Environmental History of the German Elbe River-interactions among the ecological, economic, and political environments

M. S. Adams[a, d, f], B. Hale[b], T. Gaumert[c], M. Bergemann[c], B. Ohm[a, e,] C. D'Elia[g].

[a] Nelson Institute for Environmental Studies, University of Wisconsin, Madison 53706 USA, E-mail msadams@wisc.edu, and bwohm@wisc.edu

[b] Franklin College Switzerland, Via Ponte Tresa 29, 6924 Sorengo (Lugano), Switzerland. E-mail bhale@fc.edu

[c] Wassergütestelle Elbe, Wassergütestelle Elbe, Neßdeich 120-121 D-21129 Hamburg. E-mail wge@arge-elbe.de

[d] Corresponding author

[e] Department of Urban and Regional Planning, University of Wisconsin, Madison, WI 53706 USA

[f] Department of Botany, Birge Hall, 430 Lincoln Drive, University of Wisconsin, Madison 53706 USA

[g] University of South Florida-St. Petersburg

Abstract

The political, economic and management history of the Elbe River is reviewed in relation to environmental changes that have occurred over time in this major European river. The historical changes from the 19th century to the present in flood plain area, fisheries, environmental quality of the river, and institutional management regimes including their policies are reported. In particular, emphasis is placed on evaluation of post World War II changes in contaminants loading to the river, both during and after the period of Communist-government dominated regimes in the middle and upper parts of the Elbe catchment. Topics involving water quality management in the Lower (tidal) Elbe are also treated in some detail. Comparisons of some of the historical management issues or the Elbe as a whole are made with selected North American river systems.

Environmental History of the German Elbe River-interactions among the ecological, economic, and political environments

Introduction

The Elbe is an important river of Central and Northern Europe, and along with the Rhine and the Danube, is one of the three main rivers within Germany. The character of the river has changed dramatically since the mid-19th century, reflecting changes in the river channel and the watershed. Economic events, such as industrialization with its associated pollution and the development of the river as a shipping channel have interacted with political events, such as the world wars and the rise and fall of Communist Eastern Europe to alter dramatically the natural hydrological, geo-morphological, and ecological conditions of the river. In this paper, we examine some historical factors (industrial, governmental) impacting the environmental status of the river (fisheries and water quality). We pay particular attention to the region of the Lower Elbe, which integrates changes from the entire watershed. In closing, we consider some international comparisons with three other rivers.

The Elbe Watershed

The Elbe originates in the Giant Mountains (a.k.a. Krkonose in Czech, Riesengebirge in German) of the Czech Republic and flows 371 km before crossing into the German State of Saxony (*Sachsen*). From there, it travels an additional 727 km before emptying into the North Sea at Cuxhaven, Germany (Figure 1). The river is typically divided into three main sections: the Upper Elbe, which extends from the source in the Giant Mountains to river-km 96.0 at Schloss Hirschstein in Germany; the Middle Elbe, which runs further to river-km 585.9 at Weir Geesthacht; and the Lower (tidal) Elbe, which completes the course to river-km 727.7at Cuxhaven. The total length is 1094 km (International Commission for the Protection of the Elbe 2005). The Elbe catchment is 148 248 km^2, with two-thirds in Germany, one third in the Czech Republic, and some very small areas in Poland and Austria (International Commission for the Protection of the Elbe 2005). The catchment of the Lower

Elbe (estuary) is 13 255 km^2. The discharge rate of the Elbe at the German-Czech border averages 311 cubic meters per second, and at the entry to the North Sea 860 m^3 s^{-1} (Bergemann 2006).

Since the year 1100 the area of natural flood plain has been reduced from 620 000 ha to only 84,000 ha, so the present area that can be naturally flooded is only 14% of what could be available at present (ARGE ELBE 2006, International Commission for the Protection of the Elbe 1998). While the main channel of the Elbe is extensively dammed by impoundments within the Czech Republic, only one dam blocks the river channel in Germany at Geesthacht, located above Hamburg, 141 km upstream from the confluence with the North Sea. The tributaries to the Elbe (Figure 1) are extensively dammed in both countries (172 dams in Germany and 120 in the Czech Republic); these structures also impact the environmental quality of the river system as a whole. The channel of the Elbe has been extensively modified for shipping through the widespread use of groynes (wing-dams). Wirtz (2002) has estimated that "during the 19th and early 20th century, 7,000 groynes were constructed to make the River Elbe in Germany navigable. Of these, 1200 (as of 2002) were broken and due for repair." While these structures have increased the reliability of commercial transport along the river, they significantly alter the natural functioning of the river.

The political history

The Elbe River has been influenced by a complex geo-political history, which has had profound impact on the environmental quality of the river. The layers of governing institutions affecting the management of the river are numerous. We nonetheless provide a brief overview of the institutional structure of the river's management needed to understanding the river's environmental history.

In the mid-1860's, the Elbe flowed through a variety of political landscapes (Gaumert 2000). The uppermost sections of the Elbe fell within the Kingdom of Bohemia, part of the Austro-

Hungarian Empire. When the river crossed into what is now Germany, it flowed first through the Kingdom of Saxony, and then through the Kingdom of Prussia. The short stretch of the river that flowed through the Principality of Anhalt (near Dessau) would become important in later years for conservation, as it contains the area that now forms the core of the river-landscape Elbe Biosphere Reserve. Further downstream, the left bank of the Elbe contained the province of Hannover, while the right bank bounded the duchies of Mecklenburg-Schwerin and Lauenburg, the City-State of Hamburg, and the Duchy of Schleswig-Holstein, respectively. From 1871 through to the end of WWI, all the German regions merged into the German Reich. Following WWI and through WWII, the former Austro-Hungarian controlled (upper) stretches of the river fell under control of Czechoslovakia, and the German sectors first under the Weimar Republic and then the Third Reich.

From 1945 - 1990, the Upper and Middle Elbe stretches (i.e., the uppermost 840 km of the river) were controlled and managed by the Communist regimes of the former Czechoslovakia and German Democratic Republic ("East Germany", i.e. the Deutsche Demokratische Republik, or DDR). The Lower Elbe was under the control of the Federal Republic of Germany ("West Germany", i.e. the Bundesrepublik Deutschland or BRD). Following the collapse of the Eastern Bloc in 1990, the river came under control of primarily but not exclusively the governments of the Czech Republic and the re-unified Germany.

Management Structure

The current management structure of the river and its watershed starts at the uppermost level with the European Union (EU), of which the Czech Republic and Germany are both members (Figure 2). The European Water Framework Directive (*Europäische Wasserrahmenrichtlinie*) requires countries to set ecological standards for water quality and achieve a "good" level by 2015. Further, the Habitats Directive (*Fauna-Flora-Habitat Richtlinie*) requires a certain level of protection for protected areas and endangered species.

The next level of management comes from the national governments of the Czech Republic and Germany. Since the catchment of the Elbe also includes small parts of both Austria and Poland, are also involved in the Elbe's management. The Czech Republic's strong central government is extensively involved in the management of the river, while the German federal government has distributed somewhat more authority to the individual Federal States (*Bundesländer*) bordering the river (seven) and those in which the river's catchment is located (three). The federal government of Germany has a role in managing aspects of the river and certain of its tributaries as “federal waterways” (*Bundeswasserstraßen*), as do the Federal States (e.g., the *Schifffahrtsverwaltung Hamburg*, which manages shipping within the State of Hamburg). Other federal and state institutions play a regulatory role with respect to economic issues pertaining to the river. The Federal States have coordinated their efforts through establishment of the *ARGE-Elbe* (a working group for the monitoring of the Elbe water quality) and its research and monitoring facility, the Wassergütestelle Elbe.

