Ing. Dr. Vladimír Novotný, P.E. , DEE.
Environmental and Water Resources Consultant
Newton, Massachusetts, 02458, USA

Developing Ecoregion and Barriers to Agricultural and Urban Pollution to Control Eutrophication in the Water Supply Reservoir for Prague

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Švihov reservoir (http://www.flickr.com/photos/20076267@N04/2810811623)

Developing Ecoregion and Barriers to Agricultural and Urban Pollution to Control Eutrophication in the Water Supply Reservoir for Prague

Vladimir Novotny[1]

Abstract

The proposal suggests general steps for developing a plan for prevention of algal and cyanobacteria blooms and, hence, control of eutrophication or hypertrophy with a specific focus on the Švihov Reservoir providing more than 70% of the water supply for the capital city of Prague. The reservoir is a part of the Želivka River watershed system. This document outlines the necessary research activities leading to a plan to avert the impeding collapse of the system caused by excessive nutrient inputs from land uses, a misuse throughout the watershed stimulating excessive algal blooms of cyanobacteria. Such algal blooms are endemic to numerous reservoirs and ponds throughout the Czech Republic. Starting with the assessment of the current and future water quality situation in the stream and reservoir system, the proposed plan will outline the necessary landscape, point source and in stream measures to reach a "good ecological status" of the receiving water bodies, including the reservoir. The plan should be tiered and include implementing barriers to presently uncontrolled diffuse pollution, in addition to the reduction of excessive use of agricultural chemicals and point source controls. The plan will outline the needed best management practices as well as changes in fertilizer applications. Key components to be considered should also be landscape modifications to include protective buffer zones, wetlands, and afforestation. The proposed comprehensive research and subsequent plan will be adaptive, based on monitoring and modeling, and include immediate and long term actions throughout the watershed and in and around the impoundments. The proposal outlines development of the Želivka River watershed into an ecoregion containing eco-agriculture with eco-communities in a landscape that attenuates and buffers pollution loads from use of land and community living. Other components of sustainable living are producing agricultural and other goods, green designs, and development of alternate energy including biogas, as well as restoration of impaired streams and reservoirs to provide good quality water and complying with the goals of the Water Framework Directive calling for "good ecological status".

[1] Professor, Department of Civil and Environmental Engineering, Northeastern University, Boston 02115, USA (on a sabbatical leave 2008-2009) . Fulbright Senior Specialist.

Microcystis aeruginosa (Courtesy Czech Academy of Science)

Introduction – Statement of the Problem and Urgency to Solve It

The capital city of the Czech Republic, Prague (Praha) uses drinking water from two sources, the Švihov Reservoir in the Želivka River watershed and from alluvial wells Káraný supplied by infiltrated water from the Jizera River. Želivka is a modern coagulation filtration water treatment plant where aluminum sulfate is added, followed by ozonization and chlorination providing 74 % of the drinking water demand of 1.2 million people living in Prague. It also supplies water to several hundred thousands of people residing in the Central Bohemia and Highlands (Vysočina) regions. The maximum peak capacity of the plant is 6900 l/s but the current production is less than one half, 3 100 l/s. The Želivka water treatment plant is one of the largest in Europe and the largest in Czech Republic for drinking water production..

Raw water is brought to the plant from the Švihov Reservoir by several pumps. Water intake from the reservoir is via two intake towers that enable withdrawals at multiple levels. Treated water is delivered to Prague by gravity flow in a 52 km long underground aqueduct.

In addition to water from the Želivka River and water from Káraný (Jizera River), Prague also has an older water treatment plant in Podolí that can take and treat water from the Vltava (Moldau) River. This plant is now in a stand by mode.

Water quality from the Švihov Reservoir, after treatment, is the worst of the three sources (Švihov Reservoir, the Vltava River, and Káraný) with respect of COD and nitrates. Recently, triazine pesticides have been found in the Želivka water in concentrations exceeding the public health standards by an order of magnitude. Nitrate levels are also very high exceeding in many places the WHO and European Community standard of 50 mg/L of NO_3^-/L which would be equivalent to the US standards of 10 mg/l of nitrate nitrogen (Pečenka et al., 2006). This standard is for the protection of infants from nitrate poisoning and does not control eutrophication.

The excessive inputs and concentrations of nitrogen and phosphorus from the watershed into the stream and reservoir system of the Želivka River stimulate eutrophication, which is a process of enrichment of the water bodies by primary productivity of organic matter. Traditionally, scientists and water quality specialists described eutrophication as progressing from oligotrophic, mesotrophic, to eutrophic states. The eutrophic state was considered to be followed by a conversion of the water body into a wetland and ultimately ending as a dry land (Roehlich, 1969; Novotny, 2003). With the exponential increase of the nutrient inputs from agricultural and urban point and nonpoint sources after 1960 due to intensification of agriculture ("Green Revolution"), a category of *hypertrophy* and *hypertrophic* water bodies was added, which denotes a troublesome non wetland post eutrophication state of the water body exhibited by excessive bloom developments especially of noxious species of cyanobacteria (Freedman, 1995; Chorus and Barton, 1999; Pace and Groffman, 1998; Vollenweider and Kerekes, 1980). Characteristic of these states are presented in Table 1.

Currently, the Švihov water treatment plant and the reservoir are the last barriers standing between the sudden blow up of the most serious water problem, the cyanobacteria blooms that are endemic to the Želivka reservoirs as well as many other reservoirs and ponds throughout the Czech Republic (Bláha and Maršálek, 2003). A "bloom" is massive accumulation (10^4 -10^6 cells/L) of a single or coexisting nuisance species (Paerl, 1988) that is exhibited by scum, failure of filtration systems in water treatment plants due to excessive clogging; smell of water due to anoxic conditions resulting in emanation of hydrogen sulfide and bad aesthetics. Anoxia or even anaerobic conditions cause fish kills and change the entire biotic system to that favoring no or reduced dissolved oxygen levels. Colonies of cyanobacteria prevent light to penetrate into the reservoir because the turbidity expressed by the Secchi disc depth is less than 1 meter. Cyanobacteria also produce toxins that are damaging or even lethal to plants, organisms and humans (Bláha and Maršálek, 2009).

The phenomena of occurrence of blooms have been known, studied and fought for years (Roehlich, 1969). For example, in the 1980s a hypertrophic Lake Delavan in Wisconsin suffering from severe algal blooms was restored by a massive overhaul and clean–up that included control of point and nonpoint sources of phosphorus from the watershed, changing the lake's hydraulics, creating a headwater riparian wetland, massive and complete eradication of carp and buffalo fish overpopulation and subsequent restocking with a balanced fish population, phosphorus precipitation in water and sealing of sediment by application of aluminum sulfate (Wisc. DNR, 1989). However, in the last twenty years the problem has reached alarming proportions on a large scale (Bláha and Maršálek, 2003; Znachor et al., 2006) throughout the Czech Republic. It has been estimated that cyanobacteria blooms (Hejzlar, 2006) now impair 70 % of impoundments in the Czech Republic.

Table 1 Trophic status of impoundments (Source US EPA, 1974)

Water Quality	Oligotrophic	Mesotrophic	Eutrophic	Hyper-trophic*
Total P (μg/L)	<10	10-20	20-80	> 50
Chlorophyll – *a*	<4	4-10	10-25	>20
Secchi disc transparency depth (m)	>4	2-4	<2	<1
Hypolimnetic oxygen (% saturation) in summer	>80	10-80	<10	0

Calculated from the Carlson Index set as 60. See Novotny (2003)

The perseverance of these organisms, even in harsher conditions such as a up to five years reductions of the nutrient content in water, indicates that controls are difficult after the hypertrophic conditions develop. Hence, prevention and control of cyanobacteria blooms require a hierarchical forceful approach to reduce the loads of nutrients, protection of the reservoirs and their tributaries and control nutrient levels in the sediments before the onset of hypertrophy. Recent research on the hypertrophic Lake Taihu ("hu" means "lake" in Chinese) by Dr. Hans Paerl from the University of North Carolina, (personal communication) indicates that a remediation program of already impacted water supply reservoirs must be on all fronts. i.e., availability of phosphorus and nitrogen must be reduced in water and sediment and the notion of focusing on a limiting nutrient, only, may not be enough. Lake Tai is the largest freshwater lake in China and provides drinking water to millions of people. Currently, excellent and cutting edge research is being conducted in the laboratories of the Czech Academy of Science in Brno and České Budějovice.

Water Quality Situation in the Švihov Reservoir and its Tributaries

The Švihov Reservoir is the largest drinking water reservoir in the Czech Republic. The reservoir was formed on the Želivka River, a tributary of the Sázava River, by a 58 meter high and 850 meters long earth dam. The average depth of the reservoir is 18 meters. The reservoir is 38 km long with an area of 1432 ha and provides, when near its operating level, 246 million m^3 of useful storage. At the maximum water level elevation of 377 m asl (meters above sea level) has a water volume of 267 mil. m^3.

The report of the Povodí Vltavy (Vltava River Water Management Agency) by Hejzlar et al., 2006 provide a bleak picture of the water quality in almost all water bodies in the Želivka River watershed and worsening quality in the Švihov Reservoir, which was also confirmed by Pečenka et al. (2007). The problems and solutions were summarized by Novotny (2009). Many other important water bodies in the Czech Republic are affected by cyanobacteria blooms or on the verge of becoming hypertrophic, including Orlík, Brno, Vír, and Nové Mlýny Reservoirs and the fact that 70 % of impoundments are affected (Hejzlar, 2006; Bláha and Maršálek, 2003), including legendary Máchovo Jezero (Mácha's Lake), indicates the problem is already beyond serious and must be taken as an emergency situation in the country. It was noted the water quality of the Švihov Reservoir had been judged by authorities by the WHO standard for drinking water of 50 mg of NO_3^-/L (roughly equivalent of 10 mg of NO_3^--N/L standard in the US) derived from the public health limit to prevent methaemoglobinemia (blue baby disease). Meeting this inappropriate standard in the context of controlling eutrophication has given the authorities a false sense of security when an "average" N content is below the WHO public health limit. The limits for preventing eutrophication are much smaller, less than 1 mg-Total N/L during the vernal period and using averages only means that 50% of cases will be worse.

