WATER CONSERVATION TECHNICAL BRIEFS

TB10 – Water Contamination Management in Agriculture

SAI Platform

July 2010

WATER CONSERVATION

TECHNICAL BRIEFS

TB10 – Water Contamination Management in Agriculture

Continuing population growth, urbanisation, rapid industralisation, and intensifying food production are all putting pressure on water resources. This technical brief attempts to give an overview of surface and groundwater contamination due to agriculture activity, particularly looking at the main pollutants released through agriculture. Following an overview of the different pollutants, this brief discusses sediments, nutrients, pesticides, over-irrigation practices, salination, livestock pollution and its movement to surface and groundwater.

The structure of the technical brief is as follows: Section 1 and 2 set out the background to the contamination of water sources due to agriculture activities and its causes. Section 3 assesses the differences between surface and groundwater contamination. Section 4 presents an overview of the different contaminants caused by agriculture and their impacts on surface and groundwater. Section 5 explores contamination by sediments, nitrogen, phosphorus, pesticides, excessive irrigation, salinity and animal waste and their movement to water courses. Section 6 outlines a case study of sugarcane production in Brazil. Finally, Section 7 recommends some further reading - documents and websites.

Contents

SECTION 1: CONTAMINATION OF WATER FROM AGRICULTURE

Contamination of water by agricultural land us causes major pressure on the quality of surface and groundwater. Agricultural processes such as tillage, ploughing of the land, use of pesticides, fertilisers, over-irrigation, spreading of slurries and manure can cause the contamination of water. Drainage can rapidly carry leachates such as nitrogen to surface water. Accidental spills from milk dairies and/or pesticides can also affect the quality of water. For example, in northern climates, the runoff from frozen ground is a major problem, especially where manure is spread during the winter.

Nutrients, particularly nitrogen and phosphorus from fertilisers promote algae growth and premature aging of lakes, streams, and estuaries (a process called eutrophication). Suspended sediment impairs aquatic life by reducing sunlight, damaging spawning grounds, and may be toxic to aquatic organisms. Pesticide residues that reach surface water systems may also affect the health of freshwater and marine organisms.

SECTION 2: SOURCES OF WATER CONTAMINATION

Sources of water contamination can be classified as point and nonpoint water sources.

- **Point source** pollution originates from a single, identifiable source.[1] Point sources of contamination from agriculture may include animal feeding operations, animal waste treatment lagoons, or storage, handling, mixing, and cleaning areas for pesticides, fertilisers, milk spillage, silage liquor, cattle and pig slurry.[2]

- **Nonpoint source pollution** (NPSP) or diffuse water pollution is described[3] as contamination arising from land use activities that is dispersed across a catchment or sub-catchment and does not arise as a process effluent, municipal sewage effluent or an effluent discharge from farm buildings.
  The main characteristics of nonpoint sources are that they respond to hydrological conditions, and they are not easily measured or controlled directly (and therefore are difficult to regulate). As opposed to the control of point source contamination, the measures to manage the hazards from diffuse agricultural sources are usually more complicated. Conventionally, in most countries all types of agricultural practices including animal feeding operations are treated as a nonpoint sources.[4]
  For example, diffuse pollution from agriculture provides about 40% of the nitrogen load in the Danube River and 50% in the Baltic Sea.

SECTION 3: Surface and groundwater pollution contamination

Water quality problems, caused by point or nonpoint source pollution, can affect surface and groundwater quality. Primarily the contamination arises through the leaching of nutrients, pesticides and animal waste, and soil runoff and sedimentation.

The intensification of agricultural activities has led to the contamination of freshwater. Groundwater resources are vulnerable to contamination. When animal waste, fertilisers, and pesticides are applied to cropland, some residues remain in the soil after plant uptake and may leach into subsurface waters, or the residues may move to surface water by dissolving in runoff or adsorbing into sediment. In addition, spray drifts during application may carry pesticides to surface waters.

Figure 1: Main pathways by which agricultural pollutants can reach surface and groundwater. Source: http://www.ars.usda.gov/is/np/Phos&Eutro2/agphoseutro2ed.pdf

Contamination entering a groundwater system poses a potential threat to the viability of the aquifer as a groundwater resource.
Thus methods for assessing the vulnerability of an aquifer to contamination and calculating the risk of this pollution to the water supply are important components in aquifer protection and groundwater resource management. Once contamination enters the pore/fissure/fracture system of an aquifer the effects of variable pore size, differential flow velocities and spatial heterogeneity mean that remediation of the aquifer is often a difficult, time consuming and costly process.

Two principal features of groundwater bodies distinguish them from surface water bodies[5]:

- Firstly, the relatively slow movement of water through the ground means that residence times of pollutants in groundwater are generally orders of magnitude longer than in surface waters. Once polluted, a groundwater body could remain so for decades, or even for hundreds of years, because the natural processes of through-flushing are so slow. If groundwater does get polluted it can be difficult to clean up.[6]
- Secondly, there is a considerable degree of physico-chemical and chemical interdependence between the water and the containing material.

The extent to which various agricultural practices pose a risk of transfer of pollutants to water depends on several factors, primarily the weather, in particular the amount and timing of rainfall. The underlying geology, in particular the soil and sub soil type are also important, as is the connectivity of the land to a water body. The slope of the land, the presence of direct connections such as water channels and fissures and its proximity to a water body all influence the risk of diffuse pollution occurring.[7]

SECTION 4: OVERVIEW OF AGRICULTURAL IMPACTS ON WATER QUALITY

Fertilisers, manure spreading, pesticides, irrigation practices, agrochemicals and toxic leachates can contribute to the degradation of water quality if not managed adequately. The table below depicts an overview of the main agricultural activities that impact on surface and groundwater.

