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EurAqua 09.95

Land Use Change and Water Resources - Proceedings

November 1994

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EurAqua

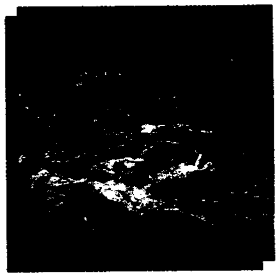
European Network of Fresh Water Research Organisations

FIRST TECHNICAL REVIEW

Land Use Change and Water Resources

Assessing the impacts of land use changes on stream flow and groundwater in terms of their effect on yield, extreme events, water quality and aquatic ecosystems

Proceedings



Institute of Hydrology, Wallingford, UK - 02-04 November 1994

What is EurAqua?

EurAqua is a European Network of Fresh Water Research Organisations, it includes15 publicly-funded Research organizations from 15 EU and EEA Countries, represented at Directors level.

Who are the Members of EurAqua?

EurAqua members are non profit research organisations who are also institutional (or significant) advisers to their Governments. For operational matters, membership is limited to a maximum of one organisation per Country, thus, Full Members are considered as "Linking Organisations" and must provide a channel of communication with all other partners in their own countries. They are invited to establish their own national networks of communication and information to include all partners dealing with fresh water research in the Club activities. A full list of Members is provided on the back cover of this document..

What are the aims of EurAqua?

1. *To promote the transfer of knowledge from the science base into policy decisions at National and Union level in matters relating to fresh waters to support sustainable development and achieve a better quality of life.*
2. *To encourage and facilitate collaboration between researchers and scientists to identify and analyse opportunities for research and development and explain and promote these to advance the management and environmental protection of our fresh water resources.*
3. *To make relevant expert advice readily available for use within the Union to support international cooperation activities and enhance the competitiveness of associated industries and service organisations.*

What are the activities of EurAqua?

1. *Holding of network meetings twice a year, attended by one "Linking Organisation" from each Country who provide a channel of communication with other interested parties. Broad decisions on network activities are made during these meetings in which a consensus is sought.*
2. *Organisation of Technical Reviews each year in specialist subjects where invited scientists and engineers from all EU Countries can discuss the priorities for research and arrange collaborations. Publication and wide circulation of proceedings especially within EU institutions.*
3. *Preparation of a Network Newsletter twice a year to provide a channel for communication between the various publicly funded research organisations carrying out research in the field of continental fresh water, and with other institutional partners with which the network would have established regular contacts. This Newsletter includes news from the network life (decisions made during meetings, information about technical reviews) along with subjects of common interests such as news on coming EU opportunities.*
4. *Exchange of Scientists and other activities such as joint publications...*

EurAqua

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Land Use Change and Water Resources

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Contents

Note from the Editor

Due to the impossibility of obtaining black and white versions of all figures printed in this volume, some had to be copied from colour originals. As a result, the quality of some illustrations is very poor.

Country Paper for Belgium - Brussels and Flemish Regions

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1 Preface

This Country Paper for Belgium summarizes recent issues relating to land use change and water resources in the Brussels and Flemish regions. These regions cover 45% of the total land area of Belgium. Table 1 shows the areas, population numbers and population densities in each of the main regions of the country. The information in this paper is based mainly on two reference documents, viz. WATER VOOR GROEN (Water for Green: Proceedings of the 4th Flemish Scientific Congress for Green-provision, Brussels, 29-30 June 1984, 780 pp) and WATER POLLUTION, Section III. 6, 81 pp. in "Leren om te keren", Milieu- en Natuurrapport Vlaanderen (Environment and Nature Report Flanders), Vlaamse Milieumaatschappij (Flemish Environment Agency), Leuven/Apeldoorn, Garant, 1994. More specific references on related topics are given at the end of the paper.