Figure 1 Sedlice Reservoir in the Želivka River system during cyanobacteria bloom. Picture taken in summer 2003 by the Biology Center of the Czech Academy of Sciences)

Pečenka et al. (2007) reported the average nitrate concentrations in the water from the Želivka Water Treatment Plant are higher than those in the Vltava River that already has hypertrophic reservoirs (e.g., Orlík), cyanobacteria are already developing in the Švihov Reservoir and its headwater basins. Note the pea soup appearance of the cyanobacteria bloom on Figure 1 showing Sedlice Reservoir on a tributary of the Želivka River. Sedlice is a forbay of the Švihov Reservoir originally built to provide protection to the main reservoir from the pollution from the watershed and reduce sediment load. The average concentrations of phosphorus and nitrogen in the key tributaries have already exceeded the limits for hypertrophy and are exceeding 100 µg/L of phosphorus and 20 mg/L of NO_3^--N, respectively. The use of average annual concentrations in judging the water quality status is misleading because the key period is vernal (spring) which exhibits, as the Pečenka's et al. report documents, the highest concentrations carried from diffuse (nonpoint) sources by runoff and snowmelt flows.

As already pointed out, all headwater reservoirs and arms of the main Švihov Reservoir are already infested by cyanobacteria. Today, Sedlice and other smaller forbay basins (e.g., Trnávka, Nemčice) are more sources of the cyanobacteria than sinks of pollution. It is only the large volume of the body of the Švihov Reservoir (Figure 2) and the plug flow in the reservoir preventing the cyanobacteria algal bloom infestation reaching the dam and the intake into the water treatment plant of the Prague water supply system. Nevertheless, the cyanobacteria have already appeared in the Švihov Reservoir (Hejzlar et al., 2006). When the algal blooms reach the intake the treatment plant is defenseless against filter clogging and only partially effective for removing the toxins, color, and bad taste before the entry of water into the water supply systems. As it happened in other localities (for example, Lake Taihu in China providing drinking water to millions), without expensive redesign of the treatment process, the treatment plant will be decommissioned for the duration of the algal bloom, which may be in months and ever after the modification the quality of produced water will be poor.

Figure 2 Aerial view of the Švihov Reservoir. Photo provided by Professor Jiri Wanner, VŠCHT.

Causes of high nutrient content in the Želivka watershed

Figure 3 shows the increase of nitrate nitrogen concentrations in the Želivka River taken from et al. (2006). The onset of the increase of nitrate concentration in the river and its tributaries is similar in many other countries that started intensification of agriculture almost at the same time, early 1960's. Before the onset of the intensification of agriculture, the arable area in the watershed was larger than today (53% in 1948 vs. 48% in 2000) and the two most significant land use conversions happened by building the large water supply Švihov Reservoir and increase of forested land throughout the watershed (from 27% in 1948 to 29% in 2000).

The excellent article by Lexa et al. (2006) focusing on the cause of high nitrate content in the tributaries of the Želivka River has shown and analyzed the multiplicity of causes of the increased nutrient concentrations, focusing on nitrate pollution. Most of them are related to the intensification of agriculture. Some of them also cause phosphate pollution (see also Novotny, 2009). These are:

- *Inorganic fertilizer applications* are an obvious source of the nitrogen and phosphorus in the receiving water bodies. Before the intensification onset, farmers and cooperatives used manure that enriched the soils with organic matter containing organic N that slowly decomposed in the soil to ammonium. In the pre-green revolution times, in most cases, crops took up most of the nitrogen and fertilizers applied to soils. Lexa et al (2006) showed inorganic nitrogen applications increased from 8.9 kg/ha in 1950/51 to highest application of 110 kg/ha in 1989/90, then dropped to 58.9 kg/ha in 1995/96 and increased again to 71 kg/ha in 2000/2001 (Figure 3).

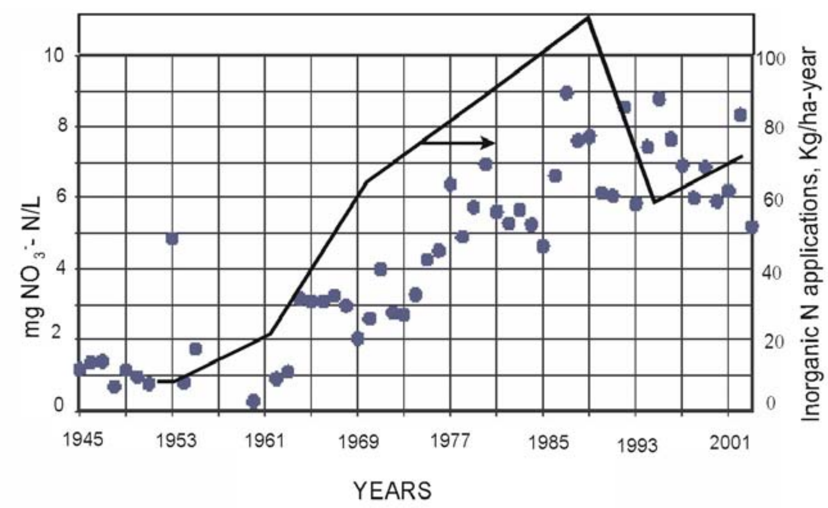

Figure 3

Concentrations of nitrate-N in the Želivka River in Švihov and industrial nitrogen fertilizer application. Data compiled from various sources by et al. (2006)

- *Feedlots.* Lexa et al (2006) suspected release losses of dung water from large feedlots with high animal densities operated by cooperatives could be additional sources of nitrogen. Organic nitrogen and ammonium in dung water could be relatively quickly oxidized to nitrate. A very common problem with farming all over the world is manure spreading over frozen soils which results in spikes of nitrogen and phosphorus in receiving water bodies in agricultural zones during spring rain and snow melts.

- *Agricultural tile drainage.* Lexa et al. (2006) and Doležal and Kvítek (2004) documented the loss of denitrification capability of the agricultural systems caused by installing tile drainage in lowland saturated soils that were before the agricultural green revolution mostly wet land meadows with springs adjoining the streams, including also vegetated riparian buffers. At that time (before 1960) saturated lowland soils, often wetlands or saturated meadows provided denitrification of nitrate brought by shallow groundwater flow from upland cultivated lands by which it was converted to nitrogen gas. Hydrologically, the cultivated upland soils were recharge areas and the lowland wet lands and meadows were discharge zones.

After installing tile drainage, wet saturated soils were drained and became aerated, hence loosing their denitrification capability which requires anoxic conditions provided by soil saturation and the concentrations significantly increased.

- *Urban drainage and sewage disposal.* Hejzlar et al. (2004) illustrated the dilemma of the municipal and other communal wastewater loads. In 1960, coinciding with the green revolution – intensification of agriculture, communities in the Želivka River watershed did not practice wastewater treatment and many did not have sewers. Laundry was done using soaps and excreta in smaller communities ended up in outhouses and in some cases as fertilizer along with manure. With collectivization of agriculture came combined sewers that conveyed most of wastewater and part of stormwater into the receiving water. Hejzlar et al. reported that municipal as well as other communal wastewater discharges contribute 90% of phosphorus to the receiving water bodies in the Želivka River watershed and about 15% of nitrogen. This seems to be a surprisingly large disproportion especially with phosphorus which is the key nutrient. The current WWTPs practice nutrient removal and most achieve nitrogen effluent nitrogen levels less than 10 mg/L and phosphorus less than 1 mg/L However, overflows from the combined (unified) sewers (CSO), common throughout the watershed, which on average may happen fifty times per year, bring a substantial portion of the untreated sewage into the nearest surface water body. Studies in the US indicate that almost ½ of the nutrient load from a community may originate from CSOs.
- *Erosion*. Erosion is a natural process accelerated by anthropogenic land use practices. The anthropogenic erosion occurs both as a result of poor agricultural practices of plowing the land and urban construction and landscaping. Both can reach high erosion rates on high slope fields of up to 100 tons of soil loss per hectare in a year or more than 10 tons/ha in a single event in the absence of erosion control practices (Novotny, 2003). Erosion as expressed by the well known Universal Soil Loss Equation (USLE) is a function of rainfall intensity, soil erodibility, slope and size of the eroded area, land cover, and whether or not erosion control practices are implemented (Wischmeier and Smith, 1965).

In the Želivka watershed most of the agricultural erosion occurs in uplands and is strongly related to the type of soils and the plowing techniques. The worst plowing practice resulting in the largest sediment loads is so called up and down slope which seems to be favored by farmers because of ease of plowing on hilly fields. If simply plowing is changed to contour plowing, sediment losses from fields can be reduced by about 50% without any change of productivity. A very popular planting technique in the US is so called no-till planting in which plant residues are left on the field and become soil organic matter (Figure 4). Hence, highly reduced erosion losses of fertilizers will not have to be compensated by additional fertilizer amounts. Many best management practices can be used ranging from change to soil conservation plowing, crop rotation, strip cropping no-till planting, use of land covers (mulches), silt fences and sedimentation ponds used to control construction erosion (Novotny, 2003).

The no-till planting not only reduces dramatically soil erosion by building up soil organic matter it is also carbon sequester. Typically, soil organic matter content of intensively operated agriculture using industrial fertilizers is 1%. A good conditioned soil should have organic content about 5%. Organic matter in soil is about 50% carbon, 5% nitrogen and 1% phosphorus. Hence, increasing organic carbon content in the soil by 4% and assuming the top soil depth of 0.5 meters and soil specific density of 1.5 tons/m^3, approximately 150 tons of carbon will be sequestered by each hectare. Furthermore, if soils erosion is reduced from 30 tons/ha-year to less than 5 ton/ha-year and each ton of soil contains 5 % of organic matter[2] this would retain 63 kg/ha of nitrogen and 12.5 kg/ha of phosphorus, respectively, which otherwise would be needed to be replaced by industrial fertilizers and the loss would end up in the receiving waters.