Table 1: Agricultural activities and its impacts on surface and groundwater quality[8]

Agricultural activity	Impacts	
	Surface water	Groundwater
Sediments	Turbidity; Sediments carry phosphorus and pesticides adsorbed into sediment particles; siltation of river beds and loss of habitats and spawning grounds.	Not an issue in most locations.
Nutrients	Runoff of nutrients, especially phosphorus, leading to eutrophication causing unwelcome taste and odour in public water supply, excess algae growth leading to deoxygenating water and fish kills.	Leaching of nitrate to groundwater; excessive levels are a threat to public health.
Pesticides	Runoff of pesticides leads to contamination	Some pesticides may leach into

	of surface water; dysfunction of the ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impacts from eating contaminated fish.	groundwater causing human health problems from contaminated wells.
Irrigation	Runoff of salts leading to salinisation of surface waters; runoff of fertilisers and pesticides to surface waters with ecological damage, bioaccumulation in edible fish species, etc. High levels of trace elements.[a]	Enrichment of groundwater with salts and nutrients (especially nitrate).

SECTION 5: CONTAMINANTS AND MOVEMENT IN SURFACE AND GROUNDWATER

A. Sediments

A prevalent source of agricultural water contamination is soil erosion . Sedimentation occurs by detachment (erosion), transport, and deposition of soil by the action of moving water or wind. The movement of soil by water or wind occurs in three stages:

- Erosion: particles or aggregates are eroded or detached from the soil or rock surface
- Transport: detached particles or aggregates are transported by moving water
- Deposition: soil transported is deposited as sediment into nearby lakes or stream

Water erosion rates are affected by the rainfall energy, soil properties, slope, slope length, vegetative and residue cover, and land management practices. Rainfall impacts provide the energy that causes initial detachment of soil particles. Soil properties like particle size distribution, texture, and composition influence the susceptibility of soil particles to be moved by flowing water.[9]

Movement to surface and groundwater

[a] E.g. selenium.

Sediments have detrimental effects on surface water. An excess of sediment can increase the turbidity of the water, therefore decreasing the penetration of light In addition, other pollutants like fertilisers, pesticides, and heavy metals can get attached to the soil particles and be transported into the water bodies, causing algal blooms and lead to depleted oxygen levels, which pose a risk to aquatic life.

In general terms, sediment movement into groundwater is generally not an issue in most locations. However, there are places, such as areas of karst[b] topography, where sediment and sediment-borne pollutants can enter groundwater through direct links to the surface. [c]

B. Nutrients

Major sources of nutrients include commercial fertilisers, manures, and other organic materials such as crop residues, irrigation water[d] and soil reserves. Nutrients pose a serious threat to water quality due to enrichment, especially of phosphorus and nitrogen. This can lead to enhanced plant growth and depleted oxygen levels.

Fertilisers such as - potash, nitrogen (N), and phosphorus (P) are highly soluble and may reach the water table if applied in excessive amounts.[e] When applied in excessive amounts on the farm or improperly stored they may lead to unacceptable or even toxic concentrations in local, regional, and even national groundwater systems.

In most of Europe, agriculture is a dominating anthropogenic source of pollution with N and P.[f] The estimates of agricultural diffuse loss range from about 0 to 30 kg/ha for nitrogen and about 0 to 1 kg/ha for phosphorus.[10] The highest loss is found in agriculturally intensive regions in the north-western part of Europe, where the average fertiliser consumption per country is commonly about 40–70 kg/ha of nitrogen and 8–13 kg/ha of phosphorus.[11]

---

[b] An area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.

[c] Vegetative cover and residue may protect the soil surface from rainfall impact or the force of moving water

[d] Specially from irrigation with wastewater. See Technical Brief on Wastewater irrigation fro more information.

[e] N and P, are the nutrients of greatest concern for water quality.

[f] Nitrogen contamination may arise from a variety of sources: municipal sewage, animal manure, atmospheric deposition, biological N fixation, soil organic N, and/or nitrogen fertilisers.

Movement to Surface and Groundwater

The movement of applied nutrients is primarily driven by leaching and the movement of water and eroded soil, but the specific transport pathways are largely determined by the characteristics of the nutrient source, soil characteristics, and related environmental conditions (e.g., soil temperature). The manures spreading on frozen ground can result in high levels of contamination of receiving waters by pathogens, metals, phosphorus and nitrogen leading to eutrophication and potential contamination.[12]

Leaching of soluble nutrients to groundwater can occur as chemicals are carried with precipitation or irrigation water moving downward past the root zone to the groundwater table.[13] Nutrients may also reach groundwater by direct routes such as abandoned and irrigation wells, pores and/or fissures. Such pathways are especially significant because transport through soil is bypassed, eliminating any opportunity for adsorption or uptake.

An over-application of irrigation water can enhance leaching of nutrients to groundwater by carrying dissolved nutrients quickly below the root zone. Water left in ponds in surface depressions due to large runoff events can be a significant source of nutrient transport to groundwater.

a. Nitrogen

N compounds and reduced forms of N (ammonia gas or dissolved ammonium compounds) are generated mainly from agricultural activities and livestock as shown in the figure 2 below.[14] These nitrogen compounds may dissolve in rain or soil water to form acids, or may be taken up as nutrients by plants and soil microbes in upland catchments, and then subsequently released in acid form associated with nitrate leaching at a later date.