Table 1: Demographic figures for 1992, Belgium

region	area (km^2)	population	population density per km^2
Brussels	162	950,339	5,866
Flanders	13,512	5,824,628	431
Wallonia	16,844	3,293,352	196
Belgium	**30,518**	**10,068,319**	**330**

2 Important trends in recent land use change having implication for water resources and factors determining identified trends in land use change

With ever increasing pressure on the earth's natural resources environmental problems are, and will remain, a high priority for research. One area of particular importance is research into the effects of land use change on water resources. Both surface and subsurface waters are subject to increasing use for a wide range of purposes including drinking water supply, agricultural production and urban and industrial development. Proper management of the available water resources has to take account of each of these competing interests.

The concern of the scientific community in Flanders with regard to water resources management has resulted in a number of key-publications covering relevant aspects of surface water, soil water, and groundwater. Van der Beken (1973) discussed the importance of detailed soil information (soil maps and soil databases) for the management of soils and water resources. In 1984, the fourth Flemish Scientific Congress organized a workshop on quantitative and qualitative aspects of the Flemish water policy (Anonymous, 1984). The congress themes covered all components of the hydrological cycle and discussed the importance of water in relation to agriculture, forestry, nature conservation, recreation, and rural planning. A recent overview of environmental problems relating to water resources can be found in VMM (1994).

Changes in land use over the past 30 years are summarized in Table 2. Over the past 30 years the area occupied by forest and farm land has fallen by 8% and 14% respectively. As a consequence of the rapid growth of many towns and cities, the area of land classed as urban has increased. The area of non-agricultural rural land has also increased.

Table 2 Changes in land use in the Brussels and Flemish regions (ha and %)

Land Use	1965		1975		1995	
Forest	124 121	(100)	118 211	(95)	114 768	(92)
Urban	200 668	(100)	226 123	(113)	299 447	(149)
Non-agricultural rural	82 426	(100)	92 882	(113)	123 001	(149)
Farmland	957 757	(100)	927 575	(97)	827 575	(86)
of which:						
field crops	480 122	(100)	465 080	(97)	414 941	(86)
pasture	422 139	(100)	408 914	(97)	364 829	(86)
field horticultural crops	40 264	(100)	39 003	(97)	34 798	(86)
fruit growing areas	15 049	(100)	14 578	(97)	13 006	(86)

With the modernization of agriculture in Belgium, which started in the early sixties, farm sizes have increased and the number of farms has fallen from 270,000 in 1959 to 84,000 in 1991. In 1959 21% of the non-professional workforce was employed in agriculture. In 1991, this figure had fallen to about 2.5%. In order to remain profitable agriculture has had to maintain continuous growth through specialization, intensification, and mechanization. The five most important external factors that determine the spatial development of agriculture in Flanders are (Viane et al., 1993): the Common Agricultural Policy, (2) GATT-agreements, (3) environmentally oriented measures, (4) changes in consumption pattern, and (5) changes in trade pattern. Farmers that are unable to respond to these changes have been forced to leave agriculture. It is likely that the recent Gatt-agreements will further increase competition amongst farmers resulting in a continued contraction of agriculture in Europe and Flanders. The current 'set-aside' policy of the European Union is likely to enhance this trend. As a result of these changes the area of agricultural land is likely to further decline so that by the year 2000, the total area of farm land will have fallen by an estimated 5% (Nysten, 1994).

In contrast forestry is likely to become a more important form of land use in the twenty-first century. According to the study 'Long-term Planning Forestry' (Lange Termijnplanning Bosbouw, 1993), the total area of forest land is expected to more than double to around 250,000 ha by the year 2050.

The area of land classed as urban and non-agricultural rural areas has increased by almost 50% over the past 40 years. The increase in rural areas is partly attributed to nature reserves. In 1970 nature reserves in Flanders occupied about 1,820 ha. Today, this are has increased to more than 5,000 ha. With the continued increase in environmental awareness, this area is expected to grow further. The fastest growing land use in Flanders has been urban

development, with an increase of almost 100,000 ha in 30 years. According to Van Hecke and Dickens (1994), this area will increase by a further 18% over the next 10 years.