To help manage this complexity and coordinate management efforts, the various authorities in the whole river's catchment have formed the International Commission for the Protection of the Elbe (the *Internationale Kommission Schutz der Elbe* or *IKSE*). Management of protected areas along the river is both international and national in scope, with an important example being UNESCO's Biosphere Reserve Flusslandschaft Elbe. According to UNESCO-MAB (2007) “this biosphere reserve now covers a long extent of the Elbe River, extending over five German Länder (Brandenburg, Mecklenburg-Vorpommern, Niedersachsen, Sachsen-Anhalt and Schleswig-Holstein). The Flusslandschaft Elbe Biosphere Reserve represents one of the biggest contiguous floodplain forests in Central Europe”. The Reserve length along the river exceeds 400 km.

In 2003, the Elbe River Region Association (FGG Elbe) was formed, for the purpose of insuring that the European Water Framework Directive would be established in the German part of the Elbe catchment. Within this Association, there is participation from all ten of the relevant Federal States of Germany. These are seven Federal States of the ARGE-Elbe (those bordering the river) and the three within the catchment but not bordering the river.

Environmental changes in the Lower Elbe (the Elbe estuary): 1840-2007

The river as a whole, including its estuarine sector, maintained a relatively pristine condition until the middle of the 19th century. Beginning with the expansion of Hamburg Harbor in the Lower Elbe in 1840, engineering projects began drastically altering the Elbe including within the estuary (Lower Elbe). These included channel dredging, channel grading, and construction of levees. During the same period, after the great fire in Hamburg, two projects planned by Lindley were constructed. One was a central drinking water system which supplied Hamburg with unfiltered water from the Elbe; the other was a central sewage system for the city. In 1892, the proximity of the sewer outlet to the drinking water inlet led to a cholera epidemic (Adams, Kausch, and Gaertner 2000).

Improvements in the condition of the river, such as the re-appearance of fish species absent from the Elbe for 100 years and the reduction in water pollution (Adams et al. 2001) can lead to misunderstood conclusions regarding the environmental health of the Elbe. The Lower Elbe, in particular, suffers from the many interventions that have occurred to improve and maintain its economic functions, but that have transformed the river into a channelized, unbranched system. One major intervention has been a step-wise deepening of the shipping channel in the estuary from 4.5 m in 1843 to 14.5 m below the mean low-water level in 1999 (Bergemann 2006). The current has weakened in the smaller branches of the estuary, and is now focused in the shipping channel. This, combined with the construction of dikes increasingly closer to the river, has increased the tidal range at Hamburg from 1.8 m in 1843 to 3.65 m in 2004. Tidal pumping has also become a significant factor: during periods of low freshwater discharge, the flood (upstream) current velocity is higher than that of the maximum ebb current. This increased upstream current transports sediment upstream, which often deposits in the side channels of the Lower Elbe. The impact of increased sedimentation combined with the filled-in, deserted harbor basins in Hamburg has reduced flood storage volume in the upper estuary. The changes in tidal current have shifted upper limit of brackish water upstream 25 km during the last 50 years; the high-turbidity zone has also shifted upstream. Both of these changes greatly modify habitats for fish and other aquatic species.

Storm floods now lift water levels of the estuary up to 4 m above average flood level (Bergemann 2006), when strong north-west winds blow up through the funnel-like opening of the estuary to the North Sea. Although the construction of levees is a 1,000 year-old practice along the Elbe estuary, levee construction has changed since the 1970's with the newest and highest levees lying very close to the river banks. This has shortened the dike line and cut off some of the river branches; additionally some dams have been built near their mouths to the Elbe and these are closed at flood stages. All of these changes have resulted in loss of active floodplains. This loss along with the decreased friction in the deepened main channel increases storm flood danger, which are further aggravated by rising sea level and greater number of strong storms.

The Lower Elbe also suffers from seasonal (summer) oxygen deficits that now occur annually downstream from Hamburg that results in massive fish kills in the estuary. The causes of these events are several-fold. First, nutrients in the Middle Elbe produce mass concentrations of algae that die in the waters near Hamburg. Secondary pollution resulting from rapid decay of algae near Hamburg alone now equals 50% of the level of pollution that used to occur from untreated wastewater (Gaumert and Bergemann 2007, Bergemann 2006). The situation is exacerbated by slow transport downstream from Hamburg, which permits high levels of bacterial degradation of the algal mass, which depletes oxygen levels of the water column. This mass die-off of the suspended algae is a result of the great water depth needed for the large container ships, which means the light supply at depth is insufficient to insure a positive photosynthesis balance.

Changes in water quality of the German Elbe: 1986-2005

In the post-WWII period through the 1980's, the Elbe was considered one of the most polluted rivers in Europe. The pollution primarily resulted from effluents from the industrial economies of the East German and Czechoslovakian industries upstream. With the collapse of the Eastern bloc economies, the water quality situation in the Elbe improved dramatically. The data in Figures 3-5, which derive from the annual report (ARGE ELBE 2005), show substantial reductions in the load of most nutrients and pollutants carried by the Elbe at three locations in Germany between 1986 and 2005 (Table 1). The years 1986 and 2005 were selected by the ARGE Elbe for this analysis partly due to the relatively comparable flows of the river during these two years (715 and 670 cubic meters per second at Neu Darchau in 1986 and 2005, respectively). The overall reductions from 1986 to 2005 are a clear demonstration of the changes in material loadings to the river and reflect trends seen in previous studies related to the collapse of the Eastern Bloc economies of the former East Germany and Czechoslovakia (Adams et al. 2001, Adams et al. 1996).

Table 1: Water quality monitoring stations along the German Elbe

Station	**Km***	**Description**
Schmilka	4.1	in Saxony, just downstream from the German-Czech border
Schnackenburg	475. 5	in Lower Saxony where the river crossed the border from East (GDR) into West Germany (FRG)
Seemannshöft	628.9	in the tidal Elbe at Hamburg

* measured in Germany from the border with the Czech Republic.

The reductions are consistent across most transported materials and sampling stations. Two exceptions stand out: suspended solids at Seemanshöft (Figure 3) and beta-hexachlorocyclohexane (β-HCH) at Schnackenburg (Figure 5). Suspended solids at Seemanshöft have increased by 100%, compared to the reductions observed upstream at Schmilka and Schnackenburg (ARGE ELBE 2007). This surprising situation is associated with the high phytoplanktonic production in the Middle Elbe. Algal production in the Middle Elbe is higher than previously at least in part due to the reduction in toxic materials in the water column, despite the large reductions in nutrient loading (Gaumert and Bergemann 2007). As the algae travel downstream and start to decay, they encounter flow resistance around the city of Hamburg due to the previously discussed tidal pumping. Thus, the decaying algae remain in the vicinity of Hamburg for longer periods of time, increasing the levels of suspended materials in this stretch of the river, as well as depleting the water of dissolved oxygen.

The increase in β-HCH is related directly to the downstream transport of this chemical following the dredging and cleanup of the formerly heavily polluting East German chemical processing plant of I. G. Farben, at Bitterfeld/Wolfen. I. G. Farben, with its many plants (including Bayer, BASF, Agfa und Hoechst), was until 1939 the world's largest chemical cartel (Sutton 2000). In contrast to the alpha and gamma isomers, □-HCH is also relatively unaffected by degradation by aerobic bacteria.

Chloride transport in the Elbe has also experienced an interesting history along the Elbe, peaking in 1967 at 5.6 x 10^6 t/a (to date unpublished data, calculated by author M. Bergemann on the basis of 52 values measured in 1967 at Teufelsbrück, downstream of Hamburg harbor close to Seemannshöft). This corresponds to an overall salt transport of 16 x 10^6 t/a, a rather substantial increase from 1850, when salt transport at Seemannshöft measured 1,000,000 t/a. In 1986, chloride transport had already declined from its 1967 level to 4.1 x 10^6 t/a, and has experienced even greater decreases since then (Figure 3). The reasons for the decrease likely relate to the closure of facilities related to the mining industry and changes in production technologies.