Since nitrate is used in all fertilisers, contamination of water resources is relatively common.[15] Nitrate leaching contributes to acidification of upland waters, with damage to aquatic ecosystems including plants, invertebrates and fish. However it has recently been suggested that nitrate leaching may also be associated with nutrient enrichment of upland waters that contain biological communities adapted to very low nutrient levels.[16]

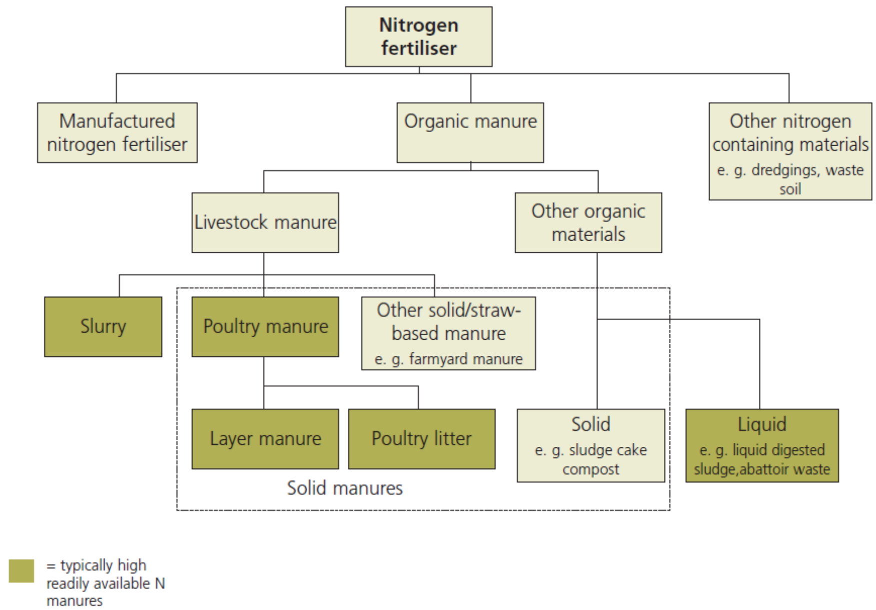


Figure 2: Nitrate fertilisers. Source: Guidance for Farmers in Nitrate Vulnerable Zones. http://www.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/help-for-farmers.htm

Nitrogen can be transported to surface waters through runoff, erosion, and subsurface flow as explained below. The nitrogen cycle is depicted in figure 3 below.

- Some N in the form of ammonium can be lost by erosion along with organic N attached to soil particles.[g]
- Soluble N can be carried in surface runoff, but most soluble nitrate is lost via leaching through the soil. The potential level of leaching is reliant on soil type, crop, climate, tillage practices, fertiliser management, and irrigation and drainage management.
- Leached nitrate may move into surface waters through shallow subsurface flow or be transported to deeper groundwater.

[g] Nitrogen can volatilize directly from fertilisers such as urea and ammonia and from manure; N lost to the atmosphere in this way may be washed from the atmosphere by rain a great distance away. Nitrogen can also be lost to the atmosphere as harmless nitrogen gas through denitrification. Other factors influencing nutrient movement include topography, precipitation patterns, and, of course, land use and management.

- Up to one third of the nitrogen entering soils on intensive farms may end up leaching down through the soil into groundwater.[17] Nitrate is normally the nutrient most susceptible to leaching to groundwater. Readily soluble nitrate moves easily in the liquid phase. This nitrogen-rich groundwater will eventually flow into and pollute drains, streams, lakes and coastal water.

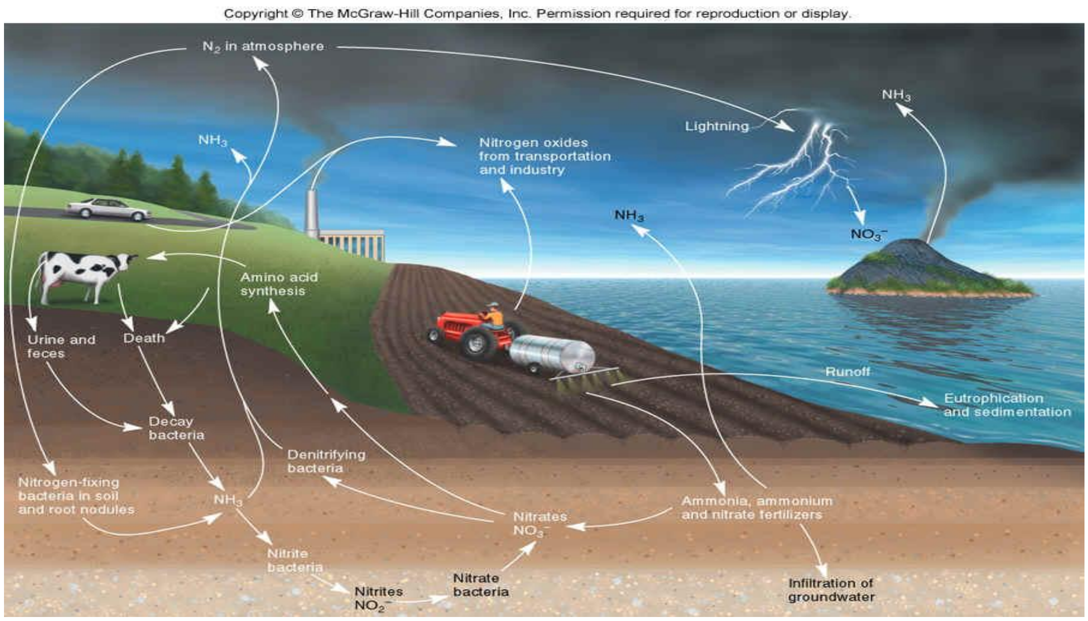


Figure 3: Nitrogen cycle and routes to water courses. Source: http://faculty.southwest.tn.edu/rburkett/ES%20-%20%20understanding_the_environment.htm

Data from UNEP suggests that European rivers have the highest nitrate loads transported to the marine environment. Comparing data from the last two decades, North American and European rivers remained fairly stable, while major river basins in south-central and south-east Asia recorded higher nitrate concentrations.[18] Improvements in nitrate concentrations can be detected at