3 Impact and quantification of the trends in land use change on water resources and future trends

Based on some indicative numbers of annual water consumption in the Flemish region over a period of almost 30 years, an attempt has been made to analyze the impact of land use change on groundwater and surface water resources. The predicted annual water consumption for 1995 was compared with consumption rates for 1965 and 1975 (see table 3). Detailed figures on water consumption for 1995 were compiled from published data and from our own calculations. Six different sectors of water consumption have been distinguished: (1) domestic consumption, (2) livestock, (3) active water use in irrigation, (4) industry, (5) shipping, and (6) passive water use (evapotranspiration) of forest land, urban zones, and agriculture.

Domestic consumption

Assuming that daily water use per capita has remained constant at 180 l/person there has been a slight increase in domestic water consumption of 7 % since 1965 relating to the increase in population over this period. In reality, however, water consumption per capita has increased along with an improvement in the standard of living so that the actual increase in domestic water consumption may be higher.

Livestock active water requirements

A detailed assessment of active water requirements for livestock production is given in Hubrechts et al. (1993) for the year 1995. These figures are based on values of specific daily water use for different types of animals. Data on livestock numbers in the Flanders region is available from the National Institute for Statistics (Nationaal Instituut voor de Statistiek, 1993). Water use for 1965 and 1975 was calculated assuming a constant value of daily water use multiplied by the smaller livestock numbers for those years. The total number of cattle in 1975 was taken to be only 35 % of the 1995 numbers whilst the numbers in 1965 were a further 15 % lower than the 1975 estimate. The total increase in water consumption for livestock production over the past 30 years is estimated to be 55 %.

Table 3 Water consumption in the Brussels and Flemish region (million m3/year)

Sector	1965	1975	1995
Domestic consumption	356	367	379
Livestock active water requirements			
pigs			12
beef cattle and cows in milk			13
horses and mules			0.3
sheep			0.05
rabbit			0.03
poultry			2
Subtotal	17	20	27
Active water consumption in irrigation (50% dry year)			
greenhouse industry			23
field crops			61
pasture			71
field horticulture crops			3
fruit growing area			30
Subtotal	101	133	188
Industry	436	493	591
Shipping	1298	1458	1750
Passive use (evaporation & transpiration)			
forest	590	562	545
agglomeration	201	226	299
rural area	206	232	308
farm land			
field crops	2281	2209	1971
pasture	2005	1942	1733
field horticultural crops	191	185	165
fruit growing area	71	69	62
Subtotal	5545	5426	5083
Total consumption	7753	7897	8018

Active water consumption in irrigation

The term 'active water consumption in irrigation' refers to crop use of water artificially added water. Active water consumption for different crops was calculated by the one-dimensional water balance model SWATRER (Dierckx et al., 1986) for a 50% dry year. The calculations take account of variation in soil and plant parameters. The amount of irrigation water required is equal to the difference between the calculated potential and actual evapotranspiration. Data on water consumption for 1965 and 1975 were obtained from Beernaert (1978). Although detailed figures are missing for 1965 and 1975, the general trend indicates that active water consumption in irrigation has almost doubled over the past 30 years.

Industry

Water use by industry has increased by 36% since 1965 (Beernaert 1978). This estimate does not, however, include water used for cooling.

Shipping

Large volumes of water are needed to allow navigation in canals. Large differences in altitude can exist along the profile of a canal necessitating the use of sluices to maintain constant water levels and to reduce flow. Input of water into the canal system in Flanders is mainly from the river Meuse. Increased industrial activity from 1965 to 1995 increased the need for water for purposes of shipping by 35 %.

Passive use (evaporation and transpiration)

Passive water consumption, unlike active consumption, is the use of water by the natural processes of evaporation and transpiration from soil water and groundwater. This discussion considers passive consumption of water by forest, urban areas, farm land and non-agricultural rural land . Annual evapotranspiration from forest and farm land is assumed to be equal to 475 mm. Urban and non-agricultural rural areas are considered to have annual evapotranspiration rates of 100 mm and 250 mm, respectively.

The water use of the different land use types is based on accurate data relating to land cover for 1995. We have assumed a reduction in the area of forest land of 5% between 1965 and 1975, and of 3% between 1975 and 1995. The total area occupied by urban and non-agricultural rural land use was assumed to have increased by 3,000 ha/year from 1965 to 1975 and by 5,000 ha/year from 1975 to 1995. This increase coincides with the decrease in the area occupied by farm land. The total passive water use decreased by 8% from 1965 to 1995.