Historical trends in the Elbe fisheries since 1840

Domestic sewage and industrial wastes were already affecting fisheries in the 19th century (Von dem Borne 1883). Many investigations followed at the turn of the century on the most important species for the fishery: the sturgeon, the salmon, and the eel. The decline of the sturgeon population was attributed to over-fishing (Blankenburg 1910, Ehrenbaum 1913, 1916) whereas deterioration of habitat through construction projects and an increasing pollution with sedimentary deposits were thought to be the major factors causing disappearance of the salmon from the Elbe (Albrecht 1960, Bauch 1958, Lelek 1976, Mann 1968). As populations of salmon and sturgeon declined, the eel became the central object of fishery investigations. In addition, fish diseases and local population decimations due to pollution continued to be important.

When the herring and sprat catches in the Outer Elbe (the area of the North Sea into which the Elbe flows) decreased, the sea-based fishermen turned their efforts to catching butt (common name for flounder in the Elbe Estuary) at the mouth of the Elbe (Mann 1968, Riedel-Lorje and Gaumert 1982, Schnackenbeck 1926). The Lower Elbe fishermen feared that this would lead to over fishing, resulting in a long-lasting dispute between these two groups. A major problem contributing to the controversy was the specific identification of the Elbe butt and the flounder. This question could not be resolved until Ehrenbaum (1914, Ehrenbaum 1916) and Schnakenbeck (1926) confirmed the two to be the same species (*Platichthys flesus*).. Government regulation became important in 1917 when the Prussian Fishery Statute set limits on the butt catch but this did not solve the social issue of competition between the two groups of fishermen

Immediately following WWII, fisheries activity in the Lower Elbe decreased greatly and the fishing activity of the Germans in the North Sea and the Atlantic was reduced. When the fisheries resources were re-opened to the Germans, the Elbe fishermen faced competition from sea-based fisheries. Changes in consumer preferences also impacted Elbe fisheries, fish markets developed interests in different fish in different seasons. The impact of this economic shift was somewhat similar to the changes that occurred at the beginning of the 20th century with the advent of the steam-driven fishing boats, which allowed faster fish to be caught, as well as more fish. Catches of fish from the sea increased, while freshwater fish from the polluted rivers experienced a decrease in demand.

An additional handicap to the Elbe fisheries came from the increasing load of contaminants in the Elbe stemming from communal and industrial wastewaters. The accumulation of phenols and other pharmaceuticals in fish tissue altered the taste of Elbe fish and the fish became more difficult to market. By the 1980's, increasing environmentally-related concerns and improved analytical methods to determine concentrations of toxins in fish products further limited the feasibility of the Lower Elbe fisheries. The governmental agencies advised against consumption of fish from the Elbe, and the State of Schleswig-Holstein spoke of prohibition of marketing of fish from the river. Protests followed from Lower Elbe fishermen, resulting at one point in a blockade of the shipping channel at Hamburg (Goes 1981). Demands came from the Hamburg Senate, to immediately take steps against the pollution of the Elbe. The Wassergütestelle Elbe was established by the West German States of Hamburg, Lower Saxony, and Schleswig-Holstein with the task of monitoring the Elbe environment from the East German border with West Germany (at Schnackenburg) to the North Sea (at Cuxhaven). Issues of international politics arose when the Wassergütestelle Elbe determined that the greatest part of the pollution load came from upstream of the East/West German border, i.e., from the two communist countries of Czechoslovakia and East Germany (ARGE ELBE 1988).

Immediately following reunification of Germany, the contaminant loading to the river decreased sharply due to the impact from closure of industrial sites (which were no longer competitive on the world market), changes in production processes, and the installation of modern sewage treatment plants within the former East Germany and Czech Republic (Adams et al. 2001). These changes prompted hope that the Lower Elbe fishery could return to a market-status. However, the contaminant-load in the fish has not improved as quickly as the water quality. Still in 2004 some fish species, e.g. eel, still demonstrated increased contaminant levels (ARGE ELBE 2005). Furthermore, all seven Federal States bordering the Elbe recommend that no more than 1 to 2 kg of Elbe fish be consumed by adults per month.

The power industry also continues to affect the Lower Elbe fisheries. Electric power production facilities (fossil-fuel based) employ large quantities of river water for cooling purposes. However, when the water is returned to the river, it increases the average water temperature in those sections. It has been estimated that this use of Elbe river water for cooling of electric power plants kills 55 tons of fish per power plant per year (Moeller 1989, Rauck 1980, Sprengel 1991). Calculated on the basis of water utilization for cooling of power plants, and data on fish concentrations per unit volume of water measured at individual power plants, the total quantity of fish (greater than 5 cm length) at three sites (Brunsbüttel, Brokdorf und Stade) per year (multi-year average) can be expected to be reduced by at least 150 tons per year (Sprengel 1991). Planktonic eggs and larval stages as well as fish up to 5 cm length are seldom retained, according to the calculations from the power plants. The average concentration of fish larvae in the Lower Elbe between Hamburg and Cuxhaven is about 7.3 animals per m^3 (Moeller 1989). The best calculations show that four X 10^9 (four billion) fish larvae and an unknown quantity of small fish pass through the cooling systems of these power plants of the Lower Elbe per annum, and the death rate for these organisms has to be 100%.. The Wassergütestelle staff also agree that this is the minimum value.

The previously discussed seasonal oxygen deficits also create problems for the fish in the Elbe. The “oxygen valley,” as it is referred to by German scientists, serves as an ecological barrier to the transit of fish trying to move upstream in the river. Thus, it is an especially serious problem for fish such as salmon, sea-trout, young stint, flounder, and eel. The situation has become further aggravated by the deepening of the shipping channel---the result being that the same water surface must service a larger volume of water with oxygen. Thus, the current situation is such that the “oxygen economy” of the Elbe near and below Hamburg is “overloaded”, as a consequence of the physical modifications to the tidal Elbe over the course of the last 100 years. As recently as June, 2007, in Hamburg, outcries from the general public and from the Elbe fishermen, and press coverage in the city demonstrated the extent of public concern over this important issue.

Despite the lingering concerns about bio-accumulated contaminants in the fish, an encouraging recent development in the Elbe is the increase in number of fish species present to 100. In fact, looking at the entire Elbe system from its source to the North Sea, the species richness now approximates that of the pre-industrial era (Gaumert 2000). In addition to the decreasing contaminant load of the Elbe, the construction of a fish ladder on the only dam on the German part of the Elbe has also improved the river habitat for fish. The fish-ladder was built in 1998 along the south shore of the Elbe at the Geesthacht Weir above Hamburg. Since its construction, it has allowed migratory fish species such as the Salmonids to access upstream habitat in the Middle and Upper Elbe, as well as in the tributaries of those stretches.

Not all of the increase in species is due to the return of previously native fish. Introduced species have also established themselves in the Elbe (Table 2). Further, at least five species (including some carp and pike-perch) have returned, but their status as native or non-native has yet to be determined fully. Some of the newly established species in the Elbe are typically Mediterranean fish: thicklip grey mullet (*Chelon labrosus*), red mullet (*Mullus barbatus*), and European pilchard (*Sardina pilchardus*). These species have primarily been found in the waters around the mouth of the Elbe in the Wadden Sea and the lower stretches of the tidal Elbe. One major factor facilitating the expansion of these species is climate change, both in terms of increase water temperatures and alterations in the flow of the Gulf Stream (Schubert et al. 2006). Increased water temperatures have also contributed to the northward shift in cod populations, which also may have made room for the new species.