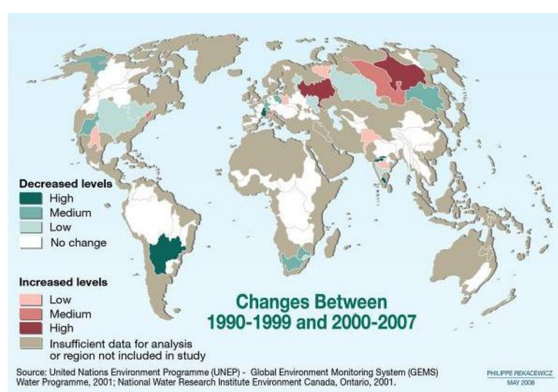


Figure 4: Nitrate changes between last 2 decades. Source: http://www.unep.org/dewa/vitalwater/article101.html

most Swiss river monitoring stations and about half of the Indian river stations, whereas nitrate has increased or remained the same in most Japanese and Russian river stations.[19] Elevated level of nitrates[h] and pesticides are recorded in most OECD agricultural areas, with quality standards being exceeded regularly where farming is particularly intensive.[20]

b. Phosphorus

Agriculture is also one of the largest contributors to P pollution, along with various point sources.[21] P compounds are usually insoluble and remain fixed in the soil structure or are washed away by surface water.

The majority of P lost from agricultural land is transported via surface runoff[22], mostly in particulate form attached to eroded soil particles. Because P is so strongly adsorbed to soil particles, the P level in the soil is a critical factor in determining loads of P delivered to surface waters. Increased residual P levels in the surface soil can lead to increased P loadings to surface water, both attached to soil particles and in dissolved form. Soluble P losses from cropland can also be significant if runoff occurs very soon after heavy addition of phosphate fertiliser.

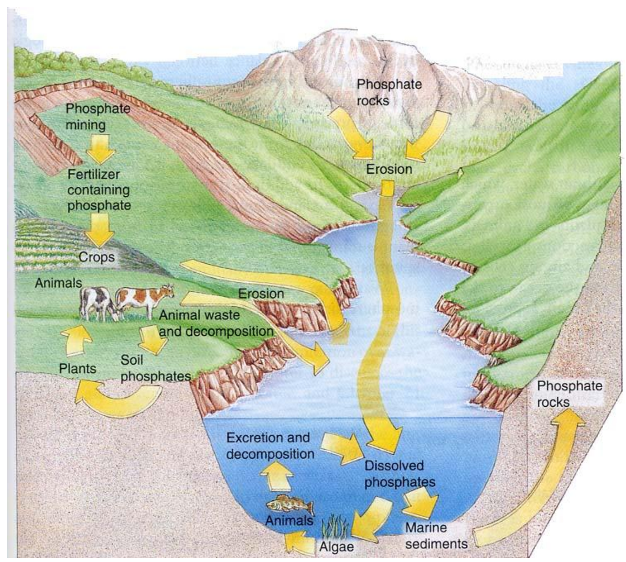


Figure 5: Phosphorus cycle and movement to water courses. Source: http://vincejtremante.tripod.com/cycles/phosphours.htm

Although generally considered a less important mechanism than surface runoff, P leaching followed by shallow lateral subsurface flow can contribute dissolved P to surface waters under high water table conditions. This mechanism becomes more

[h] The EU quality standard for groundwater is 50 mg/l. Source: Directive 2006/118/EC of the European Parliament and of the Council http://europa.eu/

important in soils with large accumulations of P that saturates surface soil absorption capacity leading to downward movement of P.

Leaching of phosphorus to groundwater is generally not a significant problem. However, organic soils and sandy soils, which lack the iron and aluminium oxides important for P adsorption, are exceptions.

C. Pesticides[i]

Pesticides are mainly organic compounds and can be subdivided into ionic pesticides and non-ionic pesticides. Due to their inclination to take on positive or negative charges in an aqueous environment, ionic pesticides are usually far more soluble than non-ionic pesticides. Nevertheless, pesticides in solution may be fixed in the soil or unsaturated zone by soil organisms and by adsorption to organic matter (peat) or clays.
Nowadays, the use of many chlorinated pesticides[j] has been restricted. The most commonly used pesticides today include organophosphorus compounds (e.g., chlorpyrifos, diazinon and malathion) and carbamates (e.g., aldicarb, carbaryl, carbofuran and oxamyl)[23], both of which are relatively soluble and biodegradable.[24] In Europe, despite greater awareness of the harm pesticides cause to the environment and human health, dependence on pesticides has not diminished.[25]

Movement to Surface and Groundwater

Pesticides may enter surface water or groundwater primarily as runoff following application to crops, atmospheric deposition, though inappropriate disposal or accidental release. The potential of a pesticide to contaminate drinking water is determined by its solubility and biodegradability; the method of application; and environmental factors such as soil, weather, season and proximity to water resources.[26]

---

[i] For more information on Pesticides and Integrated Pest Management see Technical Brief on IPM: A guide to protect water quality.

[j] The first organic pesticides were chlorinated hydrocarbons such as DDT, aldrin, dieldrin, chlordane, endrin, heptachlor, lindane and pentachlorophenol. These compounds are relatively insoluble, and tend to concentrate on soil surfaces instead of dissolving in water. However, they are resistant to biodegradation and can accumulate in food supplies, leading to toxic concentrations in some predator species. Accordingly, use of many of these chlorinated pesticides has been restricted over the last several decades.