Summary of changes in water consumption

The fastest growing sector in terms of water consumption is active water use in irrigation with an increase of 88% over the past 30 years. However, the total amount of water consumed by this sector is about 25 times less than by the largest water users (passive water consumption by evapotranspiration). Active water use for livestock increased by 55% but represents the smallest absolute amount of water required (almost 300 times less than the largest consumer). Industry and shipping both show an increase of 35-36 %. Of note in Table 3 is the large amount of water needed for shipping, almost twice the amount required by industry. The sector with the slowest growth rate is domestic consumption, with an increase of 7%, but with a total volume almost equal to industrial use. The largest component of water use is evapotranspiration, which is more than ten times larger than the volume required for domestic consumption. However, water consumption by this sector has reduced by 8 % over the past 30 years.

Over the past 30 years, a considerable volume of surface water and groundwater has been used for industry and shipping. The water consumption by these sectors has increased by about 35%. The continuation of these large growth rates in the future will increase the pressure on available water resources. These two sectors require special attention because of the large amount of (1) high quality water needed for industrial production and (2) surface water for shipping taken from rivers which are often of international importance.

The data for farm land suggest a continuing increase in active water consumption. There are a number of factors that may accelerate the present trend. Due to increased competition resulting from Gatt-agreements, farmers will be forced to improve the quality of agricultural produce. One important factor that influences food quality is water availability. Field crops, horticultural crops, and fruit benefit from irrigation in a variety of ways including reduced water stress, reduced frost damage, improved microclimate (cooling) and improved pest control. The water used by this sector has to be of good quality and as such irrigation may become a major competitor for water at the local scale, along with domestic and industrial water users.

Water balance for the Flemish region

Table 4 shows the water balance for the Flemish region. The total rainfall (= input) for a 50% dry year is 780 mm or 1.06×10^{10} m^3 water per year over an area of 1.36×10^6 ha. Total water consumption (= output) for 1965, 1975, and 1995 was obtained from Table 3 and has also been expressed in mm/year. The water balance is then simply the difference between input and output. This results in a positive balance of 212, 201, and 193 mm for 1965, 1975, and 1995 respectively. The available amount of water (calculated as the difference between input and output) has thus been reduced by 9% over the past 30 years. This is an average of 3% every 10 years. Given the current level of knowledge it is difficult to assess the critical level of annual recharge required to preserve the currently available water resources. This critical level will presumably be different for surface water and groundwater. It will also depend on the particular characteristics of the different aquifers and surface water bodies.

Sources of drinking water

The growth and prediction of the future growth of drinking water supply in Flanders is given in Figure 1. The graph shows an annual increase in supply of 29,500 m^3/day. In 1991 48.8% of water supply in the Flemish community originated from surface water and 51.2 % from groundwater. The relative contribution of both sources and their growth is given in Figure 2. Of note in Figure 2 is the faster growth of groundwater supply compared to surface water supply. Groundwater wells for water supply are distributed evenly throughout all of the provinces in Flanders. The major source of surface water is the Albert and Nete Canal (linked to the river Meuse) in the province of Antwerp. This represents 89.2% of surface water supply in the Flanders region.

Table 4 Water balance of the Brussels and Flemish region in mm/year and m^3/year

	1965	1975	1995
Total rainfall in average year			
mm/year	780		
area in ha	1 364 790		
million m^3/year	10 645		
Total water consumption			
mm/year	568	579	587
million m^3/year	7 753	7 897	8 018
Balance between rainfall and consumption			
mm/year	212	201	193
million m^3/year	2 892	2 748	2 627

Groundwater resources and quality aspects

A small number of studies have investigated groundwater resources and/or quality on a regional scale (e.g. Flanders). Bronders (1989) carried out a regional groundwater study for Central Belgium which provides a good overview of the regional groundwater discharge areas. In a similar study Batelaan and Desmedt (1994) attempted to of delineate potential areas of groundwater discharge for nature reserves.

