET, 2006).

From the Russian Academy, Ermakova (2006) reported that 36% of pups born to pregnant rats fed Roundup Ready GM soya starting from before conception were severely stunted compared with 6% fed non-GM soya. Ermakova recorded that within 3 weeks, 55.6% of the progeny of GM-soya fed rats died. This was 6 to 8 times higher than pups of rats fed non-GM soya. One-third of the surviving rats in the GM-fed group showed markedly reduced body weight and lacked normal internal organ development. There was controversy from some scientists about the 2006 study that was replied to by Ermakova (2007).

In Canberra, Australia, Prescott et al. (2005) found that a previously harmless protein in beans when transferred to peas via gene splicing caused inflammation of the lungs of mice and provoked reactions to other proteins in the feed. Immunological and biochemical studies carried out for the first time on the transgenic protein revealed that it processed differently in the alien species. It turned an innocuous protein into a strong transgenic protein immunogen that caused immune reactions against multiple other proteins in the diet. It provoked dangerous food sensitivities: allergies. Such gene splicing can be considered a threat to public health until there is proper assessment of the immune potential of all transgenic proteins.

There is no answer yet to the question of whether the ingestion of transgenic foods directly or through a food product (tofu, milk, beef), short- or long-term, can cause a gene mutation in humans. There is also the question of whether illnesses or genetic damage can be caused in humans by inhalation of pollen released during the flowering of a GM crop. Environmental groups working with independent plant geneticists oppose gene splicing from one species to a different one to modify crops until some of the questions on gene transfer through a food chain are adequately answered. The fact is that genetically engineered crops have not been used for a long enough time for epidemiologists to be able to determine the physiologic effects they may have on consumers.

## *Conventional Hybridization*

In contrast to their opposition to genetic engineering, environmental groups support established hybridization methods to impart desirable intraspecies attributes to improve food or fodder crop agriculture. These include the fore mentioned resistance to disease, pests, and drought. In addition, a success in traditional hybridization that imparts a property to a crop to discriminate against the uptake of heavy metals or other pollutants from soils would be important to the global food stock. It would permit cultivation of crops in contaminated soils without posing a health risk to consumers and the need for time-consuming and costly remediation. However, the standard hybridization technique is a very slow process. Society would be better served if hybridization results could be obtained more quickly. This may be possible using DNA data on the same species to identify intraspecies specimens with desired traits that can be bred into the species through conventional hybridization.

## *Marker-Assisted Selection (MAS) for Conventional Intraspecies Hybridization*

The gene splicing approach may soon have strong competition for breeding favorable properties into plants. Current research into more rapid and efficient hybridization does not require gene splicing from one species to a different species to produce seed for crops with sought after properties that protect them. This methodology, called marker-assisted selection (MAS), uses the results of DNA testing to select individuals within a plant species with desirable genetic qualities to become parents in a new generation of food crop seed stocks (Grimaraes et al., 2007). Assisted implies that the selection can be influenced by other factors such as environment and expected progeny differences. MAS is especially attractive because it improves on conventional hybridization by speeding up the process of developing seed stock with one or more than one trait that improves a food crop.

Plant geneticists have used genomics based on DNA data to map food crop genomes and identify genes that carry attributes cited previously such as resistance to pests, diseases, and drought, as well as increased yields and when possible, higher nutritional values. They then scan plants from the same species, either cultivated or from the wild, to identify those with the genes that carry the sought for traits. Once specimens with one or more of the targeted genes are found, plant geneticists cross breed them with cultivated commercial varieties of the same species to impart a specific property to the next generation of cultivated crops. In this way, there is no molecular splicing transfer of genes from unrelated species into the genome of a food crop to better its productivity and quality.

A major advance in the use of MAS is the ability of plant geneticists to identify genes that carry desirable traits for hybridization at the seedling stage. This reduces the time to develop new crop varieties by at least half compared to traditional hybridization.

Marker assisted selection in hybridization keeps the breeding of stronger varieties of commercial crops within a species and averts possible health problems for consumers from transgenic crops. Some of the targeted crop attributes are related to a single gene (e.g., resistance to pests). Others have markers that are in complex genetic clusters that may be affected by environmental factors. The identification of complex gene clusters and an understanding of factors that may affect them are the subjects of ongoing research. In response to the results achieved to date, environmental groups cautiously support MAS for directed hybridization.

## *MAS Information Sharing*

A free exchange of information on plant genomics and property-defining genes as they are identified in new seed stocks can benefit farming and food production globally (Dargie, 2007). This clashes with life sciences companies that seem to strive to control and commercialize seed stocks through patent protection. There is no doubt that as MAS research extends to more food crops, there will be an accommodation to the benefit of food deficient nations by agribusiness interests or where patent protection is not covered by legislation. This will cover both intraspecies cultivar improvement by hydridization and for interspecies improvement by genetic engineering. The accomodation will follow the example of pharmaceutical companies that hold patents on high-cost HIV-patented drugs and pharmaceutical companies that manufacture their generic equivalents. The generic medications are now distributed to many HIV-infected persons in poor and less developed nations at reasonable costs to governments and NGOs.

## *Nutrient Replenishment*

Although genetic engineering, classical hybridization, and MAS directed hybridization can ease or resolve some agricultural problems, they cannot solve a fundamental one. This is the problem of replenishing nutrients that drain from soil as crops grow season after season and year after year.

The utilization of man-made chemical fertilizers is an option followed in conventional farming. In this case, and as noted in an earlier chapter, the application of carefully measured amounts of chemical fertilizers has advantages for the agriculturalist and for the environment. Focused application of man-made fertilizer maximizes crop yield and quality and saves on expenditures for chemicals that in the past have been applied in excess. It minimizes nutrient-rich runoff that might otherwise harm intruded aqueous ecosystems by causing algal blooms that can originate "red tides" as well as excessive biological oxygen demand (BOD) that leads to eutrophication in water bodies.

These results notwithstanding, more agriculturists in addition to organic farmers are opting for the use, at least in part, of natural fertilizers. This also minimizes nutrient runoff and is economically advantageous. It eliminates the expense of chemical fertilizers. If natural pesticides are used as well, farmers can generate more income by being able to grow organic crops that are increasingly in demand by consumers.

## *Nutrient Replenishment: Natural, Natural With Treatment*

Natural fertilizer (e.g., "green manure" [plowed in crop wastes such as roots, stalks and other residues], compost, animal dung) is used in much of the developing world as a soil conditioner. In some under developed countries, farmers use human waste directly. This is a dangerous practice because bacteria, viruses and other contaminants in the waste may translocate from soils to food crops and can sicken and even kill consumers.

In industrialized societies, sewage sludge is collected and treated to destroy harmful bacteria and viruses. The dried sludge has been pelletized or pulverized and applied on farmlands with good results. However, although bacteria and viruses are removed from sewage sludge for field application, heavy metals are not because of the high costs involved. They can release into soils as the sludge decomposes and possibly mobilize into crops thus putting consumers at risk of ingesting metals contaminated foods.

The metals problem can be managed by monitoring crops grown in soils amended with treated dried sludge. This is the *modus operandi* at many farms in countries where sludge is used. The monitoring will signal if food crops bio-accumulate one or more metals (e.g., Cd in rice) to levels that can be dangerous to consumers if they are ingested during extended periods of time. If this situation arises, scientists may recommend an economically feasible soil amendment as was described in Chap. 6 that will limit mobility of a metal or group of metals in question. Alternatively, agriculturists can cultivate food crops that naturally discriminate against metals uptake from a sludge-amended soil.

## *Organic Agriculture Without and With Natural Component Chemicals*

Pest- and disease-resistant field crops are being grown at organic farms sowing natural varieties. New crops with pest- and disease-resistance properties are being bred by traditional hybridization methods. Although this process is slow, it avoids resorting to genetic modification. There is an expectation that MAS directed hybridization will speed up the breeding of more food crops with properties that allow optimal growth of high yield and high quality products.

### Without Chemicals

When conditions and crops being grown favor it, farmers rotate crops and/or intersperse known disease- and insect-resistant varieties with those susceptible to attack to protect them. Farmers also commonly control pests with insect traps and by introducing predators that feed on pests but do not otherwise affect an ecosystem. Both organic and conventional farmers use one or more of these "non-chemical pesticide" methods to maintain healthy crops and their yields.

Examples of insect use in pest control are ladybugs and lace bugs that are bred and sold to farms for release to vegetation that is subject to damaging attack by aphids. Similarly, predatory mites are used to control spider mites.

### With Chemicals

Farm produce categorized as organic may be grown pesticide-free as described above. It cannot be classified as organic if synthetic chemicals are used to assist crop growth. State laws allow the organic designation for produce that is grown with the assistance of "natural" chemical sprays and powders. These must be derived from natural sources (extracted from plants, insects, or mineral ores). They must be applied to land free of synthetic chemicals for 3 years, with equipment that has not been used for synthetic chemical application for 3 years. The natural chemical sprays and powders most used in the United States are oils (as insecticides) and sulfur (in fungicides). Insecticide oils are used on 22 different crops (e.g., almonds, walnuts, strawberries, cotton) and sulfur-based fungicides are applied to 49 different crops (e.g., alfalfa, avocados, watermelons, mint). Together with copper-based fungicides, the natural biocide sulfur-based and oil-based compounds are used in conventional and organic farming and make up a full 25% of United States pesticide use. The organic-farmed crops they are applied to comprise more than 3% of the crop production in the United States.

There are concerns about the use of natural pesticides. First, significantly more of the organic pesticides must be used per acre than synthetic pesticides because of their lower effectiveness. They also degrade more rapidly than synthetic compounds and thus need more applications to protect crops. Second, their toxicological effects are largely unknown. Third, the length of time they persist in the growth environment and the full extent of their effects on the environment are unknown. What we do know is that about half of both synthetic and natural pesticides are carcinogenic when high dosages are used in in animal tests (Gold et al., 1992). This being understood, there are many vendors who offer tested and proven pest control products to organic farmers for use with field crops and in orchards, often with guaranteed results if they are applied as directed.

An example of a natural pesticide is a 99.3% pure garlic extract (Garlic Barrier7) that is marketed as an effective insect repellent. When diluted with water at a 50:1 to 99:1 proportion, one gallon of the extract can treat 10-12 acres (4-5 hectares). It protects various crops such as row crops (e.g., soy beans, peanuts), alfalfa, wheat, cotton, and orchards and fields of flowers and ornamentals from harmful insects for 12-14 days. It must be reapplied regularly throughout the growing season. The garlic repellent does not harm beneficial insects. According to users, the costs compare well with the costs of synthetic chemicals. In addition to repelling insects, the garlic treatment has the added benefit of protecting vegetation from mammalian pests such as deer and rabbits. Birds are safe where it is used. Man-made pesticides kill millions of birds annually.

## *Without Herbicides*

Weeds rob the soil of moisture and nutrients and reduce crop yield per acre. Organic farming does not use herbicides to kill weeds but rather relies on hand weeding or hoeing which are labor intensive, or on tilling. These practices may expose soil to erosion and to moisture loss and create a problem in areas with a delicate water balance. No-till or low-till farming is preferred in order to minimize soil erosion (Chap. 6). This is effective where agriculturists use herbicides that will do "virtually" no harm to insects or animals while eliminating weeds. The "virtually" aspect dissuades organic farmers from using them.

## *Organic Farm Products*

The use of natural fertilizers and pest control techniques is successful and is the basis for efficient and effective organic farming. Product yields are excellent and the benefits of higher prices for organic grown foodstuff attract more farmers "to go organic" as they plan for the future. The market for organic food products promises to continue the expansion it has experienced over the past several years. Organic farm produce, once found only in specialty markets, now occupies prominent space in popular supermarket chains.

One problem food growers experience when they want to move into organic farming is that man-made chemicals remain in soils. Planning for future organic cropping at these farms includes remediation to remove pollutants until soils are reclaimed to natural conditions. This is feasible if an investment in remediation will be offset by long-term economic gain.

## Seawater Farming: Integrated Agriculture/Aquaculture

Large global populations, perhaps 1.5 billion people, live in marine coastal areas, many in arid/semi-arid regions. Several of these populations suffer from poor perspectives for development, a lack of employment opportunities, and poor health and education services. They often live a subsistence existence. Glenn et al. (1998) reviewed the possibility of irrigating crops with seawater with the aim of bringing relief to the fore mentioned suffering coastal populations.