Figure 3 No-till planting. Seeds are placed in the small ridge created by the planter and covered. Weeds are killed by a biodegradable herbicide. The method improves soil quality and retention capacity by increasing soil organic content which also optimizes soil moisture. Soil organic matter speeds up break down of pesticides and increases both infiltration and soil water retention. Building up the soil organic carbon is a an efficient mechanism for sequestering carbon.

[2] Erosion process is selective for organic matter and fine particles that have lower specific weight than soil minerals. This is called enrichment by erosion (see Novotny, 2003)i

There are two problems with soil erosion pertinent to the transport of nutrients to the water bodies by erosion. While nitrates move to the receiving water bodies primarily with the shallow groundwater, phosphorus, organic nitrogen in soil organic matter and, to a great extent, ammonium (adsorbed on soil particles) move with soil particles. The load of these forms of nutrients is then directly correlated to sediment loss. Second, because a substantial fraction of the nutrients and organic matter that retains the nutrients in the soil is lost by unmitigated erosion, farmers (cooperatives) apply more industrial fertilizer to compensate for the losses that can be substantial.

Proposed Research

Goals and Objectives

The major goals for restoring the Želivka River and the Švihov reservoir are:

1. Reversing the progress of hypertrophy in the water supply reservoirs providing most of potable water to the capital city of Prague and avert a possible catastrophe caused by the massive developments/blooms of especially noxious blue-green algae – cyanobacteria.
2. Bringing the surface waters heavily contaminated by nitrogen, phosphorus and pollutants to the WFD required "good ecological status" and, by doing so, restoring the integrity of the receiving waters by providing conditions for a balanced aquatic life, and supporting (limited) recreation, fishing, and aesthetics.
3. Reduce point and diffuse source pollutant loads from the watershed to the levels commensurate with the assimilative capacity of the water bodies (considering also a margin of safety).
4. Restoring the land ecology throughout the watershed inasmuch as it would provide buffering to the movements of potential remaining pollutants from the source areas and also provide conditions for eco-agriculture and other land uses.
5. Develop a demonstration small watershed (Community of Obrataň) where the most effective proposed best management practices and point sources controls would be implemented, tested and used as an example for educating the farming community, other citizens and managers throughout the country.
6. Identify hazardous lands and buffer zones to be converted to a new sustainable use such as growing woods and grass for energy production. Such conversions will reduce soil and nutrient erosion losses (upslope areas) and denitrify and remove nitrogen from shallow groundwater and base flow in riparian zones converted to wetlands.
7. Because of the fact that the Czech Republic is one of the largest per capita emitters of green house gases causing global warming, the system should provide conditions for carbon sequestering and production of carbon neutral green energy.
8. Establish stakeholders interaction and collaboration for fast education, research results dissemination, advising and implementation.
9. Prepare proposal and plan for establishing the Želivka River watershed as a sustainable ecoregion containing urban eco-communities and supporting eco-agriculture.

Developing Protective Barriers to Nutrient Inputs into the Prague Water Supply Reservoir and Control Eutrophication and its Adverse Effects

Sustainable Ecologic Water Resources System

Sustainable development has been defined as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland et al, 1987). In elaborating concepts of sustainable development, the literature has emphasized that people, including farmers, city dwellers and the society as whole - are participants in an ecosystem, and that they are ultimately dependent upon the renewability of the ecosystem resources and services. A sustainable development is one that balances the social needs and economic use and development of a water system with protection attaining or protecting a good environmental status as it is required in the US by the Clean Water Act and in the European Community by the Water Framework Directive.

In the Želivka watershed the social benefits of the use of land and water resources are tremendous and include, above all, the well being and health of the citizens using water from the system. The citizens residing in the watersheds and visitors could have additional social benefits of recreation, nature and water enjoyment, tourism in addition to a good and healthy water supply but these benefits were taken away from them by the poor water quality and poor ecological status of the almost entire surface and groundwater system in the watershed. Surface and groundwater in many parts of the watershed are not suitable for human use because of the extremely high nitrate content. Water from reservoirs, other than about 50 % of the Švihov impoundment, is also dangerous to the health of swimmers as well as animals and other biota because of toxins (Bláha and Maršálek, 2009). The problem of the Želivka River system and of the water supply is the use and misuse of land in the watershed and, to a lesser degree, effluent and urban runoff discharges.

Economic benefits and cost also to be considered include the use of water and agricultural production as well as discharging treated and sometimes untreated wastewater and urban and highway stormwater throughout the watershed. The agriculture sector is also overusing the system by excessive use of fertilizers. The intensive agricultural production without environmental controls and implementation best management practices apparently compensates the lack of erosion control and good balanced fertilizer (including manure) management by increased use of industrial fertilizers. Excessive erosion causes a loss of top soil carrying the nutrients and organic matter, which then must be compensated by industrial fertilizers. Economically, it is a no win situation where farmers are paying more for fertilizers and citizens are loosing their water supply and recreational opportunities. According to the science of the environmental economics, without effective regulation and incentives, producers and economic users in the watershed (farmers, urban developers and managers) do not include the social and environmental cost of the resources lost by their activities in their managerial reasoning and behavior (Novotny, 2003). Considering also a possibility, that some of the past, present and potential future losses may be irreversible, the current situation in the watershed is highly unsustainable. The economic damage by the potential future loss of the system for water supply, even temporarily during the cyanobacteria seasons, would be tremendous.

The ecological status in the Želivka River surface and groundwater system must change from on the verge of collapse into a sustainable and ecologically healthy system that would guarantee good water to the citizens of Prague and of the two additional regions as well as to restore the aquatic ecology to a good status and, in doing so, reduce GHG emissions. Such a system would be socially fair and highly desirable, ecologically sustainable, and economically profitable if social cost of pollution is accounted for. As pointed out, a mesothrophic Švihov and other reservoirs as well as good quality of streams and groundwater complying with the water quality standard, would satisfy the “good ecological status” requirement of the European Community. This will require a reversal of the current practices of overuse and misuse of land and would convert the watershed into a functioning ecologic system and the cities and villages into “eco-communities” minimizing the nutrient and other pollutant discharges into surface and groundwater systems. The strategy of the abatement and related research must be hierarchical and progress from the pollution source areas to the receiving water body and include also restoration of the water bodies themselves. The progression of barriers can be characterized as follows (Novotny, 2003):

In the agricultural areas:

1. Identification quantitatively of hazardous land and land use practices that emit high levels of nutrients and propose controls such as
   a) Selection of crops and crop rotation that would minimize nutrient losses
   b) Matching fertilizer applications to the crop needs by judicious fertilizer management and a significant reduction of industrial fertilizer use, potentially by switching partially or fully to organic farming
   c) Wide use of erosion and soil conservation best management practices (Figure 5)
   d) Conversion of highly hazardous lands to grass land and woodland and potentially using the grown biomass to produce biogas and biofuel. Growing corn for biofuel production is highly inefficient (more energy is used and greenhouse gas (GHG) is emitted than produced) and economically controversial (increases cost of food).
   e) Judicious manure management, storage and spreading. Manure cannot be applied onto frozen soils or snow covered fields.
   f) Disconnection of drainage and conversion of the land to wetland stimulates denitrification in groundwater and carbon sequestration by growing trees and brush for energy. Wetland meadows due to their root depth are not as efficient for nutrient removal from contaminated graund water as long root woods that can be grown for biogas and energy (Figure 6 and 7).

Figure 5

Typical countryside in Wisconsin showing anti erosion and soil conservation best management practices

Figure 6

Restored riparian wetland in Iowa that could be effective for removing nitrates from shallow groundwater and base flow

2. Land best management practices aimed at intercepting the pollutant movement from the source areas to the receiving water
   a) Grass and vegetative borders
   b) Riparian buffers zones with fast growing woods (Figure 7)
   c) Grassed swales
   d) Ponds

Figure 7

A buffer strip in Iowa showing fast growing woods that could remove nutrients and sequester carbon

In urban and highway zones

1. Continue and expand nutrient removal at the public wastewater treatment plants (WWTP – ČOV).
2. Develop sludge handling system that would also accept grass and wood grown on the converted hazardous lands and produce biogas and recover phosphorus (struvite).
3. Discontinue using combined sewers which may represent a substantial portion of the nutrient load.
4. Urban runoff conveyance should be converted from fast conveyance in sewers into storage oriented systems on the surface. If combined sewers cannot be converted, combined sewer overflows must be intercepted, stored and sent for treatment into the WWTP or by some other means (e.g., pond wetland combination)
5. Develop sustainable disposal systems for used water (and possibly reuse) and excreta for small distributed communities other than standard septic systems that have very poor nutrient removal efficiencies.
6. Highway runoff has relatively lower nutrient concentrations but contains most of the toxic loads from an urban area or roadway and the runoff pollution must be safely controlled to prevent spills into the water supply system.
7. Consider converting the communities into "ecocities and ecovillages" that would minimize emission of pollutants to very low levels with recovery of nutrients (especially phosphorus), reclaim water for various uses such as irrigation, toilet flushing as well as energy from used water. It should be pointed out that such a system of ecocities and ecovillages as well as land conversion to nonpolluting lands is now being implemented in the watershed of the Miyun Reservoir supplying most of the drinking water to Beijing, the capital city of China.

In the impacted water bodies (Švihov, Trnavka Nemčička, Sedlice and tributaries) conduct monitoring and develop models for preventing hypertrophic conditions and achieving the "good ecological status"

1. Inventory the mass of nutrients and overwintering cyanobacteria stored in the sediments of the hypertrophic water bodies, nutrient release rates under ???oxic, anoxic, and anaerobic conditions; and conditions for releasing resting cyanobacteria into water column and forming blooms.
2. Estimate the maximum allochthonous (from outside) and autothonous (in lake) loads of the limiting nutrient (phosphorus) that would attain and maintain eutrophic (first goal) and mesotrophic (ultimate goal) status in the Švihov Reservoir.
3. Investigate the effect of various management alternatives and scenarios leading to the attainment of the water quality goals, Such means may include
   a) Physically by removing the heavily nutrient laden sediments from the reservoir
   b) Chemically by phosphorus precipitation and sediment sealing by coagulation with aluminum sulphate and other similar coagulants

c) Biologically by elimination of overwhelming bottom feeding low quality fish (carp) and replacing them with a balanced fish population including carnivores. Carp[3] and similar fish (e.g., buffalo in the US) resuspend sediments and cause phosphorus and ammonium release from sediments into water column.

d) Aeration of the hypolimnium

e) It is not advisable to rely on excessive concentrations of nitrates in the hypolimnium and anoxic conditions to control the release of nutrients from sediments. Such conditions imply zero oxygen concentrations in the hypolimnion and high nitrate levels are one of the key stressors stimulating cyanobacteria development.

