

# Capacity Building of Spatial Planners for Flood Risk Management in Urban Environment through Decision Support Systems and Interactive Learning

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## ABSTRACT

New instruments are presented to give spatial planners the capacity to integrate flood aspects in their urban development plans according to the requirements of the new EU Flood Directive. Risk awareness and risk management technology are fostered through a new concept of interactive learning based on an idea of David A. Kolb. To stimulate motivation and to raise flood awareness a flood animation centre has been developed which demonstrates the flood risks through haptic methods, e.g. flood cylinder model, a flood box and video material. The theoretical background and the new EU flood policy of integrative flood risk management are incorporated into a new web-based e-learning platform. It supports the auto-didactic learning and self-control through an interactive questioning-answering sequence within a virtual trainer.

An innovative Decision Support Tool has been developed which enables spatial planners to create planning scenarios and mitigation measures and to evaluate their hydrological, ecological and economic impact. This information system, called *Kalypso Planner-Client* is an application-oriented instrument, based on the international standards set by the Open Geospatial Consortium (OGC). The support for most web-based services (WMS, WFS, SCS) ensures a high level of interoperability of the GIS-based data.

**Key words:** Flood Risk Management, Interactive Learning, Decision Support, Spatial Planning

## 1 INTRODUCTION

Due to the increased occurrence of flood hazards in Europe politicians and decision makers have agreed on concerted and coordinated actions and released some important water acts and administrative regulations (*Guidelines for Forward-Looking Flood Protection* by the Federal Water Commission of all German States (1995), *Water Act to Improve Preventive Flood Control* by the German Federal State (2005), *Directive on the Assessment and Management of Floods*, released by the EU-commission in 2006, but still under debate). They will result in high requirements for the management of water-courses in urban environments. The new policy, to "give the water more space", means expanding the relationship between the city, space and water, and setting a new, changed benchmark for building, planning and expansion of the city. It is necessary to create a basic understanding and awareness about the impact of urbanization on the hydrological cycle and the flood risk at spatial planners. In the future, the water needs to be included as an important component in the existing and current city planning. The spatial planners should be informed about sustainable flood mitigation measures regarding their houses and have to be familiar with the "living with flood" principle. This is even more important since the climate changes favour extreme weather situations, and heavy rain and flooding become increasingly likely.

Spatial planners have to adapt their urban development plans to the flood risk. The German Water Act prohibits new urban developments in inundation areas of 100-year probability. Exceptions are only permitted if no other alternatives exist and a couple of strict requirements are fulfilled, e.g. no isolated new developments, no changes in surface runoff and no increase of risk. The hydrological effects and necessary mitigation measures need to be studied on a catchment level and to take into account all relevant aspects of water management, soil management, land use and nature conservation. Measures to reduce vulnerability require adaptation strategies, which favour the strengthening of resilience by local scale measures and non-structural measures in contrary to traditional flood defence through building infrastructure (dikes and walls). Within the EU Interreg IIIb project FLOWS new instruments have been developed for spatial planners to build up their capacity for coping with these new requirements. They will be presented within this paper. A Decision Support Tool supports the

impact assessment of the urban development plan on the hydrological cycle and the determination of efficient mitigation measures based on mathematical models and Multi-Criteria-Analysis. A web-based e-learning platform and an interactive learning program have the objective to raise risk awareness and to provide the knowledge in flood risk management. The developed technologies as well as the pedagogic principles applied in the new learning program will be presented and their application demonstrated at a pilot study carried out in the City of Hamburg.

## 2 METHODOLOGY

The consequence of the new EU and German water policy is that spatial planners need not only the information about the flood risk in their planning area but have to contribute to the risk management. They have to develop appropriated mitigation and adaptation strategies to control the impact of flood to an acceptable residual risk level in their urban development plan. The integration of hydrologists and flood experts in the planning process would help to accomplish this task. However, this expertise is seldom available in the preliminary conceptual phase where the spatial planners develop the general solution. At this stage, cardinal mistakes could be implemented into the concept, which cannot be corrected so easily in the later planning stage. Thus, the spatial planner needs already in this phase appropriate risk awareness, the capability to study the effect of his planning concept and a decision support in the development and assessment of flood mitigation and adaptation strategies. This flood management competence does not exist at spatial and urban planners. In general hydrological and hydraulic training is not part of their university programs. Reliable assessment of flood risk and efficient mitigation measures need the quantification of the hydrological water cycle in dependence on different planning scenarios. It was one of the surprising outcomes in the FLOWS-project that spatial planners were requesting access to sophisticated software tools as they want to do hydrological impact studies on their own to get a feeling about the hydrological system and the effect of their planning.

