THE NEXT STEP - INCORPORATING DIFFUSE POLLUTION ABATEMENT INTO WATERSHED MANAGEMENT

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INTRODUCTION

More than fifty years ago Aldo Leopold, Professor at the University of Wisconsin and a pioneer of land/watershed conservation, wrote a paradigm for watershed protection and conservation (Leopold, 2001):

> *A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends to do otherwise.*

This ethical standard in a modified form was made a key rule of the US Clean Water Act that has a goal of *restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters.* The Act also defined *pollution* as anything that downgrades the integrity of the water body. Such downgrade can be caused by the discharge of pollutants from various (point and diffuse) sources, by habitat degradation due to a change of hydrology, invasion of foreign species and other actions by humans. Leopold also extended the rule of environmental ethics as:

> *The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land.*

Thus, the notion of land extends to the general ecological terrestrial system. This system includes both human and nonhuman biotic system - ecology. This is important to diffuse pollution abatement because it means that land and water are intertwined in the general ecological system and both must be protected, preserved and, if damaged, restored to their best use. Leopold, however, realized that

"*ethic of course cannot prevent the alteration, management, and use of these 'resources' but it does affirm their right to continued existence, and, at least in spots, their continued existence in a natural state.*"

Diffuse pollution, the most pervasive type of pollution, is difficult to manage and control. Diffuse pollution can be local, regional and transboundary. The Black, Adriatic or North Seas, Chesapeake Bay and the Gulf of Mexico are examples of large water bodies affected by transboundary (interstate in the US) sub-global inputs of diffuse pollution. These large water bodies have one symptom in common - they suffer from excessive inputs of nutrients from farming operations and cities located often hundreds to thousands of kilometers upstream and brought in by large tributaries, the Danube and Don Rivers for the Black Sea, the Po River for the Adriatic Sea, the Susquehanna and Potomac Rivers for the Chesapeake Bay, and the Mississippi River for the Gulf of Mexico.

The result is the same, excessive algal development in the upper zone of the water body and hypoxia in the deeper zones. The information contained in the "Harmful Algal Bloom and Hypoxia Research and Control Act of 1998" (PL 105-383) specifies 53% of the United States estuaries experience hypoxia (reduced oxygen levels) or anoxia (no oxygen) for at least a part of the year. 19,000 km^2 (7000 sq mi) area in the Gulf of Mexico of Louisiana and Texas suffers from hypoxia (Figure 1) (Rabalais et al, 2002). Similar situations occurs in Europe. Eutrophication of surface and coastal waters is one of the prime examples of a global diffuse pollution problem affecting both developed and developing countries. It has recently emerged as a major problem and the problem is worsening, following the intensification of industrial agricultural practices, the "green revolution" of the late 1960s. The increase in fertilizers use and intensive animal husbandry resulted in order of magnitude increases of nutrient inputs into surface and coastal waters. The occurrence of Gulf of Mexico hypoxia (Figure 1) is attributed primarily to the nitrogen fertilizer inputs and organic soil nitrogen mineralization far upstream in the Mississippi River watershed (Burkart and James, 1999).

In developing countries, increasing population and resulting migration is leading to megacities that have a poorly functioning or non-existent sewerage systems. Deforestation of subtropical and tropical forests is a severe diffuse pollution problem. It has root causes in population increase that drives the poor population to practicing slash and burn agriculture, sometimes subsidized by governments. Deforestation is also caused by the demand for cheap wood at a price that does not include the dame cost to the forest and the environment. Population and economic pressures in developing countries lead to intensive and unsustainable agriculture resulting in excessive soil losses.