Since 1984 AMINAL (Environment, Nature, and Land Development Administration) has been involved in the collection of groundwater data on a routine basis. The monitoring network covers the whole of the Flanders area and consists of three levels (Van Damme, 1993). The primary level consists of a network of piezometers located in areas which are not subject to human influence. At present, this encompasses about 275 sampling locations. The second and third level comprise groundwater observation wells located in areas that are influenced by human activity. These levels are not yet fully operational. Beside this course network, drinking water companies operate detailed networks for most of their own groundwater supply sites. From 1984 onwards, protection areas have been defined around groundwater supply sites in Flanders. The initial analyses performed on this data relate to a range of aquifers in the provinces of Brabant and Limburg (Meyus and De Smedt, 1993), East and West Flanders and Antwerp (De Breuck and Bolle, 1993), Limburg (Van Autenboer et al., 1993) and Brabant (Loy and Goossens, 1993)).

Figure 1 Water consumption in Flanders
1983 - 2000

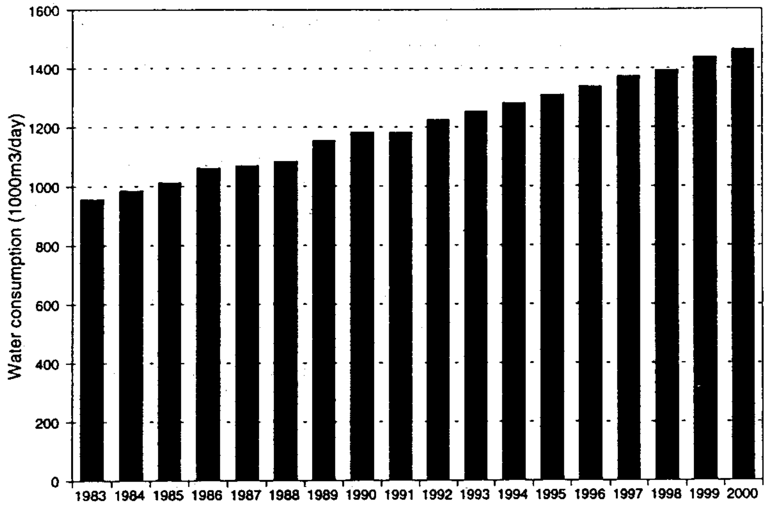
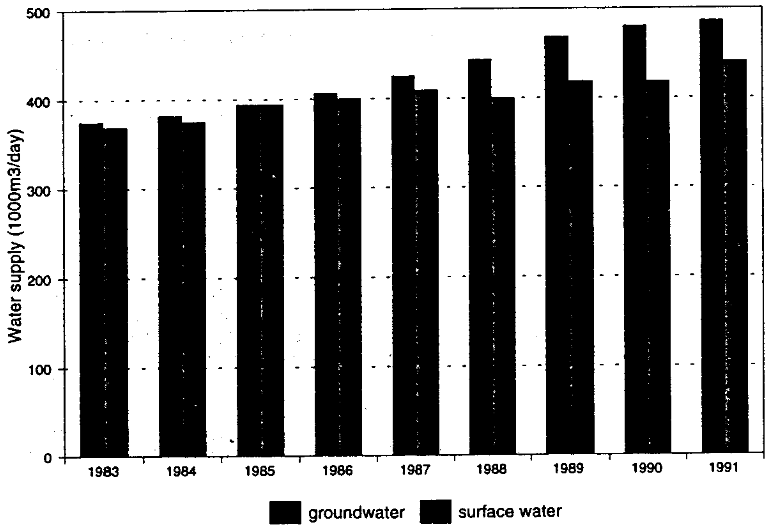


Figure 2 Water supply in Flanders
1983 - 1991



A state-of-the-art review on several aspects of drought for the whole Flemish region can be found in Van der Velden et al. (1994). An analysis of the pumped quantities, groundwater levels and some hydrochemical parameters was performed for each aquifer at the regional scale. Over the period 1987-1993 most aquifers exhibited a decline in the height of the water table. In many cases this decline is attributed to dry winters which caused reduced recharge between 1989 and 1992. Comparison of pumped quantities is difficult due to poor records. Both the cretaceous aquifer of the province of Limburg and the carboniferous aquifer of West-Flanders clearly appear to be overexploited. In the latter area the water table has fallen by 2 m a year with a total decline of more than 80 m.

