European Sediment Research Network

Acronym: SedNet

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Key action 1.4.1 *Abatement of water pollution from contaminated land, landfills and sediments*

WORK PACKAGE 2
SEDIMENT MANAGEMENT AT THE RIVER BASIN SCALE

Minutes of the third workshop

Modelling and other decision-support tools for sediment management

10th to 11th November 2003, Lleida University, Lleida, Spain

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APPROVED BY Workshop participants	**DATE** December 2003	
		Pages

Background to the workshop

This workshop represents the third in a series of four workshops being organized by Work Package 2: *Sediment management at the river basin scale* (previously named Working Group 4: *Planning and decision-making*) of SedNet. The previous two workshops were:

Existing guidelines and the EU Framework Directives, 28-29 October 2002, Silsoe, UK

Sources and transfers of sediment and contaminants in river basins, 26-28 May 2003, Hamburg, Germany

The minutes of these workshops can be found at: www.sednet.org/wg4.asp

The themes of the workshops reflect the aims and objectives of WP2 within the overall structure of SedNet, and the deliverables that WP2 will provide to the SedNet community and the EC: for further details see the SedNet website (www.sednet.org). The present workshop is entitled:

Modelling and other decision-support tools for sediment management

and represents a logical progression in the themes of the workshops of WP2.

Aims and Objectives

The main objectives of this third workshop are as follows:

1) To identify the main tools that are available to provide information on sediment, and associated contaminants, including their sources, transfers, transport and deposition in river basins;
2) To identify the uses of these tools, with particular focus on modelling techniques;
3) To identify their relative strengths and weaknesses; and
4) To identify how they can be used within sediment management programmes, frameworks and legislation.

Working Structure

As with previous WP2 (WG4) workshops, this workshop took the form of a discussion forum with keynote presentations at intervals throughout the meeting to focus thought and catalyse debate to satisfy specific objectives. Prior to the workshop, a discussion paper for each keynote presentation, outlining the key points and structure, was sent out to all workshop attendees to allow preparation for the discussions.

Each keynote was followed by a lengthy period of discussion in which key points were transcribed to flipcharts to summarise the outputs and conclusions of each session.

An optional fieldtrip to local sites of interest was organised and led by Ramon Batalla, Damia Vericat and Albert Rovira. The fieldtrip started after lunch on the Tuesday. The party visited reservoirs along the Ebro River where sediment management is of concern, and also saw a demonstration of suspended and bedload sampling equipment.

Programme

Activity	Title	Presenter/driver	Duration (min)	Start Time
Monday 10th November				
Welcome	Welcome to the workshop	Ramon Batalla (University of Lleida, Spain)	10	1.30
Introduction	SedNet: from mission to overall workshop objectives	Jos Brils (SedNet coordinator)	20	1.40
Introduction	Introduction to WP2 activities and progress	Phil Owens (leader of WP2)	10	2.00
	Structure of WP2 book	Phil Owens	10	2.10
Discussion			30	2.20
Coffee			30	2.50
Keynote	Methods and techniques to measure, sample and quantify sediment transfers in fluvial systems	Celso Garcia (University of the Balearic Island, Spain)	30	3.20
Discussion			60	3.50
Wrap-up	Review of today's session	Phil Owens	30	4.50
Close				5.20
Tuesday 11th November				
Start	Aim of the session	Ramon Batalla	10	9.00
Keynote	Predicting of "sedimentgraphs" for small agricultural catchments	Kazimierz Banasik (Warsaw Agricultural University, Poland)	30	9.10
Discussion			60	9.40
Coffee			20	10.40
Presentation	Other tools and approaches for sediment management	Phil Owens, Harald Koethe & Marc Eisma	20	11.00
Discussion			30	11.20
Wrap-up	Review of workshop and outputs	Phil Owens	60	11.50
Close of workshop		Ramon Batalla	10	12.50
Lunch or departure (13.00) Followed by optional field trip to local sites of interest				

Co-ordinating committee

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List of participants

Name	Organisation	Country
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Kazimierz Banasik	Warsaw Agricultural University	Poland
Ramon Batalla	University of Lleida	Spain
Jos Brils	TNO	The Netherlands
Marc Eisma	Rotterdam Municipal Port Management	The Netherlands
Joaquim Farguell	University of Barcelona	Spain
Celso Garcia	University of the Balearic Islands	Spain
Carlos Gomez	University of Alcala de Henares	Spain
Joachim Karnahl	University of Stuttgart	Germany
Harald Koethe	Federal Institute of Hydrology	Germany
Feliciana Licciardello	Universita degli Studi di Catania	Italy
Phil Owens	NSRI, Cranfield University	UK
Rosa M Poch	University of Lleida	Spain
Albert Rovira	University of Lleida	Spain
Joan M. Verdu	Department of Agriculture, Catalan Government	Spain
Damia Vericat	University of Lleida	Spain

Presentation 1 - Welcome to the workshop - Ramon Batalla (University of Lleida, Spain)

Ramon outlined and identified the basin-scale sediment delivery process, from headwaters to the sea. He described some of the sediment problems within the sediment delivery cascade, with particular reference to the situation in Spain, including:

- Gravel mining and abstraction
- Reservoir sedimentation issues (see his Workshop 1 Discussion Paper for more details)
- Hungry rivers resulting from a sediment deficit.

These sediment issues are important for the basin-scale functioning of a river and in turn may lead to problems associated with:

- Water quality
- River ecosystems (especially fish habitats)
- Mass movement processes
- Undermining of bridges and other structures.

There is therefore a need for a much greater understanding of:

- Sediment erosion, delivery and transport processes
- Associated costs of sediment management and remediation measures
- The associated benefits of these

In particular, there is a need for the development and application of monitoring and modelling techniques and decision-support tools. These tools greatly assist with the integration of knowledge, management and policy.

Presentation 2 – SedNet: from mission to overall workshop objectives – Jos Brils (TNO, The Netherlands)

Jos Brils described the history and role of SedNet, including its mission and objectives. In particular, he focussed on recent changes to the structure of SedNet including the changes to the Work Packages, the deliverables, and the networking. Most of these points can be found at the SedNet website and the reader is directed to this for further information. Of particular interest to this workshop and WP2 are:

- Change from Working Group 4 to Work Package 2 – Sediment management at the river basin scale
- Deliverables include production of workshop reports/fliers and a WP2 book (ca. 200 page) on Sediment management at the basin-scale

Presentation 3 – Introduction to WP2 activities and progress – Phil Owens (National Soil Resources Institute, UK)

Phil described the role of WP2 within the broader SedNet structure with emphasis on recent changes to WP2. He described many of the outputs and deliverables from WP2 (including reports, discussion documents, publications, networking activities, joint projects, associated conferences and workshops etc.) most of which are on the SedNet website. He also described the previous two workshops and the programme, format and objectives of this workshop (see start of this document for further details).

Presentation 4 – Structure of the WP2 book – Phil Owens (NSRI, UK)

The title of the ca. 200 page book will by *Sediment Management at the River-basin Scale*. A first draft structure of this book is:

Chapter 1: Characteristics of river basins
1.1 Definition of a river basin
1.2 Description of river basin environment
1.3 River basin functioning
1.4 Conceptual map of a river basin

Chapter 2: Sediment and contaminant transfers in river basins
2.1 Sources
2.2 Transport processes
2.3 Pathways
2.4 Fluxes of sediment
2.5 Deposition and storage

Chapter 3: Basin scale perturbations to sediment transfers
3.1 Perturbation to sources
3.2 Perturbation to transport, pathways and fluxes
3.3 Perturbation to deposition and storage

Chapter 4: Basin scale sediment management
4.1 Current legislation and regulations
4.2 Current guidelines and guidance
4.3 Current policy (water, soil and waste)
4.4 Current decision frameworks
4.5 Current EU networks and initiatives

Chapter 5: Sustainable solutions for sediment issues
5.1 Stakeholder inventory
5.2 Different perspectives on sediment management
5.3 Sustainable solutions

Chapter 6: Societal Cost Benefit analysis
6.1 Scope of societal Cost benefit Analysis
6.2 Methodology of cost-benefit analysis
6.3 Environmental liability

Chapter 7: Risk management related to river basin scales
7.1 Elements of risk
7.2 Conceptual basin models
7.3 Risk management concepts for river basin scale
7.4 Transboundary risk management

Chapter 8: Decision support tools for sediment management
8.1 Modelling
8.2 GIS and remote sensing
8.3 Source tracing techniques
8.4 Other tools

Chapter 9: Decision making at the river basin scale
9.1 Integrated/holistic management of contaminated sediments
9.2 The decision making process
9.3 The role of legislation, policy and networks
9.4 A new decision framework for holistic management

Chapter 10: Conclusions

Presentation 5 – Methods and techniques to measure, sample and quantify sediment transfers in fluvial systems – Celso Garcia (University of the Balearic Islands, Spain)

See the Discussion Paper by Celso Garcia for further details

Notes from the discussion session

For sustainable sediment management we need to use the same tools in order to provide basic data. Coupling of this data to appropriate models should provide the best solutions to sediment issues and problems.

In 2003, we believe that we have enough measurement and monitoring tools for most sediment issues.

As a minimum, what tools do we need? Although this in part depends on the question/issue.

An important question is: are we using the monitoring and measurement tools that we have available to us to monitor and measure river sediment fluxes in a meaningful and appropriate way?

As yet, we probably do not have a clear message as to why we must assemble sediment transport and flux information for sediment management.

For bedload, we are able to model it but we need good hydraulic and bed material data. In the case of suspended sediment, we need to be able to measure and monitor it.

Sediment availability is the key for suspended sediment and bedload.

What does measurement and monitoring of river sediment tell us?

- It tells us where the sediment is coming from (its source)
- It tells us how much is being transferred (fluxes)
- It provides us with an understanding of the basin-scale sediment system
- And thus help with the questions that we have or might have of the sediment system
- It can be used to predict sediment response to changes in the system (thus relevant to WFD and Habitats Directive)

There is clearly a minimum level of information required that can be used to provide the information needed for the reasons listed above. And thus a need for a measurement and monitoring network throughout Europe.

It is important that we link sediment quantity and sediment quality.

Research recommendations:

- We need more measurement and monitoring of sediment in large rivers in Europe
- We need better in-situ sediment quality measurement and monitoring tools
- We need better ways of extrapolating in-situ point measurements to catchment scales
- We may have most of the measurement and monitoring tools that we need, but not necessarily the data required to model systems
- We have tended to focus efforts on river channel systems but we must also direct attention on monitoring and measuring sediment dynamics in floodplain, reservoirs and harbors.

<u>Presentation 6 – Predicting of "sedimentgraphs" for small agricultural catchments – Kazimierz banasik (Warsaw Agricultural University, Poland)</u>

See the Discussion Paper by Kaz Banasik for further details

<u>Notes from the discussion session</u>

An initial series of questions were:

- Do we have enough models at present?
- Are we over-dependent on US-based models?
- Will capital and time investment give a big enough return to warrant the improvement in the accuracy of models?

There is clearly a need for more data to test river sediment models (there are lots of physical gaps in our databases).

We need to assemble information on:

- What models do we need to use from our tool-box?
- What model is for what question? Existing models may include:
    - Erosion models
    - Sediment transport models
    - Sediment deposition models
    - Models that deal, with short, medium or long timescale

There is a need to develop better and more integrated catchment-scale models of sediment dynamics.

Are the models at a sufficiently good level at the moment? And if not, why not? They require:

- A better understanding and degree of complexity
- Increased computational power/capacity

Is the time necessary for model development too long for today's management issues?

(post-workshop comments from Bernhard Westrich) There are a variety of different types of models available, which include: physically based models, conceptual models, statistical models and regression models.
- they can handle processes with different scales in time and space
- there are 1-d models (mostly for the fluvial part of the system) and 2-d

models (local description like reservoirs, habors, groins etc.)
- a weak part is the link between sdiment production in the catchment and the input to the rivers
- we have poor knowlegde in modelling geochemical and biological processes causing degradation, transformation etc. There is no realistic risk assessment possible without taking into account such processes associated with mobilization of contaminated sediments. It is important for immision and environmental impact.
- we must also focus on flood events because of the enormous erosion capacity, long distance transport and dispersive immission of particulate contaminants.
- spatial variability of sediment properties must be considered by using appropriate tools.

Some example of models being used in Europe at present, include:

1) Soil erosion and sediment delivery (land to waters)
- EUROSOIL
- Morgan-Morgan-Finney
- USLE (and RUSLE)
- Sedimentgraph
- PSYCHIC

2) Sediment transport and deposition models
- Sobek 1/2D
- Cosmos 1/2D
- HEC.RAS
- HEC6
- Mike 21C 2D
- Telemac 2D
- Deft 3D
- Sedimentgraph

This represents a list of examples and members of the SedNet community are asked to submit additional examples to philip.owens@bbsrc.ac.uk.