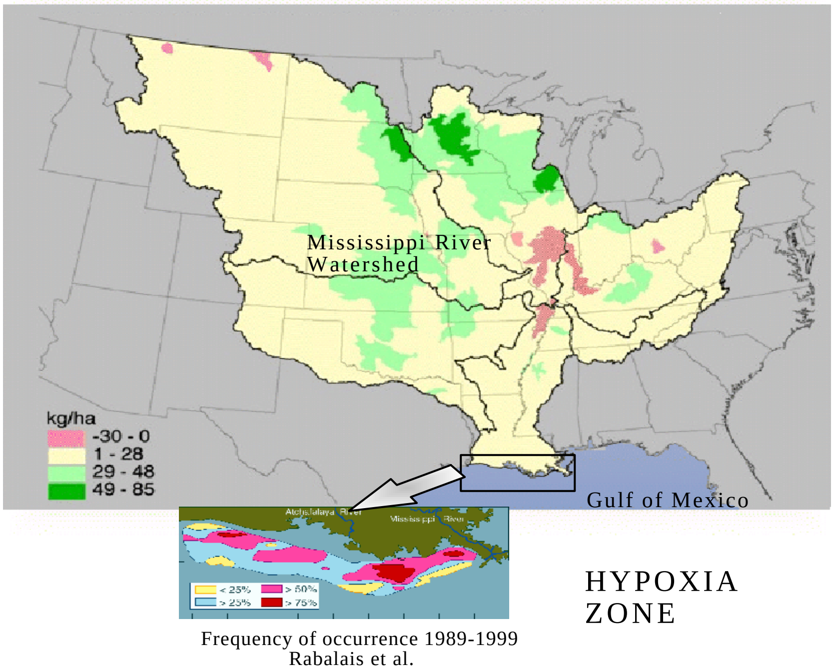

Figure 1 *1Mississippi River nitrogen excess agricultural loads (from M. Burkart and D. James, USDA ARS, Ames, IA) and hypoxic zone in the Gulf of Mexico (Rabalais et al., Louisiana Universities Marine Consortium, Chauvin, LA)*

However, before the diffuse pollution becomes a global or large scale regional problem affecting seas, it is a local problem affecting small rivers and lakes. It is manifested by a loss of use and resource value of local surface water bodies and groundwater aquifers. At the end of the last century, in the US, more than 50 % of receiving water bodies were not meeting their water quality goals. A similar situation, maybe even worse, can be found in other countries. Because past cleanup efforts focused primarily on point sources and removed pollutants dangerous to human health (raw sewage and industrial wastewater, pathogenic microorganisms), at present, both aquatic life and human health are affected. Many aquifers and drinking water reservoirs have been contaminated by nitrates and surface waters by algae and tri-halomethane precursors. Recreation opportunities on rural streams, that fifty years ago exhibited good water quality, diminished because of diffuse agricultural pollution. Also, on the local scale in and near the major urban areas, metals and other toxic substances may be a problem, especially in the sediments. Some problems have been caused by past discharges that have been either reduced or ceased but their legacy is in sediments and contaminated soils of floodplains and watersheds. Such cases include PCB contamination of sediments in many streams.

A comprehensive, turn of the century study by the US Geological Survey (1999), focused on the status of the US waters and the extent of diffuse pollution and found that

- Highest levels of nitrogen occur in streams and groundwater in agricultural areas
- Phosphorus loss from fertilizer application and livestock iamounted to less than 20 percent of phosphorus applied to land
- Pesticides - primarily herbicides - are found frequently in agricultural streams and shallow groundwater
- High concentrations of insecticides can sometimes be found in urban streams that commonly exceed the guidelines for protection of aquatic life;
- Urban streams have the highest frequencies of occurrence of DDT, chlordane, and dieldrin in fish and sediments. Complex mixtures of pesticides commonly can be found in urban streams;
- Concentrations of phosphorus are elevated in urban streams. These concentrations commonly exceed 0.1 mg/L;
- Hydrology and land use are the major factors controlling nutrient and pesticide concentrations in major rivers and concentrations in the receiving waters are proportional to the extent of urban and agricultural land use throughout the watershed. Other key factors are soils and slope.
- Groundwater (base flow in rivers originating from groundwater sources) can be a major source of nutrients and pesticides to streams.

Progress has been made in the last thirty years since in the1970s diffuse pollution was made a focus of national clean- up efforts. For example, in the Lagoon of Venice watershed, annual nutrient loads have been cut by half from 10 000 tons of nitrogen and 3 000 tons of phosphorus and the effort is continuing to bring the loads down to the safe loading capacity for the lagoon. The Master Plan for the Lagoon, accepted in the 1990s, calls for restoration of wetlands in the watershed, basin-wide implementation of best management practices, and further reduction of urban and industrial dry and wet weather sources, including collection, storage of overflows and advanced treatment or urban sewage and runoff.