Groundwater pollution by nitrates, phosphates, heavy metals, herbicides, and organic components has been identified in many parts of the Flanders and Brussels region. Maebe (1989) showed that there is a positive correlation between the nitrate concentration in groundwater and the ammonium emission associated with the production of animal manure.

Surface water resources and quality aspects

The mean annual rainfall for the Flanders region is 780 mm/year with extremes ranging from 1243 to 311 mm. There is generally no water shortage. Estimated evapotranspiration and water-uses are given in Table 3. The domestic daily consumption is estimated at 110 l/day/capita with the overall consumption normalised at 180 l/day/capita. The total length of navigable rivers and canals in the region is 1,150 km whilst other watercourses total about 20,000 km. The total number of waste water discharge points is estimated to be 40,000. The area of open water surfaces (lakes) is 59 km^2.

Surface water quality in the Flemish Region is monitored in two ways:

- the Belgian Biotic Index (BBI) (NBN T92-402) based on a count of macro-invertebrates;
- the Basis-Prati-Index (BPI) based on physico-chemical analysis.

The present (1992) networks consist of 861 sampling points for BBI and 994 points for BPI. The results of both types of monitoring show that surface waters in the region are currently of very poor quality. The class-percentages for 1992 are listed in Table 5. There has been a slight improvement (10%) in the overall quality of surface waters as shown by the BBI over the past 10 years. The overall BPI result shows a decrease of the "very bad" class (58.1 % in 1989).

Table 5: Surface water quality for 1992 based on BBI and BPI index.

	BBI	BPI
very good	2	0
good	17.1	1.8
average	39.4	17.1
bad	14.6	42.8
very bad	27.0	37.9

Nitrogen and phosphorus are nutrients responsible for high levels of eutrophication in most surface waters whilst heavy metals and organic micro-pollutants result in the pollution of sediment beds. As a result of this pollution the dredging of rivers and canals and disposal of the dredging material is a major problem. No information exists about the relative importance of point and non-point sources of pollution. The high population density and the intensive character of agricultural activities (arable land, industrial husbandry) are indexes of land use and related pollution problems. With simple rule-of-thumb calculations it is possible to demonstrate that in many river catchments a waste water treatment efficiency of 90% is not necessarily a guarantee for substantial improvement of the surface water quality.

Shallow groundwater resources interact with surface waters (see section on groundwater). The "Manure-Act", presently under discussion but heavily criticized by agricultural pressure groups, aims at a better equilibrium between manure-production and disposal practices and should bring considerable improvement of the nutrients problems both in surface and groundwater after the year 2005.

4 Overview of research addressing land use change effects on water resources

Several groups based at universities and at governmental institutions in Flanders have research and technological development programmes concerning land use and/or water resources. An overview of relevant organisations is given below for Flanders. Although the list includes most universities and governmental or semi-governmental institutes that are involved in "water research", the list may be incomplete. The majority of the institutes are members of the Water Research Centre (Studiecentrum voor Water), which is an official Research Centre sponsored by the Flemish Region and opened in 1985. The main objectives of the WRC are to carry out and to coordinate research related to all aspects of water management, water supply, and water treatment. In the list only Dutch names are given.