A beautifully integrated planned development project based on seawater farming has been successful in the Eritrean coastal desert. For this farming, seawater is brought directly from the Red Sea through a 5 km long canal to salicornia fields. *Salicornia* is a genus of succulent plants that is unique because it can grow normally in fields irrigated with salt water. Young shoots of *Salicornia*, cooked and topped with a butter sauce, have the taste of spinach and asparagus with a fine, smooth texture. *Salicornia* shoots are exported to Europe where they are considered a gourmet vegetable. The mature plant also provides a seed that produces a high quality edible oil and a high protein food. The species *Salicornia biglovii* has a 30% oil yield. After processing a *Salicornia* harvest, the large amount of remaining biomass is used for particleboard, firebricks and animal fodder. In the Eritrean coastal desert, raising livestock is the main terrestrial economic endeavor. The availability of high protein fodder is desirable.

Some seawater from the canal is directed into shrimp tanks and then passes from them into three salt lakes for use in aquaculture. The shrimp species is suitable for profitable farming because it tolerates variations in salinity, temperature, pH, and oxygen. In 2003, the first shrimp harvest was worth almost $12 million. Tilapia is grown in the salt lakes for food and to make a variety of products including shrimp feed from recycled fish heads. Waste from the aquaculture lakes is carried by water to fertilize the salicornia farming. Seawater then filters into the soil and flows back to the Red Sea. This seawater farming has boosted the food stock for local, nearby, and more distant populations. It created employment for hundreds of Eritreans, mainly women, with prospects to employ thousands, and has improved a health system and created educational opportunities for those who want to use them. This seawater farming is restricted to coastal deserts because the seawater salinity would damage inland ecosystems. The financial and social success of this integrated operation is a model for planned development projects in suitable coastal desert environments worldwide. Development teams in Sonora, Mexico, and the Tiruvarur District in Tamil Nadu State, southern India, are planning the installation of seawater farms following the operational, economic, and social success achieved in coastal Eritrea.

## Planning for Chemical Problems in Global Warming Scenarios: The Future is Now

Global warming and climate shifts are viewed as physical and biological threats to the Earth's environments and ecosystems. The physical changes brought on by global warming will hamper the Earth's capability to service society's biological needs (e.g., water, food) to achieve and maintain a good quality of life. The IPCC report issued in April 2007, cites five expected key impacts of global warming and climate change: (1) 75-250 million people across Africa could face water shortages by 2020; (2) agriculture fed by rainfall could drop by 50% in some African countries by 2020; (3) crop yields could increase by 20% in East and Southeast Asia, but decrease by up to 30% in Central and South Asia; (4) 20–30% of all plant and animal species will be at increased risk of extinction if temperatures rise between 1.5-2.5°C; and (5) glaciers and snow cover are expected to decline, reducing water availability to $1\frac{1}{2}$ billion people dependent on glacial runoff for their water supply (e.g., on the Indian subcontinent, in South America). This is in light of expanding populations, especially in Africa and parts of Asia.

Add to these key impacts, the health problems that will surely develop worldwide as global warming and climate change progress. Precursor events already signal the health effects of global warming and climate change. For example, long-term and more frequent heat waves will affect the poor, the old, the young, the ill, and the immobile segments of society more than others comprising a population. In this case, a precursor event may have taken place in Europe during the summer of 2003. Thirty thousand people, mainly from the categories given above, died from heat-related illnesses. Almost half of the deaths were in France. Most of the deaths were in cities. Cities are warmer on the average by 9°F ($\sim$5°C) and have less of a cooling effect at night than in the surrounding countryside. The city populations will also be exposed to more frequent smog conditions from the accumulation of ground-level ozone, particles, and soot. This will put people with heart disease and lung illnesses at risk of severe health attacks. In a warmer climate, vector-borne diseases such as malaria and dengue fever, transmitted by insects and animals, are likely to increase together with yellow fever, schistosomiasis, viral encephalitis, lyme disease and others. In Papua, New Guinea, for example, malaria is breaking out in once-cooler areas where the disease was unknown. Crop failure, cited in the previous paragraph, will cause malnutrition from nutrient deficiency and starvation. When this happens in areas with chronic water shortages, there can be epidemics of diarrheal disease. Whereas about 25% of the global population suffers now from chronic water shortage, this figure could be more than 50% by 2025. At the other end of the water spectrum, higher temperatures and more rainfall in some regions could result in an increase in food-borne diseases such as salmonella, hepatitis and cholera. More and sustained rainfall can cause flooding that people and their property and increases water-borne diseases. The possibility for flooding from climate change increases 50% for Africa and four-fold for Central and South America. A preview may be in a long-term flood event in Bolivia during 2007 that affected about one-third of the country. Southern

Mexico was also ravished by heavy and sustained rainfall. Europe has suffered from recent abnormal flood events.

The regions that may be most affected by the physical and health impacts of global warming and climate change are in Africa, Southeast Asia, and the Indian subcontinent. Nonetheless, most other nations will suffer from these impacts as well. This underscores further the urgency for all nations to work together to deal now with global warming. It is imperative as well that all nations plan now to adapt to these changes in order to decrease the vulnerability of their citizens to the previously cited effects of global warming. The planning can be as simple as providing bed netting as a defense against malaria-carrying mosquitoes, as complicated as the safe use of pesticides, or as essential as having competent medical care available to all.

Project planners and their environmental consultants may not often associate global warming with chemical changes in the earth's surface/near-surface environments. Yet the chemical effects of global warming added to the biological and physical disruptions it causes, together assault the vitality of ecosystems. Chemical changes that global warming can be expected to cause in the atmosphere in the future will affect the quality of surface waters and groundwater and influence soil fertility and physical stability of soils. The probable range of chemical changes and their effects on development envisioned for a nation or region must be factored in with probable physical and biological changes when planning and making decisions for investments in proposed long-term ventures. The following paragraphs will examine how these changes affect human populations and productive, stable ecosystems. There is a reasonable expectation that projected effects of global warming based on long-term measurements and computer models can provide guidance in planning for existing and future ventures in all development sectors. This is especially true for agriculture worldwide that depends on climate, and water and soil quality. The data will affect land-use planning in coastal/near-coastal areas at continent-ocean interfaces and around island nations or outposts. This is true as well for nations or regions with growing populations and those with changing demographics (Chap. 2). The quality of a good life for future generations depends on responding to global changes and problems that affect the earth's ability to provide basic essentials.

## *Global Warming Effect on Atmospheric Chemistry*

Warmer surface temperatures cause a greater evasion of volatile contaminants into the atmosphere, such as Hg from oceans or Hg and As from soils and ore bodies. Large volumes of terpenes and other organic compounds volatilize into the atmosphere from trees and other vegetation. Atmospheric deposition transfers chemical pollutants to water and soil from which they can invade a food web and diminish the biologic functions of ecosystem inhabitants. Previous chapters stressed that contaminants can translocate from soil to vegetation to birds, fish, animals, and humans, or from surface water and springs to birds, fish, animals, and humans. Also, warmer oceans and increased evaporation load more water into the atmosphere and augment the force and intensity of tropical storms. A result can be a likelihood of more instances of forest fires started by lightning strikes. Wildfires release great masses of soot and other particles into the atmosphere. Respiration of these solid contaminants, some carrying chemical pollutants, can cause bronchial and other illnesses by accumulating in the lungs (e.g., blocking alveoli). This noted, development planning has to take into account the probability of global warming influences on chemical changes in the atmosphere that would likely affect terrestrial and aqueous ecosystems and planning for their futures.

## *Global Warming Effects on Water and Soil Chemistry*

Rising sea level increases coastal erosion and extends the reach of seawater surges inland during wind-driven, high-energy tropical storms or hurricanes (aka typhoons, monsoons). The seawater 3.5% salinity invasion of brackish or freshwater ecosystems inland disrupts them. The salt water carried to agricultural fields via storm surges can cause soil salination that may diminish crop yields. To reestablish a productive soil, the salt must be washed out naturally or flushed out with irrigation to reclaim it. This is detailed in Chap. 9.

Long-lasting and intense storms over land will cause flooding. Floods flush large volumes of fresh water downstream through ecosystems. This changes the chemistries of water bodies such as salt marshes, swamps, and estuaries. Different organisms that are harvested commercially such as clams, oysters, and crabs each live and grow to maturity within a well-defined salinity range of their habitat, such as an estuary. Long-term changes in salinity in these ecosystems can threaten the immediate future of commercial harvesting. More flooding also means that there is more water to move potentially toxic contaminant elements and compounds from "temporary storage" (e.g., mine tailings or non-secure landfills) into otherwise stable and productive environments.

An antithetic chemical effect from rising sea level is that salt water will move as a bottom water wedge up estuaries and fjords worldwide causing a permanent change in the salinity (chemistry) towards the heads of the water bodies. It will dispossess mobile life forms from their salinity-zoned estuarine and fjord ecosystems. The higher salinity water can inhibit growth of less mobile organisms, disrupt their reproductive cycles, or even kill them unless they adapt to salinity changes or move to salinity "friendly" waters.

Salinity changes in sensitive estuarine and fjord fisheries can cause decreases in productivity and output of spawning grounds for estuarine, fjord, and ocean fish and shellfish. This, together with less abundant harvests of food fish because of over fishing, can add to a global high-protein food deficit and hurt local economies dependent on fisheries. To counter what likely could be an increasing nutritional/economics environmental problem, governmental and international organizations have set fish catch quotas for selected species in national waters and the open ocean. In addition, fisheries administrators planning for the future have to be aware of other changes in marine ecosystems that originates in part from global warming. One such change is the already observed food fish species migrations catalyzed by changing water temperatures. It should be noted that rogue- fishing vessels contribute to over fishing and the harvesting of protected species. If caught, in national or international waters, the vessels can be impounded and sold, and their crews fined or jailed.

Another negative environmental chemical intrusion that can result from rising sea level is a landward saltwater intrusion of freshwater in aquifers that open to the sea. This will happen when the pressure of ocean waters pushing into an aquifer (from rising sea level) exceeds the pressure of fresh water resisting the inland movement. The intrusion is in the form of a saline water wedge pushing inland along the bottom of the aquifer. This contaminates freshwater in the aquifer and leaves well water non-potable and unusable for irrigation of most crops.

A pressure-driven inland movement of ocean waters into a California aquifer intruded more than 3 km (2 miles) inland and caused the loss of well water sources for drinking, hygiene and irrigation. This was the result of high well water use inland that lowered the pressure of freshwater in the aquifer pushing seaward to the point where it was exceeded by the pressure of salt water invading the aquifer. The inland advance of the saline intrusion inland was halted by the use of a pressure ridge in a series of wells designed by hydrologic engineers. The pressure ridge directed seaward balances the pressure from the saline intrusion and keeps the seawater at bay. Project planners evaluating water availability in coastal zones have to consider the pressure balance situation for an aquifer source that may be affected by global warming.

## *Climate Shifts*

Climate shifts are driven in part by global warming. They affect the flora in ecosystems and the fauna it supports. There will be positive or negative effects on soil productivity depending on several factors. These include regional changes in temperature and humidity, precipitation, the length of growing season or crops per season, and orientation with respect to the sun and hours of exposure to sunlight. Mobility of nutrients and other chemical elements will be less in drier climates, whereas a wetter climate favors greater element mobility in dissolved and particle states. Soil regeneration or replacement by disintegration and decomposition of subsurface rock (Chap. 6) is slow in human time frames (scores to 100s or 1000s of years). The rock to soil evolution is more efficient in warm to temperate, humid to wet climates than in drier and/or cold climates. Thus, as shifting climates slowly change from dry to humid or humid to wet or from wet to humid or humid to dry, agriculture will change. Similarly, as climate changes evolve from cold to cool to warm, or cool to warm to hot or from hot to warm to cool, or warm to cool to cold, agriculture will change. Shifting climates in agricultural zones will dictate in grand part new production/distribution pathways that planners have to envision as they assess global development prospects. This is especially true in a world that has to strive to provide the essential macro- and micronutrient sustenance needs for a population that may be 50% greater by 2050.

Table 8.2 presents the probable effects of climate change on agriculture and food security. The changes are slow in a human time frame. There is time to plan to adapt to them. Table 8.3 summarizes climate shift-induced physical hazards by geographic region, chemical changes they bring to ecosystems, and the effect of these on agricultural productivity.