Table 2: Fish species known to be invasive in the Elbe River (ARGE ELBE 2007)

Latin name	Common name
Oncorhynchus mykiss (WALBAUM)	Rainbow trout
Salvelinus fontinalis (MITCHILL)	Eastern brook trout
Hypophthalmichthys molitrix (VAL.)	Silver carp
Ctenopharyngodon idella (VALENCIENNES)	Grass carp
Hypophthalmichthys nobilis (RICHARDSON)	Bighead carp
Pseudorasbora parva (TEMMINCK & SCHLEGEL)	Stone moroko
Ameiurus nebulosus (LE SUEUR)	Brown bullhead
Acipenser transmontanus	White sturgeon
Acipenser baeri (BRANDT)	Siberian sturgeon

General Discussion

As described earlier, the Elbe River has experienced a complex political history, and this history has impacted the river's historical and current management, its water quality, as well as the economics and ecology of its fisheries. Following WWII, the upper and most of the middle sections of the river was under Communist control. Political differences between East and West prevented meaningful dialogue regarding proper management, and the river environmental quality suffered accordingly. Vast quantities of pollutants entered the river upstream from West Germany. The fall of the barriers between East and West have provided for renewed opportunity to improve the river, and much has been accomplished. The formation of international organizations (e.g. the International Commission for the Protection of the Elbe) and a strong, nationally-supported monitoring organization within Germany (the ARGE Elbe and its research and monitoring station the Wassergütestelle Elbe) have proved a boon to the chance for continuing improvement. Water quality and the health of fish, as well as numbers of fish species in the river, have improved but there remain many serious problems. The conflicting use of the river for economic purposes (increased shipping and the associated alterations to river channel) and ecological values remain to be resolved.

In looking toward the future of the Elbe River's environmental capability to support healthy fish populations, it is important to consider the potential dual impact of climate change and demands on water use within the basin, as these factors of course affect flow within the river and thus may well modify the fisheries environment. Welcomme and Halls (2001) and Welcomme (2005) pointed out that "the increasing demands that are being placed on water for a range of human uses are leading to growing control over flow in rivers by storage, abstractions, transfers, channel modification and controlled releases", and he stresses that both change in flow and change in "timeliness and form of the modified hydro graph" can be expected to affect fish in many different ways. Because of these impacts on rivers, the quantity of fish harvested in many of the world's rivers is declining, and "species assemblages are being modified with the disappearance of some native species and the establishment of exotics". Reducing this trend will depend on retaining "environmental flows" in the rivers so as to enable most of the native species to survive. Currently in the Middle Elbe, flow in some dry periods is reduced to the point that some shipping traffic (e.g. passenger boats) has to be limited. The Elbe has very significantly recovered its native species, but is now subject to invasive species; also, the appearance of the Mediterranean fishes in the "outer Elbe" offshore at the edge of the Wadden Sea may be a harbinger of the future as a consequence of global warming.

The issue of long-term impacts from groynes (the most visible man-made structures along the river) may still not be completely resolved. Wirtz (2002) reports that "during the 19th and early 20th century, 7000 groynes were constructed to make the Elbe navigable, and of these, 1200 are broken and due for repair". Measurements were being set up in 2002 to try to determine if groynes "intensify floods by accelerating discharge, have little impact or even protect dykes by reducing flow velocity". Following the severe flooding on the Elbe during August 2002, much controversy followed relevant to the possible relationship of these groynes to the impact from flooding.

One of the challenges facing the management of the Elbe is the analysis of impacts of future projects. As mentioned earlier, the Elbe was in a relatively healthy state until the middle of the 19th century. Since that time, water and floodplain engineering projects have combined with water pollution and watershed develop to degrade the ecological quality of the river and many of its associated ecosystem services. A simple comparison of the state of the river today with the river during the Cold War gives a misleading impression about the sustainability of the river system. Certainly the improvements in water quality and the return of native fish species are to be lauded. However, significant alterations remain in place: for example, the deepening of the shipping channel, the development and diking of the active floodplain, as well as the damming of the river and its tributaries all bring significant changes to the system. Is the goal of achieving “good” ecological status as required under the Water Framework Directive attainable, when one compares the state of the river today with that of the middle of the 19th century?

Comparison to Other Systems

The challenge of managing and restoring a river system heavily modified by human society is far from unique on the Elbe, although certainly the political history of the Elbe adds some uniqueness to its situation. We finish this examination of the Elbe by comparing the situation of three other rivers struggling with similar ecological issues: the Wisconsin, the Hudson and the Columbia.

The ***Wisconsin River*** lies within the State of Wisconsin, USA, and has an overall length of 688 km from its source in the north of Wisconsin to its confluence with the Mississippi. As in the case of the Elbe, the Wisconsin River struggles with a long-term problem of industrial contaminants, from paper mill effluents and other sources that affect fish. The aesthetic integrity of the lower section (148 km) of the Wisconsin River is administratively protected by the Wisconsin Department of Natural Resources (DNR) through Wisconsin Act 31, dating from 1989, that created the Lower Wisconsin State Riverway (Lower Wisconsin State

Riverway Board 2007). There are no impoundments on the river throughout the entire length of the Riverway, from below the dam at Prairie du Sac to the Mississippi at Prairie du Chien. Due to this lack of impoundments, the entire lower section of the Wisconsin River is structurally analogous to the situation of the Elbe River in Germany from the Czech border 586 km to Weir Geesthacht, above Hamburg. Within the Wisconsin State Riverway, the DNR administers performance standards as well as land acquisition programs, and requires permits for structures, timber harvesting, utility facilities and other activities (Lower Wisconsin State Riverway Board 2007).

On a different structural basis, the Wisconsin River upstream from Prairie du Sac bears some analogy to the Elbe within the Czech Republic, because of presence of dams in both situations. Though similar structurally, the two regions differ with respect to conservation of biodiversity. The Wisconsin Valley Improvement Company (WVIC) is a private corporation operating 21 reservoirs so as to maintain a uniform flow in the Wisconsin River (Wisconsin Valley Improvement Company 2007). The WVIC also helps to coordinate the operation of 25 hydro-electric plants within the system, owned and operated by ten electric utilities or paper companies. The WVIC reservoirs control runoff from about 1/6 of the headwaters catchment of the river and act to reduce flood flows by as much as 30%.

Some of the reservoirs are complex systems, an example being the reservoir behind the Burnt Rollways dam on the Eagle River - the reservoir consists of 20 lakes ("Three Lakes Chain of Lakes") connected along the river by small channels. Similar to other places in northern Wisconsin, this Three Lakes chain on the Eagle River is important to tourism, with many shore-line cottages, fishing, and pleasure boating on the lakes. The forested shoreline of these lakes (second-growth following massive devastation due to logging that ended in the early part of the 20th century) and relative solitude provide value in terms of wildlife such as nesting eagles, ospreys and diving birds such as loons (M. Adams, personal observations). Wisconsin has long been a leader in the United States' environmental movement, and the State's purchase of land surrounding the 2,550 ha-Willow Flowage in the headwaters area (tributary to the Wisconsin River) in the 1990s is an example additional to that of the establishment of the Lower Wisconsin Riverway. The Willow Flowage is near the confluence of three rivers and five smaller streams, and the flowage exists as a result of the construction of one of the WVIC dams built in 1926 (Bishop and Miazga 2000). Only about 5 percent of the shoreline is in private ownership. Those lands purchased and protected by the State of Wisconsin surrounding the Willow Flowage constitute 3856 hectares and provide abundant protection for wildlife, including wolves. These land purchases that proved so vital to conservation of natural areas in the upper Wisconsin River region were supported by funding from Wisconsin's Stewardship program, which may be threatened in the future (The Nature Conservancy 2007).