Governmental (Federal)
- Koninklijk Meteorologisch Instituut (KMI)

Governmental, Flanders Region (Environment and Infrastructure Department)
-Waterloopkundig Laboratorium Borgerhout
-Dienst Waterbouwkundige Werken en Hydrologisch Onderzoek
-Dienst Hydrologie

Semi-governmental
-Antwerpse Water Werken (AWW)
-Aquafin
-Openbare Afvalstoffenmaatschappij voor het Vlaamse Gewest (OVAM)
-Provinciaal Instituut voor Hygiëne van Antwerpen (PIH)
-Provinciale en Intercommunale Drinkwatermaatschappij der Provincie Antwerpen (PIDPA)
-Vlaams Instituut voor Technologisch Onderzoek (VITO)
-Tussengemeentelijke Maatschappij der Vlaanderen voor Waterbedeling (TMVW)
-Vlaamse Maatschappij voor Watervoorziening (VMW)
-Vlaamse Milieumaatschappij (VMM)

Universities
-Laboratorium voor Algemene en Toegepaste Mikrobiële Ekologie van de Universiteit Gent
-Laboratorium voor Bodemfysika van de Universiteit Gent
-Laboratorium voor Chemische Ingenieurstechnieken en Industriële Scheikunde van de Vrije Universiteit Brussel
-Laboratorium voor Industriële Mikrobiologie en Biochemie van de Katholieke Universiteit Leuven
-Departement Chemische Ingenieurstechnieken van de Katholieke Universiteit Leuven
-Laboratorium voor Hydraulica van de Katholieke Universiteit Leuven
-Dienst Hydrologie van de Vrije Universiteit Brussel
-Laboratorium voor Farmaceutische Mikrobiologie van de Universiteit Gent
-Instituut voor Land- en Waterbeheer van de Katholieke Universiteit Leuven
-Departement voor Historische Geologie van de Katholieke Universiteit Leuven
-Fonds voor Technologisch Onderzoek van het Limburgs Universitair Centrum
-Laboratorium voor Anorganische Scheikunde van de Universitaire Instelling Antwerpen
-Laboratorium voor Biologisch Onderzoek van Waterverontreiniging van de Universiteit Gent

-Laboratorium voor Experimentele Geomorfologie van de Katholieke Universiteit Leuven
-Laboratorium voor Hydraulica van de Universiteit Gent
-Laboratorium voor Toegepaste Geologie en Hydrogeologie van de Universiteit Gent
-Onderzoeksgroep Natuurbehoud en -Beheer van de Universitaire Instelling Antwerpen
-Laboratorium voor Hydrologie van de Universiteit Gent

However, little of the research that has been carried out in these institutes is concerned directly with investigating the effects of land use changes on water resources. Of note is the work of Van der Beken and Vanlishout (1980) which is concerned with the effect of urbanization on high discharges. Other relevant work includes that by Bultot et al. (1988a, 1988b, 1990, 1992, 1994) and Gellens (1991) related to climate change. Mallants and Badji (1991) investigated the changes in the water balance of a river catchment resulting from afforestation and deforestation.

In some research programmes land use has been assessed in a traditional way, through field survey (De Blust et al., 1994) or the evaluation of census data (Van der Beken and Vanlishout, 1980). However, technical and methodological progress in the field of remote sensing has stimulated research on the processing and interpretation of information obtained by satellites and areal photography (Coppin et al., 1986; Borry et al., 1988a). Similarly to other spatially distributed data such as soil characteristics and topography, more data relating to land use are becoming available in digital form and are being integrated in Geographical Information Systems (GIS) or related data structures (Borry et al., 1988b; Van Orshoven et al., 1988). They are used in a range of applications in the field of agriculture (Eerens et al., 1991; Van Orshoven et al., 1992), forestry (Rampelberg et al., 1993), ecology (Gulinck, 1991; Gulinck et al., 1991; Paelinckx et al., 1991), and hydrology (Abts and Vereecken, 1991; Mallants and Badji, 1991; Batelaan et al., 1993a).

Research efforts in Flanders relating to the assessment of the effects of land use change on water resources include:

- regional groundwater flow investigation for drinking water purposes and the geohydrology of ecological systems (Batelaan et al., 1993b);

- modelling the rainfall-runoff transformation using empirical, conceptual, or physical models with system variables and parameters that are spatially variable (distributed model) or constant (lumped model). The rainfall-runoff system can be treated as deterministic or stochastic (Bauwens and Vandewiele, 1989; Vandewiele et al., 1991; Ramos et al., 1992);

- modelling of water flow and contaminant transport in the unsaturated and saturated zone (De Smedt et al., 1991; Vanclooster et al., 1993; Mallants et al., 1994);