Presentation 7 – Other tools and approaches for sediment management – Phil Owens (NSRI, UK), Harald Koethe (Federal Institute of Hydrology, Germany) and Marc Eisma (Rotterdam Municipal Port Management, The Netherlands)

Phil Owens described how sediment tracing and sediment fingerprinting techniques can be used to provide information on sediment sources, sediment delivery and sediment storage in river basins that could be used for sediment management at the basin scale. Further information is contained in a Discussion Paper presented later in these minutes.

Harald Koethe. Based on a work by Guy Engelen (see enclosed document) Harald Koethe described what a Decision Support System (DSS) for integrated river basin management is and how sediments are involved. As an example he pointed to the pilot DSS for river Elbe (see enclosed document and http://elise.bafg.de/?3469). He concluded that quantity and quality aspects of sediment management are important factors in such a DSS but not finally integrated in such a system yet. Consequently, the following questions have to be answered in the future: How to deal with DSS for sediment management? Which demands, modelling tools and techniques are necessary to include in a DSS for sediment management?

Marc Eisma discussed issues relating to modelling and other tools for sediment quality issues. Many of the points raised by Marc were raised in his Workshop 2 Discussion Paper. This is included in these minutes and the reader is directed to this for more information.

Notes from the discussion session

Research needs

There is a clear need for a depository of sediment data. Key questions here are:
- Who controls existing (and future) data? European E.A.?
- What is available?

Why do we need more and better data?
- Model verification
- Feed into cost-benefit and risk analysis

What data is needed:
- Sediment fluxes (suspended sediment and bedload)
- Sediment quality
- Soil erosion
- Sedimentation in rivers (and floodplains), reservoirs and harbours
- Amount of gravel abstraction

There is a clear need for a harmonised EU sediment monitoring network. The WFD initiative and momentum could and should be used for this.

Summary and key recommendations

What does measurement and monitoring of river sediment tell us?
- It tells us where the sediment is coming from (its source)
- It tells us how much is being transferred (fluxes)
- It provides us with an understanding of the basin-scale sediment system
- It can be used to predict sediment response to changes in the system (thus relevant to WFD and Habitats Directive, and climate change)

At present we probably have the measurement and monitoring tools to provide us with the necessary information to address most river sediment issues, but we may not be using the tools to their best use for sediment management.

We have some of the modelling tools required for sediment management but there is a need for more data to test these models.

There is a clear need to ensure that sediment (quantity and quality) is routinely measured and monitored (at least at a minimum, basic level) as part of a European-wide sediment monitoring network. One way forward would be to include such a network in national programmes to implement the WFD (and possibily the Soil Thematic Strategy). This needs to be done in a harmonised way throughout Europe.

Work Package 2 Discussion Paper

Methods and techniques to measure, sample, and quantify sediment transfer in fluvial systems

Celso Garcia
University of the Balearic Island, Spain

Introduction

A striking aspect of work on fluvial systems is the wide range of methods and techniques used to estimate sediment transport. A considerable amount of effort typically is involved in developing transport estimates, which have remained largely in the domain of small scale research. This is unlucky, because many large-scale problems in fluvial geomorphology would benefit from the availability of an efficient means of estimating sediment transport, both in basic and applied research. Topics such as watershed response to changes in land use or flow regime, migration of sediment slugs through a channel network, or the sediment history of riparian ecosystems, require large scale sediment budgets to provide historical content and to establish cause and effect (Wilcock, 2001). However, given the variety and complexity of natural channels and the number of purposes for which a transport estimate is useful, it is not surprising that many methods exist and it is unlikely that any single method would meet all objectives under all circumstances. This diversity requires a broader discussion of which methods might provide efficiency, accuracy and consistency in a wide range of situations, and it is worthwhile, given the potential benefit that could provide to a wide range of basic and applied problems.

Sediment transfer in fluvial systems

The transfer of sediments through defined channel reaches is summarised in the sediment budget (Ashmore and Church, 1998; Ham and Church, 2000), expressed as:

$$V_o = V_i - \Delta V \qquad (1)$$

Wherein V_o is sediment output and V_i is sediment input to a reach. The storage term, ΔV, is measured as the net difference between erosion of island and floodplain deposits into the active channel, reconstructions of islands and the floodplain by sediments deposited from the active channel, and scour and fill of material within the active channel. The equation can be reduced to a mean transport rate by integration over some arbitrary period, usually the time between successive surveys.

At catchment scale, the sediment budget concept means a framework for integrating the various components of catchment sediment delivery, including the sources, transfer pathways, sinks and output of sediment, by ensuring that each aspect of sediment delivery is quantified and then assessed in terms of its relationship to the overall catchment response (Walling, 1983, Philips, 1991; Walling 1999). Assembling the information required to construct a detailed catchment sediment budget represents a difficult task and, consequently, most budgets are restricted to very small drainage basin or a single component of the budget (Walling and Collins, 2000).

Within the sediment transfer, the transport of sediment is often divided into three types: wash load, suspended load, and bed load:

- Wash load is very fine material which remains suspended within the flow at all times. It is a small component of the total load and is rarely considered in detail.
- Suspended load consists of coarser material kept in the flow by turbulent energy. This material is composed mainly of fine grained sediments found on catchment slopes and upper channel banks, in overbank deposits and on the bed. Once entrained, this material moves primarily in suspension, possibly for a long way.Bed load is a combination of several processes (traction and saltation) Saltation involves particles leaving the bed for short distances. The transition between saltation and suspended load is unclear as suspension is an extension of the saltation process. Bed load material comprises those sediments found on the bed and lower banks of a river that move comparatively short distances along the bed.

Selection of monitoring sites for measuring sediment transfer

Sampling site selection within a study catchment is an important consideration in the design of a monitoring programme for measuring the sediment transfer. However, a principal consideration for any research programme is the choice of a suitable study catchment. Walling and Collins (2000) proposed to include some considerations:

- Selection of a river basin of suitable size. As catchment area increases the complexity of the spatial variability of erosion and sediment delivery increase.
- Selection of a river basin for which rates of erosion, deposition and sediment delivery can be reliably quantified using the available measurement techniques.
- Selection of a river basin within reasonable travelling distance, so the monitoring and fieldwork programmes can be undertaken within the financial constraints of the project
- Selection of a river basin with some pre-existing background data.
- Selection of a river basin which is broadly representative of the environmental conditions for a particular region or country.

For large alluvial rivers, it could be useful to develop a framework and blueprint for the study designed to ensure that such study recognise the continuity and connectivity of the fluvial system by encompassing the relevant temporal and spatial scales (Environment Agency, 1998). This enables researchers to design experimental and monitoring programmes that provide all the information necessary to support progress in our understanding of river channel form and processes (Thorne, 2002).

The choice of sampling sites within the study catchment is the next step. In fact, to develop effective sediment monitoring strategies needs considerable time and effort in order to design, install and maintenance a sediment monitoring station or establishing sediment transport measurement programme. Overall, monitoring sites must be valid for collecting information that is representative of the drainage basin and the processes of sediment transfer.

Measuring suspended sediment transport

There is a broad relationship between suspended load concentration and water discharge. This considerable scatter is due to a range of factors, including: catchment geology, season, sediment exhaustion or rainfall intensity; and within individual floods there is hysteresis due to exhaustion of sediment available for transport.
Estimation of suspended sediment transport and average sediment concentrations requires the integration of continuous data on streamflow with discrete measurement of sediment concentration. Available methods for measuring suspended sediment in rivers can be divided into those based upon the collection of suspended sediment samples and those based upon turbidity monitoring (Walling and Collins, 2000).

Traditionally, the simplest and cheapest way of collecting suspended sediment samples is to use plastic bottles submerged into the streamflow by hand. However, because sediment concentrations can vary, spatially and temporally, in the stream cross section, a manual sample may not be representative of ambient concentration, and so a range of manual sampling devices have been designed to collect representative suspended sediment samples: instantaneous samplers, point-integrating and depth-integrating samplers. This manual sampling devices are useful for collecting infrequently samples but on a regular basis.
It is well known that suspended sediment transport is highly episodic and that *c.* 90% of the annual load is commonly transported within only c. 10% of the time (e.g. Walling and Webb, 1987). There is, therefore, an important need to focus sampling activity during flood events, when the suspended sediment transport primarily occurs and it is essential to sample. For this reason, a range of automatic suspended sediment samplers have been designed and utilised: from the single stage sampler to a complex automatic sampler that pump and collect water samples at predetermined times or water levels (Walling, 1984). It is evident, that the cost of automatic sampler equipment may represent and important constraint in many studies, and it is not clear the extent to which individual instantaneous samples can be assumed to be representative to a sediment transported during a longer periods (Philips et al. 2000).
Depending upon sampling frequency, suspended sediment load can therefore be easily calculated, where rapid temporal fluctuations in suspended sediment concentrations are unlikely. In the absence of a detailed temporal record, sediment loads can be estimated using conventional load calculation procedures, e.g. a sediment-rating curve approach.

Regular but infrequent water sampling (daily, weekly, or monthly), commonly results in the underestimation of suspended sediment transport (Walling and Webb, 1981). Research has demonstrated that detailed characterisation of the high frequency variations, and in particular storm period variations in suspended sediment transport, is essential for the accurate assessment of suspended sediment transport. High frequency water sampling has been increasingly carried out with in situ turbidity sensors (Gippel, 1995). These sensors are linked to a datalogger and turbidity is recorded at a predetermined frequency. These instruments can be used to measure suspended sediment concentrations up to ca. 20,000 mg l^{-1}. The turbidity records must be calibrated using manual water samples in order to derive a concentration record. Thus, the complementary use of turbidity meters and automatic water samplers it is the recommended monitoring strategy for the calculation of the suspended sediment load and yield in rivers (Walling and Collins, 2000).

Measuring bed load transport

The typical choices for estimating bed load transport in a river are to use a formula or to directly measure the transport rate. Field measurements offer the possibility of greater accuracy, but at greater time, cost and effort. Bed load is a catch-all term for the processes of grain sliding, rolling and saltation, and its movement is a poorly understood phenomenon (Church, 1985). Bed load constitutes an important component of the total sediment yield of a drainage basin, lying between 0 and 50%, depending upon whether the local environment is humid or arid and whether the channel bed is composed of sand or gravel. It may have a significance beyond its relative contribution in that is channel-forming, but its denudational role is generally inferior to that of suspended sediment (Reid and Frostick, 1994).

The relationship between stream discharge and the entrainment and deposition of bed particles remains vague. In fact, bed load appears not to move steadily. All observations that have been made with sufficient temporal resolution reveal short term fluctuations in transport (e.g. Ehrenberg, 1931; Emmet, 1975; Reid et al., 1985). Within a stream cross-section there are zones that exhibit higher rates of transport than others and, clearly, this presents a challenge in terms of sampling adequately across a channel width. The temporal variations in bed load transport rates can occur on several scales (Reid and Frostick, 1994). Sediment pulses can occur over time periods ranging from seconds up to several months (Gomez et al., 1989). This non-uniform variation in transport volumes has caused much difficulty in establishing representative sampling methods (Gomez and Troutman, 1997). As a result, there is a noted lack of data on transport rates, especially in gravel-bed rivers.

Bed load transport in rivers has been directly measured almost exclusively by sampling small incremental river widths with some type of bucket or basket sampler:

- *Net and basket samplers*. The standard sampler for bed load is the Helley-Smith sampler (Helley and Smith, 1971). It is a pressure-difference bed load sampler developed specifically for use in rivers where sediment ranged in size from coarse sand to medium gravel. The sampler had a 7.62 cm x 7.62 cm orifice leading to a mesh bag that holds about 10 kg of sediment. It has a 100% sediment trapping efficiency for grains ranging from 0.5 to 16 mm (Emmett, 1980). Several versions of the original sampler have evolved, including slightly altered cable-supported samplers, a wading-rod version, and a scaled-up sampler of twice the original orifice size. The relative handling ease and potential for effectively catching fine and medium gravel make the Helley-Smith sampler attractive for short term field measurements at different sites. Typical procedures consist of sampling at about 20 equally spaced cross-channel locations (Klingeman and Emmett, 1982). Because of the large spatial and temporal variability characteristic of bed load transport, measurement programs require a large number of samples (Hubbel, 1987).
- *Buckets and pit traps*. These consist of a bucket or tube sunk vertically into the bed (Church et al., 1991), usually with an inner sleeve that can be emptied. This method can give a good estimate of the total mass of sediment moved during the flood event. One successful modification of this technique was the design of automatically recording pit traps, with a pillow (Reid et al., 1980) or a load cell (Lewis, 1991) placed within the trap to weight sediment as it accumulated. Instantaneous observations required permanently installed equipment. To date, these samplers have been used to investigate temporal and cross-stream variation in sediment transport rates and associated

hydraulics, and have been deployed in relatively small river systems. The main drawbacks of buckets and pit samplers are the installation effort and the fact that they can be inaccessible and can fill rapidly at large transport rates.

There is another kind of bed load recorders, which required large scale installations, as the *vortex bed load sampler* (Milhous, 1973; Tacconi and Billi, 1992) or the *conveyor-belt bed load sampler* (Leopold and Emmett, 1997). The first sampler develops a vortex flow to move bed load through a flume embedded in the floor of a weir structure. The bed load and a portion of the streamflow are removed to an off-channel pit, where the bed load sample is collected. The conveyor-belt consists in a concrete trough extended across the river with a slot into which falls sediment. A belt carries laterally the sediment to the bank and dumps the load into a hopper, which stands on a large weighing scale.