Developing research projects to save the Želivka water supply system from an ecological collapse

Ecosystem services provided by the Želivka water resources system are the goods and services derived from natural and managed ecosystems upon which human welfare depends. Because of the intensification of land use, these services are in decline, especially in agricultural ecosystems. Ecosystem services are essential in maintaining human welfare as well as ecological integrity, yet these services can be affected, in addition to natural changes, by land use and management actions. In addition, agricultural lands are experiencing significant land use changes as demonstrated by the rapid conversion of these lands from traditional farming use, to intensive and alternate farming practices, to urban development, and to non-agricultural use (e.g., transportation).

The US EPA description of the research needed to develop a balanced multiuse sustainable agricultural ecosystem has been recently published[4]. A research program followed by an action plan focusing on ecosystem services should provide an organized approach in developing basic and applied fundamental knowledge leading to a delivery of scientifically based information for advising and guiding agricultural and urban management, social, and policy decisions. Using a systems approach, the proposed research will assess the ecosystem services, evaluate multiple ecosystem services interactions and attributes at geographic scales. As more services become monetized, the issues of scale become increasingly important. One service should not be provided at the expense of other services and the long-term productivity of the system. For example, water supply services cannot deny other services of the ecosystem, such as agriculture, without compensation and, on the other hand, other proximate users of the ecosystem (agriculture, urban, transportation) cannot pollute beyond the assimilative (safe loading) capacity of the system to accept their discharges and waste (e.g., excess fertilizer) and infringe in this way water use for other purposes. The society has clearly designated water supply as the primary use of the Želivka water resources system but this does not mean that the other uses such as attaining and maintaining a healthy and balanced aquatic life ("good ecological status" required by WFD) or sustainable agriculture can be overlooked. Hence, a discourse among the users must be a part of the entire effort to bring the ecosystem from the point of collapse to a well functioning

[3] Unlike in the US, carp is a very popular eating fish in the Czech Republic but it was proven to be harmful to the water quality of standing waters affected by nutrients with large storage of nutrients in the sediments. Complete carp eradication was one of the means of restoring the Lake Delavan in Wisconsin.

[4] http://es.epa.gov/ncer/rfa/2009/2009_star_ecosystem_services.html

multiple use system. It is obvious that the resulting system will be between a full conversion of the watershed into a forested/grassed land and the current unsustainable status. The most recent information on the land uses in the watershed is

	%
Arable land	47.8
Meadoews and pastures	12.3
Forests	29.0
Urban (built)	1.2
Other	9.7

Other lands include orchards and unsewered scattered settlements. The dominant land use that may contribute the largest loads of nutrients is agriculture. Future agro-ecosytems would be embedded in a larger landscape mosaic of rural and urban communities that drain to natural and engineered water bodies and are connected within airsheds via climate and weather patterns. This embedment contributes, in part, to the environmental externalities associated with agriculture, especially those related to the quality of air and water resources. An externality arises when upstream polluters (agri-businesses, cities, industries, drivers on freeways and highways transecting the watershed) are disconnected from the economic impact their dischargers have on the downstream users of water (Prague) and there is no market mechanisms how the downstream users can recover the damages by pollution. The damages are economical (more costly treatment of water or even cost of substitute water) or cost of days lost to waterborne disease or by inability to use the water resource for recreation. The society must decide through their representatives or legal system how to resolve the externality problem. This is typically done by regulation and/or transferring payments.

Figure 8 is an idealized schematics of land services in predominantly agricultural watersheds such as the Želivka River during the conversion from the natural land to intensive agriculture and finally to a sustainable functioning multiuse ecosystem. The arms of the "star" show the most important components of the "sustainability triangle", i.e., social/public health components (infectious diseases, carbon sequestrations), economics (crop and forest production, flow regulation), and environment (habitat and biodiversity, air and water quality regulations).

Adaptive Planning, Implementation and Management

In general, the watershed research on the impact of land uses on water quality is arranged based on the scale of the area which range from a more or less uniform hazardous field or land (< 10 ha), to a more heterogeneous subwatershed (< 10), smaller stream watershed, to a regional watershed (~1000 km^2). At each scale the parameters of impact may be different. On a small scale the quantity of fertilizer applied, crop and land use type, slope, storm characteristics are important. On a large scale, land use and geology may be the most important factors. In general, the research activities can be characterized as

Project Activities

1. Baseline: Identify and quantify the quality and quantity of the multiple ecosystem services provided by the selected agroecosystem at the farm, subwatershed (community) or watershed/regional scale;
2. Ecosystem change: Evaluate how ecosystem services and agricultural practices under changing ecological thresholds/functioning are impacted by major environmental stressors (see stressor list below); and
3. Management strategies and tools: Develop quantitative strategies to mitigate and respond to environmental impacts caused by stressors on agricultural lands so that ecosystems function sustainably to optimize ecosystem services. Physical, biological, and economic benefits and trade-offs of various agricultural practices supporting ecosystem services should be considered. Management strategies should be used to develop scale specific decision support tools for: a) producers of agricultural systems at the whole farm level, and/or b) managers and policy makers of natural resources at a watershed or regional scale.

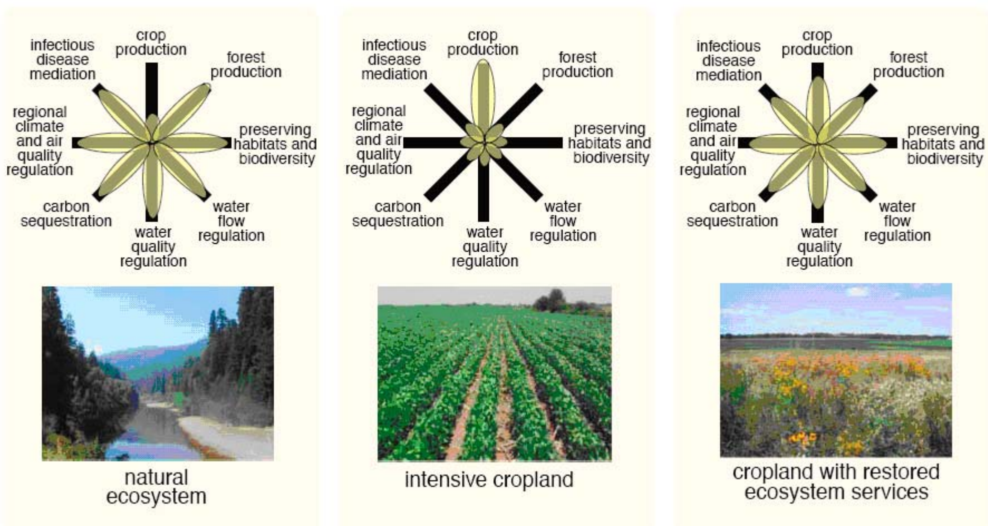

Figure 8 Three hypothetical landscapes illustrating the types and magnitude of services associated with different types of ecosystems. Natural ecosystems can support many ecosystem services at high levels, but not food production. An intensive cropland produces food in abundance, but comparatively little of the other services. A managed cropland can support a broad portfolio of ecosystem services (Foley et al. 2005).

Main Stressors

Climate Change: Climate change has the potential to irreversibly alter ecological processes in agricultural ecosystems, such as agricultural lands, forests and rangelands that provide ecosystem services. Research should address the potential long term of climate change on the most important adverse parameter which is the frequency and magnitude of the cyanobacteria blooms. Cyanobacteria prefer warmer temperatures and the occurrence and density of blooms may be increasing with climatic warming. However, quantitativly, the effect of warming on cyanobacteria development is not known and must be researched by modeling (Hellweger et al., 2008). The project will identify management options for these ecosystems as climate-driven physical, ecological and societal thresholds are approached to avoid irreversible changes in ecological processes that support ecosystem services. The research should also impement carbon sequestering into the management system.

Reactive Nitrogen: Nitrogen from farms and feedlots is a major source of ecosystem pollution (i.e., air, soil, and water systems). Agroecosystem projects impacted by reactive nitrogen should develop methods to increase nitrogen efficiency in the system by improved uptake and availability to plant and animal systems that result in improved ecosystem services; and determine effective ways to interrupt the nitrogen cycle to reduce the impairment of ecosystems services by nitrogen. Projects should develop process-based models to estimate leakage of nitrogen in agroecosystems, for example, into groundwater and to predict where improvements in ecosystem services are likely through better nitrogen management. The project will focus on the evaluation and estimating of drainage of originally wet saturated soils that in doing so lost their denitrification capability (Figure 9).