The Consultative Group on International Agricultural Research (CGIAR) believes that yields of existing crop varieties will fail in warmer climates. The Group report emphasizes that growing seasons will be shortened and areas will receive greater or less rainfall in amounts that will be more variable. Photosynthesis slows as temperature rises, retarding plant growth. For example, rice yields fall 10% for every degree centigrade rise in nighttime temperature (Peng et al., 2004). Such effects could lead to large-scale famine in developing countries in the future unless plant geneticists are able to breed new strains of staple crops such as corn, rice, wheat and

**Table 8.2** Climate change: agriculture and food security

| |
|---|
| I. Some agricultural zones will benefit from shifting climate whereas other will suffer diminished productivity |
| II. Temperatures will rise more near the poles than near the equator so that climate shifts will be more pronounced at higher latitudes. In mid-latitudes (45-60°) zones could shift from a minimum of 150 km to a maximum of 550 km. Shifts such as these in all latitudinal zones will affect agricultural and livestock production. |
| III. Soil moisture will change with shifting precipitation. Evaporation and precipitation will increase as well as will the frequency of intense rainfall. Wetter versus loss of soil moisture. Droughts become more severe. Seasonal shifts in precipitation will give less moisture in summer in mid-latitude continental areas with increasing rain and snow at high latitudes during winter. |
| IV. Higher temperatures will influence productivity. Some crops will benefit whereas others will suffer. Weeds increase in higher latitudes. Insects and plant diseases expand poleward threatening crops. |
| V. More carbon dioxide in the atmosphere could boost productivity. Stimulates photosynthesis. Increased water use efficiency. Good for wheat, rice, barley, cassava and potato in cooler, wetter ecosystems. But countered by high temperature, precipitation, pest infestation and nutrient availability. |
| VI. Marine fisheries yield will be unaffected but mix of species harvested will change. |
| VII. Food security risks are mainly local and national as countries take measure to adapt. |
| VIII. Landless, poor and isolated populations, often working isolated agricultural systems in semi-arid and arid regions, are most at risk. These are Sub-Saharan Africa, South, East and Southeast Asia, tropical areas of Latin America and some Pacific Island nations. |
| IX. Effective policies that can improve food security as climates shift include changes in crops and crop variety, improved water management and irrigation systems, adapting planting schedules and tilling practices, and better watershed management and land-use planning. Examine changing production with distribution modes to cope with fluctuations in crop yields. |

(source: http://unfccc.resource/iuckit/fact.10.html)

**Table 8.3** Projected regional physical hazards from global warming and chemical effects on ecosystems and productivity (modified from IPCC, 2001)

Africa -

Grain yields are expected to decrease; less water will be available and desertification will worsen because of reduction in average annual rainfall, especially in southern, north and west regions of the continent; soil salinization; coastal areas in Egypt, Nigeria, Senegal, Gambia, and southeast Africa will suffer loss of land and damage to inland ecosystems from inundation and erosion, with consequent dislocation of populations.

Asia -

Food production in arid/semi-arid and tropical zones of the region will likely decrease because of high temperatures, drought, flooding and soil degradation; northern areas may show increase in agricultural productivity. Inundation and more and intense tropical storms will likely displace tens of millions of inhabitants of low-lying coastal areas of temperate and tropical Asia and destroy productive inland ecosystems there by repetitive saline water intrusion.

Australia and New Zealand -

Predicted to show better productivity for temperate crops initially with changes likely as climate change continues. Much of the region will become drier and become more likely to suffer very damaging wild fires; but other areas will suffer more, intense heavy rains and tropical storms that will cause flooding and storm and wind damage.

Europe -

Southern Europe will be prone to drought with consequent decreases in agricultural productivity while agricultural productivty will likely increase in northern Europe. Flood hazards will increase in some areas. Half of the Alpine glaciers could recede by the end of this century. Heat waves and less reliable snow condition may change traditional summer tourism and hurt winter touristic activities.

Latin America -

Floods and drought will become more frequent. Yields of important crops will likely decrease in may parts of Latin America. Subsistence farming in northeast Brazil will be threatened. There will likely be increased exposure to diseases such as malaria and cholera.

North America -

Food production overall could benefit from modest warming but with strong negative regional impacts such as declines in agricultural productivity in Canadian prairees and the U.S. Great Plains. Inundation and coastal erosion, flooding and more storm surges will put people, property and inland ecosystems at greater risk in Florida and along the southeast Atlantic coasts. Diseases such as malaria, dengue fever and lyme disease may spread in North America. There could be more heat-related deaths.

Polar Regions -

These will suffer most from global warming. Already the extent and thickness of Arctic sea ice have decreased, permafrost has thawed, and species distribution and abundance have been affected. Even with stabilization of the greenhouse effect, these trends may continue with irreversible damage to ice sheets and changes in global ocean circulation and sea levels.

Small Island States -

These will be impacted most by inundation and loss of land, coastal erosion, damage to inland.

sorghum adapted to a warmer climate, perhaps by MAS directed hybridization or carefully researched and thoroughly tested genetic engineering. Additionally, in order to feed growing populations, drought-resistant strains of corn and sorghum will have to be bred for dry areas of Africa which scientists predict will become drier

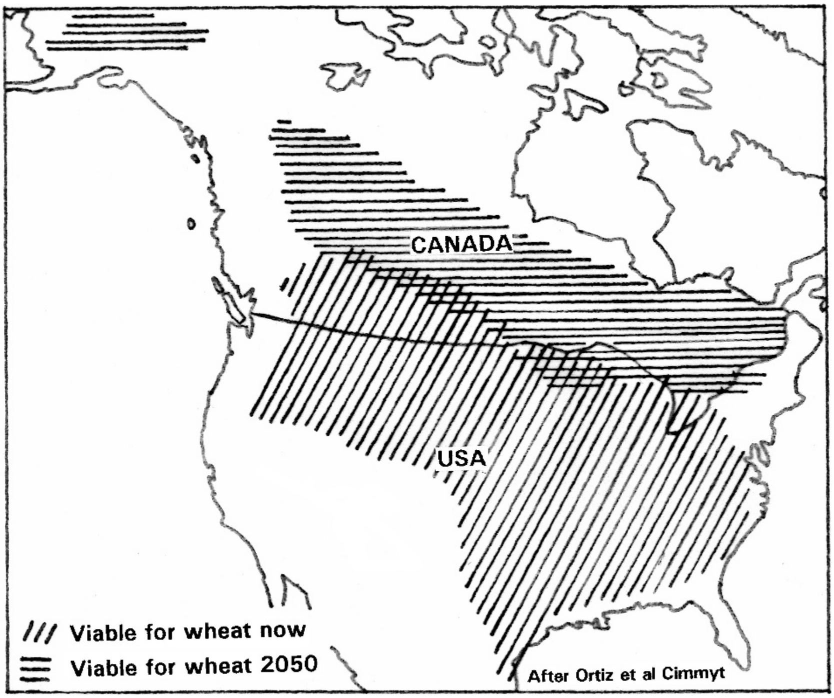


**Fig. 8.1** New research shows the extent of a northward shift of wheat-growing in North America that may result from global warming and climate shifts. Map is generalized and is simplified because existing boundaries are highly complex (after Ortiz et al., in press)
Source: http://news.bbc.co.uk/2/hi/science/nature/6200114.stm

with climate shifts. CGIAR estimates that in 50 years, South Asia's wheat cropping area which produces 15% of the world's wheat today will be reduced to half its size in this region of increasing population (Chap. 2). Figure 8.1 shows areas of Canada and parts of Alaska now too cold for growing wheat but which may be prominent wheat growing areas in 50 years. In contrast, farming areas in the continental United States may shrink greatly as global warming and climate shift continues (Ortiz et al., in press). In light of these probable climate changes in growing zones, the breeding of new plant stocks by conventional hybridization, genetic engineering, and MAS directed hybridization that are pest- disease- and drought-resistant, and with higher nutritional value, as previously discussed, should focus now on the breeding of climate-resilient food plants. As noted at the beginning of this section, the shifting of climatic zones will affect chemical element mobility/immobility responses in surface/near-surface environments. This has to be taken into account by planning teams when assessing development projects that are expected to endure into the future at least 50 years. The expectation is that during this interim, bio-technical and pure science advances will continue to improve the global food situation.

## Planning and Investment

Reduction in emissions and in effluent discharge of chemical pollutants into the earth's surface/near-surface environments from existing or proposed development projects will help to preserve healthy environments. Unless a good degree of pollution reduction is achieved, ingestion of pollutants will cause a drop in human productivity because of their effects on ecosystems and because of employee or employee family sickness and lack of focus on the job, or because of absenteeism. Without reduction of contaminants from an offending facility that damage an ecosystem, authorities can call for its closure. However, closure disrupts the social and economic fabric of a population and can have serious political consequences so that remediation is called for. Reduction in emission or effluent discharge from existing operations requires investment to ensure future benefits. A decision on investment based only on economics depends on an objective costs/benefits analysis. Certainly, there is a political interest in social stability because of employment and taxes that functioning sectors provide for a community. New development sectors with minimal pollutant output will bring the same benefits to a community. Previous chapters have underscored the fact that financially able governments may subsidize pollutant abatement equipment or make it fiscally attractive to companies through tax benefits for investment in pollution control equipment and its maintenance. This can serve to bring emission or discharge of contaminants to the earth surface/near-surface environments to permissible levels. It can be much more costly to reengineer an operation to abate pollution than to build technologically advanced pollution control equipment into utilities, factories, and other undertakings from the start.

Development proposals in the planning stages have to deal with local, national, regional, and global awareness of the pollutants that development ventures could generate (Table 4.3). The awareness manifests itself not only in consultant reports but also in well-informed citizen groups with scientifically sound expertise as to all aspects of pollutant generation and control possibilities. Funding for any venture has to allow for existing laws that regulate the maximum permissible concentrations of specific pollutants that can be emitted into the atmosphere or be discharged onto land and into surface waters.

Costs/benefits analyses include long-term costs (e.g., replacement parts and general maintenance of equipment) necessary to keep pollutants in emissions and effluent discharges at or below maximum permissible concentrations as regulated by local or national governments. The costs/benefits assessments must also allow for modification of pollution control equipment if new regulations reduce permissible contaminant concentration levels. The costs are balanced against long-term benefits (i.e., profits) for the continued and efficient functioning of a facility.

A question that comes up is how long is long-term? For many mining projects, this might be $>25$ years depending on the volume of an ore body, the price of the commodity, and the rate of extraction. For agriculture commodities this might be open-ended if farmers follow sustainable farming practices. Industrial and manufacturing projects can have $>50$ years as a reasonable projection to work with for evaluating costs/benefits relations.

The fact is that costs versus benefits can be determined rather accurately for proposed ventures and the duration of time they are expected to be productive. The fact is that investment in best available pollution control technology and allowances for modification as better technologies evolve are cost-effective in the long run, socially necessary, and politically important. It is a human rights abuse for any government to allow pollutant-generating facilities to continue to function without setting a realistic schedule for the installation or modification of pollution control mechanisms. To ease regulated requirements for pollutant emission or effluent discharge from functioning plants for political reasons is wrong. Such a proposal was made by the USEPA by a directive from the 2002 executive branch prepared so as to to benefit corporations with coal-fired electricity-producing facilities. It was wrong. It sidestepped a sitting government's responsibilities to its citizens as well as a nation's global responsibilities. Challenges to federal legislation by several states to lower permissible levels for Hg emissions and for As concentrations in drinking water below those proposed by the USEPA were successful. Easing regulations is a grave mistake that puts cleaning up global environmental problems in second place after economic benefits (for corporations and stockholders) and harms populations worldwide.

Chemical pollution of the earth's surface/near-surface environments and the ecosystems they sustain can and must be controlled for today's populations and for future generations who will inhabit our fragile planet in the future. The costs/benefits analyses to sustain chemically secure environments with clean atmospheres, safe waters, and fertile soils will show a yield of less profits for industry, but profits nonetheless. The choice is clear on whether to strive to maximize profits for stockholders at the expense of humanity or to accept lesser profits and preserve the future of the planet for all: accept lesser profits.

## Afterword

Surface/near-surface environments that have been harmed in the past and are being harmed today by the introduction of chemical contaminants can, in many cases, be restored to their natural conditions by human intervention. Planning for a future with half again or more humans on earth and the need to sustain them with food, water and necessary products has to include plans for ecosystem restoration to achieve that end. The following chapter discusses remediation methodologies that are being used and some that are being researched to assure clean air, safe water, and fertile soils to meet the needs of existing populations and those of future generations.

# Chapter 9
# Remediation/Reclamation Options for Polluted Environments: Feasible or Not

Polluted sites endure from mining and manufacturing during Roman Empire times, from the beginnings of the industrial revolution, and through modern times. Pollutants mobilized from source sites invade and harm productive ecosystems and their human inhabitants worldwide. Nonetheless, many less developed countries are rapidly moving to increase their industrial bases without giving proper legislative attention to the control of pollution that the investment enterprises they approve are likely to impose on ecosystems and the populations that they host.

Many areas polluted by natural processes or from human activities have been identified globally and prioritized in several countries for remediation, and in the case of soils, reclamation. Relatively few have been cleaned up. Instead, some dangerously polluted areas have been evacuated and quarantined while environmental agencies seek funds for remediation by proven methodologies. Other dangerously polluted sites have not been put off limits and continue to be occupied and used (e.g., for agriculture). Some governments do not give a high priority to the use of economic assets for the clean up and preservation of ecosystems. This is a grave misjudgment not only for the protection of human resources that are a nation's intellectual backbone, but also for the conservation of living natural resources and productive land.