Another instrument is the *in situ magnetic detection*. This device records the magnetic signals of clasts with implanted magnets (Ergenzinger and Conrady, 1982) or the faint signals from remanent magnetism in iron-containing clast (Ergenzinger and Custer, 1983). This device could detect naturally and magnetic pebbles and cobbles at a rate of 2 per second. The sensitivity of this device permits detection of an estimated 40% of the coarser material (>32 mm) (Bunte, 1996).

Indirect methods, as the *scour chains* (Hassan, 1990) or studies with *tracer or painted stones and scour chains* have revealed a great dealed about the net changes from sediment transport and deposition within a stream reach (Laronne et al., 1992; Haschenburger and Church, 1998). Bed material transport, under certain assumptions, can also be estimated through back-calculation of sediment transport from changes in channel morphology. The *morphologic approach* estimate sediment transport by measuring erosion volumes over some time period(s). This method has been increasingly used and refined (e.g. Ferguson and Ashworth, 1992, Lane et al., 1995, Ashmore and Church, 1998). Techniques include *repeated topographic surveying* of the bed (Ferguson and Ashworth, 1992; Lane et al., 1995), *topographic mapping of aerial photos* and GIS (Ham and Church, 2000) or *digital photogrammetry* (Lane, 2001). This last technique can be used to quantify grain scale and bedform scale surface morphology for both exposed and inundated areas. At larger scales, it is now possible to quantify automatically river channel pattern, and to use digital photogrammetry to construct DEMs of wide rivers at a high spatial (0.5 m point spacing) and temporal (event-based) resolution. Refraction correction for clear water rivers and empirical depth estimation algorithms for turbid rivers reduces the traditional dependence upon survey for wetted areas (Lane, 2001). An example of this technique is shown in Table 1.

Table 1. Reach volume estimates derived from mean bed levels obtained using different methods (Lane, 2001)

Method	Approximate downstream spacing (m)	Reach volume (m^3) above zero datum	Error in volume (m^3)
"Ground truth" ground survey	1	1,708,884	≠ -
Photogrammetry – Uncorrected	1	1,710,679	1,795
Photogrammetry – corrected	1	1,709,080	196
Ground survey – 44	10	1,709,254	370

sections			
Ground survey – 18 sections	25	1,705,665	3,219
Ground survey – 9 sections	50	1,714,384	5,500
Ground survey – 5 sections	100	1,687,395	21,489
Ground survey – 3 sections	200	1,817,605	108,721

≠ Volume calculated using a grid based data set with a 1 m grid spacing

This table suggest that conventional cross sections would need to be spaced at somewhere between 10 and 25 m intervals to produce an error similar to that associated with the photogrammetry without clear water correction. This compares with the current spacing in use of 200 m. These volume errors really need to be judged with respect to actual volumes of change. For instance, if over a given time period, there is more than 6,500 m^3 of change in this reach, 25 m spaced cross sections would just identify a significant change (assuming an uncertainty of ± 3219 m^3 per survey). The greater the change, the lower the relative error (Lane, 2001)

Recently, a new methodology for channel change detection has been developed and applied to a wide gravel-bed river (Lane et al., 2003). This is based upon construction of digital elevation models (DEMs) using digital photogrammetry, laser altimetry, and image processing. The estimates of volume of change, using this methodology, produced more reliable erosion and deposition estimates as a result of a large improvement on spatial density that synoptic methods provide.

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Work Package 2 Discussion Paper

PREDICTING OF SEDIMENTGRAPHS
FOR SMALL AGRICULTURAL CATCHMENTS

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A procedure for prediction of suspended sediment load, washed from a small river catchment by heavy rainfall, has been developed by using the concept of instantaneous unit hydrograph (IUH) and dimensionless sediment concentration distribution (DSCD). New equation of the instantaneous unit sedimentgraph (IUSG) is presented, and a procedure for estimating sediment routing coefficient, which is a key parameter of the IUSG, based on measured data of rainfall-runoff-suspended sediment is applied. Data from a small agricultural catchment in East Central Illinois, as well as from a few small catchments in Poland are used to investigate lag times.

KEY WORDS: sedimentgraph, wash load, watershed lag times

INTRODUCTION

Estimates of sedimentgraphs (graphs of suspended sediment load associated with hydrographs caused by rainfall) are essential for sediment yield assessment, providing input data for prediction models of sediment deposition in reservoirs, designing efficient sediment control structures, and for water quality predictions. In these cases, and especially in the frequently considered non-point pollution models, in which sediment is a pollutant and transports other pollutants, it is important to estimate sediment transport accurately during individual storms.

An idea of sedimentgraph model introduced by Williams (1978) was used in previous investigation (Banasik, Woodward 1991, Banasik, Blay 1994). A new definition of instantaneous unit sedimentgraph (IUSG) was developed (Banasik, 1994, Banasik Walling 1995). The IUSG was incorporated into sedimentgraph model (SEGMO), based on lumped parametric approach.

The sedimentgraph model, which was developed for predicting watershed response to heavy rainfall, consists of two parts; a hydrological sub-model and sedimentology sub-model. The hydrological submodel uses the Soil Conservation Service CN-method to estimate effective rainfall, and the instantaneous unit hydrograph (IUH) procedure to transform the effective rainfall into direct runoff hydrograph. The sedimentology submodel uses a form of the modified Universal Soil Loss Equation to estimate the amount of suspended sediment produced during the rainfall-runoff event and the instantaneous unit sedimentgraph (IUSG) procedure to transform the produced sediment into sedimentgraph.

IUSG PROCEDURE DESCRIPTION

The IUSG is defined as time distribution of sediment generated from an instantaneous burst of rainfall producing one unit of sediment. The IUSG presented here is based on the IUH derived by Nash (1957) i.e.:

$$u(t) = \frac{1}{k \cdot \Gamma(N)} \cdot (t/k)^{N-1} \cdot \exp(-t/k) \qquad (1)$$

and the first-order kinetic equation written in dimensionless form and termed the dimensionless sediment concentration distribution (DSCD):

$$c(t) = \exp(-B \cdot t) \qquad (2)$$

where u(t) are the ordinates of the IUH (1/hr), N and k are the Nash model parameters: N is number of reservoirs (-), k is the retention time of reservoir (hr), Γ(N) is gamma function, c(t) are the ordinates of the DSCD (-), B is sediment routing coefficient (1/hr), and t is time (hr).
The IUSG is calculated by the formula:

$$s(t) = \frac{u(t) \cdot c(t)}{\int_0^\infty u(t) \cdot c(t)\, dt} \qquad (3)$$

which after inserting into it the equation 1 and 2, and solving it, produces the following formula (Banasik, 1994):

$$s(t) = \frac{B \cdot k + 1}{k \cdot \Gamma(N)} \cdot [t(B + 1/k)]^{N-1} \cdot \exp[-t(B + 1/k)] \qquad for\ B \geq -1/k \qquad (4)$$

where s(t) are the IUSG ordinates (1/hr). The IUSG has three parameters N and k which are also IUH parameters and a third, the sediment routing coefficient B.

The characteristic values of the IUSG i.e. time to peak could be calculated from the formula:

$$t_{ps} = \frac{(N-1) \cdot k}{1 + B \cdot k} \qquad (5)$$

and the maximum ordinate of IUSG could be computed from the equation:

$$s_p = \frac{1 + B \cdot k}{k \cdot \Gamma(N)} \cdot \frac{(N-1)^{N-1}}{\exp(N-1)} \qquad (6)$$

where t_{ps} is the time to peak of IUSG (h), and s_p is the maximum ordinate of IUSG (1/h).
As the respective values for IUH are calculated from the equations:

$$t_p = (N-1) \cdot k \qquad (7)$$

and

$$u_p = \frac{1}{k \cdot \Gamma(N)} \cdot \frac{(N-1)^{N-1}}{\exp(N-1)} \tag{8}$$

where t_p is time to peak of IUH (h), and u_p is the maximum ordinate of IUH (1/h), so the ratio of the characteristic values of IUSG and IUH could be computed from the formulae:

$$\frac{t_{ps}}{t_p} = \frac{1}{(1 + B \cdot k)} \tag{9}$$

and

$$\frac{s_p}{u_p} = 1 + B \cdot k \tag{10}$$

It is clear that when B equals zero the characteristic values of IUH and IUSG would be the same and right side of equation 4 assumes the form of the Nash' IUH (Eq. 1). It could be also found, from the Eq. 9, that for B>0 time to peak of IUSG is shorter then time to peak of IUH, and peak value of IUSG is higher than peak of IUH (Eq. 10).

EMPIRICAL ESTIMATION OF SEDIMENT ROUTING COEFFICIENT

One of the characteristic values in rainfall-runoff modelling is the retention of the system or lag time, which is defined as the time elapsed between the centroids of effective rainfall and the direct runoff hydrograph. For the IUH derived by Nash, the lag time is estimated using the formula:

$$LAG = N \cdot k \tag{11}$$

For the IUSG, the lag time (LAG_s) could be calculated using the equation:

$$LAG_s = \frac{N \cdot k}{1 + B \cdot k} \tag{12}$$

Making use of the equation 11 and 12, the routing coefficient B can be computed using the formula:

$$B = (LAG/LAG_s - 1)/k \tag{13}$$

Since the LAG, LAG_s and k can be estimated from rainfall-runoff-suspended sediment data, the routing coefficient B, can be estimated using equation 13.

Using measured data of rainfall-runoff events the lag time could be calculated as:

$$LAG = M_{1Q} - M_{1P} \tag{14}$$

where M_{1Q} and M_{1P} are first statistical moments of the direct runoff hydrograph and the effective rainfall hyetograph (h), respectively. Many attempts have been made to establish the relationship between the watershed lag time and basin characteristics (e.g. Snyder, 1938, Watt and Chaw, 1985, Chang-Xing Jin, 1992). Respectively, based on measured data, the lag time for sedimentgraph, LAG_s, is defined as time elapsed between centroides of sediment production graph (similar to effective rainfall hyetograph) and sedimentgraph, and could be computed from formula:

$$LAG_s = M_{1S} - M_{1E} \tag{15}$$

where M_{1S} and M_{1E} are first statistical moments of the graph of direct suspended sediment rate, and the graph of sediment production (h), respectively. Data from small agricultural watersheds were analysed by author et Al. to investigate the relationship between LAG_s and LAG, and the results will be discussed during his presentation.

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Work Package 2 Discussion Paper

Tracing techniques for sediment management

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Introduction

Within the last few decades, sediment tracing and sediment fingerprinting techniques have provided a considerable amount of information on:

- where sediment is coming from (its source)
- soil erosion and redistribution on land
- sediment delivery from land to rivers
- contributions from bank erosion
- sediment fluxes within rivers
- sediment deposition and storage on floodplains and in lakes and reservoirs
- basin-scale sediment budgets

Such information is central to our understanding of the sediment system within river basins. It may be true to say that sediment tracing and sediment fingerprinting techniques offer more potential as tools for providing the information for sediment managment than any other, but that to date these techniques have not been used to their potential for sediment management, although their use and application within the scientific community is well-established.

This SedNet WP2 Discussion Paper is not meant to be an exhaustive review of tracing and fingerprinting techniques but will illustrate the use and potential of such techniques by reference to examples based on work undertaken by the author.

Sediment tracers

There are a variety of tracers that can be used to monitor the movement of sediment within the environment. A useful review of tracers for fine-grained sediments can be found in Foster and Lees (2000), and in Sear *et al*. (2000) for a review of coarse-grained sediment tracers. The reader is also directed to Dearing (2000) for more information on natural mineral magnetic tracers. One group of tracers that have received considerable attention over the last three decades are fallout radionuclides and the following section will focus on these, with specific reference to caesium-137. Fallout radionuclides that have proven to be useful for tracing fine-grained sediments include caesium-137 (^{137}Cs), unsupported lead-210 (^{210}Pb) and beryllium-7 (^{7}Be). In all cases, these radionuclides are delivered from the atmosphere to the soil surface by wet and dry fallout, with wet fallout in association with precipitation being the dominant process. Once these fallout radionuclides reach the soil surface, they tend to bind (almost irreversibly) with fine soil particles and organic matter in the upper layers of the soil profile. Subsequent redistribution within the environment, therefore, is mainly associated with soil erosion and sediment transport and deposition processes. In consequence, these radionuclides and others may be used to trace the movement of soil and sediment within river catchments. For a useful review of the use of these radionuclides as tracers see Zapata (2002). The following focusses on the use of ^{137}Cs as a tracer of fine-grained sediment in river basins.