The history of the ***Hudson River***, in the State of New York, USA, as a polluted, working river is well documented (Manning 2005). Manning discusses how “multiple contaminants in the river are a result of decades of industrial dumping in the water; however, based on studies performed by multiple government agencies (e.g., the US Environmental Protection Agency and the US Army Corps of Engineers) and private contractors, polycyclic chlorinated biphenyls, or PCBs, are the primary chemicals of concern (COC).” The river's decades of contamination is now followed by one of the largest and most expensive cleanups of rivers in American history. Similar to the historical situation of the Elbe, in the Hudson River, a single entity (in this instance General Electric) “contributed most of the PCBs to the river, primarily through use of PCBs for capacitor manufacturing at Hudson Falls from 1952 to 1977 (Manning 2005).” PCBs totaling 5,000 kg/year were discharged to the river at Fort Edward and Hudson Falls. Also like the Elbe, the Hudson suffers from an ongoing problem of a cycle of settling, resuspension, and re-release of pollutants (PCBs); long-term solutions require dealing effectively with this cycle, as well as sealing off sources that continue polluting the river with PCBs (Manning 2005). Also as is the case for the Elbe, the picture for the Hudson is complicated by pollution entering from its tributaries and complexities arising from the tidal exchanges in the estuary.

As in the Elbe, fisheries in the Hudson River too have experienced similar problems both due to pollution and fishing pressure (Limburg, Moran, and McDowell 1986). The latter reported that “Hudson River fishermen in the eighteenth and nineteenth centuries harvested many species, and during the 19th century American shad and the two sturgeon species were the most heavily sought (Cheney 1896)”. These species were over-harvested in the late 19th century, with the peak of shad over-harvesting in the 1890's, and precipitous declines in catches thereafter (Stevenson 1899). Similar to the impact of industrialization in the Elbe catchment, the rapidly industrializing New York City area created serious pollution: oyster fisheries were generally destroyed by the 1920s (Franz 1982) and water pollution resulted in unpleasant flavor to most of the fishes (Division of Fish and Game 1964). Despite these problems, fisheries still provided livelihood for some fishermen during much of the 20th century. The Hudson benefited from environmental legislation passed in the early 1970's (such as the National Environmental Policy Act in 1970 and the amended Clean Water Act in 1972) and saw decreases in pollution and recovery of the river (Limburg, Moran, and McDowell 1986). This contrasts with the Elbe, where the division of the river between the West and Communist East governments meant West German pollution laws did not apply to the upstream water quality. However, U.S. legislation was less effective in dealing with organic pollution in the form of PCB's which ultimately resulted in closure of the most important commercial fisheries. By 2001 commercial effort in the Hudson reached an all-time low (Shapley 2001). As in the case of the Elbe, toxic substance contamination became widespread in the Hudson and in that river has remained serious, having a fundamental impact on fisheries, with fish early in the 21st century often containing as much as 10-fold greater levels of PCBs than Great Lakes fish.

The ***Columbia River*** in Canada and the States of Washington and Oregon, USA, began to experience serious pollution from Portland beginning in the 19th century. By early in the 20th century, concern for the river's water quality and public health was increasing. Tests done in 1927 showed heavy pollution in the Willamette River (the tributary of Columbia that flows through Portland). Salmon fingerlings died and oxygen levels were very low in the Willamette. Wastewater treatment was finally started in 1952, but much needed to be done. The State of Oregon regulated all point-source pollution discharges by 1968, and in 1972, new federal requirements under the Clean Water Act came into play (Portland Bureau of Environmental Services 2007), establishing national wastewater treatment standards and permit system; Portland subsequently established its own Clean River Action Plan which serves as a “comprehensive approach to achieve long-lasting water quality improvements”. This plan addresses “many problems to help meet multiple regulatory requirements, such as the Clean Water Act and Endangered Species Act” (Portland Bureau of Environmental Services 2007).

The history of the Columbia River system's fisheries provides an interesting comparison with the Elbe and a somewhat different perspective (Oregon State University 1998, GIlden and Smith 1998). In the former situation, the salmon and steelhead fisheries are the primary focus. Since the 1700's, salmon have been impacted by the increasing population and economic developments in the Pacific Northwest. As the indigenous populations who had fished the rivers were decimated by European diseases, salmon were increasingly utilized by the European settlers. Construction of dams was affecting salmon runs by the 1890's, and hydro-electric and flood-control projects reduced areas accessible to salmon by 50%. Other impacts on the salmon fisheries came from grazing, irrigation, logging, mining, over-fishing, pollution, urbanization, ocean conditions, and predators. Although plans for improvement of salmon fisheries of the Pacific Northwest are common, some do little more than repair the damage from past development projects. Increasing population in the Pacific

Northwest emphasizes the importance of the historical perspective in aiding our understanding of the potential future status of the salmon in this part of North America.

Several Oregon State University publications (Oregon State University 1998, GIlden and Smith 1998) report on the issues affecting salmon mortality in the Pacific Northwest as of 1996. These include dams that block passage to habitat, change water temperatures, reduce flow of rivers, increase nitrogen levels and allow more predation. Destruction of wetlands and estuaries reduces habitat, and logging increases silt and disturbs spawning beds. Urbanization reduces habitat and increases pollution, and irrigation reduces river flows. Unscreened water diversions entrap fish. Depending on hatchery fish reduces diversity of wild stocks. The Oregon State University work also points out that “Out of approximately 1000 native anadromous stocks in Oregon, Washington and California, 106 are extinct and 314 are at risk of extinction”. Hatcheries (as of 1998) were producing two-thirds of the salmon in the Columbia River.

Conclusions

The Elbe, as one of the most significant flowing-water systems of Central and Western Europe, has been and remains today a river of major importance. A large human population and major cities are within its catchment. Its fisheries have been important for centuries, and the river has been important the ecology of wildlife. Great political upheavals are part of its history. Today the river, most particularly its lower reach, serves as a major transportation route for shipment of goods in and out of Europe. The ecology of the Elbe has improved dramatically since the dramatic changes of government in the early 1990's, but major environmental problems remain. Effluents containing toxic wastes still enter the river, particularly from within the Czech Republic. These effluents negatively impact the fisheries of the entire river. Flooding in shoreline landscapes and cities continues to be a problem, as a result of the particular history of dike construction. Steps need be taken to remove un-needed dams in tributaries to allow fish migration and to improve the Elbe's ecology in line with the European Water Framework Directive. Commercial pressures to deepen the shipping channel of the Lower Elbe remain, and these steps will continue to challenge the improvement of the ecology of the Lower Elbe and damage its fisheries. Continued efforts now in place for international collaboration among the countries that contain parts of the catchment of the Elbe will be of increasing importance in the future. Preservation programs such as the UNESCO's establishment of a major Biosphere Reserve on the Elbe are extremely important steps to link conservation of biodiversity with the needs for sustainable development. Comparisons are easily made to demonstrate the environmental problems of the Elbe are not limited to that river, but occur also in rivers elsewhere. A better knowledge of the historical, environmental issues associated with the Elbe River can be important to the field of environmental education, a topic to be addressed by the authors.

Literature cited

Adams, M. S., U. Ballin, T. Gaumert, B. W. Hale, H. Kausch, and R. Kruse. 2001. Monitoring selected indicators of ecological change in the Elbe River since the fall of the Iron Curtain. *Environmental Conservation* 28 (4):333-344.

Adams, M. S., H. Kausch, T. Gaumert, and K. E. Krüger. 1996. The effect of the reunification of Germany on the water chemistry and ecology of some selected surface water bodies. . *Environmental Conservation* 23:35-43.

Adams, M. S., H. Kausch, and K. Gaertner. 2000. Historical changes and a modern program to improve the ecology of the Alster River of Germany. *Urban Ecosystems* 4:171-192.

Albrecht, M. L. 1960. Die Elbe als Fischgewässer. *Wasserwirtschaft-Wassertechnik* 10.

ARGE ELBE. 1988. Schwermetalldaten der Elbe von Schnackenburg bis zur See 1984 - 1988. Hamburg: Wassergütestelle Elbe.

———. 2005. Gewässergütebericht der Elbe. Hamburg: Wassergütestelle Elbe.