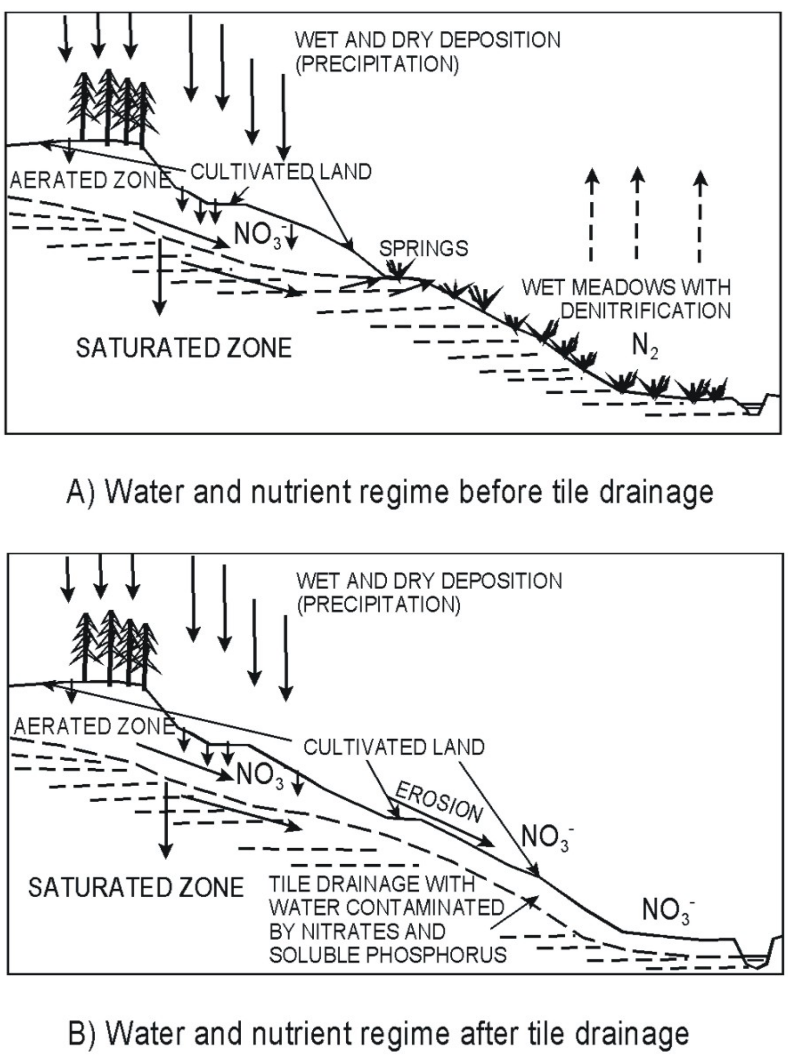

Figure 9

Water and nitrate movement before and after drainage. Before drainage wet water saturated riparian meadows and wetlands denitrified nitrates carried from fields by groundwater flow. Adapted and replotted from Lexa et al. (2006)

Bioavailable Phosphorus. From literature it is known that the intensity and frequency of noxious and dangerous toxins producing cyanobacteria blooms are related to both nitrogen and phosphorus levels and the N/P ration. In most cases phosphorus is the limiting nutrient. Also the survival and nurture of encapsulated thick wall (akinetes and cysts) and filamentous forms of cyanobacteria in the sediments depends on phosphorus levels in the sediment and reapperance of the bloom is triggered by the phosphorus levels among other factors in the water column. The project will develop new generation of agent based models capable of simulating the complex behavior of the resilient behavior both in the water column and the sediment. However, not all forms of the total phosphorus may be available. Phosphate can adsorb on the sediment and become less available. The adsorption process follows the Langmuir isotherm model and is related to the sediment clay content and pH (Novotny, 1981).

Soil and Land Degradation: Changing land use and land cover can sometimes lead to degradation of the soil resource due to erosion and structural changes, soil saturation or drainage, and contamination. This degradation of soil and landscapes puts stress on agroecosystems (including agricultural, forest, and range lands) and diminishes the capacity to provide important ecosystem services. Research under this stressor should use, improve, or develop process-based models to evaluate risk and determine effective strategies to avoid or mitigate the loss of ecosystems services in areas sensitive to these stressors. Under this category the project will investigate and find efficient remedies for increased soil erosion (by soil conservation best management practices), loss of organic matter (by no till; planting and crop rotation), by drainage (see above), and by implementing swale drainage, ponds and wetlands in the drainage system.

At the current state of water quality of the Želivka River and considering the very high magnitudes of the nutrient loads coming from the poorly treated point sources (herein combined sewer overflows are considered as a point source) and uncontrolled nonpoint sources in the watershed, the first goal is to prevent and control hypertrophy. The second goal, carried out contemporarily, is to plan for the attainment of the final goal which would be to bring the Švihov and other reservoirs (e.g., Sedlice, Trnávka, Němčice) close to the EU defined "good ecologic status" for drinking water impoundments and water bodies which for the Švihov and other reservoirs would imply mesotrophic status. Achieving a "good ecologic status" also implies that other services of the water resources will also become available such as providing conditions for a balanced natural aquatic life, secondary and limited primary recreation, tourism, and fishing, etc. Hence the approach must be tiered and recurrently adaptive. The adaptive planning, implementation and management approach is needed because of the uncertainty of the current state of the art science and modeling regarding the impact of various control measures on the occurrence of cyanobacteria and algae in general.

It is paramount that the scientific centers in the Czech Republic fully participate and focus, in collaboration with international partners, on improving the level of the scientific knowledge and modeling the effects of nutrients on algal population of impoundments. As pointed out, the dramatic emergence of cyanobacteria bloom outbreaks throughout the world in the last two decades (earlier in the Czech Republic), has left, to some degree, scientists and planners unprepared. For example, in the US funding for this type of research is grossly inadequate, experts are few, and adequate models are now only being developed. The aforementioned centers of Czech Academy of Science (Hydrobiological Centre in České Budějovice and Centre for Cyanobacteria and |their Toxins in Brno) are in the forefront of the research and recognized worldwide.

The adaptive approach under the current situation cannot focus only on abatement of point sources which are not the main cause of the hypertrophic situation. The fact that only about one half of the Švihov Reservoir is the last barrier between the advanced front of the cyanobacteria blooms – hypertrophy does not provide much time before the rest of the reservoir becomes hypertrophic resulting in a full ecological collapse of the reservoir the all bad consequences for the users of water in Prague.

The complex and layered hierarchical schematic of impacts and processes affecting the biota in water bodies is shown on Figure 10 There are no comprehensive models that would describe the entire process.

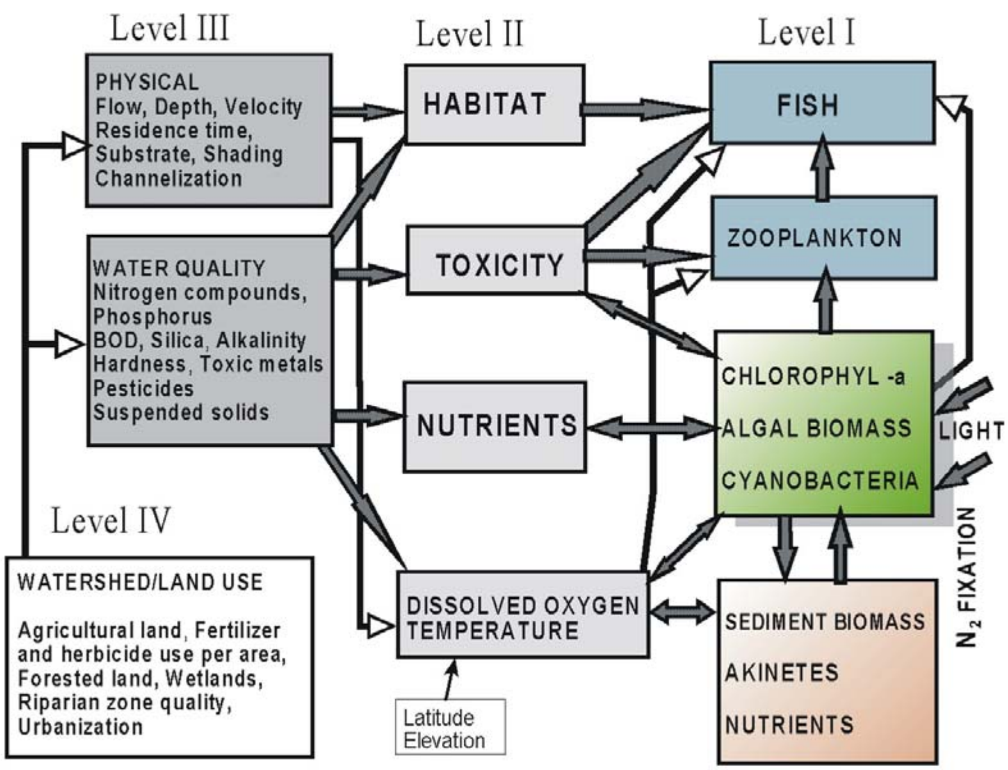

Figure 10 Hierarchical effect of stresses on occurrence and density of cyanobacteria

Developing the Plan to Prevent the Collapse of the Želivka River Ecosystem and Converting it into Ecoregion

The planning process for controlling hypertrophic status of the Želivka River system would be characterized in the US as the Total Maximum Daily Load process which is very similar to that under the EU Water Framework Directive (WFD). The following research and planning phases will form the process towards restoring the Želivka River Ecosystem and converting it into a sustainable ecoregion with ecocities and supporting a viable and sustainable eco-agriculture:

I. Assessment to the current situation and trends

Assessment requires both field monitoring and retrieval of data from numerous data bases such as from the Hydrometeorolgy Institute, land use distribution, soil characteristics, maps, etc. Assessment also uses statistical and GIS models for synthesizing the data into a meaningful and understandable form. Assessment activities will focus on and synthesize information on (see also Appendix):

a. Watershed characteristic, land use, geology, soils, demographic, geomorphology, etc.

b. Precipitation, flows, hydrological characteristics, groundwater

c. Fertilizer use and composition, crops, crop yields

d. Pollution sources and loads of nutrients, pesticides and other pollutants

e. Trophic status and water quality of the Švihov and other reservoirs, current and past trends, as well as the main ??stem and major tributaries of the Želivka River. Fluvial morphology characteristics of the reservoirs and streams.

f. Assessment of the reference minimally impacted water bodies (e.g., Jankovský potok and/or some other water body in the nearby Sázava River watershed). These water bodies will serve for establishing the attainable ecological and water quality goals.

Data will be analyzed by statistical distribution, trend and multiple regression and cross-correlation analyze models. STATGRPAHIC©, MATLAB and other statistical software will be used to develop the data analysis models.