Caesium-137 is an artificial radionuclide produced in the 1950s and 1960s due to the atom-bomb tests. It has a very distinct fallout history reflecting the timing of these bomb tests and the test-ban treaty of 1963 (Figure 1). In parts of Europe, there was also a peak in 1986 associated with the Chernobyl incident, although this was of regional significance. The ^{137}Cs that was eject into the atmosphere and stratosphere tended to circulate the globe, such that ^{137}Cs fallout occurred worldwide, with latitudinal and regional variations in fallout amounts reflecting the location of the bomb-tests (there were more in the Northern Hemisphere) and rainfall patterns. There may also be some local variations in fallout that merit consideration when using ^{137}Cs as a tracer (see Owens and Walling, 1996).

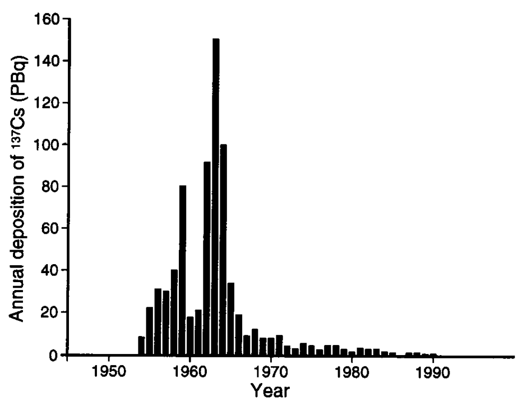

Figure 1 – Temporal pattern of bomb-derived ^{137}Cs fallout to the Northern Hemisphere (from Owens *et al.*, 1997).

Once the ^{137}Cs reached the soil surface it was tightly bound to fine soil particles. Generally there is only limited vertical movement of ^{137}Cs within the soil profile, which is predominantly associated with the movement of soil particles. In undisturbed soils, biological activity means that there is an approximately exponential depth distribution of ^{137}Cs with depth (Owens *et al.*, 1996). In cultivated soils, the ^{137}Cs is mixed within the plough layer by tillage processes (Owens *et al.*, 1996). Subsequent horizontal movement within the landscape is mainly by erosion and sediment transport processes. In consequence, once a relationship has been established between the amounts of ^{137}Cs present in a soil profile and the erosion/deposition rate (cf. Owens and Walling, 1998), measurements of ^{137}Cs activity can be used to estimate soil erosion rates in both uncultivated and cultivated fields (see Figure 2).

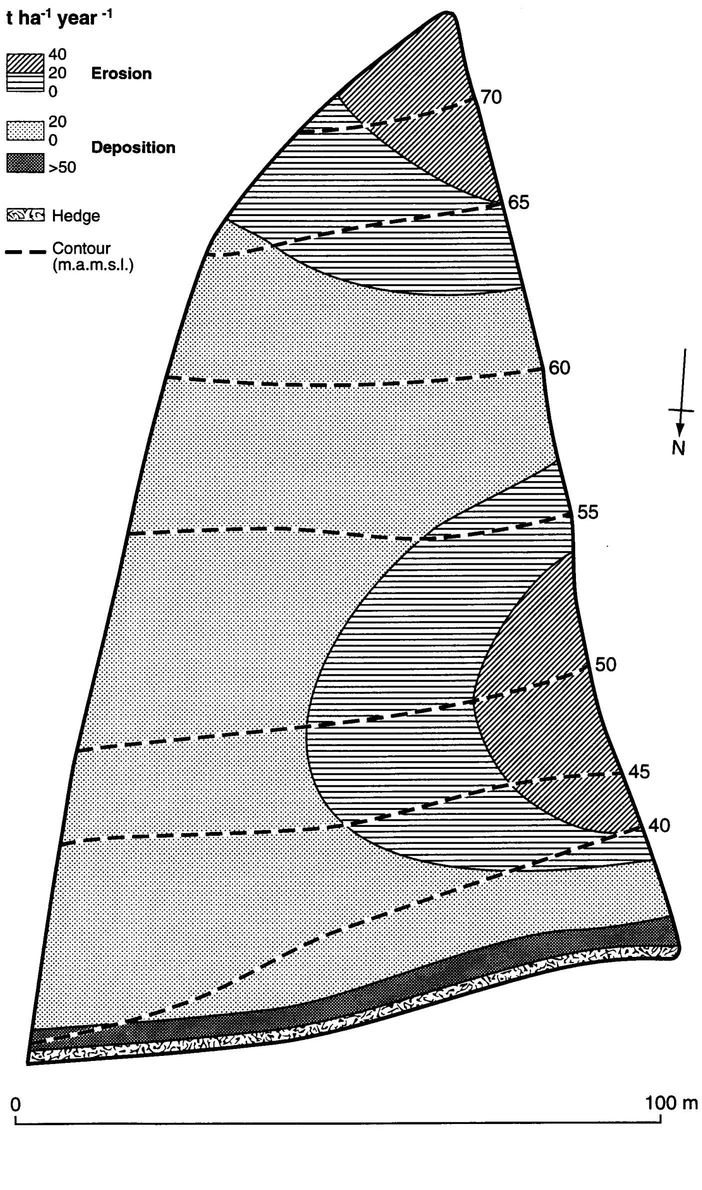

Figure 2 – Estimates of soil erosion and deposition within a cultivated field in Devon, UK, based on ^{137}Cs measurements (from Owens *et al.*, 1997).

Because of the well-known temporal pattern of ^{137}Cs fallout, ^{137}Cs measurements can also be used to estimate accumulation rates in areas of sediment deposition, such as lakes and floodplains. Thus, for example, the maximum concentration of ^{137}Cs in a sediment core collected from a floodplain can be assumed to equate to the period of maximum fallout in 1963, thereby providing a core chronology. If multiple cores are collected across a floodplain surface, it may be possible to determine floodplain storage of sediment and associated sediment conveyance losses due to overbank sedimentation processes (Figure 3).

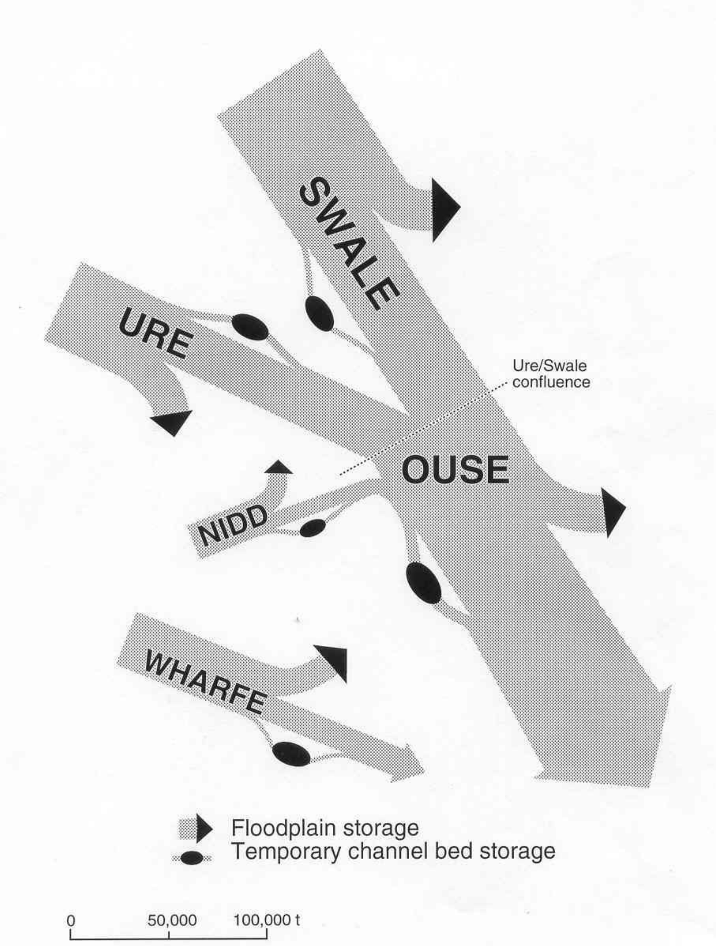

Figure 3 – The role of floodplain and channel bed storage in the sediment budget of the main channel reaches of the Rivers Ouse and Wharfe, UK (from Walling *et al*., 1998).

In this way, ^{137}Cs measurements can be used to estimate erosion and sediment redistribution rates on land, and sedimentation rates on floodplains and in lakes and reservoirs. In turn, it may be possible to use ^{137}Cs measurements to estimate basin-scale sediment budgets (Figure 4).

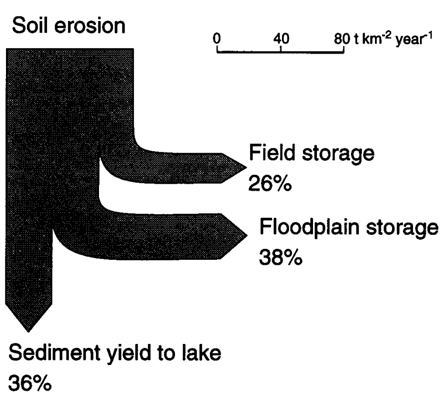

Figure 4 – Sediment budget for the Start basin, Devon, UK based on ^{137}Cs measurements (from Owens *et al*., 1997).

In addition to estimating sediment deposition rates and sediment budgets for "clean" sediment, it is also possible to use the tracing approach to estimate rates and amounts of deposition and storage of sediment-associated contaminants, and thus to determine catchment contaminant budgets (Walling and Owens, 2003). In this case, estimates of sediment redistribution and storage are linked to the contaminant content of the sediment (see Figure 5).

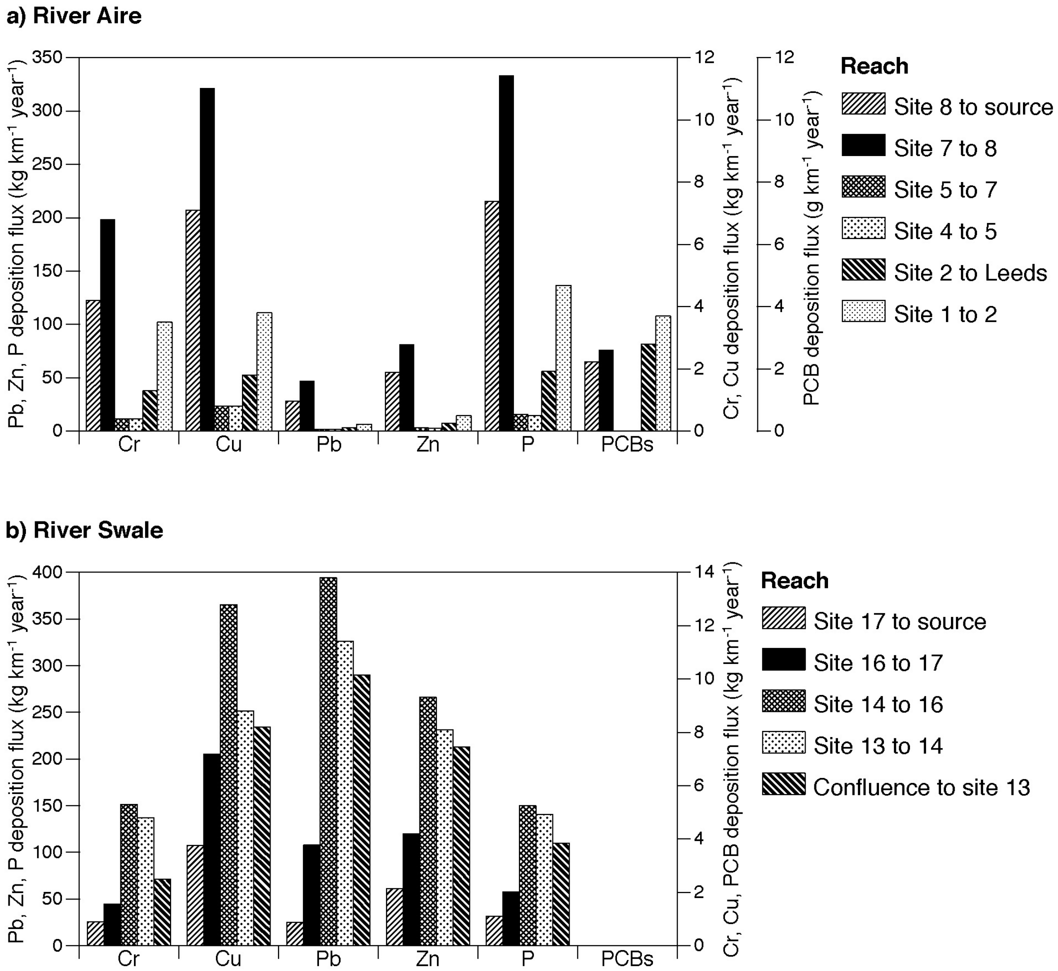

Figure 5 – Downstream variation in the deposition of sediment-associated contaminants on the floodplains bordering the main channels of the Rivers Aire and Swale, Yorkshire, UK (from Walling and Owens, 2003)

Sediment fingerprinting

One of the main questions of interest when trying to understand sediment behaviour in river systems and when trying to implement appropriate and cost-effective management solutions, is to identify where the sediment is coming from. In this respect, a useful tool is sediment fingerprinting. Detailed descriptions of the methodology can be found in He and Owens (1995), Collins *et al*. (1998), Walling *et al*. (1999), Owens *et al*. (2000) and Carter *et al*. (2003). Simply, physical, chemical and/or biological properties of the sediment in question (i.e actively transported or deposited sediment) is used to make a fingerprint of that sediment, which is then compared to an equivalent fingerprint signature for potential source materials. The link can be either qualitative or alternatively (un)mixing models can be used to make quantitative estimates of relative contributions from various sources (cf. He and Owens, 1995; Walling *et al*., 1999; Owens et al., 2000). The use of composite fingerprints (using a variety of different soil-sediment properties such as radionuclide, mineral magnetic and geochemical properties) coupled to mixing models can enable sediment sources to be identified according to land use types (i.e. woodland topsoil or pasture topsoil or channel bank material) or spatial regions (ie. contributing tributaries or geological regions) with a river basin (Figure 6). Thus in the case of Figure 6(a), of the order of 60% of the sediment is derived from the erosion of topsoil in pasture/moorland and cultivated soils. In consequence, measures to control bank erosion would only at best reduce the suspended sediment load by ca. 40% However, reduction of channel bank erosion is likely to be a relative cheap solution for reducing the river sediment load compared to the reduction of sediment delivered from the land.