———. 2006. Das Einzugsgebiet der Elbe. Hamburg: Wassergütestelle Elbe.

———. 2007. Anzahl der Fischarten und Rundmäuler im deutschen Abschnitt des Elbestromes--interne Arbeitsunterlagen. Hamburg: Wassergütestelle Elbe.

———. 2007. Gewässergütebericht der Elbe-2005., edited by T. Gaumert and M. Bergemann. Hamburg: Wassergütestelle Elbe.

Bauch, G. 1958. Untersuchungen über die Gründe für den Ertragsrückgang der Elbefischerei zwischen Elbsandsteingebirge und Boizenburg. *Zeitschrift für Fischerei und deren Hilfswissenschaften.* 7.

Bergemann, M. . 2006. The Elbe Estuary. In *North-Atlantic Estuaries: Problems and Perspectives, Seine-Aval Special Issue,* edited by J. C. Dauvin.

Bishop, J.C. Jr. , and V. Miazga. 2000. Solitude on the Willow Flowage. Review of Reviewed Item. *Wisconsin Natural Resources Magazine*, http://www.wnrmag.com/stories/2000/dec00/willowflo.htm.

Blankenburg, U. 1910. Von der Störfischerei in der Elbe. *Der Fischerbote* 2.

Cheney, A. N. 1896. Shad of the Hudson River. In *First Annual Report of the Commissioners of Fisheries, Game and Forests*. Albany, NY.

Division of Fish and Game, New York State Conservation Department. 1964. The Hudson: Fish and Wildlife. A report on fish and wildlife resources in the Hudson River Valley. Albany, NY: Hudson River Valley Commission

Ehrenbaum, E. 1913. Über den Stör. *Der Fischerbote* 5:142-149.

———. 1914. Neue Untersuchungen über den Elbbutt. *Der Fischerbote* 6:93-99.

———. 1916. Zum Antrag auf Erhöhung des gesetzlichen Mindestmaßes für den Stör. *Der Fischerbote* 8.

Franz, D. R. 1982. An historical perspective on mollusks in Lower New York Harbor, with emphasis on oysters. In *Ecological Stress and the New York Bight: Science and Management* edited by G. F. Meyer. Columbia, SC: Estuarine Research Federation.

Gaumert, T. 2000. Entwicklung der Artenzusammensetzung der Fischfauna in der Elbe im Zeitraum 1991 - 1999. . In *Die Elbe von 1990.*, edited by W. Leiser: Internationales Kommission zum Schutz der Elbe.

Gaumert, T., and M. Bergemann. 2007. Sauerstoffgehalte der Tideelbe - Entwicklung der kritischen Sauerstoffgehalte im Jahr 2007 und in den Vorjahren, Erörterung möglicher Ursachen und Handlungsoptionen. Paper read at 9. Sitzung des Elberates at Berlin.

GIlden, J., and C. Smith. 1998. A Changing Columbia Basin. Corvallis, OR: Oregon Sea Grant.

Goes, W. 1981. Angst und Geld - das haben wir Altenwerder Fischer nie gehabt. *Hamburger Abendblatt*, 13 February 1981.

International Commission for the Protection of the Elbe. 1998. Strategie zum Hochwasserschutz im Einzugsgebiet der Elbe. Magdeburg: Sekretariat des Internationalen Kommissions zum Schutz der Elbe.

———. 2005. Die Elbe und ihr Einzugsgebiet. Ein geographisch-hydrologischer und wasserwirtschaftlicher Űberblick. Magdeburg: international Commission for the Protection of the Elbe.

Lelek, A. 1976. Veränderungen der Fischfauna in einigen Flüssen Zentraleuropas (Donau, Elbe und Rhein). *Schriftreihen der Vegetationskunde* 10:295-308.

Limburg, K. E., M. A. Moran, and W. H. McDowell. 1986. *The Hudson River Ecosystem.* New York: Springer-Verlag.

Lower Wisconsin State Riverway Board. 2007. *Lower Wisconsin State Riverway* 2007 [cited 2007]. Available from http://lwr.state.wi.us/.

Mann, H. . 1968. Die Beeinflussung der Fischerei in der Unterelbe durch zivilisatorische Maßnahmen. *Helgoländer wiss. Meeresunters.* 17:168 - 181.

Manning, J. *PCBs (Polychlorinated Biphenyls) in New York's Hudson River.* 2005 [cited 9 July 2007. Available from http://EnvironmentalChemistry.com/yogi/environmental/200510hudsonriverpcbs.html .

Moeller, H. 1989. Changes in fish stocks and fisheries: the lower Elbe River. . In *Historical Changes of Large Alluvial Rivers: Western Europe*, edited by G. E. Petts, H. Moeller and H. A. Roux. London: John Wiley.

Oregon State University. 1998. A Changing Columbia Basin, 1770-present. Review of Reviewed Item., http://www.orst.edu/instruction/anth481/fish.html.

Portland Bureau of Environmental Services. *The evolution of wastewater treatment in Portland*. City of Portland 2007 [cited. Available from http://www.portlandonline.com/bes/index.cfm?&a=41962&c=31031.

Rauck, G. 1980. *Mengen und Arten vernichteter Fische und Krebstiere an den Rechen des Einlaufbauwerkes im Kraftwerk Brunsbüttel, sowie Testversuche zur Reaktion von Fischen auf die Elektroscheuchanlage auf der Basis vondort anfallenden Fischproben*. Hamburg: Veröff. Inst. Küsten- und Binnenfisch.

Riedel-Lorje, J. , and T. Gaumert. 1982. 100 Jahre Elbeforschung - Hydrobiologische Situation und Fischbestand 1842 - 1943 unter dem Einfluss von Stromverbau und Sieleinleitungen. *Arch. Hydrobiol./Suppl.* 61:317-376.

Schnackenbeck, W. 1926. Biologische Untersuchungen über den Elbbutt und die Schleppnetzfischerei in der Unterelbe. *Der Fischerbote* 18:232-241.

Schubert, R., H.J. Schellnhuber, N. Buchmann, A. Epiney, R. Grießhammer, M. Kulessa, D. Messner, S. Rahmstorf, and J. Schmid. 2006. Die Zukunft der Meere - zu warm zu hoch, zu sauer. In *Globale Umweltveränderungen*. Berlin: Wissenschafftlicher Beirat der Bundesregierung.

Shapley, D. 2001. Valley fishing industry fading; interest flagging among the young. *The Poughkeepsie Journal*.

Sprengel, G. 1991. Experimente zur Scheuchwirkung von elektrischem Strom auf Fische., math.-nat. Fak., Univ. Kiel.

Stevenson, C. H. 1899. The shad fisheries of the Atlantic coast of the United States. In *U.S. Commission of Fish and Fisheries, Part XXIV. Report of the Commissioner for the year ending June 30, 1898*. Washington, D.C. : Government Printing Office.

Sutton, A. C. 2000. Wall Street and the Rise of Hitler. Place Published: Studies in Reformed Theology. www.reformed-theology.org/html/books/wall_street/index.html (accessed.

The Nature Conservancy, . Web site reference <>. *Stewardship Fund Action Alert* 2007 [cited. Available from http://www.nature.org/wherewework/northamerica/states/wisconsin/news/news1289.htm.

UNESCO-MAB. *Biosphere Reserve Flusslandschaft Elbe* 2007 [cited. Available from http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?code=GER+01&mode=all.

Von dem Borne, M. 1883. *Die Fischereiverhältnisse des Deutschen Reiches, Oesterreich-Ungarns, der Schweiz und Luxemburgs*. Berlin: W. Moeser Hofbuchdruckerei.

Welcomme, R.L. 2005. Predicting the water requirements of river fisheries. In *Water for Food and Ecosystems 2005*. The Hague, Netherlands: U.N. Food and Agriculture Organization.