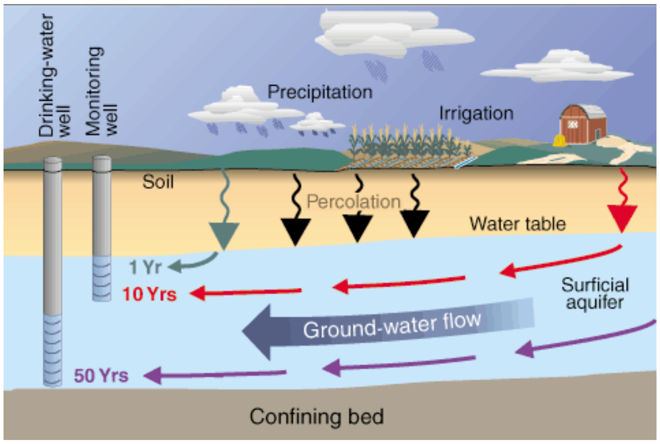


Figure 6: Pesticides in ground water http://ga.water.usgs.gov/edu/pesticidesgw.html

Losses of pesticides to runoff generally range from <1 to 5% of applied amounts, depending on various factors. Losses are usually greatest in the 1 to 2 weeks after application, and are highly dependent on storm events. Often, pesticide residues are only detectable in the first storm event after application.

Most pesticide contamination of streams, lakes, and estuaries occurs as a result of runoff from agricultural and urban areas. Runoff carries with it a mix of suspended soil particles and any pesticides which were either attached to the particles or dissolved in surface moisture just before runoff began.

Pesticides can enter surface water from the atmosphere in the form of drift or rainfall. Drift into surface waters can be serious locally if the pesticide is highly toxic to aquatic organisms, as in the case of many insecticides. Rain and fog have been shown to contain pesticide residues, particularly during the spring planting season. However, neither drift nor rains are major contributors to surface water contamination when compared to runoff.

A more significant problem is pesticide contamination of groundwater; several of the most widely-used pesticides (e.g. atrazine, simazine, aldicarb) have the potential to leach though soils under normal agriculture use.[27] Movement of pesticides into groundwater can occur through leaching after normal applications or by more direct pathways not related to normal uses (i.e. spills and direct contamination).Full knowledge of the physico-chemical and biological characteristics of the compounds involved and the local hydrogeology is essential to assess the risk of groundwater contamination by pesticides.

In addition, pesticides can be moved downward toward groundwater as rain or irrigation water percolates through the soil. Such a leaching process is controlled by the properties of the pesticide, the properties of the soil, the weather, and hydrologic loading.

Pesticide properties: There are hundreds of pesticides and each one has a unique set of properties which determine if it is more or less likely to contaminate groundwater. The most important are[28]:

- ***Persistence:*** measured in amount of time required for 50% to be degraded (half-life). The more persistent a chemical, the more likely it will find its way into groundwater.
- ***Adsorption:*** measured by how much of the chemical binds to soil, when shaken in water, as opposed to that which dissolves in water. The greater the adsorption ability of a pesticide, the less likely it will leach through the soil.
- ***Application Rate and Method:*** measured in amount of active ingredient applied per acre. Pesticides requiring higher application rates may have an increased chance of leaching into groundwater. Pesticides applied to growing crops are less likely to have the opportunity to leach than those applied to the soil.
- ***Solubility:*** The solubility of a compound in water, such as an insecticide, is a measure of how easily it goes into solution with water. When these compounds go into solution they are capable of leaching or running off into bodies of water. The solubility of pesticides, are usually given in parts per million (ppm) or in some cases as milligrams per litre (mg/l). This is the number of milligrams that will dissolve in one litre of water at saturation.
- ***Soil Properties***: Pesticides often are applied to, or wash into, soils, where they may be adsorbed, degraded, or leached into shallow groundwater. The properties of the soil that most influence these processes are discussed below. In addition to the soil properties listed here, any management practice (e.g., tillage) that impacts on the

Bioremediation using enzymes

CSIRO has developed an enzyme-based product that can rapidly degrade pesticide residues. This bioremediation solution reduced organophosphate levels in cotton irrigation wastewater by 90%. The naturally occurring soil bacteria - fed on chemicals - reduce them to non-toxic compounds by degradation of the chemicals by extracted enzyme action. Landguard ZIM-A enzyme product for degradation of benzimidazole fungicides is used in Australia and removes organophosphates from wastewater contaminated with sheep dip or other pesticides. For more information see http://www.csiro.au/files/files/pn0v.pdf properties or structure of soil has the potential to affect the movement of pesticides to groundwater.

- ***Organic Matter:*** measured as a fraction of the soil by weight. Most pesticides bind tightly to organic matter in soil so higher organic matter contents reduce the risk of leaching.
- ***Clay:*** measured as a fraction of the soil by weight. Clay can bind many pesticides and it tends to reduce or slow the movement of percolating water. These two effects combined result in lower leaching risk with increasing clay content.
- ***pH:*** measured on a scale of 0-14, with most soils falling in the 5-8 range. Generally, lower pH values will reduce leaching of pesticides and increase their rate of degradation.
- ***Depth to Groundwater:*** not exactly a soil property but often closely related. The farther pesticide residues have to leach to reach groundwater, the greater the chance of biological or chemical degradation. Although degradation rates decline rapidly below the root zone, most pesticides will degrade slowly as they move toward the groundwater table.
- ***Weather***: Warmer or cooler temperatures will speed up or slow down degradation, respectively.
- ***Hydrologic Loading:*** The addition of water to areas of pesticide application is key to the transport of pesticides toward groundwater. Precipitation or irrigation in excess of evapotranspiration rates and soil water holding capacity can move pesticides deeper into the soil profile and increase the likelihood of pesticides leaching into groundwater aquifers.
- ***Spills:*** Although some soils are very good at adsorbing and degrading applied pesticides, high concentrations of pesticides which result from spills overwhelm all these processes. Highly contaminated soils can be a long-term source of contamination because percolating water will continue to carry the pesticide into the groundwater. Although the movement of pesticide residue is through leaching, a spill is still considered a point source.
- ***Direct Contamination:*** Groundwater can be contaminated directly in many ways. Some of the most serious include surface water movement into wells, or drainage into limestone channels.