Consequently, catastrophic algal blooms of *Ulva* in the 1980s have disappeared and the lagoon is now in a better shape but has not yet recovered.

MAINTAINING AND IMPROVING INTEGRITY OF THE RECEIVING WATERS IS THE GOAL OF POLLUTION CONTROL EFFORTS

The root cause of diffuse pollution is the use or misuse of land by humans. However, one has to look at diffuse pollution as being a conse-quence of a hierarchical progression of root causes of the impairment of the receiving water bodies (Figure 2). The pollution loads from the watershed are one source, habitat degradation by stream modification and change of lands surrounding the water body are another cause. These stressors create a risk or a probability that aquatic species indigenous to the water body will disappear. At the same time, the stressor may cause increased risk to public health and risk of gastrointestinal disease to those who want to use the water body for swimming and other contact recreation. The ultimate result is the degradation of the aquatic ecological system exhibited as disappearance of species of organisms that would otherwise thrive in the unimpacted water body and a loss or impairment of the beneficial uses of the water body. Furthermore, an unhealthy water body showing signs of severe biotic degradation may also be unsuitable for human uses such as contact recreation, fish and shellfish consumption or water supply.

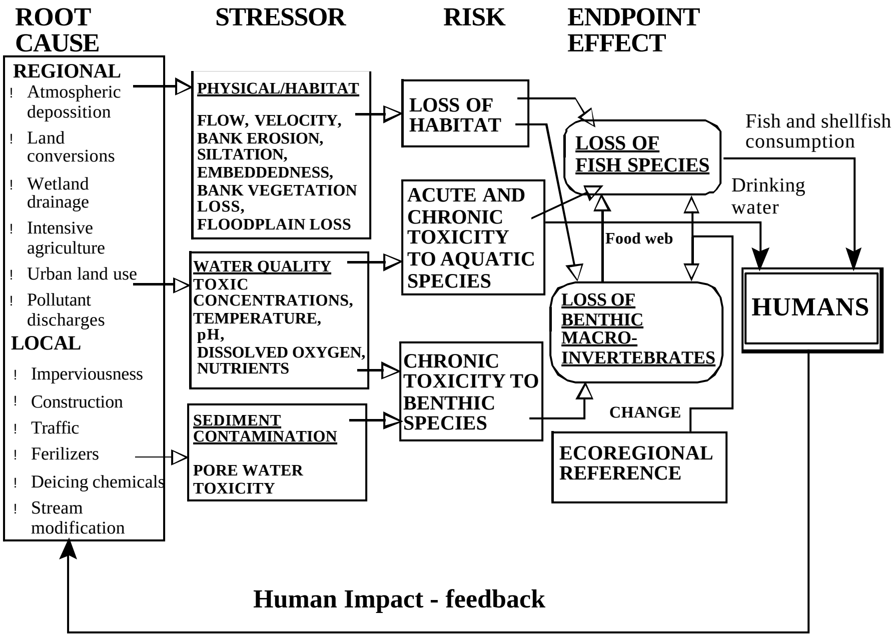

Figure 2 *Hierarchical progression of risks from the root causes linked to diffuse pollution to risks and end points - biotic integrity (from Novotny ,2003)*

At the end of the last century, a major change occurred in the understanding of what is pollution and what should be the goal of water quality and pollution control, both in the US and Europe (Box 1). The focus of the pollution control efforts in the last century was on a few chemical parameters (BOD, few toxic metals, one or two nutrients) and pollution abatement was equated with bringing concentrations of these pollutants into compliance with water quality standards. However, based on the "land/water body ethics" preambles incorporated into the Clean Water Act and Water Framework Directive, the goal of water quality management and pollution control is to restore and maintain the integrity of the receiving water body (CWA) and/or reach its ecologic potential (WFD) and also consider the important human uses (contact recreation, water supply and others). Both goals mean the same.