In the United States, only a small number of the more than 1300 sites the USEPA classifies as highly polluted have been reclaimed during the past 25 years. Many have been quarantined. The remediation that did lead to reclamation was paid for by the Superfund, a clean-up fund legislated by the government (Comprehensive Environmental Response, Compensation and Liability Act of 1980) during the 1980s and financed by assessments on the nation's petroleum and chemical industries. The law was passed after the revelations about Love Canal in New York and the health problems suffered by inhabitants at what was a buried chemical waste disposal site on which homes and a school were built. The Superfund Act allows the USEPA to clean up sites that are dangers to communities and to force those companies responsible for the pollution to clean up the sites or reimburse the USEPA for doing it. Love Canal was successfully reclaimed by the year 2000 after excavation of polluted soils and chemical containers, many leaking, and subsequent restoration of the excavated area with clean soil. The cost was tens of millions of dollars. The site is being used anew for residential housing. The lesson learned from this is that

F.R. Siegel, *Demands of Expanding Populations and Development Planning*,

investment in remediation of polluted areas can reclaim an environment so that it can be used again. Sadly, Superfund legislation that mandated support by industries was weakened by the 2000–2006 U.S. administration business-friendly policies that would preserve industry profits. This, and high costs for remediation, have caused unconscionable delays in the remediation of Superfund sites which remain unusable and hence non-productive.

Other areas are at risk from pollution that has not yet reached health-critical levels. In some cases, state/provincial or local governments passed environmental regulations that override federal laws and require immediate measurable relief from continued pollution of threatened areas. Some regulations set permissible concentrations for contaminants in air, water, or soils, at values lower than federally mandated ones. Where this has been done, the environment is cleaner and safer for humans and other ecosystem populations.

## Two Pollution/Remediation Scenarios: Present and Past

One major environmental problem the public and governments have to attack more vigorously is to curb contaminant output at functioning pollution-generating sources. Some polluters will voluntarily retrofit effective and efficient abatement equipment into their plants and factories, even when this requires major investment. Others will not. In such cases, discussion between the owner of a polluting business, community leaders, and responsible politicians can lead to a voluntary solution. It is gratifying when an owner responds positively and invests in pollution control. A polluter may choose not accede to public demands to alleviate or stop contaminating air, water, and soils that degrade public health conditions. In this case, a community can exert political and economic pressures that will encourage a business to invest in technology that alleviates pollutant release to an environment.

In democratic societies, this approach is driven by political action committees that wield power through their influence on critical voting blocks. Economic pressures can bring changes that limit contaminant discharge. The pressures may include loss of sales (income) from consumers who buy products and services only from conforming companies, or the promise of costly legal action. If these approaches are not successful, pollution abatement can be mandated through balanced legislation. As reiterated in previous chapters, governments can pass legislation that includes tax advantages and/or subsidies that ease the financial burden of investment in pollution control technologies. Well-drafted laws will have provisions that allow health and government authorities to take over or shut down a pollutant-generating facility if the polluter does not respond to the proffered benefits. The legislation can lend support for a class action suit against a polluter if emissions and/or discharges from a facility are demonstrated to have caused human sickness and undue harm to an environment's sustainability and hence, productivity.

A more complicated problem exists for environments that carry the pollution burden of the past. These are abandoned factories and plants that were not subject to environmental legislation during their operations, or for which laws were not enforced. The aim for restoration of these environments is the same as in the cases of businesses that are presently sources of pollution: to design a remediation program that will reclaim them and reestablish healthy and productive ecosystems. This requires funding to carry a program through to fruition. The cleanup funds can come from companies that polluted the sites and juxtaposed areas or from targeted taxation in which a government assesses industries that have a history of polluting environments a percent of earnings contribution to cleanup funds.

In less developed nations neither governments nor businesses may have economic assets to devote to a remediation/reclamation program. In this case, non-governmental organizations (NGOs), funded by donations from multinational corporations, private foundations, and the public have made significant contributions to ecosystem preservation and reclamation. However, major funding and human resources to that end must come from economically advantaged nations and international institutions such as the World Bank and regional development banks (Table 1.1). People and institutions can bring legal, political, and economic pressures on multinational industries to contribute to cleanup programs where the industries are unquestionably responsible for polluted areas. The sources of funding notwithstanding, recipient governments or NGOs should have stringent financial management reviews at sequential stages of a remediation project. This would include transparency in their fiscal operations, reasonable administrative costs, a tight rein on the use of dispensed funds, and accountability of expenditures with respect to goals set for each phase of a remediation project.

## Alleviation/Elimination of Pollution Problems: Possibilities

The first stage in planning for remediation of pollution in air, water, or soil, is the location of the contaminant source(s). This establishes whether remediation has to consider point or locally concentrated sources, or dispersed sources. Pollution may be from ongoing human activities. It may be from an installation that was a source of contaminants in the past and was abandoned when it was no longer economically viable, but from which toxic elements continue to issue and invade an environment. If a source is not readily pinpointed by observation alone, it can be found using principles of geochemistry in minerals exploration applied to environmental geochemistry (Siegel, 1997; Siegel and Kravitz, 2001).

In theory, pollution source(s) can be shut down once identified thereby halting input to an ecosystem. In practice this is rarely done because of the nature of the source(s) (e.g., mine tailings) or the reality of national security, politically sensitive employment, and other negative effects on a community's economic balance. Total elimination of contamination from working facilities such as coal-fired utilities, or from abandoned industrial sites or mines is unrealistic for most sources. On the other hand, substantial and meaningful reduction of contaminants discharged into terrestrial and aquatic environments is achievable.

The aim of remediation projects is to greatly decrease contamination input, or extract pollutants *in situ*, perhaps by 90% or more. As reiterated in previous chapters, this is possible for contaminants from many different sources by installing best available pollution control equipment in new plants or factories or retrofitting such equipment into existing ones. A reduction and control unit can be designed to minimize the output of a specific chemical element or compound, an assemblage of these, or of particles. An environment's toxic element burden can be reduced by the substitution of industrial stock materials by stock that will generate less pollution. For example, electricity-generating plants can change to low sulfur coal and oil that also has been processed to reduce metals, or to natural gas. Measured and crop-targeted use of fertilizers and pest control chemicals or the use of natural pest control compounds can reduce contamination from agricultural chemicals in farmland runoff. Similarly, capture of runoff or leachates from sources such as waste disposal sites or mine tailings in specially prepared ponds for their treatment can reduce pollution in proximate and distant ecosystems. Adoption of these and other changes recommended by environmental engineers can effectively reduce toxic elements and fine particles in emissions and effluents and relieve the intrusion into surface environments and aquifers.

## Preempting Remediation with Investment: Benefits >> Costs

New York City imports water from the Catskill Mountains 125 miles (200 km) to the north (Chapter 5). The water is naturally filtered and passes through large aqueducts to reservoirs to taps. At the beginning of the 1990s water quality declined. This was attributed to unrestrained development in drainage basins where the feed water originated and to failing septic systems in the recharge areas. Inadequate planning before development proceeded was at fault. Without improvement in water quality, New York City would have to build a filtration plant at a cost estimated at $6–$8 billion with an annual operating cost of $350–$450 million. On the basis of studies by city environmental engineers, water scientists, land-use planners and environmental economists, the city opted to restore the natural condition of the Catskill drainage area by building sewage treatment plants there, through land acquisition, and a variety of incentive plans. The cost was $1.3 billion to restore conditions for nature's filtering system. This cost was far less than that to construct and maintain the proposed city filtration plant. There were great economic benefits to taking this tactic. Clean water preserves habitats for trout and other fish that bring anglers to the area. The U.S. Fish & Wildlife Service reports that during 2001, more than 12 million men/women anglers in New York lifted the state economy by $2 billion. The sport fishing industry also accounted for more than $164 million in state and federal sales and motor fuel taxes, and provided the equivalent of more than 17,000 full-time jobs (Morrison, 2005).

The Catskill source area land-use changes and links to the New York City water quality can be considered a signal event. The effect that land-use change had on water quality highlighted a potential problem planners have to consider as they prepare for future changes in land-use that could affects water quality and water use in downstream population centers. Preemptive decisions during project planning can avoid the problem and yield short- and long-term benefits that far exceed the costs of remediation of the problem after the fact.

## Atmosphere

Inorganic and organic chemical pollutants and particles in air are respired and in some cases pose health threats from bronchial illnesses and cancer (Chapter 4). Contaminants in precipitation intrude and contaminate water and soil. They can then mobilize into the food chain and can cause sickness in consumers.

Babies, toddlers and young children benefit most from emissions controls. However, they suffer most from bad air where there is poor indoor ventilation or ineffective or no chimney emissions controls outdoors. A 7 year-old child will respire 22 times the daily dose of pollutants into his/her lungs compared to an adult. This is because children breathe more rapidly and respire more air into their developing organs, and because of differences in surface area to lung volume, metabolic rate, and activity. An adult has a much larger chest volume and a slower metabolism rate than a child.

Particles in the atmosphere originate from the same anthropogenic facilities and natural sources as chemical pollutants. They may be combustion products (e.g., from power plants, smelters, vehicles [including diesels]), or urban particles. Urban particles originate from home heating, and from microscopic bits of concrete, rubber tires, metal dust lifted into near-surface air from roadways and other sources. Fine particles are dangerous to the long-term health of respiring organisms. Medical and epidemiological research in the 1990s found that fine particles, $<2.5$ microns (μm) in diameter (designated PM2.5) reach the alveoli and cause small, permanent reductions in lung function. Subsequent reports showed a strong association between fine particles inhalation and deaths from cardiovascular events such as heart attacks and dysrhythmias. A USEPA cost-benefit analysis showed a major benefit to society from a control on particle emissions in outdoor and indoor atmospheres.

### *Capture/Immobilize Technologies*

#### Chemical Scrubbers

The installation of chemical scrubbers into chimneys at coal- and oil-fired electricity generating plants, at industrial and manufacturing facilities, and at smelters and other contaminant emission sources will decrease pollutant loading in the atmosphere. Chemical scrubbers at emitting sources are designed for capture of specific chemical emissions in a fixed range of concentrations. Where installed, used, and maintained to function at optimum efficiency, up-to-date pollutant control equipment can capture gases such as $SO_2$, $NO_x$, and $CO_2$, and the more volatile and toxic heavy metals such as As, Cd, Hg, and Pb. This is done by reacting targeted gaseous and volatile aerosol pollutants in an air stream with sprays, or by forcing them through a pool of a reacting fluid, or by using some other fluid contact method that absorbs and captures the pollutants. The end stage is the recovery of the pollutant-bearing fluid. The recovered fluid, or precipitate formed during a pollutant-fluid reaction, can sometimes be processed for recycling of the captured components.

For example, the design and installation of a scrubber system to capture $SO_2$ from the Montour coal-fired power plant in Pennsylvania U.S., is part of a development enterprise. The spray to be used is a mixture of water and pulverized limestone. A 97% removal of $SO_2$ is the expected efficiency. The pulverized limestone reacts with the $SO_2$ to give a solid byproduct of synthetic gypsum that will be used to make drywall at a nearby plant being built for that purpose. The $600 million cost of the project is high, but the immediate environmental benefit of clean air and the expectation of long-term economic gains justify the investment.

Where chemical scrubbers are used, the sequestering of $SO_2$ from coal-burning power plant and smelter emissions, and hence its mass reduction, has been effective in reducing acid rain in local and regional ecosystems. There is a corresponding reduced pollutant loading of ecosystems where heavy metals are captured together with $SO_2$ in emissions from the same sources.

Scrubber bioremediation is used for odor control of hydrogen sulfide gas ($H_2S$ - smell of rotten eggs) or to eliminate VOCs (contribute to smog) where these pollutants are generated through a flue at fixed sites. Here, the scrubbers use what are called trickling or bio-trickling filters. These are filters packed with highly active bacteria and water. The pollutant gas is absorbed into the water and degraded by aerobic bacteria to non-odoriferous harmless products.

## *Particle Capture*

In addition to the capture of pollutant gases and volatile heavy metals in chimney emissions by chemical scrubbers, particle collectors are installed to trap fine-size solids and aerosols. There are three main technologies used to clean an air stream of particles before they reach the atmosphere: 1) electrostatic precipitators; 2) baghouses; and 3) those based on cyclonic swirling of an air stream and centrifugal force, or on gravity, or on inertia.