D. Excessive irrigation & salinity

Excessive and not-efficient[k] irrigation can affect water quality by causing erosion, transporting nutrients, pesticides, and heavy metals, or decreasing the amount of water that flows naturally in streams and rivers. It can also cause a build-up of selenium, a toxic metal that can harm waterfowl reproduction.[29]

Salinity[l] is an indication of the concentration of dissolved salts in a body of water. The level of salinity in aquatic systems is important to aquatic plants as species can survive only within certain salinity ranges. [30] Salinity is a significant and widespread form of freshwater pollution, particularly in arid, semi-arid and some coastal regions. The primary cause of salinization is a combination of poor drainage and high evaporation rates which concentrate salts on irrigated land. Rising salinity can alter riparian and emergent vegetation, affect the characteristics of natural wetlands and marshes, decrease habitat for some aquatic species, and reduce agricultural productivity and crop yields.[31] Waterlogged soil, which aggravates the problem of salinity, is usually caused by overwatering and a lack of proper drainage systems. Runoff from agricultural areas fertilized with manure and chemicals pollutes watercourses and groundwater by increasing levels of nutrients.[32]

Irrigation return flows are responsible for the deterioration of groundwater quality in a large number of countries, in particular in semiarid and arid regions. When a crop is irrigated, approximately one half to two thirds of the applied irrigation water is absorbed by the soil and by the plants or lost by evaporation. The salts dissolved in water, however, remain behind and tend to accumulate in the soil. Good irrigation practice has to take into account these salts by using extra water for leaching so that it can carry the salts away. The excess water percolates down to groundwater and this return flow carries with it an increased concentration of salts. Gradually, by repeating this process, the dissolved solids content of the groundwater increases. Besides the salts, the return flow also transports fertilisers, pesticides, and animal wastes. Cases concerning the degradation of groundwater quality and contamination accelerated by irrigation return flows have been reported from many countries including the United States, India, and China.[33]

---

[k] See Technical brief on Irrigation Scheduling for more detail on efficiency.

[l] The ions responsible for salinity include the major cations (calcium (Ca^{2+}); magnesium (Mg^{2+}) ; sodium (Na^{+}) ; and potassium (K^{+}) and the major anions (carbonates ($CO3^{2-}$ and $HCO3^{2-}$) sulphate ($SO4^{2-}$) and chloride (Cl^{-}).

E. Animal feeding operations

Farming animals can become a major source of animal waste. Runoff from poorly managed farms can carry pathogen - bacteria and viruses, nutrients, and oxygen-demanding organics and solids - contaminating water. Groundwater can also be contaminated by waste seepage.

The pollutant load carried in runoff to surface waters from animal farms is affected by several additional factors such as the type of pollutants *available* for transport in the farm; the rate and path of the runoff through the farm and the *filtering* practices before exiting from the farm.

SECTION 6: CASE STUDIES

Water sustainability issues due to herbicide use in the production of sugarcane in Brazil[34]

Brazil is one of the world leaders in the production of sugar cane. Sugar cane monoculture requires a large amount of herbicides applied as a weed control agent to yields. Sugarcane is mainly produced in the state of Sao Paulo (51%) region.[35]

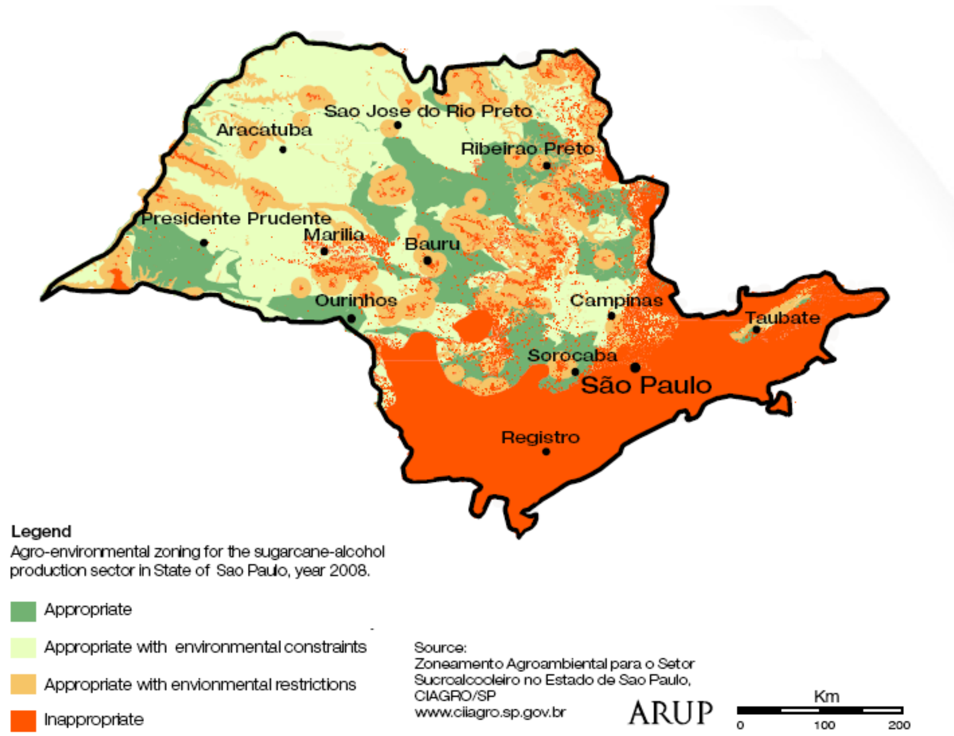
The production of sugarcane results in decreases of water infiltration into the soil due to soil compaction. Intensive sugarcane production is often associated with water quality degradation due to the use of agrochemicals. The aspects are explored in more detail in the following paragraphs.

