1 INTRODUCTION

1.1 Problem definition

The mining industry can be an important point source of contaminants in the environment (e.g. Adriano, 1986; Förstner & Wittman, 1983). Historic metal mining has caused the widespread dispersal of heavy metals in many fluvial systems (e.g. Lewin & Macklin, 1987; Moore et al., 1987; Rang et al., 1986; Yim, 1981; Mann & Lintern, 1983; Reece et al., 1978; Jones, 1986; Ward et al., 1977). Sediments are important carriers of heavy metals and when they become incorporated in one of the fluvial storage compartments, they have not entered a static environment. The subsequent cycling of sediments in a fluvial system is highly related to hydrological, geomorphological and chemical phenomena (e.g. Salomons & Förstner, 1984; Graf, 1985). After deposition, sediments and associated metals may be remobilized from the channel bottom or channel banks by mechanical erosion (Lewin et al., 1977; Marron, 1986). Within the sediment reservoirs chemical processes may cause the metals to migrate between the various solid storage compartments and can also lead to it being lost to enter ambient waters and biota (Chester, 1987). Remobilized metals may be transported as clastic sediments or solutes to be deposited or precipitated in a range of sedimentary environments both within the floodplain domain and the stream domain (Lewin et al., 1977). All these phenomena interact and vary in space and time. Their result is a dynamic spatial distribution of heavy metals within an alluvial area. A proper understanding of the dynamics of transportation, deposition and remobilization is essential for the prediction of the fate of sediment-bound heavy metals in a fluvial system.

1.2 Research objectives

The study area covers the catchment of the transboundary river Geul, that flows from northeastern Belgium into the Netherlands province of Limburg where it eventually flows into the Meuse (see Figure 2.1). Ever since the Middle Ages, important occurrences of metal ore have been exploited in the Belgian part of the catchment, near the towns of Plombières and Kelmis. The fluvial dispersal of mining wastes has caused enhanced concentrations of lead, zinc and cadmium in aquatic sediments and floodplain soils in both countries. These metals may affect the health of plants and animals that inhabit the riperian areas. Moreover, as the Geul continues to migrate across its floodplain, contaminated sediments are reworked and ultimately discharged into the River Meuse, which is an important source of drinking water in The Netherlands.
The objective of this study is to investigate quantitatively the dispersal of metal mining wastes in this catchment. An attempt is made to study a wide variety of relevant processes and to analyse their interactions within the complex entity of a fluvial system. Eventually, the data collected and knowledge obtained may be used to compile mass balances of sediments and heavy metals in the alluvial

area. Within this context this study aims at:
(1) identifying the sources of heavy metals;
(2) analyzing the hydrological factors that govern the mechanisms of metal transport and quantifying the transport rates of sediments and of sediment-associated and dissolved heavy metals;
(3) quantitative mapping of areas that are susceptible to flooding and of metal concentrations in floodplain soils;
(4) determining rates of sediment deposition and the mass storage of solid-bound heavy metals in the floodplains;
(5) analyzing the metal associations in aquatic sediments;
(6) environmental assessment of enhanced metal levels in the sediments, soils and surface waters of this fluvial system.

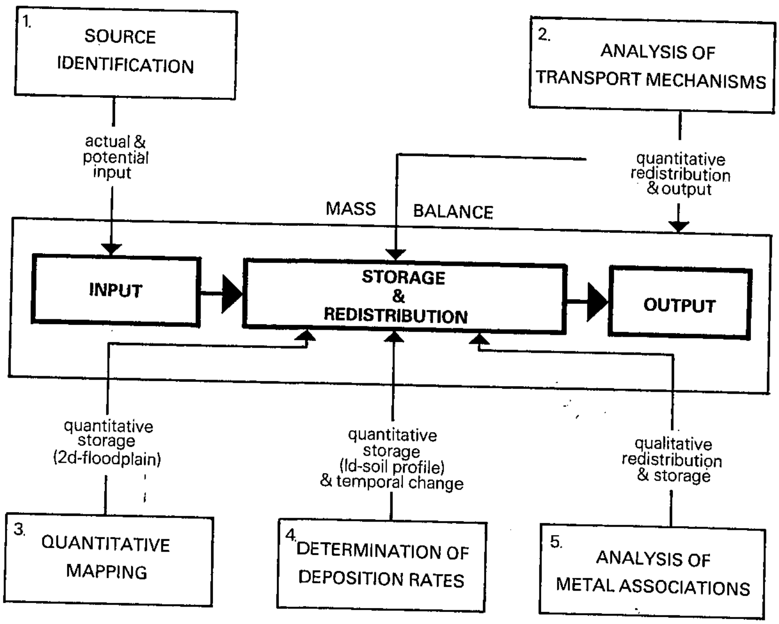

Figure 1.1 Schematic representation of the contribution of the research objectives to the compilation of an alluvial mass balance of heavy metals. (N.B.: the numbers refer to the research objectives listed in section 1.2.)