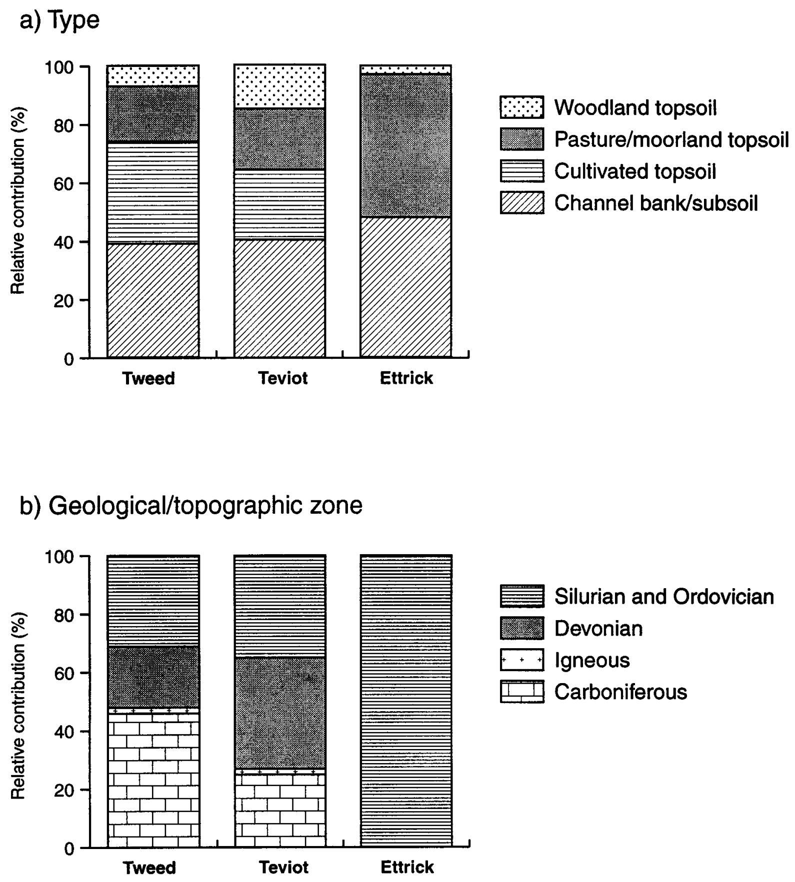

Figure 6 – The suspended sediment load-weighted contributions of (a) land use types and (b) geological/topographic zones, to the suspended sediment samples collected from the Rivers Tweed, Teviot and Ettrick, Scotland (from Owens *et al.*, 2000).

It is also possible to use the sediment fingerprinting approach to determine the sources of sediment (and in some cases the sources of contaminants) in urban river basins. Thus in the case of Figure 7, it is clear that a significant proportion of the suspended sediment transported by the River Aire (downstream of the city of Leeds) is derived from solids from sewage treatment works (STWs) and from road dust. Interestingly in this case, the contribution from these "urban" sources increases at the peak of the storm hydrograph as the urban road sediment network becomes connected to the river channel network. As much of the solids from STWs and roads is contaminated (with heavy metals etc.), clearly this has important implications for sediment and contaminant management.

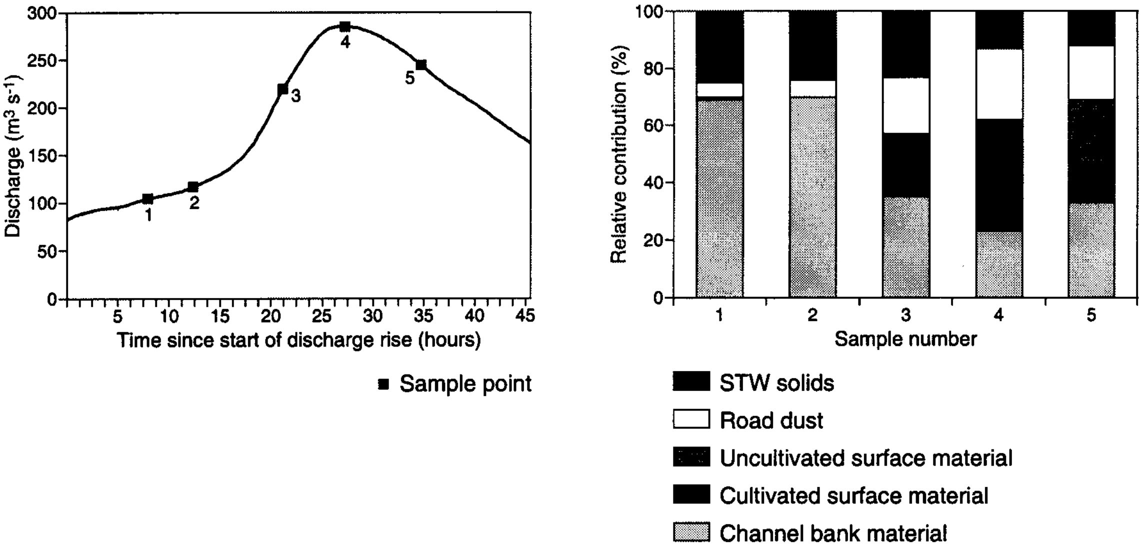

Figure 7 – Variation in the relative contribution of surface material from uncultivated and cultivated areas, channel bank material, road dust and solids from STWs to suspended sediment samples collected from the River Aire, UK during a storm event in 1998, based on the fingerprinting technique (from Carter *et al.*, 2003).

In addition to using the fingerprinting technique to identify the sources of contemporary sediment, it is also possible to use the technique to identify changes in sediment sources through time. Figure 8 shows downcore changes in sediment sources for three floodplain sediment cores collected from the River Tweed basin, Scotland, determined using the fingerprinting approach and the use of radionuclides to establish core chronologies.

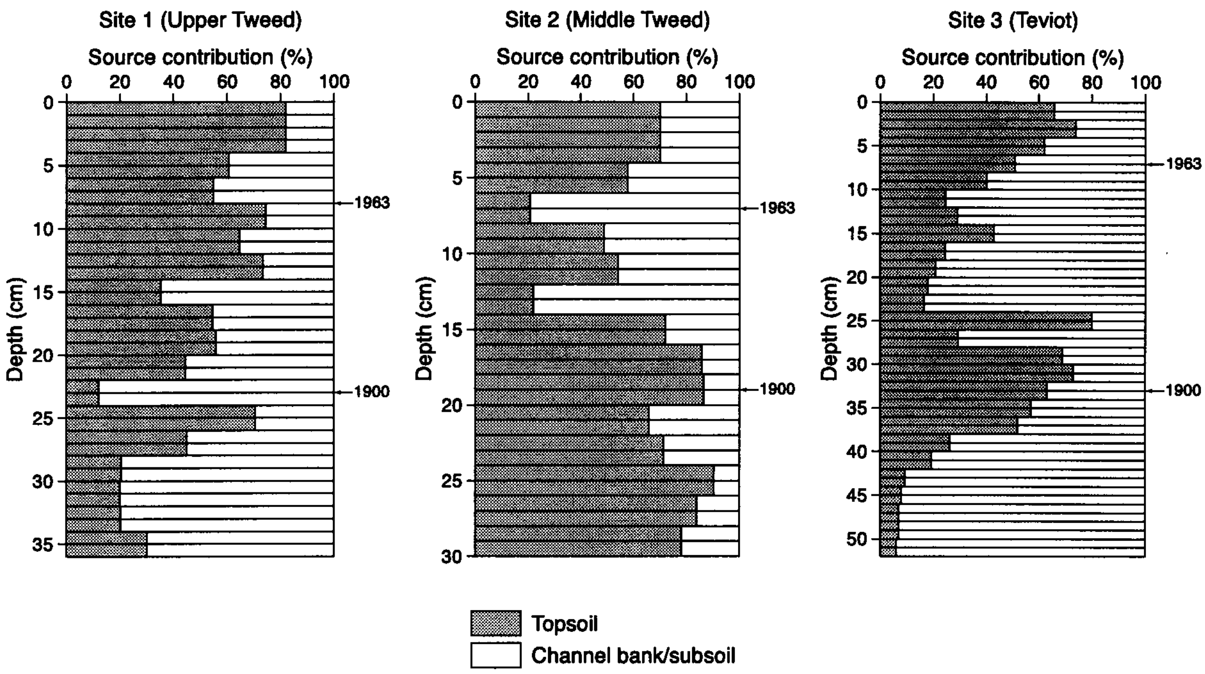

Figure 8 – Downcore changes in the relative contributions of topsoil and channel bank/subsoil sources within the upstream catchments for three floodplain cores collected from the River Tweed, Scotland (from Owens and Walling, 2002).

Conclusion

This contribution has demonstrated that sediment tracing and sediment fingerprinting techniques represent important tools that can be used to provide information on sediment sources and sediment dynamics within river basins. In particular, they can be used in combination to provide basin-scale information for sediment management. While these tools have a long history within the hydrological and geomorphological scientific communities they have yet to be used to their potential by managers and policy-makers to provide the information for informed sediment management decisions.

Acknowledgement

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Work Package 2 Discussion Paper

Sources and transfer of contaminants in river basins

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Introduction

Since in the seventies the contamination of river sediment became apparent, Dredged Material Management Programs have strongly been focussed on the control of the initial sources of contamination. In most river basins the discharging companies reached radical reductions in their discharges, which led to a significant reduction in point discharges and resulted in a significant impulse with regard to the quality of rivers and consequently to the quality of the sediments. Emission control (with a shift from point to diffuse sources) is still essential in further improving sediment and dredged material quality. It is important to translate the contaminated sediment to reduction measures at the source.

This discussion paper focuses on the modelling approaches using the immission-emission approach, in line with the WFD. With this approach the relative input of these different pathways can be calculated and also how the contamination of sediments develops in future. Sediments are a secondary source of contaminants in river basins. The most effective way of tackling this issue is through the controll of these sources of contamination. With different management approaches the latter can be achieved. Examples for management approaches are finally given in this paper.

Nowadays, a shift can be seen from chemical to biological assessment in environment permitting for the relocation of the dredged sediment. No such instrument is yet being developed for river sediments itself for the purpose of control of the initial sources of contamination. In this discussion paper the focus is on chemical parameters only, so this issue is not discussed, but should also be covered in management approaches of sediment and contamination transfer on river basin scale.

An issue of special importance is the 'historic' contamination of sediments as 'sleeping' sources of contamination in river basins. As new inputs of contaminants will continue to decrease, the relative contribution of 'historically' contaminated sediments to contamination loads in river basins will gain in importance. This process, is governed by re-erosion during high water discharges, by relocation of dredged material stemming from weirs and locks and related retention and loss processes. In this discussion paper these sources of contamination are not discussed. For sediment management purposes and for the evaluation of potential risks associated with accumulated contaminated sediments in river basins these 'historic' contaminated sediments should also be included.

Modelling approaches

The quality of dredged material is determined by the input of substances from both point and diffuse sources[1]. These sources contribute to the natural background level (e.g. erosion for nutrients and heavy metals) and elevated levels for organic chemicals, nutrients and heavy metals.

Inputs of contaminants into a river system follow different pathways and contaminant-specific retention or loss processes. Figure 1 presents the various diffuse and point sources contributing to the input of substances in a river system. Both point and diffuse sources contribute to the total contaminant load of rivers. A distinction between them is necessary for future restoration actions and determining the effect of past control measures at industrial sources.