Whichever type of particle collection system is being designed for a specific job has to carefully appraise several factors in order to achieve maximum efficiency and effectiveness. These are as follows: 1) temperature of the air stream and its filtering velocity; 2) particle load (concentrations in the range of 0.1–5.0 grains of particles/$ft^3$); 3) particle size (in the range of 0.5–100 μm); 4) moisture of the load and its acid or alkaline condition; 5) combustible potential of some particles; 6) the electrostatic nature of the particles; and 7) the impact or abrasion that can be caused by the particles. A particle capture system can be designed and engineered for installation only when these factors have been thoroughly evaluated. Off the shelf units will generally not yield the optimum particle reduction. Particle capture units are best tailored to individual emissions sources such as coal-fired utilities, foundry and steel operations, smelters, pharmaceutical and chemical producing plants, and food manufacturing facilities. Once installed, all particle control systems have to be optimally functioning and regularly maintained so as to maximize efficiency for particle removal.

### *Electrostatic Precipitators*

Electrostatic precipitators create an electrical charge that causes fine-size particles (e.g., PM2.5) to agglomerate to sizes that cannot be carried by smokestack updrafts. Sensors in electrostatic precipitator systems modify the electrical discharge across a rising air stream according to changing sizes in the ascending particles. The agglomerates accumulate as ash and cinder at the bottom of chimneys where they are recovered for disposal or later use in construction materials from which they cannot escape.

### *Baghouses*

Baghouses are assemblages of filter bags that catch and enmesh particles from a moving air stream in flues or smokestacks. The bags are made of different materials such as cotton or felt fabric, fiberglass, or synthetics such as polypropylene. The properties of a material determine under what chimney conditions it can be used, and the size, physical, and chemical nature of particles and aerosols it can effectively and efficiently entrap. For example, cotton can be used where the temperature is less than 180°F, and has poor resistance to acids, and very good resistance to alkalis and abrasion. Resistance to abrasion and breaching is important to maintain the integrity of the filter bags and thus avoid having to replace them often. Fiberglass can be used at temperatures up to 500°F, and has fair to good acid and alkali resistance, and fair resistance to abrasion. Polypropylene can be used at temperatures up to 200°F and has excellent resistance to acids, alkalis, and abrasion. Several other materials are used for baghouses as well. Cakes of agglomerated particles on the filters are removed by shaking in some cases, and by reversing pressure or by pulsing jets of air in others. Under the optimum conditions, baghouses can remove 99% of fine-size particles from an air stream.

### *Cyclonic, Gravitational, Inertial Systems*

Cyclonic, gravitational and inertial systems offer another mechanism to capture chimney particles. They cost less than the baghouses or electrostatic precipitators but are not as efficient in removing the range of particles sizes generated by some industrial processes. With the cyclone method, particles in a gas stream enter a collector unit at an angle and are spun rapidly. The centrifugal force from the circular flow throws particles against the wall where they aggregate and fall into a hopper. Gravity is the force that brings particles down in another particle-capture method when the gas flow suddenly enters a larger volume flue section, expands rapidly and loses speed with the result that heavier particles settle out into a hopper. In inertial systems, particles are moved from a gas steam to zones in a collector where stream forces are minimal so that they are able to settle into a hopper.

### *Recycling*

Advances in recycling possibilities for profit, based on industrial design and engineering have induced more companies to invest in recovery of pollutants in air flow streams for use in other industrial ventures. One was described earlier for the Montour power plant where $SO_2$ will be captured as the byproduct gypsum that will be used to manufacture drywall. Volatile heavy metals may be similarly captured and recycled for profitable use. In some cases, recycled chemical elements and compounds can reduce the need to purchase new stock chemicals, hence cutting production costs. Similarly, fly ash and cinder with high enough contents of heavy metals may be used as an “ore”. They may also have uses in which there is no possibility that the heavy metals will be released into the environment to gain access to a food chain. If this is not possible because of the nature of the ash/cinder mass and its toxic metals load, the pollutant-bearing solid matter has to be disposed of at a secure monitored site. The monitoring assures that contaminants do not evade into the atmosphere or be subject to leaching and a runoff of leachate into surface water or its seepage through a soil into an aquifer.

### *Costs and Benefits*

The investments in tailored emission pollutant capture and immobilization technologies are high whether for installation in new facilities or for retrofitting into existing ones. Also, efficiency of chemical scrubbers and particle capture systems is constantly improving as scientists develop new materials and technologies. They require investment for their adoption. Nonetheless, the investments are warranted because of benefits received from controlling pollutant emissions. First, and important to an investor, is the promise of long-term economic gain by continued operation of a profitable business. Second, and important to an investor and a population, is that as a result of improved air quality, respiratory illnesses and other health problems decrease, worker sick days decrease, and productivity improves. Third, and important to a population, is that a clean environment can be important to attract investors seeking to find locations for development projects. A new plant or factory offers employment opportunities and can lead to additional jobs in ongoing and perhaps expanding businesses that supply and service it and the community. New projects and additional employment possibilities contribute to a steady tax base on profits and incomes from businesses and employees. This provides funding for healthcare and education for workers and their families. In toto, these factors are the basis for socio-political stability. There is little doubt that long-term benefits from good investments in environmental protection outweigh the costs necessary to achieve and maintain it.

Investment in emission control systems designed and engineered to specification assures that chimney air can be cleaned efficiently as it rises. Newly built facilities should have such equipment built in from the start. They should be constructed so that modular units can be added easily as advances in technologies become available. Retrofitting of existing sources of pollutant emissions with best available chemical scrubbers and fine-size particle capture equipment will cut down on contaminants emitted to the benefit of air quality and local and regional populations. As the following sections will demonstrate, polluted surface and aquifer waters, and polluted soils are not as amenable to remediation even with significant investment.

## Waters

Natural and anthropogenic contaminants can flow from water body to water body. Streams feed lakes and rivers, and rivers discharge into lakes, estuaries, and oceans and seas. Environmental problems for humans caused by pollutants that intrude ecosystems in one water body can cause similar problems for human populations and for other life forms in water bodies they feed.

### *Heavy Metals and Organic Chemicals in Surface Water Bodies*

Water masses can be self-cleansing of heavy metals and organic chemical pollutants if the contaminant sources are shut down. The cleansing is by dilution, and by physical, chemical, and biological reactions. Some pollutants are removed from the waters by adsorption onto suspended sediments (Chapter 5), others as chemical precipitates, and still others by organisms (Chapter 5). The precipitates and settled suspended sediment can add pollutants to water body bottom sediment. Bottom feeders that ingest sediment to extract nutrients may also extract pollutants that can harm them and predators that feed on them. When polluters abate contaminant sources, clean sediment will, in time, cover the polluted bottom sediment thus resolving the bottom feeder problem in a food chain. The physical/chemical conditions that affect post-depositional mobility or immobilization of potentially toxic elements in soil as described in Chapter 6 are much the same that can affect these properties in sediment interstitial waters.

The cleansing of fluvial waters may take as little as six weeks as they flow downstream and discharge into oceans or seas. Conversely, it may take many years for polluted plumes to move through an aquifer. Lakes, estuaries, oceans, and their associated wetlands will lose pollutant loads during different interim time frames depending on water flow into and out of them and on rates of pollutant removal reactions. Capping contaminated bottom sediment with clean sediment will take longer and varies with the sediment load carried to a water body.

To reemphasize, there are two options for remediation of pollution in water bodies. The first is to greatly reduce pollutant inflow (realistic) or stop it (ideal). The second is to treat contaminant-bearing waters before they discharge into water bodies. Treatment is feasible but is not often times economically viable. Nonetheless, environmental scientists and economists demonstrated that in many cases long-term economic (and social and political) benefits far outweigh the costs of investments in remediation. Both options are successfully used.

During the 1990s, pollutants in Chesapeake Bay caused a decline in reproduction and inhibited the development and growth of commercially harvested stock such as crabs, oysters and clams. The shellfish meats were often discolored or bad tasting from contaminant bioaccumulation (e.g., Cu) and thus not saleable. Environmental legislative action by Maryland and Virginia and positive actions from owners of polluting sources mitigated the input of contaminants and the bay problems they caused. Nonetheless, over crabbing and pollution still affect the reproduction and threaten the commercial future of some organisms in the Bay such as the blue crab.

## *Nutrient-Rich Runoff − Alleviation + Control = Remediation*

There is no remediation for the millions of fish that have died as the result "red tides" caused by nutrient-rich waters emptying into oceans and other water bodies. Neither is there remediation for the countless number of benthic life forms that have died as a result of eutrophication that has as its origin the same nutrient-rich waters. Abatement of the problem is simple: alleviate or eliminate the anthropogenic sources of nutrient-rich waters and there will be a corresponding lessening of the environmental problems they cause. To do this it is first necessary to identify the nutrient source(s). The next step in countering the input is to determine how it can be reduced and then discuss possibilities for voluntary abatement by the polluter(s).

Runoff from farmlands fertilized with agricultural chemicals is greatly reduced by meting out and focusing the delivery of the optimal amount of fertilizer appropriate to each crop and soil. When the runoff sources are fields where animal fecal wastes have been spread as a disposal method, their addition can be stopped. The nutrient-rich fecal matter can be collected at their point sources (e.g., feedlots, chicken farms) and used as stock for fertilizer manufacture. This was done in the past with accumulations of bat droppings (guano) in caves. Organic wastes from slaughterhouses (e.g., for cattle, chickens, pigs) can be sources of nutrient-rich runoff as well when improperly disposed of. An option to eliminate this input source is to collect and use the discarded soft tissue wastes (combustible) as fuel in energy-generating operations.

Where pollution problems are caused by activities that flaunt legislation that is written to prevent them, most polluting facilities operators will agree to mitigation programs voluntarily when faced with the prospect of punitive measures. Sometimes they are spurred to conform with regulations by government tax incentives and subsidies. As reiterated in previous chapters, if polluting businesses do not agree to abatement, fines can be imposed or the source can be taken over or shut down. Clean up costs may be assessed for areas the businesses contaminated in the past.

## *Oceans and Aquifers: Food Source and Water Source*

Ocean and aquifer waters present special situations with respect to pollution. The oceans are a major source of protein-rich food worldwide, especially for populations in less developed countries that have extensive coastal zones. Aquifers are major sources of safe water for drinking and for irrigation of food crops. Contamination of aquifer waters decreases their usefulness.

## *Oceans*

Ocean currents, wave activity and diurnal tides continually mix, disperse, and dilute soluble and particle-borne pollutants. In spite of dispersion and dilution, some pollutants, such as those from barge loads of domestic, chemical, or industrial wastes, some containerized and some not, regularly dumped into the same areas of the ocean, especially at inshore sites, can damage marine ecosystems. In some cases, piped discharge of pollutant-bearing industrial effluents or introduction of untreated sewage directly into near shore waters has done the same. Here as in other aqueous ecosystems life forms can bio-accumulate contaminants to toxic concentrations at higher trophic levels as predators feed on prey. This has health implications for predators at the top of the food web, such as polar bear in the Arctic and humans elsewhere.

For example, an early 1990s outbreak of cholera in Peru originated from human wastes carried from land for disposal to inshore waters. Local populations regularly caught fish in these waters for personal use and for sale to local markets and restaurants. The food fish were contaminated with the bacterium *Vibrio cholerae*. Eating the fish allowed enough of the bacteria to accumulate in the small intestine to sicken consumers and originate an outbreak of cholera. The cholera was subsequently spread to other South American nations by human vectors but was arrested and prevented large-scale outbreaks. Similarly, illegal dumping of medical wastes in eastern U.S. coastal zones caused socio-economic problems but fortunately without health consequences. The medical wastes (e.g., blood bags) dumped off the New Jersey coast during the 1990s were carried by currents to shore and resulted in high-season beach resort closures from New York to Maryland. Investigators traced serial numbers on the wastes' containers back to doctors' offices. The doctors gave up the names of the groups that collected and illegally dumped the wastes. Arrests followed and pollution from these sources ceased. Most recently, however, medical wastes washed up on beaches in New Jersey and caused them to be closed during the end of the 2007 summer season. Authorities are working to trace the origin(s) of the wastes and bring the illegal dumping perpetrators to justice.

Legal waste dumping at sea is practiced by heavily populated coastal cites. Environmental agencies have designated sites and container requirements for offshore dumping, by permit, of different classes of wastes from non-harmful domestic to highly toxic in nature. The sites are selected on basis of ocean depth and current flow directions, proximity to land, and locations of fishing grounds.

Regular dumping of large amounts of wastes in near shore marine environments have created severe chemical pollution problems at some disposal sites and at locations in current flow paths some distance away. Such was the case for the New York Bight that is situated at an indentation (forming a bay) off the coast where New Jersey and New York (Long Island) meet. This is the most densely populated coastal area in the United States and the offshore sediments are the most polluted in the country.