The good ecological status of the water body, called "integrity," has been defined as the ability of the water body ecological system to support and maintain "a balanced integrated, adaptive community of organisms having a species composition, diversity and functional organisms comparable to that of natural biota of the region" (Karr et al., 1986). The "integrity" of a water body has three dimensions: physical (habitat that can fully support aquatic life), chemical (water and sediment composition that is not injurious to aquatic life), and biological and is measured typically by various indices such as the Indices of Biotic Integrity (IBIs) used in US (Barbour et al., 1997; Novotny, 2003) or saprobien index used in Europe (Kolkwitz and Marson, 1908). In the US, both fish composition and numbers, macroinvertebrate and habitat assessment indices and criteria are used in addition to chemical assessment and criteria/standards. The macroinvertebrate index is similar to that used in Europe where it has almost a 100 years tradition. Biotic composition and integrity also reflects the chemical quality of water and sediments.

Because of the three dimensions of integrity the definition of pollution has been broaden in the CWA to include any action or discharge by humans that would impair the integrity. Thus a discharge containing contaminants that impairs the chemical integrity of a stream, or riparian zone modification that impairs the habitat dimension of integrity, are all pollution. Therefore, widespread building of small dams that fragment the riverine ecosystems and act as settling basins of contaminated sediments, riparian wetland drainage, cutting down trees lining the stream and similar wide spread human actions could be considered as a special case of diffuse pollution, according to the broader definition of "pollution" included in the Clean Water Act.

Box 1 - European and US Pollution Control Programs for Diffuse Pollution
Two parallel and very similar pollution reduction programs in the US and Europe targeting diffuse pollution and including it in the overall watershed-wide water pollution control and management are:
1.*The Total Maximum Daily Load (TMDL) program* in the United states targets polluted water bodies and mandates states to develop watershed programs for these water bodies that would address point and nonpoint sources and consider also background (natural loads) and a margin of safety. This program is included in the Clean Water Act. The goal of watershed planning under this act is to bring the total daily loads (TDL) from all sources, pollutant by pollutant, below the loading capacity (LC) of the water body. The loading capacity is derived from the water quality (ambient) standards for the water body in question. The latest modification of the TMDL include a stronger emphasis on diffuse sources, inclusions and considerations of biotic indices and criteria, consideration and protection of the habitat, and use of statistically based water quality standards that could incorporate the effects of wet weather discharges.

EU Water Framework Directive is a watershed management program that emphasizes

Protection of aquatic ecology
Protection of unique and valuable habitats
Protection of drinking water resources
Protection of bathing waters

The major characteristics of the EU watershed programs under the Water Framework Directive are:

Defining what is a good ecologic potential for the water body
Definition of a good chemical status of water and sediments
Establishing zones of protection

Nearly all European countries have adopted macroinvertebrate indices as national or regional standards

Implement watershed vulnerability classification

INCLUDING DIFFUSE POLLUTION INTO WATERSHED MANAGEMENT PLANS

The new emerging direction is to consider the waterbody integrity as the foundation and planning goal. Thus the key prerogative of successful inclusion of diffuse pollution (pollution in this context is understood based on the broad definition of pollution) into watershed management is to find and define linkage between the diffuse pollution stresses and biotic endpoints and impacts on humans. The steps, partially outlined in the report of the Committee of the National Research Council (2001) are:

1. Developing statistically based water quality standards
2. Including biotic evaluation and biotic and physical water body integrity indices and standards and evaluations
3. Considering legacy pollution in sediments residing in the water body and soils of the watershed
4. Considering uncertainty in the water quality planning and evaluations
5. Developing quantitative linkages between the stressors in the watershed, including but not limited to point and nonpoint pollution discharges. This may require a new generation of statistically based models that will be used in addition to the traditional deterministic models.
6. Developing methods for watershed vulnerability classification
7. Considering watershed management plan as a continuing process and implement adaptive management