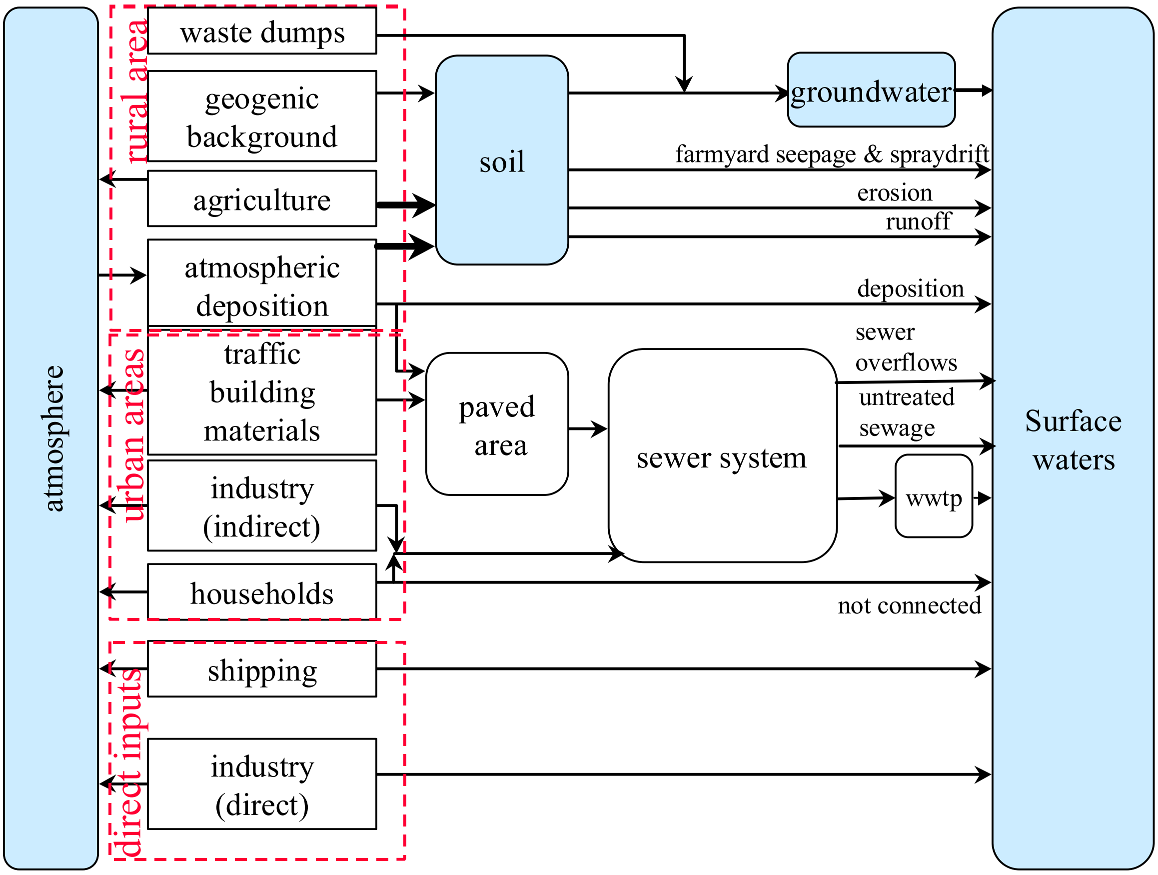

Figure 1: Flow of materials considered in a river basin.

[1] **Point sources** are *identifiable points* and are (fairly) *steady in flow and quality* (within the temporal scale of years). The magnitude of pollution is not influenced by the magnitude of meteorological factors. Major point sources under this definition included: municipal wastewater effluents; industrial wastewater effluents.
Diffuse sources are *highly dynamic spreaded pollution sources* and their magnitude is *closely related to meteorological factors* such as precipitation. Major diffuse sources under this definition include: surface runoff (load from atmospheric deposition), groundwater, erosion (load from eroded material), diffuse loads of paved urban areas (atmospheric deposition, traffic, corrosion), including combined sewer overflows since these events occur discontinuous in time and are closely related to precipitation.

Several studies focused on estimating the emissions and pathways of contaminants for large river basins or catchments (Behrendt, 1993; Behrendt, 1994; Behrendt, 1996; Behrendt, 1997; de Wit 1999). But many researchers (Olendrzynski et al., 1995; Hahn and Xanthopoulos, 1994) only investigated one particular emission source at a certain specific location (e.g. canalisation in urban areas). Whereas other studies focused on estimating riverine transported loads (Grimvall & Stalnacke, 1996; Tonderski et al., 1994) by looking at discharge-concentration relationships. These discharge-concentration relationships have been used for comparisons between both estimated emissions and transported riverine loads of nutrients (van Dijk et al., 1997; Behrendt, 1993). Most studies estimating point and diffuse emissions as well as source apportionment focus on nutrients (Behrendt, 1996; Behrendt, 1997; Behrendt & Bachor, 1998; Behrendt et al., 1999). Similar studies on heavy metals have been carried out for the Rhine (Behrendt, 1993) and Elbe catchment (Vink et al. 1999; Vink et al., 2000). Both methods are complementary.

The emission method can be validated against the total amounts transported by the river (as measured for instance at measuring stations) and its distinction of point and diffuse sources can be validated against the immission method. The immission method only gives the total of all point and all diffuse sources and does not allow for a distinction of individual sources.

Therefore, it is important to do an analysis of the source apportionment study with two different methods (emission and immission analysis) on the contribution of point and diffuse sources in drainage basins. Both methods were tested and applied to several river basins in Europe (Behrendt et al., 1993; Behrendt et al., 1999; Vink et al., 1999; Vink et al., 2000).

The modelling approach comprises basically the following steps:

1. Immission analysis: estimation of point and diffuse loads
2. Emission analysis (MONERIS) for source apportionment
3. Trends in sediment quality downstream at a sedimentation sink and link with the suspended particulate matter quality of the river
4. Future scenarios modelled and driven by reduction coefficients for the individual pathways

<u>**Immission analysis**</u>

Source apportionment (immission) can be made with water quality data from several monitoring stations in a river catchment.

One way for estimating the pressures caused by pollution is to quantify all the emissions by point and diffuse sources for the several pathways. Another method is to separate the fractions of point and diffuse loads by analysing the concentration - discharge and load - discharge relationships using data sets from monitoring stations of the main river and its tributaries.
The observed, realised load of a particular substance at a particular monitoring station is called immission. The difference between immission and emission lies in the fact that immission is the in reality occurring substance input, including losses caused by e.g. transformation whereas emission is a potential. This is already described in detail by Behrendt (1993, 1994 & 1996), where this method was applied to the Rhine and some parts of the Elbe for nutrients and phosphorous.

The method is based on difference in definition between the point and diffuse sources and their different relationship to meteorological factors such as precipitation, whereas point sources are relatively constant in magnitude, identifiable and not or less dependant on meteorological factors. The inputs by diffuse sources are highly variable and correlated to meteorological factors. An overview of the main components of the hydrological cycle is given in figure 2. According to Dyck and Peschke (1995) the discharge of a catchment can be divided into three main components:
Surface runoff, which is the net result of the overall water balance on the surface between rainfall and water losses by evaporation, infiltration, interception and depression storage.

Interflow, which is the result of the water balance in the aeration zone. This is the result of infiltration diminished by groundwater recharge, storage of soil moisture and evapotranspiration of the topsoil.
Groundwater flow, which is the difference between groundwater recharge and geological water losses and groundwater storage.
Interflow and groundwater flow are the two subsurface flow components, where interflow is equal to the fast component and groundwater flow is equal to the slow component.

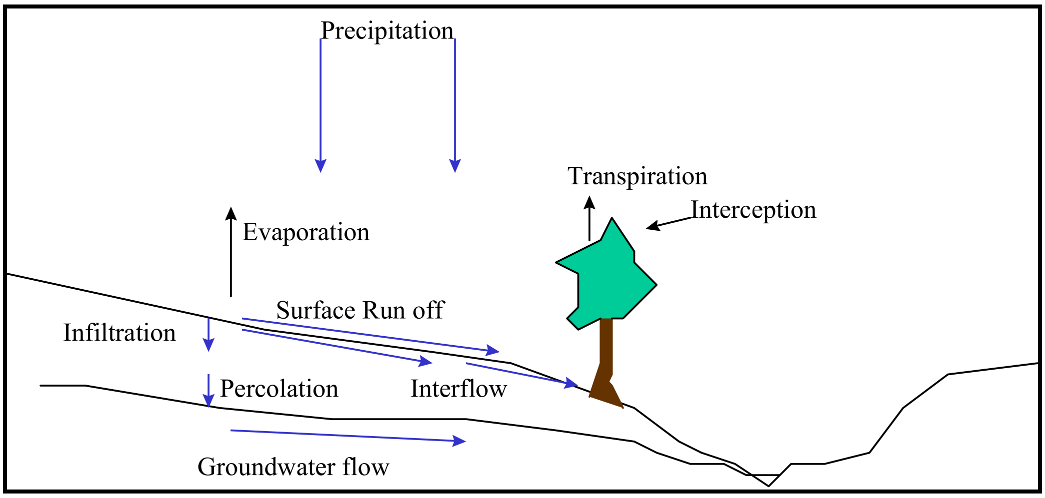

Figure 2: Overview of the hydrological cycle

This method for estimating point and diffuse portions also includes errors and uncertainties because of the uncertainties in concentration measurements. The results from the model therefore should be considered as averages. Based on the uncertainties in the estimated point wastewater flow and on the errors in the regression equations ranges for point load and diffuse load can be given.

Emission analysis of river basins

MONERIS (**MO**deling **N**utrient **E**missions in **RI**ver **S**ystems) is a tool for quantifying nutrient emissions along the various hydrological pathways in river basin. The Institute of Freshwater Ecology and Inland Fisheries developed this model (Behrendt et al., 1999). Their main aim was to quantify the nutrient emissions of whole Germany, Switzerland, Poland and the Czech Republic for the period 1983-1997 and development of scenarios for reducing nutrient inputs in the German catchments, partly in view of international regulations on reducing inputs into the North Sea and Baltic Sea.

The basic input into the model is data on discharges, data on water quality of the investigated river basins and a Geographical Information System integrating digital maps as well as statistical information for different land use types, wastewater treatment, soil types, geology etc.

Whereas the inputs of municipal waste water treatment plants (WWTPs) and direct industrial discharges enter the river system directly, the sum of the diffuse inputs into the surface waters is the result of different pathways realised by several runoff components (see figure 3).
The distinction between the inputs from the different runoff components is necessary, because the concentrations of substances within the runoff components and the processes within these runoff components are very different.

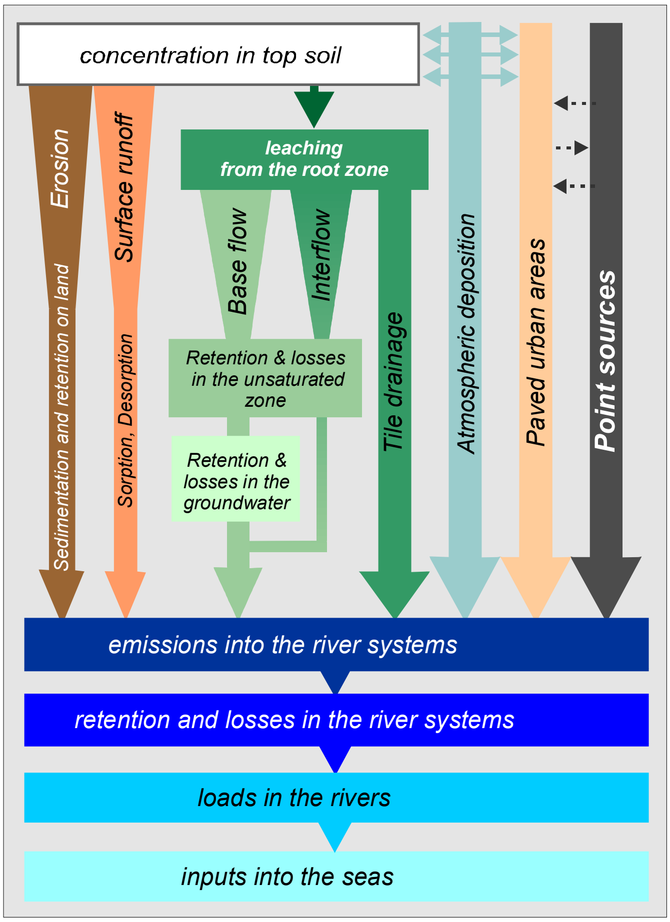

Figure 3: Pathways and processes in MONERIS

Therefore the MONERIS model takes the following pathways into account:
- discharges from point sources (industry and WWTPs)
- inputs into surface waters by atmospheric deposition
- inputs into surface waters from groundwater
- inputs into surface waters from tile drainage
- inputs into surface waters from paved urban areas
- inputs into surface waters by erosion
- inputs into surface waters by surface runoff (only dissolved inputs)

Management approaches and options for controlling sources of contaminants

As stated, sediments are a secondary source of contaminants in river basins. The most effective way of tackling this issue is through the controll of these sources of contamination. With different management approaches the latter can be achieved. Some examples for management approaches are given underneath.

Several heavy metals, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) are of concern with regard to the quality of sediments in the river catchment areas and are as well criteria for the relocation of dredged materials. Therefore the focus on pathways is made specific by focussing on these contaminants. Heavy metals f.e. are discharged through all seven pathways. Pathways like groundwater, drainage and surface runoff comprising transport in the dissolved phase could be neglected for PAHs and PCBs, because these are mainly transported bound to particles in terrestrial compartments. Inputs for PAHs and PCBs from industry can often be neglected compared to other pathways.