The Hudson River empties into a harbor estuary as it flows into the bay. In the geologic past, when sea level was lower and the continental shelf exposed as a result of the last glacial stage, the Hudson River incised a shelf valley. The upper (northern) part of the Hudson Shelf Valley (the New York Bight) is used for waste disposal as well as for transportation, recreation, commercial fishing (especially shellfish), and recreational fishing.

Sewage sludge dumped in the apex of the New York Bight, amounted to 125 million $m^3$ over 64 years, the largest deposit of sludge in the U.S. Over 80 years, 250 million $m^3$ of harbor dredge spoils laden with heavy metals and organic pollutants and construction refuse were also dumped in the Bight. During the past century, diverse sources of contaminants carried directly from land, combined with the sources cited above to deposit large masses of heavy metals, bacteria, carbon, and organic contaminants at the New York Bight disposal area. An annual dredging of the harbor adds 6 million $m^3$ of spoils for disposal. Certain areas in the Bight sometimes became hypoxic as the amount of organic matter decomposing had a high BOD (biological oxygen demand) and depleted the oxygen in what was called a “dead zone”. Fish could swim away but benthic organisms such as oysters and starfish died, starved of oxygen.

The highest concentrations of heavy metals and bacterial contamination in sediments occur in muddy deposits near dumpsites and in the northern basins at the head of the shelf valley. The basins are an open source of heavy metals and other contaminants that are diluted and dispersed as they migrate down the shelf valley and accumulate in sediments as far as 50 miles ($\sim$80 km) away. Benthic organisms, especially bottom feeders, contact and may extract contaminants from the sediment. The situation in the New York Bight and linked marine environments clearly demanded remediation of the contamination problem. Enforcement of state and federal environmental legislation that has been passed in recent years mandated the disposal of sewage in an area 106 miles ($\sim$170 km) offshore instead of the previous $>$12 miles ($\sim$20 km) restriction. Similarly, harbor dredge spoils were categorized according to degree of cleanliness or contamination for disposal at designated sites. This and improved disposal practices reduced the use of the Bight apex area for waste disposal and resulted in fewer sources of pollutants for downflow migration and a decreased concentration of contaminants near the Bight. The problem of polluted sediments in this situation has been addressed and alleviated to the benefit of marine ecosystems at the disposal sites and those linked to them in the path of the current activity.

Chemical and/or bacterial/viral intrusion of oceans are not the only threats to ocean fisheries. The human threat of over fishing may be the most dangerous environmental intrusion that threatens the nutritional needs of large and growing segments of the world's populations and deserves consideration here.

Increased harvesting of ocean fish continues to put the future of this food source and commercial fishing at risk. Worm et al. (2006) studied the impact that the loss of biodiversity in the oceans would have on ocean ecosystem services. It would result in a loss of the ability of the ocean ecosystem to produce food, and for ocean life to resist disease, filter pollutants, or rebound from stresses exerted by over fishing or climate change. These researchers predicted that the oceans would lose about 70% of existing species by 2048 and basically be fished out if over fishing and pollutant input continues at its present rate. A FAO/UN report gave the loss of species figure at about 80% by 2050. This will hurt populations' nutrition in coastal zones of less developed countries that depend on fish as their principal protein source that they could lose. It will damage the economies of populations in these countries dependent on fisheries production. This can be countered to a great degree if commercial fishing fleets catch to their quotas set by national and/or international agencies. As with other environmental protection protocols, legislation exists that punishes commercial fishing entities if they flaunt the laws. Enforcement of international fishing laws can contribute to the preservation of the ocean's cornucopia of food for future generations.

Continued over fishing or over hunting of whales on the endangered species watch list is considered by some as a crime against humanity. During November 2007, the Japanese government gave its assent for the killing of 50 protected humpback whales, 935 minke whales, and 15 fin whales in a so-called scientific research hunt to study reproductive and feeding habits of whales. Kill 10 whales for scientific research, or even 50. To kill 1000 is to flaunt the whaling moratorium signed in 1986, and other international treaties on whale hunting. The Japanese adventure will serve scientific research little. In truth, the whale meat will go to feed the needs of restaurants, sushi bars, and food desires of the Japanese public. It is wrong. The International Whaling Commission criticized the hunt stating that the Japanese were simply using science as a cover for commercial fishing. In December 2007, the Japanese bowed somewhat to international criticism, especially from Australia and other commercial and political partners and backed off from hunting the protected humpback whales but will still hunt the other 950 marine mammals.

## *Aquifers*

Aquifers can be contaminated naturally by rain water that seeps through heavy metals-rich rock types (e.g., black shale, serpentine) or through buried (hidden) mineral deposits and dissolves some heavy metals on its path to recharge an aquifer. They are also polluted by industrial and manufacturing sources that discharge contaminant-bearing fluids at the surface that can then infiltrate through an overburden to invade aquifers. Similarly, runoff of urine from feedlots (e.g., with thousands of cattle) can seep into soils and through them infiltrate aquifers unless the runoff fluids are captured at the lots and treated before discharge.

The case of As poisoning of populations in West Bengal and neighboring India illustrated how a change in physical/chemical conditions of aquifer water can result in its contamination by a dangerous pollutant. As explained in Chapter 5, aeration and consequent oxidation and decomposition of an As-bearing mineral by high volume seasonal pumping and lowering of the water table released As into the water as the toxic arsenite species. This made the water unsafe for human ingestion or farming. The question then what remediation is possible?

Remediation of polluted groundwater is difficult because of its slow rate of movement through porous, permeable rocks (one to three feet daily on the average) and the extensive areas and different depths and thickness of aquifers. When a source of groundwater contamination is identified and eliminated, a contaminated plume remains in an aquifer and moves along a flow path pushed by clean water behind it. During flow, pollutant contents can be diluted, dissipated, or reduced by chemical reactions with rocks the water flows through or by precipitation. Processes such as this help bring aquifer waters to safe chemical content levels. Polluted plumes can flow in aquifer waters for many years before they pass previously safe wells and clean waters can be pumped again. Aquifer residence time is a major factor that must be considered in a proposed remediation project.

If costs/benefits analysis supports remediation, a program can be designed for an aquifer with its unique porosity and permeability, area extent, depth and thickness, and concentrations of specific pollutants in the water. Before an aquifer remediation project can begin, the pollutant input has to be stopped or diverted away from a recharge area to a treatment facility or to an area where it will not harm an environment. One remediation mode is to drill a series of wells to intercept and extract contaminated water from the aquifer until only safe water flows through the aquifer. Another solution to the problem is to pump clean water into the aquifer under pressure to move the polluted water through the aquifer faster to the wells that intercept and extract it or to move the unsafe water past individual and municipal wells which can then pump safe water. These solutions are costly but they can decrease the time before safe water for drinking or irrigation can be pumped from an aquifer again.

When remediation of aquifer water is too costly, some contaminant problems can be solved by chemical techniques that clean the water for drinking, cooking and possibly irrigation. In the case of the As in aquifer water that threatens the well being of millions of Bengali Indians and Bangladeshis, several chemical remediation options have been devised for its removal at the well head or at a treatment facility before use (Jiang, J.Q., 2001). These are based on the response of the As species in ground water to changed chemical conditions. They require the oxidation of the $As^{3+}$ species (arsenite) to the $As^{5+}$ species (arsenate) which can then be immobilized by coagulation (e.g., by alum, $Al_2(SO_4)_3$ or ferric chloride, $FeCl_3$) and precipitation, or by adsorption (e.g., on iron-oxide-coated sand, activated aluminum or activated carbon) which effectively removes it. Other potentially toxic chemical elements and compounds may lend themselves to removal from water using low-cost chemical-based wellhead techniques. If the wellhead remediation method is used, its operation must include the secure disposal of precipitates or sorbents.

## Soils

Remediation of soils polluted by inorganic and/or organic toxic chemicals can be done by various methods. Mulligan et al. (2001) review both tested full-scale remediation technologies and those being researched in their evaluation of remediation possibilities for metal-contaminated soils and groundwater. These include excavation, chemical mobilization and extraction from a soil (sometimes boosted by a biological catalyst), and immobilization of pollutants *in situ*. In the case of some organic pollutants and highly toxic chemicals in soils, the remediation can be incineration of the soil of at temperatures up to 1300°C. The most effective and efficient method to use in a remediation project on contaminated soils depends on several factors. Among these are: (1) the geology of an area; (2) the size of the polluted area; (3) the physical, chemical, and biological character of a soil (e.g., permeability, organic content, bacterial colonies present, respectively); (4) the pollutants and their concentrations in a soil; (5) the depth that pollution reaches in a soil sequence; (6) how pollutants are bound to soil components; (7) the pollutant response to immobilization or mobilization procedures; and (8) an assessment of the impact of the remediation method used on soil ecosystem organisms and linked ecosystem life.

Economics determines if remediation is feasible, and if so, the methods that might be used. As in all remediation to reclamation programs, the long-term economic and social benefits of having natural background levels for chemical elements or compounds in a soil should be equal to or greater than the costs of remediation. The long-term benefits are cumulative when an area of reclaimed soil can be used well into the future for agriculture, as ecosystem (natural resources) habitats, or for human habitation.

### *Excavation*

Excavation is costly and generally limited to small areas ($< \frac{1}{2}$ hectare $= 1\frac{1}{4}$ acres) and a soil depth of $<1$ meter. This is a three-stage operation with the first being the excavation of a polluted soil. The second is to transport the polluted soil to a facility for treatment, or send it for disposal at a secure site where it is isolated and contained. To assure containment at a disposal site, adjacent terrain must be continually monitored. The third stage is restoring the excavated area with clean soil.

Excavation may be the only way to sanitize a contaminated soil where a continually discharging pollutant source is buried in a soil sequence. In such a case chemical and/or biological mobilization and extraction remediation or immobilization procedures will not be effective or practical. This may be where chemicals were buried in the past in containers that subsequently corroded and leaked contaminants into a soil. The chemical pollutants then migrated through the soil to the surface or into buildings constructed above a buried chemical waste disposal site. The Love Canal case discussed in Chapter 6 is an example of this. Another example is found in Washington, DC, where a company excavating foundations for high-cost housing uncovered U.S. Army military ordinance from WWI that was disposed of by burial at what was then unoccupied land. This land is now occupied by properties owned by American University and by families in homes that sell for well in excess of $1 million in nearby areas. The ordinance included mustard gas that contains lewisite, an arsenic-based chemical as well as unexploded ordinance. Subsequent soil analyses targeted several areas where As was high in playing fields and home gardens. Some homeowners believe that As-poisoning was the cause of illnesses that affected children and adults who lived in homes with high As contents in their garden soils. The U.S. Corps of Engineers contracted out the remediation program to companies that have been excavating the targeted sites several years and is still doing so. They have removed recovered ordinance, excavated and disposed of As-laced soils, and restored the excavated areas with clean soil.

For a scenario where radioactive fallout has contaminated soil, excavation would not be a feasible solution for remediation to reclaim land. This is the situation in farmlands downwind of the Chernobyl nuclear power plant explosion. A similar problem developed at waste storage sites in the former Soviet Union where improper handling of radioactive waste resulted in explosions and releases of radioactive gases and particles into the atmosphere with subsequent deposition on adjacent land. In these cases, the areas affected by radioactive pollution are extensive and about 15 cm of topsoil would have to be excavated in a soil remediation and reclamation program. Areas for remediation may cover tens of square kilometers or more. Because of this, excavation of radioactive contaminated soil in Ukraine and Belarus, for example, is not practical in economic (or physical) terms.

For example, the cost to clean up polonium (Po) contamination at the Clean Slate III site in the Nevada Nuclear Weapons Test Site was estimated at more than $22 million. This covered the excavation of soil to about 15 cm (6 in) in an area of $\sim$0.3 mi$^2$ ($\sim$0.5 km$^2$) or 1,200,000 ft$^3$ of radioactive soil. The cost of $\sim$\$18/ft$^3$ includes the following: (1) field work planning; (2) site and infrastructure and logistics preparation; (3) automated waste characterization of excavated soil; (4) excavation by removing topsoil and picking up contaminated soil with a scraper; (5) transport for processing; (6) packaging for disposal; (7) transporting to disposal site; and (8) disposal (Hoeffner et al., 2002). Extrapolation of the costs from a $\sim$0.5 km$^2$ area to tens of square kilometers or more explains in part why the clean up of the former sites of villages and farmlands has not been done by the then Soviet Union and now Russia and by Ukraine and Belarus. The radioactive contaminated sites will be quarantined and off limits to entry and use until the passage of time and decay of radioactive isotopes in the soil resolves the problem.