Water Quality and Standards - Attainability and Attainment

Nations developed, in many degrees, similar sets of chemical for both effluent (emission) and ambient (water quality). Standards for biotic integrity of water bodies are now emerging and several biotic and habitat indices have been proposed. Two major issues must be considered regarding the use of water quality standards: (1) Attainability, and (2) Attainment. *Attainability of the standards* issue stems from the first section of the CWA that establishes the goals of the act for US waters *wherever attainable.* Following the legislative mandate, the responsible state government pollution control agencies adopted nationwide criteria. However, before the TMDL or WFD plans are developed to meet the standards, a basic question that to be answered is whether the standards are attainable. There are limited circumstances where standards are unattainable such as a situation where a stream draining a wetland is having low dissolved oxygen (DO) concentrations. Low DO levels in wetland streams are natural and developing a plan for point and nonpoint source controls for improving DO to meet the nationwide DO standard would be a futile exercise. In some cases, legacy contamination of sediments and/or flood plains is a problem. US water quality regulations recognize six reasons (Box 2) that would allow downgrading of the standards or even assigning a lower use of the water body. A *Use Attainability Analysis* is a scientific effort and document that analyze the water body and makes judgement whether the uses of the body and associated standards are attainable (Novotny, 2003).

Box 2 Six reasons that may allow a change of a water quality standard or designated use of the water body (adapted from USEPA, 1994)

1. Natural water quality does not meet the standard
2. Natural, ephemeral or intermittent low flows or water levels prevent development of balanced aquatic biota protected by the standard
3. Human caused conditions result in standard excursions that cannot be remedied or their remedy would cause more environmental harm
4. Dams and other hydraulic works that cannot be removed cause the standard excursions and these works cannot be operated so that the excursions would be eliminated
5. Natural physical conditions of the water body such as lack of substrate, cover, flow, depth, pools, riffles unrelated to water quality cause the excursions of the standard
6. Meeting the standard would cause a wide spread adverse socio-economic impact on the regional or national population.

In diffuse pollution abatement plans it is also necessary to distinguish between *background pollution* and *natural water quality*. Natural water quality may have elevated concentrations of metals, low dissolved oxygen, or even some priority organics that may exceed standing water quality standards. These situation may occur in streams draining watersheds with metallic ore deposits, arid watersheds that exhibit very high natural sediment and associated pollutant concentrations during storms, wetland streams with low DO, or higher bacterial concentrations of water bodies with a large water fowl population. The natural water quality is Reason #1 that may allow modification of a standard or use while background pollution (e.g., atmospheric deposition caused by emissions) may not provide such relief and should be treated as diffuse pollution.

Attainment of the Standards

is an assessment concluding whether or not the standards are met or could be met after pollution control measures are implemented. However, the chemical standards and the chemical water quality they describe are statistical quantities and, theoretically, 100% compliance cannot be achieved. Previous formulations of water quality standards were related only to water quality during extreme design low flows or to a requirement that standards could not be exceeded at all times. Such application of the standards made consideration of diffuse pollution impossible. Diffuse pollution is a phenomenon driven by meteorological events that can be characterized only in terms of probabilities and statistical variables. Furthermore, chemical standards only do not allow consideration of such pollution causing actions and impacts as habitat degradation due to change in flow by urbanization, impounding the water body, or channelization. Efforts made by scientists and agencies to develop *wet weather* standards were unsuccessfull. Application of statistically defined water quality standards also necessitates use of statistical/stochastic models. Monte Carlo models (Novotny 2003) have been developed many years ago, but their wide application in the watershed/dif fuse pollution field is only emerging. Monte Carlo modeling is also necessary for evaluation of chronic toxicity standards that are expressed as moving averages (4 or 30 days).

Including physical and biotic integrity indices and standards

Both the new TMDL approach in the US and the European Water Framework Directive require establishing the ecologic potential for the water body. The concept of integrity of the water body, shown on Figure 2, has the dimensions of the physical habitat integrity, fish composition and diversity, and benthic macroinvertebrate composition. Description of these indices has been widely covered in the literature (see Novotny, 2003 for a review). The indices should be normalized by the values measured at the reference unimpacted water bodies of the same character. Humans are affected by eating fish, drinking water, or being exposed to water while swimming. Each exposure can be characterized as a risk. Therefore, a link to humans is also shown on Figure 2. Diffuse pollution has direct links to some key parameters determining the integrity such as embeddedness of the bottom substrate, siltation, and direct impact on composition of fish and benthic macroinvertebrates, and risks to humans. Other types of “hydrologic” pollution affect velocity, bank stability, and others.