Industry
Measures taken to decrease industrial sources are the use of cleaner raw materials, closure of the wastewater circuit, cleaner technology (best available techniques; BAT) and optimisation of wastewater treatment. Industrial cadmium, copper, mercury and lead emissions are likely to decline because of a decline in fertiliser production. Copper emissions could also decline substantially because the measures taken in the usage of copper-free paint used for ships.

Wastewater treatment plants
Measures which can be taken in WWTPs are:
- An extra denitrification step.
- A Phophorus-elimination step.
- Microfiltration or ultrafiltration (decreasing suspended solids and bound contaminants).

Atmospheric deposition
Atmospheric deposition of heavy metals cannot further be reduced, since there is no international consensus on the further reduction of heavy metals.

Generally major contributions of PAHs are due to residential heating, production processes in the steel and non-ferrous metal industries and wood impregnation with tar-oil. Contributions of combustion processes in large plants as power plants are negligible due to efficient flue gas cleaning techniques. The main reduction potentials are in production processes (application of BAT) and in residential heating by replacement of older combustion/heating systems by BAT equipment. Due to increased efficiency of the combustion processes / heat generation fuel consumption decreases. Additional possible measures are: better insulation of buildings and substitution of wood, brown coal (incl. briquettes) and hard coal briquettes with fuels having lower emission factors as gas or light fuel oil.

During the last 20 years PCB emissions to air drastically decreased, mainly due to the out-phasing of open applications and stricter regulations on the utilisation in closed systems (electrical transformers and capacitors, as hydraulic oil in mining.
Due to the high emission loads in the past to air and water PCBs accumulated in soils and sediments. With an expected further decrease of PCB emissions, re-emissions from soil and water will gain importance.

<u>Erosion</u>
Diffuse emissions caused by erosion can be reduced through erosion reducing measures in the upstream parts of river basins with high erosion rates.

<u>Urban areas</u>
Here the focus is often on maximum feasible reduction of emissions, which requires fast implementation of emission reducing measures without considering costs. The measures are often a combination of prevention of emissions at the source (e.g. active replacement of building materials) and infrastructural measures (connection to sewer systems, high purification measures).
Diffuse emissions from building materials (e.g. corrosion of galvanised steel, sheet lead and water pipes) are expected to decrease for copper, lead and zinc. Old building materials that are subjected to corrosion can actively being replaced by more environmental friendly alternatives (e.g. coating of lead sheet and galvanised steel). In new buildings alternative environmental friendly materials are used for water pipes, roof and gutters. The use of longer lasting car tyres and infiltration of run-off of roads will also reduce traffic emissions. Decoupling of paved urban areas from the sewer system is also a management option. In urban areas storage basins for rainwater could be enlarged for both separate and combined sewer systems.

<u>Shipping</u>
The assumed inputs of PAHs by shipping (ship coatings, bilge waters, spills) for the present state have a high uncertainty. PAH inputs stemming from ship coatings are expected to decrease drastically due to substitution of PAH rich coatings by alternative products. The use of environmental friendly antifoulings will reduce the emissions of copper.

Work Package 2 Discussion Paper

Developing a successful Decision Support System: a process involving collaboration

Harald Koethe submitted the following document for consideration by the workshop delegates. The original document (of the same title) is by:

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Bundesanstalt für Gewässerkunde Koblenz **Veranstaltungen 4/2002**

Einsatz ökologischer Modellsysteme zur Unterstützung von Entscheidungen bei Eingriffen in Fließgewässern, Kolloquium vom 5. und 6. Juni 2002

Introduction: managing a complex reality

Planners and policy makers face a difficult task. The world they must deal with is complex, interconnected and ever changing. Coastal zone management, watershed management, urban planning, and the design of policies for sustainable economic development all pose the problem of dealing with systems in which natural and human factors are thoroughly intertwined. Understanding the processes driving change in these systems is essential in the formulation of effective policies.

Four aspects of such systems are of particular importance.

- First, and most importantly, these systems are *integrated wholes*. Thus, while a planner or policy maker may intervene directly in only a limited part of the system, linkages will transmit consequences of the policy to many other parts of the system. Conversely, the problems the planner is dealing with may have had their origins in actions that were taken in other parts of the system in an attempt to resolve other problems.
- Second, human systems, and the natural systems in which they are imbedded, are *dynamic and evolving*; they are never in equilibrium. Policy makers thus intervene in a changing system, and at certain critical points, the consequences of even a small intervention may be both unanticipated and of major importance.
- Third, these systems are *inherently spatial*. Both natural and human systems are structured in geographic space to optimize levels of interaction among components; clustering increases opportunities for interaction, while dispersal provides protection from the effects of interaction. The consequences of planning policies depend on the spatial context within which they are implemented, as well as on the way they alter that context.
- Fourth, the world is one of *uncertainty*, and while increased knowledge and improved modeling tools may lessen that uncertainty, they cannot eliminate it. Plans and policies therefore need to be designed to incorporate and work with the uncertainty, rather than assume that it does not exist.

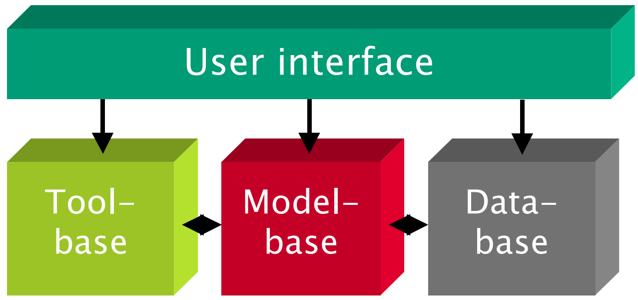

Figure 1: Basic functional components of a Decision Support System

As a result, today's policy programmes strongly advocate integrated policies for among others land-use management, watershed management, and coastal zone management, and today's research and development agendas strongly promote the development of the tools enabling the integrated approach. The work is propelled by the revolution in the computing hardware and information sciences since the beginning of the eighties, putting processing power on the desk of the individual scientist, modeller and decision maker that could not be dreamt of 30 years ago. Information systems of growing levels of sophistication go along with the increasing capacity of the Personal and Micro Computer. In particular the development of Decision Support Systems is a booming activity.

Decision Support Systems

Decision Support Systems (DSS) are computer-based information systems developed to assist decision makers to address *semi-structured (or ill-defined)* tasks in a specific decision domain. They provide support of a formal type by allowing decision makers to access and use data and *appropriate analytic models* (El-Najdawi and Stylianou, 1993). The terms '*semi-structured*' and '*appropriate*' in this definition refer to the fact that Decision Support Systems are typically applied to find answers for problems that, due to their specific nature and complexity lack an unambiguous solution method. Rather, usage of the most appropriate analytical solution methods available approximates the unique answer. Thus, the DSS provides the decision maker with a suit of '*analytic models*', which are considered appropriate for the decision domain. But a DSS is more than (1) a *modelbase* alone. Typically three more components can be distinguished (Engelen *et al.*, 1993): (2) a *user interface* enabling easy interaction between the user and the system, (3) (a) *database(s)* containing the raw and processed data of the domain and the area at study, and (4) a *toolbase* with the methods, analytical techniques, and software instruments required to work in an effective manner with the domain models and the data (Figure 1).

The Models in the DSS

Typically decision models and statistical and operations research methods are available from the modelbase of the DSS. But, more essential are the domain specific models capable of grasping the complexities of the system and the problems studied. Integrated models play a key role in any DSS in the sense that their constituting sub-models are covering, at the least in part, the (sub-)domains related to the decision problem. Moreover, integrated models explicitly include the many complex linkages between the constituting models and related domains. Thus, they provide immediate access to very rich and operational knowledge of the decision domain.

However, if an integrated model is to be a useful and reliable tool, it should have several characteristics. It should, first of all, incorporate an integrated treatment of as many of the primary system components and processes as necessary: the natural and human systems should both be represented. Policy makers are most served by models in which the time horizon, the spatial and the temporal resolution are policy problem oriented and not so much process oriented as in research models (Mulligan, 1998). They need adequate rather than accurate representations of the processes modelled and sketchy but integral rather than in depth and sectorial models. While research models are as complicated as necessary and scientifically innovative, the policy maker is better served with an instrument that is as simple as possible and scientifically proven. The models should facilitate the exploration of the merits and problems of alternative policy and planning options. This is a useful objective which can be attained with models which recognize a degree of inherent unpredictability in the world, and it avoids the unrealistic approach of calculating an optimum solution to a planning problem. It is also one which accommodates interaction among participants in a planning process, rather than pre-empting such participation as a calculated *'optimum'* solution does. As part of the Decision Support System, the models must be transparent, easy to use, and give results that are directly relevant to policy and management questions. Clearly, a fast, interactive model equipped with a graphical interface will do much better for policy exploration than large-scale sluggish model not tailored to the needs and expectations of its end-user.

The Graphical User Interface of the DSS

The user interface is the vehicle of interaction between the user and the computer. A well-designed, intuitive, and user-friendly interface will support the execution of the policy exercises to the degree considered necessary by the user: at any point in time, he should have access to the background information needed to understand the models he is working with, the processes represented, and the numbers generated (see for example: Holtzman, 1989). Without this information, models remain black boxes and learning is excluded.

The Data in the DSS

Data to run the models in the DSS are available from on-line or offline connections to external or stand-alone databases depending on the type of application developed. Most of the geographical data is available from one or more Geographical Information System which can be either a general purpose application or an integral part of the DSS.

The (end-user) Tools in the DSS

In the DSS it is the role of the models to present an adequate and truthful representation of the real world system, and, it is the role of the *tools* to enable the decision maker to work with the models. The tools are the gnomes that carry out the many technical tasks, small or large, in the background of the system. They enable to invoke the appropriate models, to prepare the input of the analysis, and to compare and evaluate the outcomes of the different alternatives generated. Tools are among the most robust elements in a DSS and can be re-used easily in new applications combined with different model bases and accessed by different types of user interfaces.

DSS development: a team at work

Decision Support Systems can only be successful if they are developed as part of an effort involving both the intended end-users and the DSS developers. This is mostly so because they are still highly technical, novel products with a high degree of sophistication, typically build by those not using them and used by those not building them. Building a DSS is an undertaking that holds the middle between a typical research project and the development of a custom defined (software) product. The team carrying out this work should therefore have specialists of both kinds. Moreover, the DSS has to incorporate knowledge and expertise of the decision domain known to the end-user. He or she is best placed to clarify the functionality expected from the system, hence can bring in this information in the project and thus partake actively in the development of the product.

A team consisting of the right kind and the right number of specialists, with practical experience in this kind of work, is as essential as sufficient resources, a good division of tasks and responsibilities, and a clear but stringent project schedule. A reasonably small team, involving not more than eight specialists working simultaneously, is for all practical purposes the most efficient. In larger teams, the work is hampered by overlap between the team members and the disciplines represented, and the management becomes complex and laborious. As to the disciplines, skills and people, the following are required:

- *Motivated and visionary end-users*
  Decision Support Systems are useful in situations where ill-structured problems call for solutions. The involvement in the project team of the problem owner is therefore a prerequisite. However, the development and application of DSS for policy making and spatial planning in socio-environmental systems is a rather new field. Hence, successful projects are those that find motivated and visionary end-users interested to work on a new breed of tools: aware of the fact that this kind of work is novel and difficult, and ready to take a risk, as success is not automatically guaranteed. At the same time they should refrain from becoming over-ambitious and prevent causing feature-creep in the project. End-users also, that are able to communicate very well with the developers and able to bring across their needs, working methods, policy problems, criteria, constraints, policy levers and policy options.
- *'Trans-discipline' and 'trans-role' domain specialists / scientists / model developers*
  Policy and planning problems related to socio-environmental systems are set in very complex systems. These systems can only be understood in their truly multi-disciplinary setting. Few will argue against this statement. However, science is still very much structured in strictly subdivided disciplines and the career opportunities of a scientist depend very much on whether he or she can excel in one of these. Yet what is needed most in order to develop effective instruments are scientists and model developers interested in interdisciplinary work, interested in looking into the domain of the other and building knowledge-bridges between the domains. They should be free of ethical and career related objections and should understand that problem solving and policy-making is different from research in that it involves applied and practical work. They should be free of the principle *'my domain, my model, my level of accuracy'* and should accept working on a common, final product. Hence they should be able to understand and respect the roles, skills and positions of the others involved in the exercise and in particular the problems and needs of the end-user.
- *An architect of the integrated model or the model base of the DSS*
  It is not enough to amass a bulk of 'good' sub-models in order to have an integrated model or model base of a DSS. On the contrary, a lot of adaptation and rebuilding is required. Similarly, it is not enough to gather a group of 'good' model builders. Individual model developers are most often proficient in their domain and the models that they develop of it. Some are not interested in going much

beyond this and build bridges with other domains. In a project team somebody will need to take the role of the 'architect' of the integrated model. He keeps an eye on the overall functionality of the integrated model and on the role that each sub-model is to carry out. He is preferentially a generalist with a very good understanding of the pitfalls of modelling in general and assists the model developers in reformulating and adapting their models. He is also a key person in facilitating the exchanges between the end-users, modellers and software developers.