Herbicides transported by water runoff from sugarcane plantations are thought to have a negative impact on surface and groundwater. The common and extensive use of pesticides in Brazil is a major issue of concern among environmentalists and researchers in the country, which is the fourth largest consumer of pesticides in the world.[36]

TB 10 - Water Contamination Management

Despite Brazilian legislation being less strict than international standards (e.g. Atrazine is still in use particularly in corn and sugarcane crops), many large scale sugarcane systems build on biological pest control (farms often have their own 'respective laboratories' as evidence shows that biological control can be cheaper than the application of agrochemicals) and pest resistant varieties.

Figure 7: Agro-environmnetal zoning for the sugarcane production in the state of Sao Paulo. Source UNEPFI



A modeling study in the region indicated the leaching potential of chemicals into the groundwater, but no evidence was found in samples taken. It is assumed that this is due to the rapid degradation of agrochemicals in the soil and their low mobility into groundwater reservoirs.[56]

Nevertheless, the perceived danger of the potential contamination of the Guarani Aquifer with agrochemicals has led to a 'zoning' of environmentally vulnerable areas. Within the state of Sao Paulo, as well as in other areas of the country, systems of 'agro-environmental zoning' have been introduced: they identify land appropriateness levels for sugarcane production (see Figure below).

SECTION 6: REFERENCES AND FURTHER READING

Water Quality

Clearing the Waters: A focus on Water Quality Solutions
www.unep.org/PDF/Clearing_the_Waters.pdf
This publication addresses the urgency of controlling pollution and preserving water quality around the world. Water quality impacts human health, water quantity, livelihood, economic activity, and climate change.

Water Quality for Ecosystems and Human Health.
www.gemswater.org/publications/pdfs/water_quality_human_health.pdf
Drawing on examples from around the world, this publication presents assessments of current water quality status and trends. It also provides an introduction to a diverse range of global water quality issues, including approaches to their identification, analysis and resolution.

UNICEF Handbook on Water Quality.2008
http://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf
This handbook provides an introduction to all aspects of water quality, with a particular focus on the area's most relevant to professionals working in developing countries. It covers the effects of poor water quality, quality monitoring, the protection of water supplies, methods for improving water quality, and building awareness and capacity related to water quality. Finally, the handbook provides an extensive set of links to key water quality references and resources.

Water Quality Outlook
www.gemswater.org/common/pdfs/water_quality_outlook.pdf
This report presents a snapshot of global water quality issues as they relate to achieving the internationally agreed goals on water, sanitation and biodiversity.

Control of water pollution from agriculture. FAO irrigation and drainage paper 55
www.fao.org/docrep/w2598e/w2598e00.HTM
The objective of this document is to delineate the nature and consequences of agricultural impacts on water quality.

TB 10 - Water Contamination Management

Environment Canada
www.ec.gc.ca/water/en/nature/prop/e_prop.htm
Properties of water and the hydrological cycle.

World Resources Institute
www.wri.org/
A pilot analysis of global freshwater ecosystems by C. Revenga et al, 2000.

Water quality for farm, garden and household use
http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/watq/fn041_2004.pdf
Compiled by Neil Lantzke, Development Officer and Tim Calder, Technical Officer

National Management Measures to Control Nonpoint Source Pollution from Agriculture
epa.gov/nps/agmm
This technical guidance and reference document is for use by state, local, and tribal managers in the implementation of nonpoint source pollution management programs. It contains information on effective, readily available, and economically achievable means of reducing pollution of surface and groundwater from agriculture. US based.

Agricultural Nonpoint Source Pollution Management Web Site
epa.gov/nps/agriculture.html
This web site features a collection of links to helpful documents, federal programs, partnerships and nongovernmental organizations that convey advice and assistance to farmers and ranchers for protecting water quality. US based.

Freshwater

UNEP Freshwater
http://www.unep.org/themes/freshwater/
UNEP's directory of freshwater information and data for environmental assessment.

United Nations GEMS/Water Programme
http://www.gemswater.org/
The United Nations GEMS/Water Programme provides scientifically-sound data and information on the state and trends of global inland water quality required as a basis for

the sustainable management of the world's freshwater to support global environmental assessments and decision- making processes

Groundwater

Groundwater Quality and Groundwater Pollution
http://groundwater.ucdavis.edu/Publications/Harter_FWQFS_8084.pdf
University of California. Division of Agriculture and Natural Resources

Groundwater contamination inventory
http://unesdoc.unesco.org/images/0013/001325/132503e.pdf
This guide contains detailed information regarding contamination sources, rating of groundwater contamination sources and the production of maps to assess groundwater risk contamination.

Water quality assessments. A guide to the use of biota, sediments and water in environmental monitoring. 2nd edition. 1996
www.who.int/water_sanitation_health/resourcesquality/wqa/en/
http://www.who.int/water_sanitation_health/resourcesquality/wqachapter9.pdf
This guide gives comprehensive and practical advice on designing and setting up monitoring programmes for groundwater quality.

Implications of groundwater rehabilitation on water resources protection and conservation: artificial recharge and water quality improvement in the ESCWA region.
www.escwa.un.org/information/publications/edit/upload/enr-01-12-e.pdf
United Nations Economic and Social Commission for Western Asia (UNESCWA).2001
The main objective of this study is to review the status of groundwater pollution and present the techniques for groundwater rehabilitation being applied in different parts of the world, including the Arab world and the ESCWA region.