Linking biotic integrity indices and their metrics to single morphological variables (e.g., imperviousness or population density) is simplistic and does not describe the cause-effect relationships. Nevertheless, it is useful for illustrating the problem. A layered, hierarchical model and analysis are necessary to quantitatively and qualitatively identify the linkages between the stresses and biotic endpoints as depicted on Figure 2. Such models are in the early stages of development.

Watershed vulnerability

In order to focus the management and planning efforts on watersheds that are most vulnerable (targeted), a vulnerability classification is necessary. Watershed vulnerability is the susceptibility of the water bodies in the watershed to deterioration under various impacts and stresses. It can be viewed as a difference between the watershed buffering capacity and pollutant loadings. Watershed vulnerability is discussed here in terms of pollutant loadings, the watershed retention capacity (WRC), and capacity controlling parameters (CCPs) that collectively govern the WRC (Salomons and Stol, 1995). This new approach has great potential for application in a classification system of watersheds suffering from diffuse pollution impacts. The concept of watershed retention and vulnerability is shown on Figure 3 and it will be discussed in more detail in the subsequent platform presentation. A vulnerable watershed is a watershed where pollutant loads from diffuse sources are reaching or exceeding the watershed retention capacity. Because point sources in most cases are discharged directly into the receiving water, the concept of watershed retention capacity and vulnerability affects primarily diffuse sources and pollution. Introducing the "watershed vulnerability" concept into water quality management brings a new view on diffuse pollution as well as on the integrity issues.

Figure 3 shows that the excess of pollutants over those retained in the watershed is released from the watershed, mostly in the form of diffuse pollution. A problem with the integrity of the receiving water body arises when releases of diffuse pollution load, in combination with point source discharges, exceed the loading capacity of the receiving water bodies. WRC processes for nitrogen retention for the entire Mississippi River watershed were considered in the N load analysis by Burkart and James (1999) and shown on Figure 1.

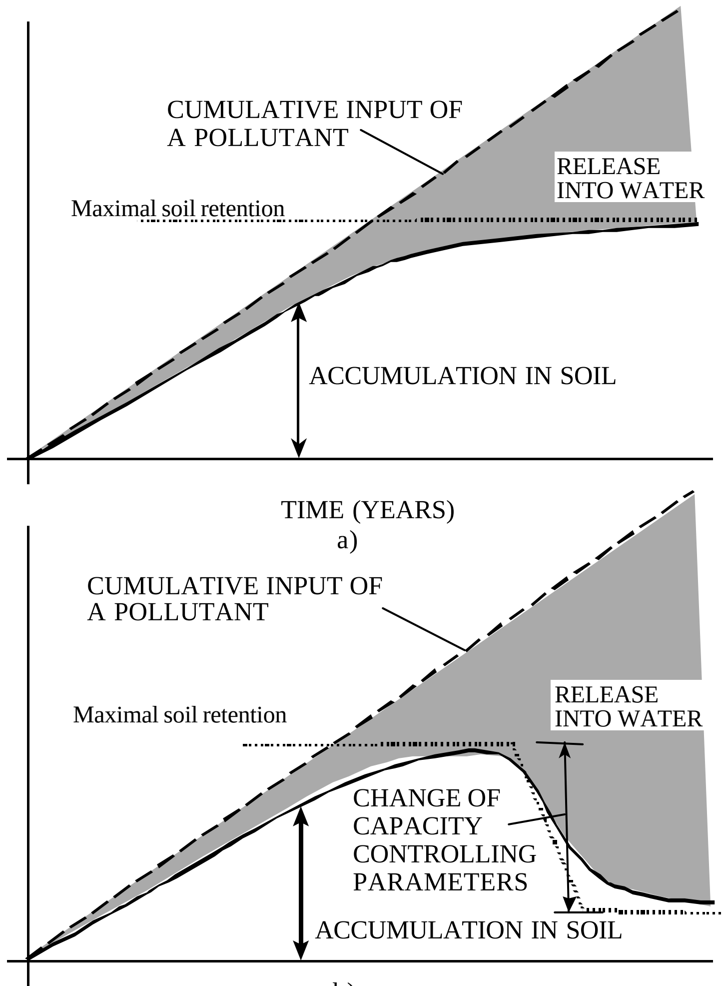

Figure 3 Concept of capacity controlling parameters in a watershed, (a) constant storage, (b) storage affected by variable CCPs (from Novotny, 2003)