- modelling of the physical and hydrochemical processes, especially the dynamic aspects, in interface zones and their implications for land use and ecology (Vanclooster et al., 1992);

- research into the identification of geohydrological and biological parameters and sampling strategies, including the design and implementation of sampling networks (Espino et al., 1994);

- research into spatial and temporal scale effects (a hydrological (sub) system is often best defined at a scales and with variables and parameters that are unable to explain interactions in a soil profile) (Mallants et al., 1994);

- research into the use of geostatistics and other interpolation techniques for the transfer of point or transect related information to the derivation of areal estimates (Bronders and

De Smedt, 1991; Diels et al., 1993a, 1993b) ;

- research into resource management using optimization and decision support techniques (Chang et al., 1992);

- sediment erosion and transport related to surface water quality in rivers and other fresh water ecosystems (Verbeelen et al., 1989; Poesen and Govers, 1990);

- river water quality monitoring;

- study of peak discharges during floods (Van der Beken and Vanlishout, 1980); and

- water balances on different spatial scales, from complete ecosystems to field size plots and from regions to river catchments, in relation to land use changes (Van der Beken and Huybrechts, 1990).

In much of this research land use is an important, if somewhat simplified, variable. The increase in spatially distributed land use information now available from new techniques has not yet been utilised to its full potential. Integration of GIS and hydrological modelling is a recent development. In the last few years progress has been made, for example, in the field of soil water balances and soil moisture studies (Lin et al., 1994) and groundwater modelling (Batelaan et al., 1994). Efforts in this direction should be further stimulated and intensified.

The research interests mentioned above are often concerned with only certain aspects of the hydrological system. There is a need for a more integrated approach on a watershed basis (Anonymous, 1989; Mallants et al., 1992). Integration of surface water and groundwater studies is needed to improve understanding of the effects of groundwater abstraction on surface water flow and aquatic ecosystems and reciprocally to predict the impact of surface water developments and uses on groundwater quality and quantity. An example of an integrated modelling approach using the MIKE-SHE hydrological modelling system can be found in Xevi et al. (1993). This study considers all possible components of the hydrological cycle at catchment scale with by way of a distributed model of the soil, crop, and aquifer characteristics of a small agricultural basin. Currently, this approach is being used to calculate the nitrogen balance of soil water, groundwater, and rivers.

Fresh water ecosystems are currently receiving increased attention. In Flanders emphasis is placed on the monitoring of the biotic aspects of these ecosystems, which include river environments, estuaries and wetlands (Denys and Van Straaten, 1990; Meire et al., 1992; Coeck et al., 1993; Verheyen et al., 1993). The abiotic boundary conditions, and in particular, the water quantity and quality demands of fresh water ecosystems, are currently receiving less attention. Research into groundwater dependent ecosystems (Batelaan et al., 1994) and water quality of rivers (Van der Beken, 1987; De Smedt, 1991) is also being conducted. The current knowledge base remains inadequate, however, especially in view of the need to restore fresh water systems which are suffering from intensive drainage, poor water quality, contaminant pollution and excessive nutrient loading. In order to improve the management of fresh water ecosystems (e.g. river floodplains, general water management, and the relation with other water users such as drinking water companies and agriculture) additional knowledge and new approaches and techniques are required.

Research in Flanders is primarily conducted at universities and to a lesser extent at government research stations. The latter are more widely involved in the coordination and supervision of research activities and monitoring work. Funding for research is made available by national and regional institutions, local administrations and the European Union. In recent years, national funding for research has become less important as funding from the European Community has increased. Research developments are controlled by the need for precautionary or preventive action and the polluter-pays principle, as embedded in the

environmental policy of the European Union.

Although research efforts are relatively dispersed throughout various institutes and organizations, efforts are under way to initiate projects amongst groups from disparate backgrounds. This is in response to the financial constraints imposed by the economic recession and the move towards interdisciplinary research. This research aims to develop integrated management models and policies that consider surface and groundwater, quantity and quality, resource and use, whilst incorporating economic data so as to allow for proper planning of regional resource management.

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