The above aims are, when achieved, all essential within the context of a mass balance study of the alluvial area (see Figure 1.1). The identification of the sources of heavy metals may provide insight into the current and potential availability of heavy metals for cycling in this fluvial system. Knowledge about the hydrological transport mechanisms may contribute to the understanding of how mass is exchanged between the metal sources and the transporting channel and how metals subsequently start cycling through the fluvial environment. The activity of the sources and the efficiency of the transport mechanism together have a quantitative control over the rate at which heavy metals enter

the alluvial domain, are redistributed thereafter and eventually leave the fluvial system. Therefore, they are thought to govern the input and output terms of the alluvial mass balance.
The (re)distribution of sediments and solid-bound heavy metals within the alluvial domain depends on the geomorphological processes that are active within the floodplain area during extreme events (i.e. floods).

Therefore, the areas that are susceptible to flooding and the pollution levels within those areas need to be mapped. Moreover, the local thickness of the contaminated soil layer will depend on the local rates of sediment deposition and erosion that may, in addition to spatial variations, exhibit considerable variations in time. Quantitative mapping techniques will be used to delineate flood zones and pollution zones in the 2-dimensional floodplain, and radio-active tracing methods will be used to relate the 1-dimensional vertical distribution of heavy metals in the soil profile to a time scale. This combined effort may provide a quantitative estimate of the total amount of heavy metals stored within the alluvial area and a qualitative estimate of the rate at which the processes of sediment deposition and remobilization take place.
In addition to estimating quantitatively the amount of heavy metals stored within the alluvial area, it is necessary to know how the metals are stored within sediments and soils, so as to be able to assess their environmental impact. The metal associations found may vary as a result of a.o. sediment-water interactions in the stream channel and diagenetic processes in the soil column. An attempt will be made to interpret the type of metal associations by taking into account the various phenomena that operate in the stream and floodplain domains.

1.3 Report structure

This thesis is a compilation of papers previously presented at scientific meetings and articles published in or submitted to international journals. References to these, in their current state slightly moderated, publications were replaced by references to chapters and paragraphs. A complete list of publications (including co-author(s) for some of them) is presented in Appendix 1. The first 6 chapters (including this introduction) were added later. Basic information on the characteristics of the study area and on the field and laboratory methods used were extracted from the original manuscripts and concentrated in seperate chapters, i.e Chapters 2 and 3 respectively. Chapters 4, 5 and 6 provide a brief (and incomplete) theoretical framework that may facilitate - to the nonspecialist - a proper understanding of the chapters following thereafter. Chapters 7-13 present the results of the investigations and they all end with a brief summary. Finally, some of the results presented in Chapters 7-13 are assembled and re-evaluated in a last synthetic chapter.
In Chapter 7 the fluvial transport of suspended sediments and dissolved and sediment-associated heavy metals is discussed. An attempt is made to identify the various sources of heavy metals and the annual mass transport is estimated. The variable quality of the sedi-

ments that are deposited on the floodplains during floods is evaluated in Chapter 8. Attention is paid to the influence of organic matter and grain size on total metal concentrations and the chemical phases of heavy metals are investigated. In addition, downstream changes of sediment quality are revealed. The effects of land use change on the discharge regime of the Geul and the dynamics of streambank erosion and sediment deposition are the subjects of Chapter 9. A quick quantitative technique for the delineation of flood zones is presented in Chapter 10, which also demonstrates the relation between floodplain geometry and soil pollution levels. Chapter 11 further explores this relation and aims at comparing various spatial prediction methods for large scale mapping of floodplain soil pollution. Chapter 12 is the logical extension of Chapters 10 and 11 in the sense that the spatial prediction techniques that perform best at a large scale are now further tested at the smaller scale of the river floodplain. In the last stage of the research, the rates of sediment deposition were estimated by measuring fallout ^{137}Cs in soil samples from various depths below soil surface. The nuclear accident at Chernobyl in 1986 provided the opportunity to study short-term sediment deposition. The results of this work are presented in Chapter 13. In the last chapter some of the results presented in Chapter 7-13 are assembled and discussed in the wider context of the geographers' perspective. A multiscale approach is used to evaluate the spatial patterns of metal pollution in this fluvial environment, mass balances of sediments and heavy metals are compiled, and an attempt is made to estimate the environmental hazards caused by enhanced levels of heavy metals in sediments, soils and surface waters.