The concept shown on Figure 3 illustrates how delivered pollutant loads to streams can increase under the same watershed loading rate when (a) the total watershed load over time exceeds the retention capacity of the watershed, and/or (b) the CCP change, resulting in a decrease of the WRC. This suggests that the extent to which the WRC has been exhausted and the potential for changes of the WRC, both of which will vary depending on the characteristics of the watershed, should be incorporated into the watershed classification system.

The large scale factors that affect the WRC and, therefore, the diffuse pollution loads are:

- Change of soil acidity and loss of buffering caused by acid precipitation and deposition (wet deposition represents only a portion of the acid input)
- Deforestation
- Land conversion (e.g., to agriculture or urban use)
- Wetland drainage
- Change of soil buffering and adsorption capacity due to effects other than acid inputs

- Loss of soil organic matter due to agricultural practices and urban construction activities
- Loss of top soil by wind and water erosion
- Change of redoxconditions by drainage

- Increasing imperviousness of the watershed by urbanization
- Surface extraction of minerals and coal

FINAL THOUGHTS - HOW LONG IT WILL TAKE BEFORE LARGE SCALE IMPROVEMENTS WILL BE NOTICED?

The majority of adverse changes in watersheds impairing water quality occurred over a period of thirty to more than one hundred years. For example, in the second half of the19th century, a major part of the watershed of the Lagoon of Venice in Italy and large portions of the States of Illinois, Indiana and southern Wisconsin consisted of wetlands. In a period of about 80 years more than 90% of the wetlands were drained, cultivated and converted to agricultural and urban uses. This conversion changed the redox status of the soils and soil cover with a concurrent large increase of suspended solids, dissolved organic matter, nitrogen, and phosphate loads from the watersheds located in the affected regions. Changes due to the acid rainfall in the Central Europe, Scandinavia or north-eastern US have been documented over the last fifty years. The dramatic nitrate increases in European streams had reached alarming levels over a period of thirty years in the second half of the twentieth century. Some changes are sudden. For example, large reductions of fertilizer and pesticide application rates occurred in Eastern Europe over a period of less than three years after the regime changes in 1989-1990.

The question whether these adverse changes are reversible by reduction or discontinuation of excessive inputs of pollutants came to light and has been analyzed recently after the political changes in Eastern Europe. Stålnacke (2003) and Holas and Hrn í⊆ (2002) analyzed the impact of dramatic reductions of nutrient fertilizer inputs in eastern Europe following the political changes in 1989. For example, in Estonia and Latvia, sales of mineral fertilizers dropped by a factor of 15 from 1987 to 1996, and the number of livestock decreased by a factor of four. Holas and Hrn í⊆ reported that the significant reductions of fertilizer use in an agricultural watershed in the Czech Republic did not result in a reduction of crop yields. Yet, in the short run of about five to ten years after these changes, decreases of nutrient inputs into east European receiving waters were far less than expected, based on the reduction of the nutrient inputs (Stålnacke, 2003). In some cases the improvement in water quality were statistically insignificant. How long it will take before the stream concentrations or loads to lakes and coastal waters are reduced, e.g., by 50 % (an EU goal for Baltic Sea), will undoubtedly be a subject of extensive research in the upcoming years. One thing; however, is clear. A watershed is a complex system for which the mass balance of nutrients involves inputs, outputs, several storages within the watershed, complex processes taking place in soils, capacity controlling factors, and different pathways of pollutants from the soil into the receiving water bodies. Reliable dynamic long term models that would describe interactions between nutrient inputs, outputs, storage etc., have not been developed yet. It is becoming apparent that it may take longer for the watersheds to recover after nutrient loads to surface and groundwater are reduced if remedial measures are gradually implemented.

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