- *Flexible and skilful software system designers and developers*

Decision Support Systems are very demanding relative to the software architectures and technologies used to implement them (see for example: Hahn and Engelen, 2000). This is partly due to the sheer number of parts that they typically entail, but also the flexibility and extensibility that is required in order to keep up with the state of the art of the domain(s) represented and the changing needs of the end-user. However, software technologies and implementation methods change constantly and very rapidly. Most are obsolete in 5 years or less. The software system designers, responsible for applying an appropriate implementation technology, need to be skilful, dependable and up to date on the latest in the domain. Such people are not abundant. A well-designed system and an appropriate development strategy will minimise the amount of 'lost' implementation effort. Yet, in the iterative development process of a DSS, some level of re-implementation cannot be avoided. Thus, the software developers responsible for generating the software code should be aware of the fact that some of their hard work might be thrown away in the next version of the system. Some will find this very frustrating and hard to take, but it is part of the process.

- *A professional 'communication' specialist (a mediator, or facilitator)*

The expertise and working methods of policy-makers and scientists are often worlds apart. Hence, when they are to work together on a complex product like a DSS, it is not uncommon that the communication and exchange of information is very difficult or non-existing. Yet, this communication is very essential. In the worst cases, the participation of a communication professional, a mediator or facilitator in the project team can be the only effective way to bridge this gap.

- *Project manager.*

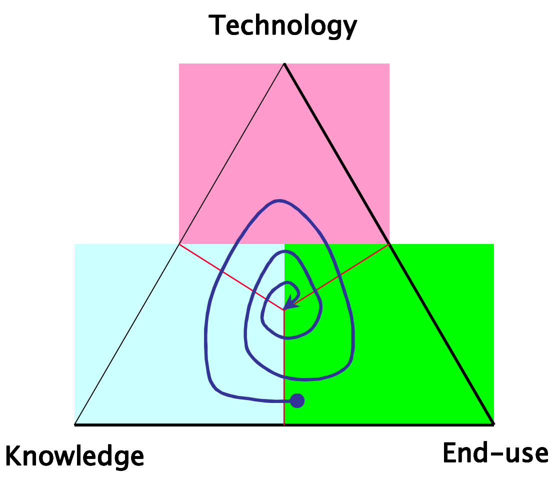

Figure 2: A successful DSS seeks to realise a balance between End-user, Knowledge and Technology aspects.

The development of a DSS is meticulous and hard work as very many little details matter and require action in order to deliver a product that is reliable and free of bugs. A strict management of the project is essential. This is not only so because more than a few people are involved in it, but also because the work is organised in clearly sequenced tasks: a model needs to be past the conceptual phase before it can be implemented and before it can be tested, validated and run. Once many such models become integral parts of a much more encompassing DSS system, the synchronisation and sequencing of the tasks becomes paramount.

Works with poorly understood requirements	+++
Works with poorly understood architecture	+
Produces highly reliable system	+++
Produces system with large growth envelope	++++
Manages risk	++
Can be constrained to a predefined schedule	++
Has low overhead	++
Allows for midcourse corrections	+++
Provides progress visibility	++++
Requires little manager or developer sophistication	++

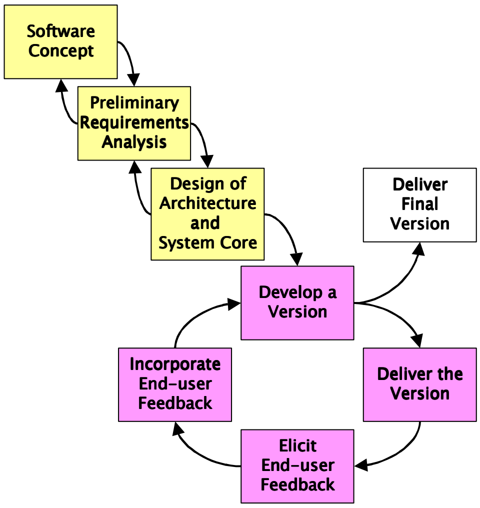

Figure 3: The iterative nature of the Evolutionary Delivery lifecycle model fits best the development of a DSS (after McConnell, 1996)

An agreed schedule, clearly defined tasks and milestones need to keep the project on track. If not the delivery of the system will be endangered and the costs will rise in a disproportioned manner.

Building the DSS

As discussed, a DSS is (1) a container of the relevant knowledge needed to support decision-making in a particular domain. It is also (2) a piece of sophisticated information technology and it is developed to serve (3) a particular end-user. These three aspects need to be given equal attention during its development. In Figure 2, this is represented by means of a triangle. The corners represent the aspects: end-use, knowledge and technology. The ideal and ultimate DSS is at the very centre of the graph. The development of a DSS, represented by the dot in the graph, starts in principle, and ideally, with a request of an end-user of the system. He is the problem owner, but rarely knows exactly what he wants, or what he can expect from the DSS. He enters a technical world that he is not familiar with and has to rely on the knowledge and skills of the DSS-developer to produce something usable and useful to solve his problem. The DSS-developer on the other hand does not know the precise context of the problem, the competence and working methods of the end-user, or the internals of his organisation. He will need to get that information from the end-user. Clearly this is a chicken-and-egg problem. It is a situation in which an iterative approach is needed, first to get the flow of information going, and further to work towards a well-balanced, ultimate product, that meets as closely as possible the expectations and needs. This is attained in a number of loops, represented by the spiralling arrow in the graph, resulting in intermediate products. An iterative approach is also desirable, because the attempt to produce a formal representation of the decision domain is very often hampered by a lack of knowledge, scientific material and data. Alternative methods, models or solution methods can be sought after and tried out before the DSS is definite and fully operational

From the above it may be clear that the development of a DSS cannot be easily reduced to the typical *Waterfall* lifecycle model in which clearly defined stages -- including: *Software concept*, *Requirements analysis*, *Architectural design*, *Detailed design*, *Coding and debugging*, and *System testing*-- are gone through strictly sequentially and in which in a late stage the technical work is carried out. A lifecycle model that fits the iterative development cycle much better is the one known as *Evolutionary Delivery* (McConnell, 1996) (Figure 3). This model advances very rapidly through the definition of functional and technical specifications to produce a first prototype of the DSS. This prototype is evaluated by the end-users. Additional specifications are giving rise to new prototypes that are consequently further impro-ved and developed iteratively. Different from 'throwaway' prototypes, the latter evolve during the project towards the intended final product. The great merit of this model resides in the fact that it provides a very tangible insight in the progress made during the project and that it enables more corrections to the requirements and technical implementation while the product is under development.

<u>Conclusions</u>

Authorities actively involved in the formulation of policies and measures aimed at managing socio-environmental systems are increasingly investing in the development of, and experimenting with, a new breed of tools. This trend is propelled by the growing understanding that policy-making should be based on an integrated approach. A few recent examples from the Netherlands implementing this vision are: **IMAGE** (Alcamo, 1994), **TARGETS** (Rotmans and de Vries, 1997), **L**andscape **P**lanning of the river **R**hine-DSS (Schielen, 2000), **WadBOS** (Engelen, 2000), and **Environment Explorer** (Nijs (de) *et al.*, 2001). But, the task ahead is still huge. Today, the scientific community cannot offer policy-makers the instruments that will solve their ill-defined problems in an absolute and indisputable manner. It probably never will. The problems encountered are too big and the knowledge available is too limited to produce unambiguous answers. But, lessons are learned on how to work with models as instruments for exploration, representing a part of the complex reality with some level of certainty. Following successful examples from the industrial community, they are made available as part of Decision Support Systems and supplemented with tools boosting their usability, usefulness and user friendliness. Thus they become 'thinking tools' that shed light on problems that otherwise would not be manageable by the human brain alone and allow a more systematic exploration of more alternatives than would otherwise be considered in a typical policy exercise. The development of these Decision Support Systems is far from trivial. It requires an effort involving both the intended end-users and the DSS developers working in a team. The end users are to define the area of application and the desired functionality. They should be complemented with experienced professional analysts, specialized in the development of DSS applications, and formally trained in computer science, as well as knowledge engineers, system analysts and model developers knowledgeable about the details surrounding the problem under study. An iterative design and development method, such as available in the *Evolutionary Delivery* lifecycle model, is most appropriate for building the DSS. This is because, typically, the precise *functional requirements* of the envisaged system are not clear at the beginning of the project. Nor is it entirely clear what knowledge and models are available or useful to represent the domain. Hence, the exact *contents of the system* are vague, making it difficult to select a detailed technical design for the system early in the project.

Based on our practical experiences (see for example: Engelen, 2000, Engelen *et al.*, 2000, Nijs (de) *et al.*, 2001, Engelen, 2002**,** RIKS, 2002) it is fair to conclude that we have learned to develop Decision Support Systems within very reasonable constraints relative to budget, human resources and development time. This is much more easy when good base material and expertise is available and when a stimulating collaboration between visionary end-users and competent DSS developers is propelling the development. However, the development phase is only the first one in the life of a Decision Support System. It needs to be followed by one in which the DSS is given an institutional role and position in the organisation of the end-user, making it a standard 'procedure' to use the system for practical planning and policy-making. It is equally fair to say that this task is even more difficult than the previous one and that it will require much more attention and effort before Decision Support

Systems will come to realise their full potential.

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Work Package 2 Poster Paper

Downstream effects of dams in the fluvial dynamics of the Lower Ebro River

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Abstract

The channel of the Lower Ebro River downstream Mequinenza and Ribarroja dams has experienced a series of morphological changes during the second half of the 20th century, mainly: a) lateral erosion, b) colonization of formerly active areas by riverine vegetation and, c) reduction of channel width. Changes have occurred after dam commissioning during the seventies. Dams alter flood frequency and magnitude, which causes a reduction of river capacity to transport sediment. Simultaneously, dams trap most sediment carried by the river from upstream, particularly coarse fractions as bedload, thus the river channel becoming the main downstream sediment source. The study describes the alteration of floods by dams and the subsequent adjustment of the river sediment transport and its morphology, through the analysis of hydrological and geomorphological field data, and historical and recent air photos. Reduction of flood magnitude (up to 25%) is especially important for the small floods in the downstream reaches near to dams. Reduction of flow competence has also diminished river capacity to transport bedload, shifting from a mean annual yield of 400,000 tonnes between 1950 and 1975 to less than 100,000 tonnes afterwards. Morphological changes indicate the river response to such alterations.

Work Package 2 Poster Paper

WEPP modelling of a small Mediterranean watershed

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Abstract

Runoff and erosion in upland watersheds can have significant negative on-site and off-site environmental impacts. The choice and design of appropriate erosion control measures can be aided by reliable predictions of watershed response under different land use scenarios. In order to be useful, soil erosion prediction models at the watershed scale must be reliable in environments that differ from those where the models were developed. The aim of this paper is to apply a physically based model, WEPP, to a small, monitored Sicilian basin in order to assess the model performance in the experimental conditions of the site and to extend the model applicability to Mediterranean conditions. The mountainous watershed was discretized by GeoWEPP into a number of subwatersheds Three simulation series were performed using three different sets of effective hydraulic conductivity values, Ke: (I) Ke was internally calculated by WEPP; (II) Ke was set at 0.5 of the field saturated conductivity measured by the Guelph permeameter both for rangeland and cropland; (III) Ke was set as in the simulation series II for rangeland and as a function of SCS Curve Number for cropland. Predicted runoffs were better correlated to the measurements of runoff in simulation series II and III, which were characterized by model efficiencies of 0.42 and 0.49, respectively. Storm runoff depth was generally underestimated for both large and small rainfall events. Simulation series II and III resulted in an overestimation of sediment yield, particularly for the smaller events.

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Work Package 2 Poster Paper

Runoff and erosion modeling by AGNPS in an experimental Mediterranean watershed

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Abstract

Runoff and erosion in upland watersheds can have significant negative environmental impacts. The choice and design of appropriate erosion control measures can be aided by reliable predictions of watershed hydrologic response under different land use scenarios. In recent decades several computer models have been developed to simulate rainfall and runoff effects at the watershed scale. Although many experiments have been conducted to evaluate the use of available watershed models, more work is needed to assess and improve model reliability in different environmental situations. To this end, a small hilly-mountainous watershed, covering about 130 ha of mainly pasture and located in Eastern Sicily, was equipped some years ago in order to further extend model testing to semi-arid Mediterranean conditions. A 6-year database is available and distributed parameters for the watershed have been developed with the aid of a Geographical Information System. In the present paper the model AGNPS (Young et al., 1989) was implemented and applied to 20 events (10 of which included suspended sediment concentration measurements), occurring from 1997 to 2001, and model results were compared to experimental data in order to test the capability of AGNPS to reproduce runoff and sediment yield measurements. The overall results seem to confirm the applicability of the model to experimental conditions, and suggest to continue the research activities in the perspective of model calibration-validation, necessary for the assessment and comparison of different management scenarios in the study area and possible further extensions to other ungauged catchments with similar characteristics.

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