Welcomme, R.L., and A. Halls. 2001. Some considerations of the effects of differences in flood patterns on fish populations. *Ecohydrology and Hydrobiology* 1:313-321.

Wirtz, C. 2002. Impacts of Groynes on Sediment Transport during the Flood Event in August 2002. In *Third Mitigation of Climate-Induced Natural Hazards Workshop*. Potsdam, Germany: HR Wallingford.

Wisconsin Valley Improvement Company. *Wisconsin Valley Improvement Company* 2007 [cited. Available from http://www.wvic.com/.

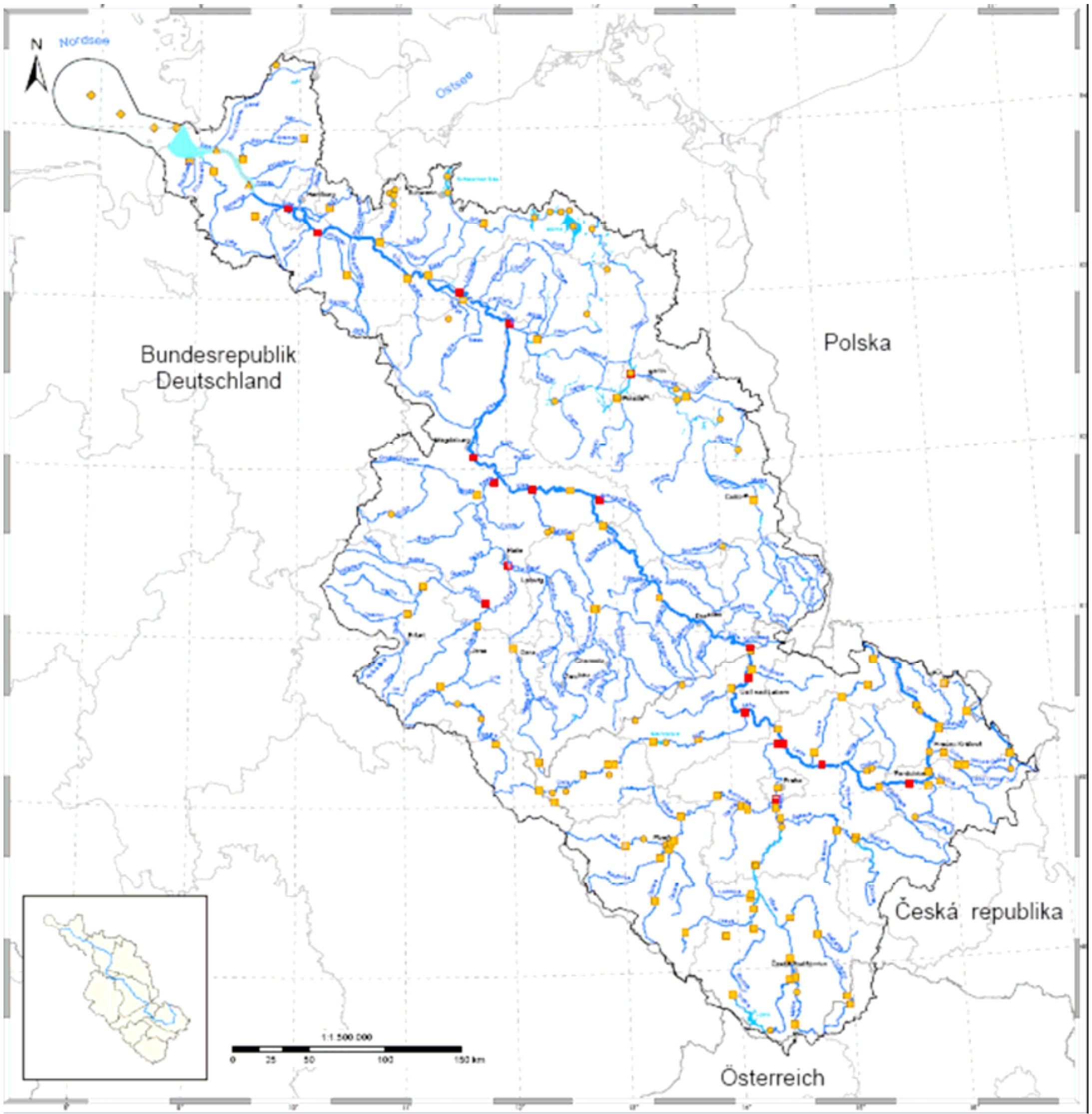

Figure 1. Catchment of the Elbe River. Source: IKSE, 2007. Overview of surface waters..

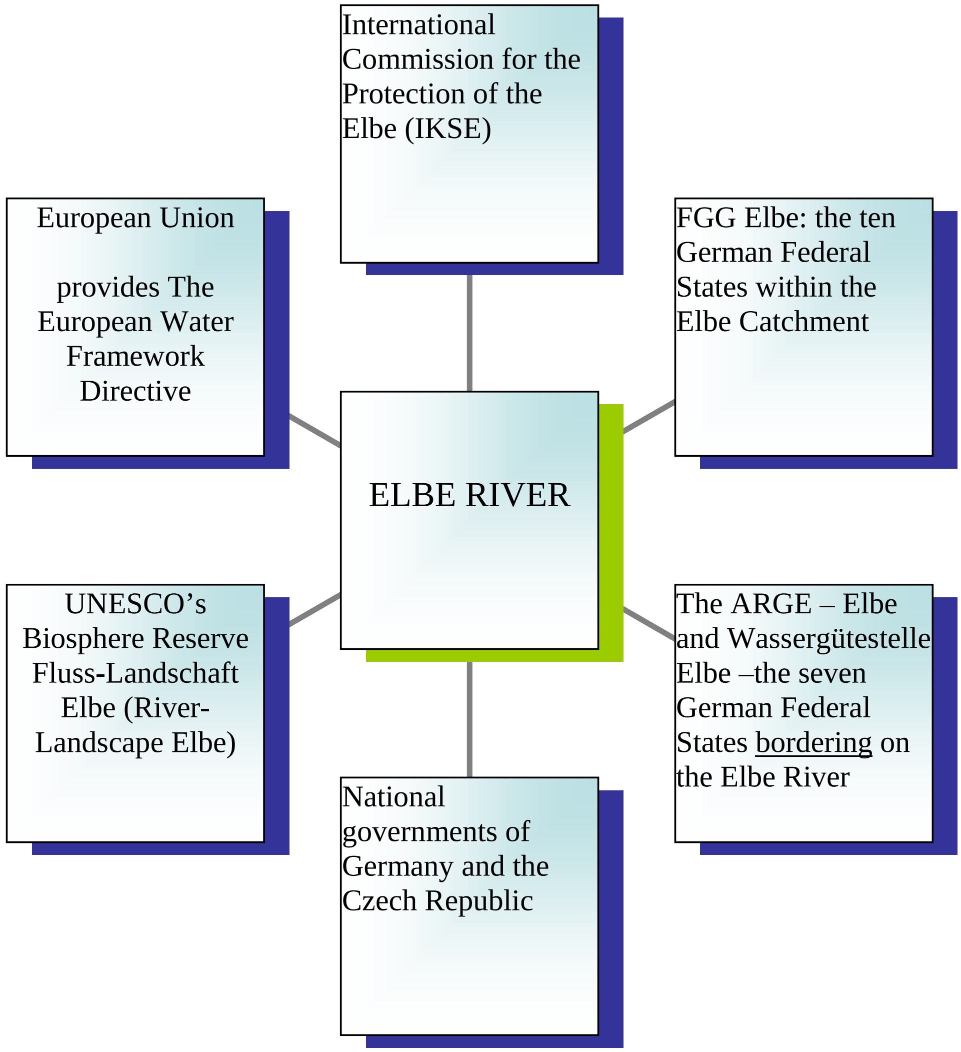

Figure 2. Generalized management structure for the Elbe River.