Agricultural water pollutants

Principle, Problems, Restoration and Management
http://www.environmentalstudies.au.dk/publica/f2004agriculture.pdf

Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution
http://www.ers.usda.gov/
United States Department of Agriculture

TB 10 - Water Contamination Management

Economic Research Service Agriculture, Information Bulletin, Number 716, May 1995

Pesticide and herbicide contamination

http://www.usgs.gov/science/science.php?term=879

Pollution resulting from chemical agents applied to crops, rights of way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents or other pests (pesticides) or kill undesirable plants (herbicides).

Phosphorus use in Agriculture

http://soils.usda.gov/sqi/publications/files/prole.pdf

PAN - Pesticide Action Network Pesticides Database

http://www.pesticideinfo.org/

Contains info on insecticides, herbicides and other pesticides.

Pesticide Fact sheets for framers

http://www.cals.ncsu.edu/wq/wqp/wqpollutants/pesticides/pestfactsheets.html

Animal Feeding Operations (AFO) Web Sites

epa.gov/npdes/afovirtualcenter and epa.gov/npdes/afo (regulations)

AFO Virtual Information Centre is a tool to facilitate quick access to livestock agricultural information in the US

OECD Pesticide programme

http://www.oecd.org/env/pesticides

This programme helps OECD governments to cooperate in assessing and reducing the risks of agricultural pesticides.

---

[1] http://www.waterencyclopedia.com/Po-Re/Pollution-Sources-Point-and-Nonpoint.html#ixzz0tZs1mvVK

[2] http://www.waterencyclopedia.com/Po-Re/Pollution-Sources-Point-and-Nonpoint.html#ixzz0tZsGndPa

[3] Defra www.defra.gov.uk

[4] http://www.fao.org/docrep/w2598e/w2598e04.htm#agricultural impacts on water quality

[5] World Health Organization (WHO). 1996

Water quality assessments. A guide to the use of biota, sediments and water in environmental monitoring. 2nd edition.

http://www.who.int/water_sanitation_health/resourcesquality/wqachapter9.pdf

[6] Source: Taken form lectures notes from MSc Environmental Technology. Imperial College.

[7] Agricultural Phosphorus and Eutrophication, 2nd Edition,US Agriculture Agricultural Research Service ARS–149 September 2003
http://www.ars.usda.gov/is/np/Phos&Eutro2/agphoseutro2ed.pdf
[8] Modified from FAO 1996. Available at:ftp://ftp.fao.org/agl/aglw/docs/idp55e.pdf
[9] http://epa.gov/nps/agmm/chap4c.pdf
[10] Source apportionment of nitrogen and phosphorus inputs into the aquatic environment. EEA Report No 7/2005. http://www.eea.europa.eu/publications/eea_report_2005_7
[11] http://faostat.fao.org/site/575/default.aspx#ancor
[12] Control of water pollution from agriculture. FAO irrigation and drainage paper 55
Food and Agriculture Organization (FAO).1996 ftp://ftp.fao.org/agl/aglw/docs/idp55e.pdf
[13] http://www.epa.gov/nps/agmm/chap4a.pdf
[14]
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15585
[15] UNICEF Handbook on Water Quality.2008
http://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf
http://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf
[16]http://www.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/help-for-farmers.htm
[17]http://www.ew.govt.nz/environmental-information/Land-and-soil/Managing-Land-and-Soil/Managing-farm-nutrients/Managing-farm-nitrogen/
[18] http://www.unep.org/dewa/vitalwater/article101.html
[19] Water Quality Outlook. United Nations Environment Programme (UNEP), GEMS/Water, World Water Assessment Programme (WWAP). 2007
www.gemswater.org/common/pdfs/water_quality_outlook.pdf
[20] OECD environmental outlook to 2030, Organisation for Economic Co-operation and Development, 2008
[21] Source apportionment of nitrogen and phosphorus inputs into the aquatic environment EEA Report No 7/2005. http://www.eea.europa.eu/publications/eea_report_2005_7
[22] http://www.wri.org/project/water-quality-trading
[23] For more information on Pesticides see PAN - Pesticide Action Network Pesticides Database
http://www.pesticideinfo.org/
[24] http://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf
[25] http://www.eea.europa.eu/publications/signals-2000/page007.html
[26] http://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf
[27] OECD environmental outlook to 2030, Organisation for Economic Co-operation and Development, 2008
[28] **http://www.epa.gov/nps/agmm/chap4b.pdf**
[29] Aquatic selenium pollution is a global environmental safety issue
Ecotoxicology and Environmental Safety, Volume 59, Issue 1, September 2004, Pages 44-56
A. Dennis Lemly
[30] UNEP, European Regional Centre for Ecohydrology (ERC), (UNESCO). 2008
Water Quality for Ecosystems and Human Health. 2nd edition.
www.gemswater.org/publications/pdfs/water_quality_human_health.pdf
[31] UNEP 2010, Clearing the Waters: A focus on Water Quality Solutions,
www.unep.org/PDF/Clearing_the_Waters.pdf
http://www.unep.org/PDF/Clearing_the_Waters.pdf
[32] Source: UNEP. 1991. Freshwater pollution. UNEP/ GEMS Environmental Library. No. 6. Nairobi.

[33] http://www.epa.gov/nps/agmm/chap4f.pdf
[34] UNEP FI Chief liquidity series. Agribusiness http://www.unepfi.org/fileadmin/documents/chief_liquidity1_01.pdf
[35] http://www.agencia.cnptia.embrapa.br/Repositorio/Cana_irrigada_Alagoas_000fizv7ena02wyiv802hvm3jwhx2ra4.pdf
[36] http://www.worldwatercongress2008.org/resource/authors/abs204_article.pdf