II. Research to develop goals, key decision loading and surrogate parameters and criteria

a. *For the water supply reservoirs and tributary water bodies* the goals are given by the requirement and standards for the sustainable good quality water for Prague, EU Water Framework Directive for achieving "Good Ecological Status" for all water bodies (reservoirs and streams) that would also consider water supply and recreation, and by the National Water Quality Standards and Criteria mandating 1st and 2nd Water Quality Class for waters directly used for water supply and 3rd Class for most of other streams and impoundments.

i. Synthesize the water quality goals

ii. Identify and develop numeric criteria for the water, the categories of water bodies in the watersheds based on their use such as reservoirs and groundwater aquifers directly used for water supply (e.g., Švihov reservoir), water bodies used for recreation (including fishing), industrial water supply, and irrigation. The WFD mandates that all water bodies must achieve "a good ecological status" which for reservoirs would imply a mesotrophic status and for running water conditions that would be suitable for propagation of a healthy and balanced aquatic biota.

iii. Translate the goals into numeric criteria and standards

b. *For urban areas* goals and criteria should be developed that would transform the communities to become eco-communities, which would include

i. Practicing sound nutrient removal and effluent reclamation in the water reclamation (treatment) plants (ČOV) providing water for various reuse purposes such as ecological flow in streams, water for irrigation, and recharging low nutrient effluents into groundwater in converted lands with high nitrate levels. This should also include sludge management and energy recovery from sludge (along with digestion of other organic solids such as those produced on converted hazardous lands, food organic waste and debris).

ii. Eliminate overflows and bypasses from combined sewers and clean water inputs into the sanitary sewer system. This could mean providing surface drainage for urban runoff wherever possible. Implementing ponds and wetlands into the surface stormwater drainage network.

iii. Practice reuse and sound disposal of solid wastes that should become available for energy production.

iv. Implementing green buffer zones in the form of parks and green areas along the water sources that would intercept and form a barrier to diffuse pollution from the urban areas and also protect the urban areas from flooding by providing storage for floodwater.

v. Minimize construction erosion especially in areas directly connected to the drainage system. Construction erosion represents often the major sediment and nutrient losses from urban areas. Construction erosion control is mandatory in many countries and includes soil conservation practices, barriers to soil movements from the construction sites to the receiving water bodies, and specifically in the Želivka River system, movement of spills and contaminated soils from the busiest D1 freeway in the ??country orcounty. Goals and performance criteria must be developed and strictly enforced.

vi. The goals of implementing alternate energy sources such as solar and wind power and passive energy savings by insulation of existing buildings and building energy efficient new "green" buildings are not directly related to the goal of sustainable water quality for water supply but they are features and reasonable long term goals for ecocommunities. They are closely linked to the water conservation and water quality goals in "water centric" eco-communities.

c. *Land use and agriculture.* Besides the economic goals of producing goods and services, the environmental goals for agriculture are

i. Minimizing soil, organic matter, and nutrient losses from farming operations. With respect to the Želivka River and Švihov Reservoir it is highly desirable, almost necessary, that the nutrient losses from fields are close to zero which will be achieved by judicious application of fertilizers that would be matching crop requirements, implementing best management practices and alternate vegetative systems on hazardous lands and providing barriers in the delivery paths from the source areas to the receiving water bodies.

ii. In addition to producing food for people and feed to animals, new agriculture also provides organic matter for energy production. However, it is highly undesirable to use crops such as corn for production of energy because this leads to increases of food prices and, on a worldwide scale, also to food shortages in disadvantaged countries. On the other hand, growing fast growing woods, grass and other energy vegetation on converted hazardous lands that would be otherwise heavily polluting the receiving water bodies and leading to their collapse, is a proper best management practice. Hence, converting hazardous lands to environmentally beneficial and barrier forming vegetation that could be harvested and converted to energy is a goal and a part of the plan of converting the Želivka River into an eco-agricultural region.

III. Research and development of models and tools to develop the plan

a. Develop an agent based or a similar flexible dynamic model for cyanobacteria in the water column and sediment, simulating appearance and intensity of cyanobacteria blooms, predation and die-off in the water column and sediments in a stratified plug flow reservoir combined with the water quality model (see for example, Hellweger et al, 2008).

b. A GIS based regional model for diffuse pollution loads from the watershed simulating erosion, soil – fertilizer – crop interaction, effect of best management practices and the delivery of nutrients and sediments from the source area to the key water bodies

c. Mechanical detailed computerized and physical (laboratory) models for processes such as

i. surface-groundwater interaction, movement and attenuation by nitrification and denitrification in soil and groundwater systems (Figure 8);

ii. conversion of WWTP (ČOV) sludge mixed with other organic materials (wood chips, grass, etc.) to methane and recovery of phosphorus (struvite) from the high concentration supernatant??? produced in the biogas production;

iii. model simulating the efficiency of buffers and other barriers in the delivery process of nitrogen and phosphorus from the source areas to the receiving waters;

iv. simple hydrological water, sediment and quality models for assessment of various best management practices;

d. A computerized centralized system for data management and information retrieval for cooperating institutes, consultancies, and sponsoring agencies. Such a data and information management and retrieval system has been developed by CDM, Inc. (Dublin office) for similar watershed planning and management in Ireland. CDM has received an award at the 2008 IWA World Water Congress in Vienna for this system and their entire WFD watershed planning. The data management system can be accessed at:

   http://www.erbd.ie/index.html

e. Web based information retrieval and education system. This system is also a part of the CDM Ireland web site.

IV. Obrataň Community and Subwatershed Demonstration Project - Ecovillage

a. The community of Obrataň (population of 800) in southeast Bohemia located on the headwaters of the Želivka River was selected as a demonstration site and subwatershed for testing anti-erosion and nitrogen leaching interruption best management practices as well as for implementing hydrological practices to minimize flooding and erosion caused by larger precipitation events that are endemic in the hilly Želivka River watershed. The nitrate levels in groundwater are currently exceeding 75 mg/L, rendering groundwater useless for water supply but attractive for irrigation that would allow eliminating nitrogen containing industrial fertilizers.

b. The research will also focus on enumeration of benefits to the agricultural cooperatives and smaller farming communities derived from implementation of best management practices and managing the community as an ecovillage. Other sustainability ecovillage features such as production of biogas from the treatment sludge (the community is sewered and has a well functioning SS, BOD and nutrient removing plant) combined with the energy organic solids (produced on converted hazardous lands and stream buffers) and excess manure. Solar panels, wind turbines and geothermal energy from pumped groundwater may also be tested.

c. Before the practices are implemented the project will establish and begin a monitoring program that will continue during and after implementation.

d. The community will then serve as a demonstration site for education of agricultural engineers, agronomers and other stakeholders, including the public, from the Želivka watershed and elsewhere.

V. Economic Research

Economic research will focus on enumerating the benefits and social costs, both tangible and intangible, of the plan to convert the Želivka River watershed into an ecoregion and the cost if the current trend towards worsening of the ecology of the surface and groundwater resources is allowed to continue. The research will also develop payment mechanisms and types of contracts between the users of water in Prague and the farming communities and cities in the watershed based on both polluter pays and benefit received principles.

The value of intangible costs and benefits can be found, for example, using Contingent Valuation Methods (scientific surveys of populations in Prague and the Želivka River watershed) which will provide information on monetary Willingness to Pay (WTP) for the benefits and avoidance of the adverse effects expected for no action or incomplete action alternatives (Mitchell and Carson, 1989).

Developing the Plan

The plan should be developed using the principles of the Sustainable Integrated Resources Management. Under the IRM concepts, used water is a resource and water saving is a benefit. IRM also considers energy savings, alternate energy sources, conversion of waste into energy, and dramatic reduction of GHG emissions. The plan will

I. **Calculate the Loading Capacity** of the reservoirs, streams and groundwater resources for nutrients and other key pollutants – the decision parameters.

II. **Develop the alternatives** to achieve the goals and resulting in loads smaller (by a margin of safety) than the calculated loading capacity for the decision parameters, The goal of these activities is to develop implementable concepts for eco-communities and eco-agriculture that would minimize the nutrient loads and guarantee good and sustainable water quality in the water supply system, conserve water in the communities and agrosystems, sequester carbon, and reduce also GHG emissions.

   b) Alternatives and development of water, used water, urban runoff and solids management in urban ecocities and ecovillages

   c) Alternatives for small unsewered settlements using natural systems for used water disposal and reclamation

   d) Crop selection, fertilizer management to bring the excess waste nutrients to zero, erosion control and soil conservation as well as reduction of delivery of nitrogen and phosphorus from the source are to the receiving water via surface (runoff) and subsurface (shallow groundwater) pathways.

III. **Development and design of barriers** including conversion of currently drained former wetlands

   a. Disconnection of old drainage (melioration) systems and converting riparian zones into wetlands, selecting vegetation with a focus on vegetation energy (methane) production by digestion with treatment plant sludge and other organic solid waste

   b. Using the R & D model developed in the research Task III-c-i evaluate feasibility and design irrigation system using high nitrate groundwater for irrigation and considering, if necessary, groundwater recharge with highly treated and denitrified urban effluents and/or low nitrate (treated) urban and highway runoff

   c. Using modeling system analysis and physical models (Task II-c-iii) to design the digestion system for sludge and organic solids produced on converted lands (grass, woodchips) and organic solid (food waste, vegetation, leaves and debris, shredded woodchips from tree pruning) and develop a system for production, sale and distribution of biogas either in the form of a gas fuel or electricity. Such a system will be first developed as a demonstration project in Obrataň and then expanded to the entire Želivka River ecoregion.

IV. **Develop a plan for restoring already damaged and overloaded water bodies**, especially the reservoirs.

The planning process for already impaired reservoirs, i.e., they are already in an eutrophic or even hypertrophic state, needs additional components because, most likely, they cannot be remedied simply by reducing the loads of pollutants (N an P) to the borderline level of the criterion in the water column. This is because the nutrients and the encapsulated and filamentous cyanobacteria are already in the sediment in large quantities (several orders of magnitude greater than in the water column during the algal bloom) and have sufficient nutrients available for their survival and even growth. Hence, reducing the loads below the loading capacity will not have an immediate effect and it may take years before significant effects are noticed. The restoration process must be comprehensive and must include actions that would first immobilize and then remove the nutrients stored in the water body.