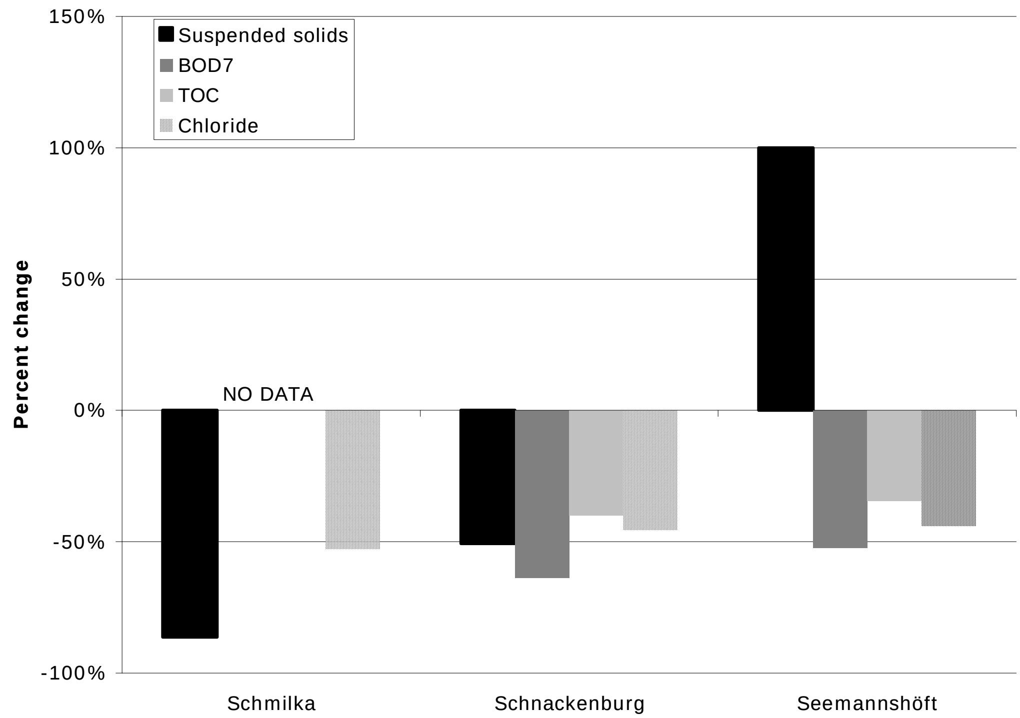

Figure 3: Selected chemical changes in the Elbe water quality: 1986 - 2005. Source: Gaumert and Bergemann 2005

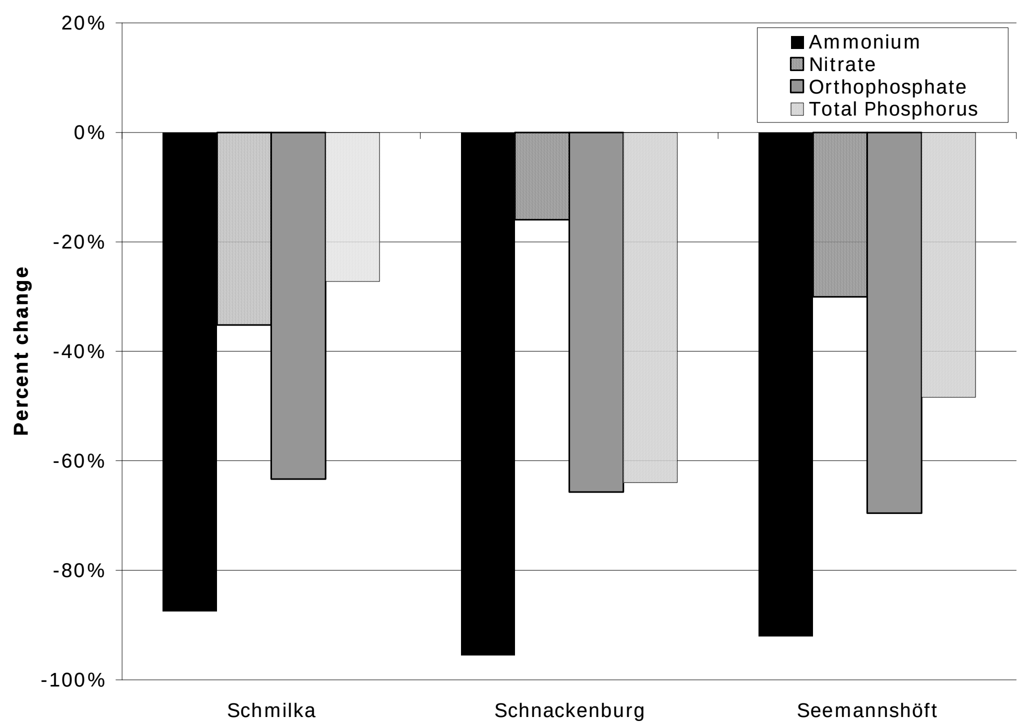

Figure 4: Changes in nutrient levels in the Elbe: 1985 - 2006. Source: Gaumert and Bergemann 2005

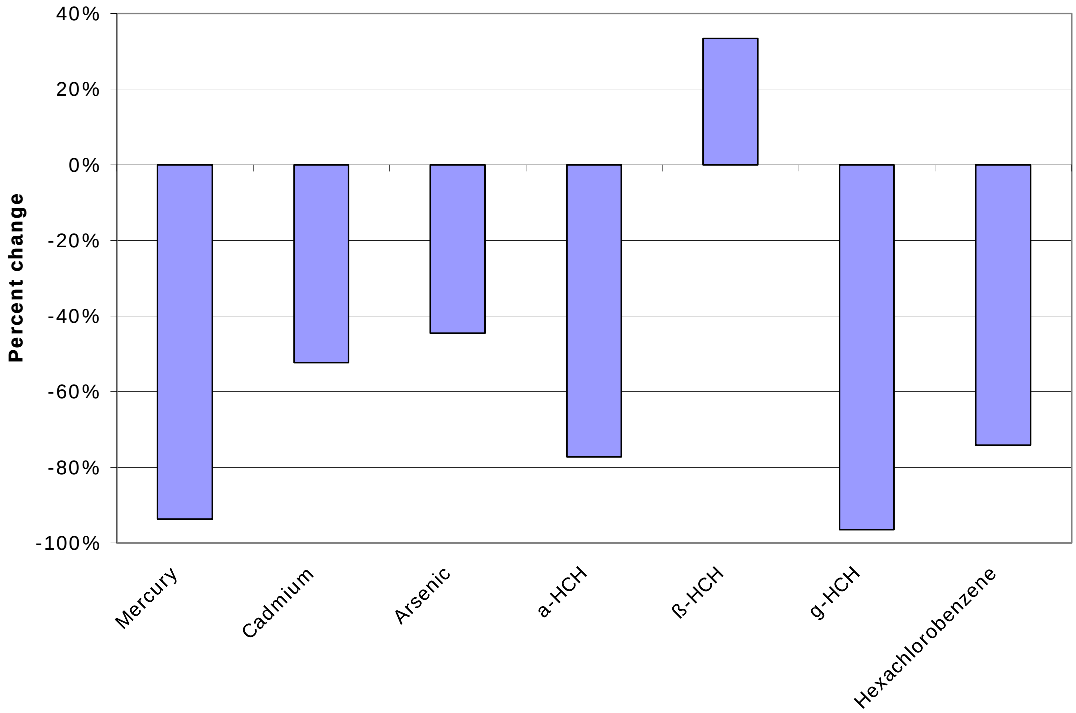

Figure 5: Changes in heavy metals and organic compounds in the Elbe at Schnackenburg: 1985 - 2006. Source: Gaumert and Bergemann 2005