## *Mobilization and Extraction - Physical-Chemical-Biological*

Some elements and compounds in soils can be chemically and/or biologically mobilized and moved under fluid or gaseous pressure through soils to where they can be captured and extracted. The solubility in aqueous solution and enhanced mobilization is accomplished for some soil pollutants by the addition of acids or peptizers to a soil. Acids that are effective in increasing solubility in soil waters include hydrochloric acid, acetic acid, citric acid, and di-Na EDTA. The amendment of soils with bacteria that change a soil reduction-oxidation potential also improves the solubility of some contaminant chemicals. In other cases, electrical methods separate heavy metals from a soil after they are mobilized using chemicals that change the pH or bacteria that alter the reduction-oxidation potential. The separation takes place when an electrical current is set up between a cathode and an anode. The heavy metal ions migrate to the anode and accumulate there for subsequent collection and transfer to a secure monitored disposal site (Virkutyte et al., 2002).

Urlings (1990) described an example of the successful extraction of the toxic element Cd from soils. Environmental engineers extracted Cd from soils in the Netherlands by flushing soils with hydrochloric acid at a pH = 3.5 (Urlings, 1990). The maximum permissible concentration for Cd is 3 ppm. Acid flushing and extraction brought the Cd soil content down from 10 ppm to 1 ppm. The cost was less than if excavation had been used as a remediation method. Data on soil characteristics (e.g., Figure 5.5, Table 6.5, Table 6.7) guide scientists on how contaminants are bound in a soil. This directs decision-making on the extraction possibilities using proven techniques.

Project managers use mobilization techniques targeted to a specific inorganic or organic pollutant, or, if necessary and actionable, to more than one pollutant. For example, Peters (1999) found that 70% of several heavy metals in soil (Cu, Pb, Zn and Cr) at a military arms testing site were in exchangeable, carbonate and reducible phases (Figure 5.5). This meant that they could be mobilized by soil washing/flushing using the chelating chemicals EDTA and citric acid. The extraction simultaneously removed $>97\%$ of Cu, Pb and Zn plus significant amounts of As, Cd, Cr, Fe, and Hg. The extracted pollutant-bearing fluids must be treated and disposed of at secure sites according to the protocols of the remediation program.

## *Immobilization*

In order to determine if immobilization of pollutants in a soil is economically practicable, it is necessary to know the size of the polluted area and the depth to which a soil is polluted. If the assessment is positive, a key to selecting an effective immobilization plan is to have data on the size distribution, mineralogy, and total chemistry of a soil. These data are used to foretell the immobility/mobility responses of harmful chemicals to proposed changes in soil conditions.

Immobilization of soil pollutants is done in different ways. One is by amending the soil so that a pollutant or an assemblage of pollutants will not evade into the atmosphere or access soil moisture, vegetation (food crops), or aquifer waters. This is referred to as stabilization. Soil pH can be adjusted so that most potentially toxic metal pollutants are essentially immobilized (Chapter 6). For example, when an acidic soil (e.g., pH = 6.5) is amended with limestone or gypsum, its pH changes to a basic condition (e.g., pH = 8). At this pH, many pollutant metals react to form metal hydroxide compounds that cannot move in the soil environment (Chapter 6). Similarly, establishing and maintaining an oxidation or reduction level in soil environments can inhibit the mobility of some chemical elements or compounds.

Most pollutants, but not all, can be immobilized by changing soil conditions such as pH or oxidation-reduction potential. Scientific consultants planning a soil remediation project have to determine if any chemical elements are likely to be mobilized under planned immobilizing conditions. Once this is done, consultants establish whether or not the availability of the mobilized chemical elements to organisms can lessen the vitality of the ecosystem or those linked to it. For example, liming a soil to bring the pH to 8 to improve the growth of a fodder crop, will mobilize the heavy metal Mo. If the Mo is taken up and bio-accumulated in the fodder, this could hurt ruminants. Ingestion of high concentrations of Mo in feed can inhibit the absorption of the essential nutrient Cu by the ruminants and cause hypocuprosis. This disease affects their condition, inhibits weight gain, and if they are dairy livestock, reduces their milk yield (Chapter 6).

Another immobilization technique is called solidification. This method physically binds and encloses polluted soils within a stable mass. Polluted soil is reacted with matter such as Portland cement or other pozzolanic-based binding agent (e.g., fly ash or kiln dust). When mixed with soil and moisture, this binding matter raises the pH that helps precipitate and immobilize many heavy metals (e.g., Cd, As). When the mass solidifies, it encapsulates and locks pollutants in non-reactive material. In some cases the soil is excavated and mixed with binding matter. The resulting solid pollutant-bearing mass is either returned for burial at the remediation site or disposed of in a monitored landfill. Where workable, the polluted soil can be mixed in place with the non-reactive substance that will solidify around it. The solidified mass is covered with clean soil. There is a concern about using the solidification method of soil remediation. The long-term stability of the encapsulated mass under different environmental conditions is not yet known for many of the cementious materials.

## *Phytoremediation*

A relatively recent advance in soil remediation methodology is the use of vegetation to extract contaminant metals from soils. Certain vegetation species tends to absorb metals from soils. For some plants the metals uptake is proportional to their concentrations in a soil. For others, there is a bioaccumulation that can be far in excess of the metals concentrations in a soil. These species are called accumulators (concentrate $>100$ ppm but $<1000$ ppm by weight) or hyper-accumulators (concentrate $>1000$ ppm or $>0.1\%$ by weight). Many have been identified by exploration geochemists using vegetation (biogeochemistry) to prospect for ore deposits hidden beneath a soil or soil-rock cover (Brooks, 1972, 1983; Kovalevskii, 1991).

For biogeochemical prospecting, the premise is that vegetation chemistry reflects soil chemistry and that soil chemistry originates with underlying rocks. High concentrations of one metal or more than one in vegetation suggests the possibility that the root system of the vegetation is tapping ore minerals in the subsurface. Dunn (2007) presents a fine review of advances in biogeochemistry during the past decade.

To be a phytoextractor that is feasible for clean up of soils contaminated with metals, vegetation must have other characteristics in addition to bioaccumulation capabilities. First, the plant should be indigenous to or easily adaptable to the climate where soil remediation is needed. Second, the plant should have a large mass since this allows a greater pollutant uptake from a soil. Third, the plant should grow rapidly and perhaps lend itself to two crops annually or to continual growth thereby increasing the rate of depletion of a pollutant in a soil. Fourth, the plant should have a deep enough root system, perhaps up to 50 cm ($\sim$20 in) so that it taps soil horizons that concentrate target metals. Fifth, the plant should be large enough so as to be harvestable using mechanical means in order to minimize labor costs. Positive research results in test plots have been achieved in different climatologic regimes (Chaney et al., 1999, 2000, 2007; Reeves and Baker, 2000; Raskin and Ensley, 2000).

Research to improve phytoextractor plant properties is ongoing. A recent study by Farwell et al. (2006) used plant growth-promoting bacteria to increase plant biomass in a natural canola (*Brassica nupus*) and a transgenic form of the species growing in a Ni-contaminated soil. The addition of the *Pseudomonas pudita* strain HS-2 bacterium significantly enhanced the biomass of the non-transgenic plant with little change in its ability to accumulate Ni. The growth of the transgenic form increased to a lesser degree but had a reduced uptake of Ni in its shoots. Farwell et al. (2006) suggest that there may be a potential use of bacteria to stimulate growth and an increase of biomass in accumulator or hyper-accumulator species. This would make them more attractive for use in phytoextraction projects.

Phytoextraction may involve amending soils to change soil characteristics so that vegetation can absorb and incorporate harmful metals more effectively. This induced accumulation or hyper-accumulation process is done by the regular addition to a soil of conditioning fluids that increase metal solubility and transport in soil waters (Vance and Pierzynski, 2001). It is most effective by sowing selected fast-growing plants in the metal-polluted soil. The estimated clean up cost is \$16–\$62 per cubic yard of soil.

A problem that could arise from the application of soil amendments that lower the pH of a soil to help a plant remove harmful metals more efficiently is that a lower soil pH could harm beneficial soil microbe colonies. Thus, it is necessary to test amendments on a specific soil before a phytoextraction project begins. For example, in 2006, Chaney and The University of Maryland were granted a patent on the use of alpine pennycress (*Thlaspi caerulescens*) as a bioremediation plant to remove Cd from contaminated soil. In the studies done leading up to the application for a patent, the researchers found that lowering the pH to 5.8–6 to optimize Cd removal had no lasting negative effect on soil microbes. The plant concentrated up to 0.8% Cd in its leaves and was estimated to be able to reduce Cd to safe levels in a soil in 3 to 10 years at a cost of $250 to $1000 per acre annually. The cost per acre to excavate the polluted soil and replace it with clean soil would be about $1 million.

Another caution in the use of vegetation to extract potentially toxic metals from soils is how to dispose of or use the harvested, metal-rich vegetation. Some consultants have proposed uses for phytoextractor harvests that are not environmentally sound and should be dismissed for bioremediation projects. For example, neither the use of metal-bearing vegetation for compost and later application to farmland nor is using it as food animal fodder are options because this would only cycle one or more pollutants into the food web. The use of dried vegetation briquettes as a fuel for domestic cooking or heating is also not an option where there is poor ventilation. The contained metals can release into the domestic atmosphere as volatiles or as particles. In special situations, it may be possible is to use dried harvested vegetation as an "organic ore" for the recovery of one or more metals. This possibility depends on the concentration of a metal in vegetation, the mass generated on a regular basis, the time frame during which the "organic ore" will be generated, the demand for a metal, and the cost of production against the sale value for the recovered commodity.

## *Marker-Assisted Selection (MAS) Hybrids for Soil Remediation*

Marker-assisted selection (MAS) directed hybridization described in Chapter 8 should be useful to breed plants for soil remediation. The phytoremediation methodology may benefit from MAS if an accumulator or hyper-accumulator plant of a targeted pollutant metal or group of metals does not satisfy all the principal criteria to be a phytoextractor. It is possible that MAS-directed hybridization within a species can impart the necessary trait(s) to an indigenous plant that allow it to be an effective and efficient "designer" phytoextractor for soil metals cleanup. This could be to grow with more mass in order to be able to absorb more pollutant, or to grow higher to be amenable to mechanical harvesting).

## *Selected Crops for Contaminated Farmlands*

It may be possible to use contaminated soil for cropping without remediation by the previously cited methods, many of which require major investment. In addition to vegetation that takes up chemical elements from soil in proportion to soil contents or that may accumulate or hyper-accumulate the elements, there is a third, sometimes overlooked category. This is vegetation that naturally discriminates against the uptake of specific chemical elements from a soil. If this vegetation is a food or fodder crop, it can be cultivated and the metal-contaminated soil used for gainful production.

## *In-Situ Degradation of Hydrocarbons*

Leaking underground storage tanks (LUST) from gasoline stations and from chemicals stored at industrial sites, discharges of solvent from dry cleaning establishments, and other sources release hydrocarbon contaminants into soils (and groundwater). This is the result of seepage of fluids through corroded walls of the tanks, from overflow, and from poor waste disposal. The organic chemicals include methyl tertiary butyl ether (MBTE) that is a gasoline additive as an octane booster, trichloroethylene (TCE), perchloroethylene (PCE), their metabolites, and other chlorinated hydrocarbons. Many sites have been cleaned up worldwide but many have yet to undergo remediation. The USEPA estimated that in 2004 there were almost 8000 sites in the United States that should undergo remediation at a cost of more than $2 billion. There are 10s of thousands of such sites in the EU.

A successful reclamation program for soils with hydrocarbon contaminants requires first that the contaminant source (LUST) be removed and second that the polluted area be accurately mapped in order to establish a containment field. The clean up can be done by bioremediation and other techniques. In bioremediation, naturally occurring anaerobic bacteria are introduced into the soil to biodegrade chlorinated hydrocarbons. Bacteria are selected to decomposed specific hydrocarbons that serve as a food-energy source. Oils or other organic liquids are pumped into a contaminated soil to feed the de-chlorination (reductive chlorination) processes by speeding up bacterial activity further energizing the remediation processes. Degradation products in soils from use of this methodology are the harmless components carbon dioxide and water. In another technique, pressurized steam is used as a heat source that removes volatile organic contaminants from soils with little impact on the surrounding environment. Chemicals that attack specific hydrocarbon contaminants can be used in the same way to degrade them to carbon dioxide and water.