V. **Develop a land use plan for the Želivka ecoregion**, logistic of its organization and management

This would be the most important output of the plan which would be a computerized land use plan on a few hectares scale outlining

i. the land uses for agricultural crop production, limits on fertilizer use, hazardous lands for conversion to wetlands and upslope erosion minimizing lands, substituting energy woods and vegetation

ii. recommended best management practice on lands including reduction or elimination of fertilizer use

iii. pollutant pathways and barriers to the delivery of pollutants from the source areas

iv. sustainable drainage and drainage patterns in agricultural zones

v. sustainable drainage in urban areas including flood plains and green environmental corridors with flood storage, ponds and wetlands, elimination or minimization of underground fast urban runoff conveyance

vi. energy (biogas) production facilities, their location and capacities based on available organic biomass

VI. **Develop a financial plan** that would establish the payments from the users (including government participation) and level of subsidies to the polluters, recognizing the fact that the polluters do not have a right to pollute but may not be deriving benefits of clean water. This implies that if the polluters receive benefits from the plan such as a reduction of the fertilizer application, these benefits should be subtracted from the subsidy.

VII. **Establish Stakeholder Interaction.** Many stakeholders such as the Municipal governments of Prague, European Community, governors (hejtmans) of the Central Bohemia and Highlands (Vysočina) Regions, local governments of communities in the proposed ecoregion, Watershed Management Agency for Lower Vltava River (Povodí Vltavy), Clean Želivka and Clean Sázava NGOs, Veolia, Ministry of Agriculture and Ministry of Environment, etc. will be a part of this grand effort to save Želivka and its water for Prague and, in doing so, convert the entire region into an exemplary and demonstration region for the entire nation and European Community. The plan must establish:

a. The stakeholder organization and interaction with the research and planning teams

b. Communication with stakeholders and general public by conferences, workshops, hearings, presentations in schools and community centers, web site, magazines and other printed materials, and scientific publications to professionals

c. Establish an intergovernmental committee structure for oversight

d. Develop a web system for stakeholder and people access to information and data (see Task III d and e on page 25)

e. Providing education

   i. *To the farming communities.* Farmers and cooperative managers must be continuously educated about the need for the change towards eco-farming and about the benefits that, in many cases, would be greater than the cost of implementation of the BMPs. The plan should suggest establishing by the regional government an agricultural extension program where district specialists would advise farming communities, using the results and maps developed by the plan, on the crop varieties, fertilizer minimization (or elimination; e.g., by using high nitrate groundwater for irrigation), best management barrier forming practices, subsidies for conversion, management and energy biomass production from hazardous lands and maximizing income using sound ecologically beneficial farming practices.

   ii. To the urban developers and planners. Planner and developers, including road and freeway builders must be educated about the diffuse pollution potential their activities are causing, about the performance criteria on their activities and penalties for violation. Developers should be strongly encouraged to include in the design and development energy and water saving buildings, commercial shopping centers, offices and other facilities. Each cubic meter saved by water conservation represents almost twice as much clean unused flow in the watershed system.

VIII. **Implementation plan**

The implementation plan is a mandatory component to guarantee the success of the proposed actions. A TMDL implementation plan should contain the following components (Novotny, 2003):

a) Implementation/control actions and management measures
b) Time line, including interim milestones for implementing the control actions
c) Reasonable assurances that the plan will be implemented in the time line
d) Legal framework under which the plan will be carried out
e) Estimation of the time it will take to attain the water quality goals
f) Monitoring and/or modeling plan designed to determine the effectiveness of the implemented control actions
g) Incremental milestones for the pollutant for which the limitations and criteria are being established for determining whether the control actions and/or management measures are meeting the water quality standards

h) Description of the process for revising the plan if the milestones of compliance with the water quality standards are not being met.

Conclusions

Protection of the Švihov Reservoir and providing water for the Prague water supply system requires comprehensive and symbiotic planning and research processes that include (1) watershed management leading to a significant reduction of nutrient loads from point and non point sources, (2) establishing protective buffer zones around the reservoirs and tributaries, (3) in-reservoir nutrient management. The planning process is tiered and hierarchical and will require use of sophisticated land based and water quality models.

The major problem threatening the reservoir is either existing or potential occurrence of nuisance algal blooms of blue green algae (cyanobacteria). The nutrient levels in the tributaries are already at levels that would indicate hypertrophic potential. The first step to prevent these nuisance blooms and keep water quality acceptable for water supply is to define appropriate water quality standards for nutrients, most likely for both phosphorus and nitrogen.

Because of uncertainty in models and estimates, the planning process and watershed and water body management must be adaptive, recurrent and include common sense immediate actions and also long term plans.

Figure 11 is a schematic outline of the activities and tasks leading to a conversion of the Želivka watershed into an ecoregion.

Collaborating institutes and consultancies

University (Coordinator of Research Activities)

University of Chemical Technology, Department of Water Technology and Environment, Prague, (Professor Jiří Wanner)

Czech Academy of Science Centers

Hydrobiological Institute, CAS, České Budějovice (Associate Professor Josef Hejzlar)

Centre for Cyanobacteria and their Toxins, CAS, Masaryk University, Brno (Associate Professor Blahoš Maršálek) ;

Other research institutes

VÚRV, ÚZEI, VÚV TGM, AGRI

NGOs

Čistá Želivka, Čistá Sázava

Ministries

Ministry of Environment, Ministry of Agriculture

Agencies

Watershed Management Agency for the Lower Vltava River, OPS Želivka, Veolia

International Experts

Professor Vladimír Novotný, Northeastern University, Boston, MA, USA (International Coordinator);

Professor Ferdinand Hellweger, Northeastern University, Boston, MA, USA (Water quality modeling and GIS expert)

Ray Earle, Watershed manager and Dublin City Council Member, Chair, IWA International Group of Specialists on Diffuse Pollution and Eutrophication);
Brian Darçy, Diffuse Pollution Coordinator, Scottish Environment Protection Agency, Edinburgh

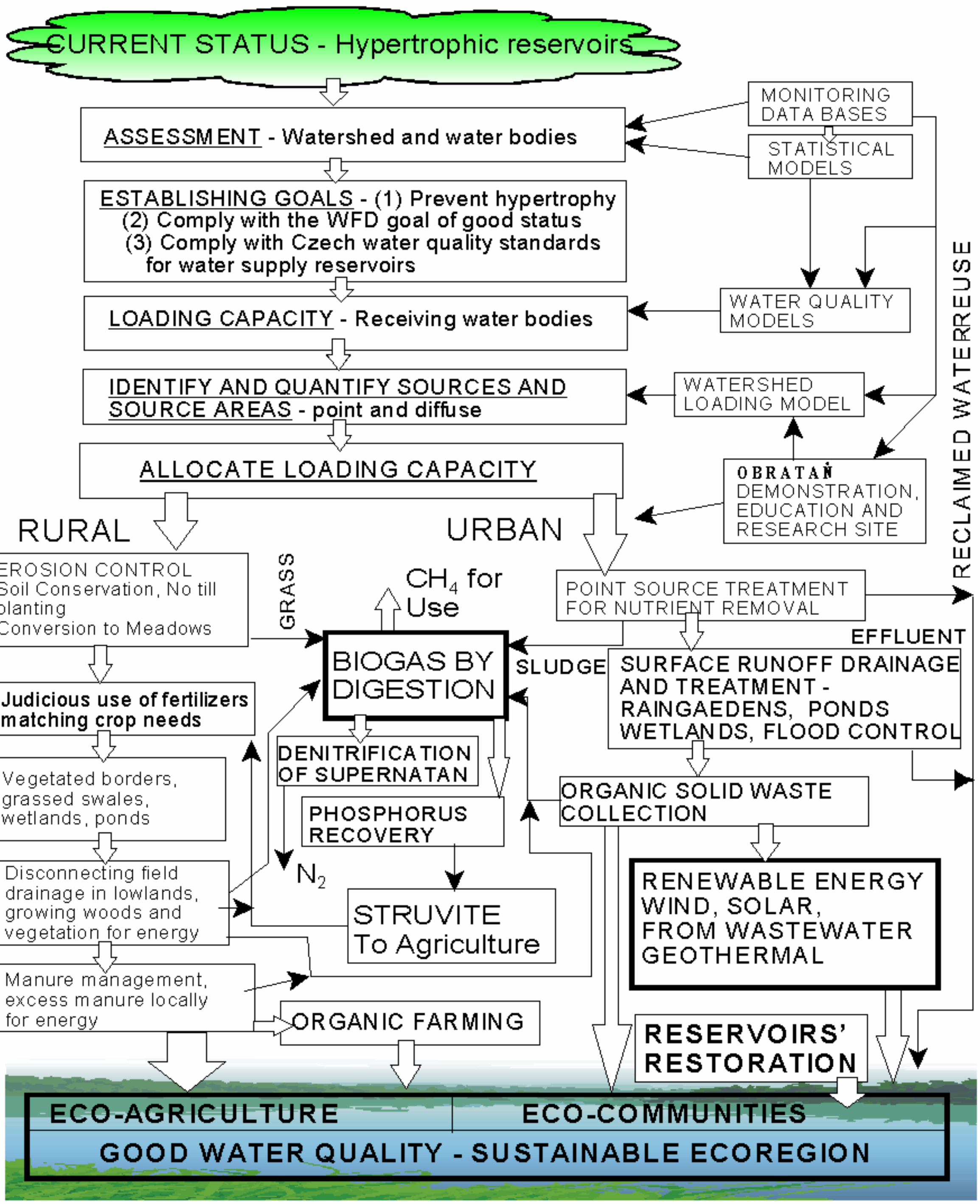

Figure 11 Schematic summary and flow chart of activities leading to good water quality and sustainability of the Želivka River watershed and water supply for Prague

Appendix – Clarifying notes on the R & D and the Plan

Task I Assessment and Monitoring

The current monitoring program has to continue and be expanded. The monitoring program must include measuring concentrations and flows at the measuring profiles.

- Watershed monitoring
  - *Monitoring of point sources* is a part of the continuing assessment of the treatment efficiencies and effluent discharge loads of the key parameters such as BOD, COD, nitrogen components, phosphorus, suspended solids, and toxic substances;
  - The monitoring program in the Želivka River and tributaries has been conducted now for a number of years and has produced a large volume of valuable data of concentrations. The program must also measure flows.
- Monitoring of water quality in the Švihov and other reservoirs

  The Sedlice Reservoir is a research water body for the Czech Academy of Science which produced a number of excellent research reports and articles.
- Monitoring and research must and will be continuous and it must be synthesized. The data are used for
  - Ascertaining the water quality situation in the watersheds and its reservoirs and the degree of impairment
  - Investigating the trends
  - Investigating causes and thresholds of eutrophic and hypereutrophic conditions
  - Developing and using models for:??????
  - Calculating loads of nutrients from diffuse sources
    - Describing attenuation of the nutrients in the receiving water bodies, also considering point source inputs
    - Describing algae development and shifts (e.g., green →blue green) in the reservoirs that would consider water column, sediment, morphological characteristics and hydrology of the reservoirs
    - Ascertaining the effect of the planned short and long term actions
- **Community/subwatershed monitoring and modeling (Obrataň) (Task IV)**
  - Obrataň was selected for detailed monitoring and testing the effects of the proposed best management practices both on agricultural and on a small urban scale. Obrataň is a community of about 800 people mostly employed in agriculture. It has a well functioning and efficient wastewater treatment plant that removes efficiently both nitrogen and phosphorus in addition to good removal efficiencies for BOD and suspended solids. On the other hand, groundwater contamination is extremely high (over 15 mg/L of nitrate N) and farming has severe problems with agricultural erosion.

- A GIS based model of the subwatershed will be developed that will be calibrated and verified by the monitoring of several storms. The model will then be used to test the effect of best management practices on the loads of sediment, nutrients and other parameters from the subwaterhed.

  In the second phase, the most efficient best management practices will be implemented. Such BMPs will include soil conservation and anti erosion measures on fields, in the drainage system and manure management as well as judicious nutrient applications and management. In addition, some hazardous lands and stream riparian zones/buffers will be converted to wetlands where grass and fast growing woods and brush will be planted that will then be converted to methane biogas along with the sludge from the treatment plant.

Obrataň will become a demonstration community and watershed.

Watershed model development will be a continuing process to be carried out at the university, academy centers, and by the planners in a cooperative effort. Data and knowledge should be synthesized and directions of the research should be regularly updated. This will require coordination between the research centers, the water utility, watershed managers and the stakeholders.

Task II Define the goals – standards for the Švihov Reservoir

Define Standards. The adaptive planning process begins with a definition of goals and pertinent corresponding standards. The EU Water Framework Directive requires to define an ecologic potential of the impaired water body that would be based on reference conditions and its use. This is a prerequisite of a basin wide water quality management plan. Both nitrogen and phosphorus should be considered. Establishing the standards is not easy and the final standards may be a compromise that in some cases in the US was achieved as a result of litigation. For example, in order to control eutrophication in thirteen reservoirs providing water supply for the City of New York, developing Total Maximum Daily Load (TMDL) standards for these impoundments was in the 1990s a subject of a long litigation between the environmental stakeholders represented by the Natural Resources Defense Council (NSDC) (the plaintiffs) and the agencies responsible for the implementation (US Environmental Protection Agency). Because water from the Švihov Reservoir is treated, the first standard could be suggested as < 20 μg P/L during the vernal growing season but its magnitude would have to be established and confirmed by the scientific research and modeling. If the reservoir is already hypertrophic this standard would not, however, bring the water quality into the mesotrophic zone.

In the Czech Republic, water quality standards for water supply reservoirs and other surface water bodies are defined by the state water quality regulations. For streams, the water quality and standards are divided into five classes, class one being the best and last?? five the worst. A "good ecologic status" is defined as achieving class three or better.

Task III - Models and Ascertaining Loading Capacity of the Reservoir

The land based models will calculate and extrapolate the loads while the water quality models are used to determine the *Loading Capacity* of the water body for the pollutants, i.e., nitrogen and phosphorus. If the Loading Capacity minus a Margin of Safety (=Allowable Load) is less than the load to the water body, the allowable load is then allocated among the sources and the loads are then restricted to the allocated load. The Loading Capacity is determined by a water quality model using the standard as a limit.

However, the behavior of the cyanobacteria bloom development is defying the rules and concepts of the traditional Vollenweider eutrophication (1975) model. Existing water quality models (e.g., WASP-Eutro; AQUATOX, QUAL-2E) typically do not explicitly consider cyanobacteria. If they do include them, they do so in a simplified manner, as a separate state variable in multi-species or –class models with different parameter values to reflect their unique behavior. The settling velocity can be reduced or set to zero to account for vertical motility, the nitrogen half-saturation constant can be set to zero to account for the nitrogen-fixing ability, and the grazing rate can be reduced or set to zero to account for grazing resistance (e.g. Lung and Paerl, 1988; Robson and Hamilton, 2004). However, although the importance of resting stages in the sediments has long been recognized, it is not included in eutrophication models. This severely hinders our ability to develop accurate TMDL (Total Maximum Daily Load) or Water Framework Directive targets for water bodies that experience cyanobacteria blooms, let alone predict when these blooms might take place. *Hypertrophic conditions*, created by cyanobacteria blooms, are also different from eutrophic or better conditions and will require approaches other than just lowering the inputs of nutrients into the impoundment.

Currently, excellent and cutting edge research is being conducted in the laboratories of the Czech Academy of Science in Brno and České Budějovice. New models are being developed such as Agent-Based Model (ABM) that better describes the lifecycle stages of the cyanobacteria (Hellweger et al., 2008). However, while ABMs have been used in other fields – economics, human behavior, traffic, they have never been in this context (eutrophication modeling) until recently. The dominant strength of the ABM agent-based approach is understandable, describing the life cycle of a large number of agents that behave in a prescribed manner when responding to multiple stresses and stimulants (nutrients). An agent-based model accounts for intra-population variability. This is one of the reasons why agent-based modeling is rapidly gaining popularity in ecological modeling of higher trophic levels, where the complex behavior of individual microorganisms has long been recognized as important. With an increased realization and understanding of the complexity of microorganisms, the extension of agent-based modeling to microorganisms is a natural progression.

Task VI – Development of a Tiered and Adaptive Plan

WFD (TMDL) planning process is either continuous or repetitive. Because of uncertainty inherent in the outcomes of the models the process is iterative and connected to the development of the models. As more data is collected and actions are implemented, models are improved and finely tuned which will result in a reduction of the Margin of Safety. The committee of the US National Research Council on TMDL (Committee, 2002) recommended the planning process *contains immediate common sense actions* and *long term actions*.

Immediate common sense actions can be implemented in a relatively short and fixed time span after the beginning of the implementation process. Examples include:

- *Implementing immediately and fully a ban on phosphate detergents.*
- *Reduction of effluent phosphorus from wastewater treatment plants to less than 1 mg/L.* This can be done simply and quickly by adding precipitating chemicals into the

activated sludge tank; the chemical is typically a byproduct of iron and steel manufacturing.

- *Reducing nutrient losses from agriculture by rapidly implementing soil conservation best management practices and stopping overfertilization.*
- *Implementing wetland treatment of wastewater in rural communities and controlling loads from feedlots and animal husbandry.*

In many cases, common sense actions are beneficial not only to the users of the potable water but also to those causing the pollution. For example, treating wastewater by wetlands provide habitat for water fowl, controlling loads from feedlots saves money to farmers (cooperatives) on purchasing more fertilizers. Similar savings can be achieved by soil conservation practices and proper matching of fertilizer use with plant needs.

After a certain but not long time period, the monitoring program should focus on ascertaining the effect of the short term actions on water quality and trophic status. Meanwhile the process of continuous research will lead to better understanding of the eutrophication process and will lead to better models.

Examples of longer term but still common sense actions are:

- *Conversion of existing and building new wastewater treatment plants for larger communities that would be based on Bardenpho technology.* Such plants remove both nitrogen and phosphorus and use less energy than the conventional activated sludge wastewater treatment plants. Adding more advanced wastewater treatment technologies based on microfiltration can attain effluent water quality commensurate to water quality of a relatively unpolluted or mildly polluted receiving surface water body.
- *Elimination of combined sewer overflows and implementing surface drainage with BMPs for urban and highway runoff.*
- *Land use changes by acquiring more land surrounding the water bodies, including tributaries, and restoring or building riparian wetlands.* Forested uninhabited watersheds provide the best protection and yield best water quality. However, vegetated buffer strips (Figure 6) or restored wetlands (Figure 7) are also very effective for removing nitrate-N (more than 90 %) and phosphorus (about 50%). Wetlands are more efficient than traditional ponds but a wetland-pond combination provides the greatest benefits. Constructing wetlands in these zones or planting vegetation that is efficient for removing pollutants could also be effective. The Czech Republic has a tradition with implementation of "passive" buffer and protection zones around the reservoirs but not necessarily around the tributaries where the pollution from diffuse sources enters the surface water body.

The TMDL report of NRC (Committee, 2002) recommends a 5-6 year evaluation cycle for assessing the efficiency of the measures that have been implemented and evaluating the accuracy and state of the art of the models, future trends, etc.

Attaining the goal of an already impaired water body

Olem and Flock (1990) and Novotny (2003) describe methods for evaluating and controlling symptoms of eutrophication and hyper-eutrophication. They have been for the first time used comprehensively in the restoration of Lake Delavan in southern Wisconsin. The obvious step is the above described process of reducing nutrient inputs from the watershed and reducing their availability in the water body which includes various watershed management and in-reservoir treatments. The relative merits and effectiveness of each depend on the relative importance and the level of the nutrient source relative to the impact on the impoundment as shown on Figure 5. Watershed management reduces external nutrient loadings while internal reservoir treatment procedures eliminate internal nutrient sources and/or their availability/mobility. In general, in-reservoir treatment, without reducing external sources, has only a short duration effect. In conjunction with a plan for improved watershed management, in –reservoir treatment may serve to accelerate the process of the water body recovery. The following types of in-reservoir treatments have demonstrated to reduce nutrient availability effectively, at least in some circumstances:

1. *Chemical precipitation of phosphorus with aluminum or iron salts*
2. *Sediment removal*
3. *Aeration*
4. *Sediment oxidation*
5. *Fish management*

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