In a hothouse experiment, Sun et al. (2004) initiated an evaluation of a suite of tropical plants for the remediation of petroleum hydrocarbon-contaminated sandy saline tropical coastal soils in Pacific island ecosystems. This contamination is commonly associated with petroleum storage tank farms. Three of the nine tropical plants studied showed the most potential for the remediation problem. These are the trees, kiawe (*Prosopis pallida*), milo (*Thespesia propulnea*), and kou (*Cordia subcordata*). They grew well in moderately saline (1%) soils in the presence of 10 gm/kg of No. 2 diesel fuel and accelerated the degradation of this petroleum hydrocarbon. In a follow up experiment the milo and kou trees were grown in tri-sector planters spiked with petroleum hydrocarbons in soil that simulated the profile at an abandoned, soil-contaminated tank farm at Hickam Air Force base, Honolulu, Hawaii. The milo and kou trees were more effective at removing a mixture of six diesel fuel components than the false sandalwood bush (Tang et al., 2004). The next research stage will be to grow them in the contaminated soil at the tank farm and assess their real world *in situ* petroleum hydrocarbon degradation effectiveness. A positive result will provide a remediation technique for abandoned and active tank farm soils at islands in the Pacific and similar global environments. This will allow soils to be reclaimed and used for local agriculture. A positive result will open up the possibility of using plants for remediation of sites contaminated by overflow or leakage from tank farms in other climatologic/soil zones.

Polychlorinated biphenyls (PCBs) in soils are a "left over" global problem. Whitfield et al. (2007) did a pilot field trial to investigate the phytoextraction of PCBs from soils with pumpkin, sedge, and tall fescue plants. These researchers concluded that all three plants exhibit potential as PCBs extractors. However, further studies are needed to determine the optimal plant density and soil conditions for PCBs phytoextraction to reveal which plant is a more efficient extractor, its feasibility given the PCBs concentrations in a soil, and the rate of uptake of the chemicals by the plants.

## *Control Salination and Preserve Soil Productivity*

The soils chapter emphasized that salination is an omnipresent farming problem that requires regular "preventive" remediation to maintain crop productivity. The remediation is accomplished by flushing soils with water to dissolve accumulated salts. Salination can be managed effectively by the installation of a subsurface drainage tile network that transports irrigation waters out of soils efficiently and thus reduces the possibility of short-term salt build up on crop root systems. This method requires a substantial investment but the costs/benefits relation favors the investment even when 10–20% annual maintenance costs for weeding and de-silting of the drains are added to the remediation (reclamation) program costs. The design for the spacing and depth of tiles in a network varies with the conditions for each project (e.g., soil characteristics, climate, crops cultivated).

The World Bank has financed the installation of drainage tile networks for irrigation-based agricultural development. In Pakistan, the cost was \$1105 per hectare (2.5 acres) for 18,000 hectares (∼\$20 million). A project covering 3300 hectares in Peru had a cost of \$1900 per hectare (∼\$6.25 million). In Egypt, a continuing project covering millions of hectares is costing between \$1800 and \$2300 per hectare (∼\$2 billion per million hectares).

A network may have to be redesigned because of agricultural or chemical reasons that can cause a change in the rate of build up of soil salination. For example, there may be change in crops, in the density of plants, or the number of crops seeded annually that require changes in the volume of irrigation water used, and patterns of water use. There may also be a change to higher concentrations of dissolved salts in irrigation waters or an increased rate of evaporation from global warming. A drainage tile network was installed in the San Joaquin, California agricultural region in 1960 to control a salination problem caused by irrigation with Colorado River waters carrying 0.08% (800 ppm) of dissolved salts. Twenty years later, as a result of a combination of factors cited above, soil salination caused annual losses of food production of >$100 million. The original drainage tile spacing was 60–100 m apart. When new networks were added 10–30 m apart, food production normalized and losses turned into profits once again.

Arid and semiarid regions (Figure 5.3) are especially susceptible to farmland damage and loss of productivity from excessive salt contents in soils. This is difficult to control with management practices cited above. Qadir et al. (2000) proposed that the salination amelioration be done by various means. The most efficient and sustainable method is by cropping in conjunction with leaching where there is sufficient irrigation water and/or rainfall. Another is by leaching excess soluble salts from upper horizons to lower depths in a soil profile. A third is by flushing salts from soils with salt crusts and a high permeability that overly a shallow water table. These latter two techniques again presuppose a sufficient water supply that is less likely in the arid/semi-arid regions. Another method is bioremediation by harvesting high salt accumulating plants in areas with low rainfall or lack of much irrigation water for flushing. The seeding of natural salt tolerant crops (e.g., similar to *Salicornia*) or seed stocks bred to that end by MAS directed hybridization can help farming in these regions and in countries where GM crops are rejected (e.g., in the EU).

## Remediation Realities

Remediation of chemically-polluted atmospheres, water bodies, and soils, is possible in many environments if targeted pollution reduction levels are realistic, if legislation supports these targets, and if economic resources are available for the remediation program. The principal key to any successful remediation program is a greatly reduced or halted input of pollutants into ecosystems from point sources or an array of sources. Air can be cleansed to acceptable "breathable" quality, and water can be made safe for drinking, cooking, hygiene, and irrigation, and for industrial and manufacturing operations and other purposes when reduction of pollutant input is coupled with best available technologies. Remediation can likewise reclaim soils for sustainable agriculture and for other development sectors. However, remediation of farmland soils presents unique problems.

Standards for allowable concentrations of chemical elements in soils to be used for food crops can be set by health professionals (Table 9.1). However, among these, optimal concentrations for metals (e.g., Cd, Cr, Cu) can be unrealistic given natural compositions of different rocks from which soils evolve which leave their chemical imprints in soils (e.g., black shales, serpentines, peridotites). The high natural concentrations in soils cannot be reduced to what may be defined as optimal agricultural contents. For man-made organic contaminants (e.g., PCBs, trichloroethelene,

**Table 9.1** Maximum permissible concentrations of chemical elements and compounds in soils that are targets in polluted soils remediation programs. Figures are given as amounts in sample solutions unless otherwise noted

| Chemical element/ compound | Maximum permissible concentrations in soil through leaching test and content test |
|---|---|
| cadmium | 0.01 mg/l (ppm) or less than 1 mg/kg (ppm) in rice for agricultural land |
| lead | 0.01 mg/l or less |
| chromium (VI) | 0.05 mg/l or less |
| arsenic | 0.01 mg/l or less, and less than 15 mg/kg in soil for agricultural land (paddy field only) |
| total mercury | 0.0005 mg/l or less |
| alkyl mercury | should not be detectable |
| copper | less than 125 mg/kg in soil for agricultural land (paddy field only) |
| selenium | 0.01 mg/l or less |
| fluorine | 0.8 mg/l or less |
| boron | 1 mg/l or less |
| cyanide | should not be detectable |
| organic phosphorus | should not be detectable |
| PCBs | should not be detectable |
| dichloromethane | 0.02 mg/l or less |
| carbon tetrachloride | 0.002 mg/l or less |
| 1,2-dichloroethane | 0.004 mg/l or less |
| 1,1-dichloroethylene | 0.02 mg/l or less |
| cis-1,2 dichloroethylene | 0.04 mg/l or less |
| 1,1,1-trichloroethane | 1 mg/l or less |
| 1,1,2-trichloroethane | 0.006 mg/l or less |
| trichloroethylene | 0.03 mg/l or less |
| tetrachloroethylene | 0.01 mg/l or less |
| 1,3-dichloropropene | 0.002 mg/l or less |
| thiram | 0.006 mg/l or less |
| simazine | 0.003 mg/l or less |
| thiobencarb | 0.02 mg/l or less |
| benzene | 0.01 mg/l or less |

(Source: http://www.env.go.j[/en/lar/regulation/sp.html or http://www.arofe.army.mil/ARO-FE% Environmental%20Bulletin/Env_Nov01_Soil,htm)
Note that the figures given above do not apply to places where natural concentrations are higher such as in proximity to certain rock types, mineralized areas, or at sites which have served for storage of toxic materials or for disposal of wastes.

benzene), the permissible contents for agricultural levels are realistic targets that can be met with remediation.

Ideally, remediation concentration targets are natural baseline contents in an area. Realistically, this may not be achievable with the financing allowed for a clean up project. The question then is whether pollutant contents in ecosystem media can be reduced to what can be called "allowable" concentrations. These are concentrations that are higher than natural baseline contents but levels that are not threatening to the health status and/or productivity of an ecosystem. This can give three results: first, air that will not cause bronchial or other health problems; second, water that can be ingested or used without short-term or long-term health or productivity risks to ecosystem inhabitants; and third, fertile soils that will sustain growth of healthy, top quality, and maximum yield crops.

There are engineering and consulting companies globally that specialize in capture/control technologies to alleviate specific site emissions of metals and/or particles to the atmosphere. Similarly, a multitude of consulting companies worldwide offer soil and aquifer (and other waters) remediation services to solve specific heavy metals and organic chemicals contamination problems. They use techniques that are specific to the problem being addressed, the physical, chemical, and biological characteristics of the contaminated earth materials, the area covered by contaminated soils and aquifers, and the volume of soil or aquifer water to be subject to remediation. Many guarantee to bring contaminant contents to natural levels, or to below legal maximum permissible concentrations where these are higher than natural ones.

The limitations on successful reclamation projects to clean up contaminated environments are both economic and political. The first is defined primarily by how much remediation will cost versus investment returns in an acceptable span of time. In addition, remediation decisions have to consider social and political benefits received. The political limitation to the success of a remediation program is defined by legal restrictions and their enforcement. Without legislated controls or enforcement of laws on toxic emissions to the atmosphere from sources cited in Chapter 4, remediation attempts can aspire only to maintain a status quo. The same applies to effluent discharges of pollutants to streams and rivers and ultimately other water bodies as well as to agricultural chemicals mass/volume uses that create run off that can disrupt ecosystems down flow.

Environmentally sound and friendly legislation with strong “enforcement teeth” in it is fiercely opposed by many business interests seeking to protect profits. Some show little regard for the environment and economic, social, and political impacts on consumers. Business interests employ lobbyists to influence votes by legislators. Lobbyists are often ex-legislators who have been voted out of office but who have ready access to former colleagues. The influence is often economic such as of contributions to re-election campaigns, or other benefits. In this way, votes can be “sold” by some politicians to “buyer” interests, notwithstanding rules set forth by ethics committees. In responsible democratic societies, the voting public can turn politicians out of office if their voting records and funding sources strongly suggest that lobbyists influenced their votes, possibly because of the funding or other tangible offerings. In their place they can vote in those politicians who will cast votes that reflect the desires of their constituents whether they are pro or con environmental friendly legislation.

The ultimate goal of all people and governmental socio-politico-economic projects they and the elected or duly appointed representatives support is clear. Its aim is to provide the basic essentials of a good life to populations from whom these have been absent. Clean air, safe water, and uncontaminated fertile soils are three keys essential to achieve this end. They are complemented by good health care, education, and employment opportunities. These attributes in a society are attractive to investors seeking to locate economic development projects. This bodes well for today’s populations and future generations of expanding populations in many parts of the world.

# Epilogue

Successful development planning is dependent on human resources, natural resources, and an environment that ensures the health and cleanliness of the ecosystems that sustain both.

The Earth's surface and near-surface environments and their vital ecosystems now support 6.6+ billion humans and 10s of billions of co-existing forms of life. These ecosystems are under physical, chemical and biological attacks that threaten their continued vitality. These are long-long-term low probability ($<0.01\%$) events, long-term and mid-term high probability ($>90\%$) risks, and short-term and existing (100% probability) threats.

An asteroid impact such as that which likely caused the extinction of dinosaurs $\sim$65.9 million years ago is an example of an extremely low probability event. Global warming in modern times is a high probability event that was initiated perhaps 200 years ago but which has accelerated during the last half century. Scientists have recorded its effects from melting ice caps and glaciers to migration of faunal and floral species caused by shifting climatic zones. If the peoples of the world do not work together to slow the rate of warming and ultimately stop it, the warming and consequent climate shifting will surely reach a tipping point and exceed the planet's life form carrying capacity. This will bring global disaster especially in light of expanding populations and the moral obligation to service their basic needs (e.g., on the African continent). Pollution of the atmosphere, waters, and soils with inorganic and organic chemical elements and compounds generated by anthropogenic activities is the short-term existing and ongoing barrier to achieve an improved quality of life for the Earth's inhabitants. This pollution is being ameliorated in a growing number of countries by legislative action and enforcement, and by increasing application of one or a combination of uncomplicated and/or sophisticated remediation programs.

Healthy populations with educated cadre and pools of human resources, with sustainable stocks of natural resources (e.g., clean water, fossil and renewable energy sources) are the foundations for successful development projects. Investment in such projects, whether residential, commercial, agricultural or forestry, manufacturing or industrial, is more likely to be made in regions with stable political, social and economic conditions. As important is the recognition by planners that successful development requires change especially with respect to adaptation to cultural norms of populations where projects will be carried out.

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