To provide spatial planners the necessary knowledge about flood risk management and the methodical framework for system analysis, an integrative approach of technical, strategic and learning tools have been developed and will be described in the following subchapters.

### 2.1 Decision Support System Planner-Client (DSS-PC)

Decision Support Systems are computer models in which a non-expert get the possibility to analyse complex problems and to find appropriate solutions (Hahn/Engelen, 2000). They range from simple assessment tools to complex systems in which scenarios of different solutions can be easily generated, their efficiency quantified by mathematical models and via a multi-criteria analysis preferences generated. In all cases, the user is the centre of the system and determines the capabilities of the system. Spatial planners have been the target group of the new DSS-PC. Through a workshop with spatial planners of the city of Hamburg the following key capabilities and requirements have been determined: The guided definition of scenarios via a GIS-tool, the quantification of the flood risk with mathematical models and the possibility to define mitigation measures and to optimise their efficiency.

Procedures	Methods
<b>Determination of Flood Probability</b>	<b><i>Rainfall-Runoff modelling Flood Frequency Analysis</i></b>
<b>Determination of Inundation</b>	<b><i>1- and 2-dimensional hydrodynamic modelling</i></b>
<b>Assessment of Damage</b>	<b><i>Modelling of the annual probable damage (on monetary basis)</i></b>

As flood risk is the product of probability of occurrence multiplied by its impact the procedure for flood risk assessments is composed of three tasks, the determination of

Tab. 1: Procedures and methods for flood risk assessment (according to Pasche 2007)

the probability of flood, the flood prone area, and the damage (Tab. 1). The first one gives the flood hydrographs and its probability of occurrence. The second one determines the flooded areas for these hydrographs and the last task the probable annual damage due to probability of flood. Mathematical

models support all three procedures. In general, simple models are preferred to keep the costs low. But the experience has shown that a poor reliability of the determined inundation areas reduces the acceptance of the stakeholders and often ended in rejection of the results. The EU COST initiative C22 – Urban Flood Management has gathered the state of the art in hydrological and hydraulic modelling, which has been the guideline and basis for the selection of hydrological and hydraulic models within this DSS-PC (Pasche, 2007). Concerning the theoretical background it is referred to this literature.

Taking into account the EU Water Framework Directive and the EU Flood Directive ecologically oriented measures should be preferred such as SUDS (Sustainable Drainage Systems), restoration of pervious surfaces, local scale retention (green roof, detention ponds) and restoration of flood plains and natural geomorphology of the watercourses. A new theoretical concept had to be developed for quantifying the retention and flood attenuation effect of SUDS within the rainfall-runoff models. It integrates the most relevant components of on-site storm water management: retention in ponds and swales, infiltration into the ground and drainage through perforated pipes. All three elements can be found in filter drains or swales (Fig. 1). The theoretical basis for the mathematical description of the infiltration and retention processes in SUDS is the continuity equation:

$$\frac{dsw(t)}{dt} = inf(t) - perk(t) - ETa(t) - i_{DP}(t) \quad (1)$$

The soil water  $sw(t)$  will change in dependence on the infiltration rate  $inf(t)$ , the percolation rate  $perk(t)$  into the groundwater, the evapotranspiration rate  $ETa(t)$  and the drainage  $i_{DP}(t)$  through the perforated pipe. The SUDS are subdivided into layers according to Fig. 1. For each layer this equation is solved in a consecutive way. For a filter drain with a swale or pond the first layer is the pond. Although being without a soil matrix the water balance in this drainage element can be described by the same equation. Only the components refer to different processes.

$$\frac{dh(t)}{dt} = P_{eff}(t) - perk(t) - EVp(t) - q_{ov}(t) \quad (2)$$

Instead of soil water content the water depth  $h(t)$  is balanced in a pond. The inflow into the pond is through effective precipitation  $P_{eff}(t)$ , the evapotranspiration always reaches the potential evapotranspiration  $EVp(t)$  as long as water is in the pond and in case of excess an overflow  $q_{ov}(t)$  occurs.

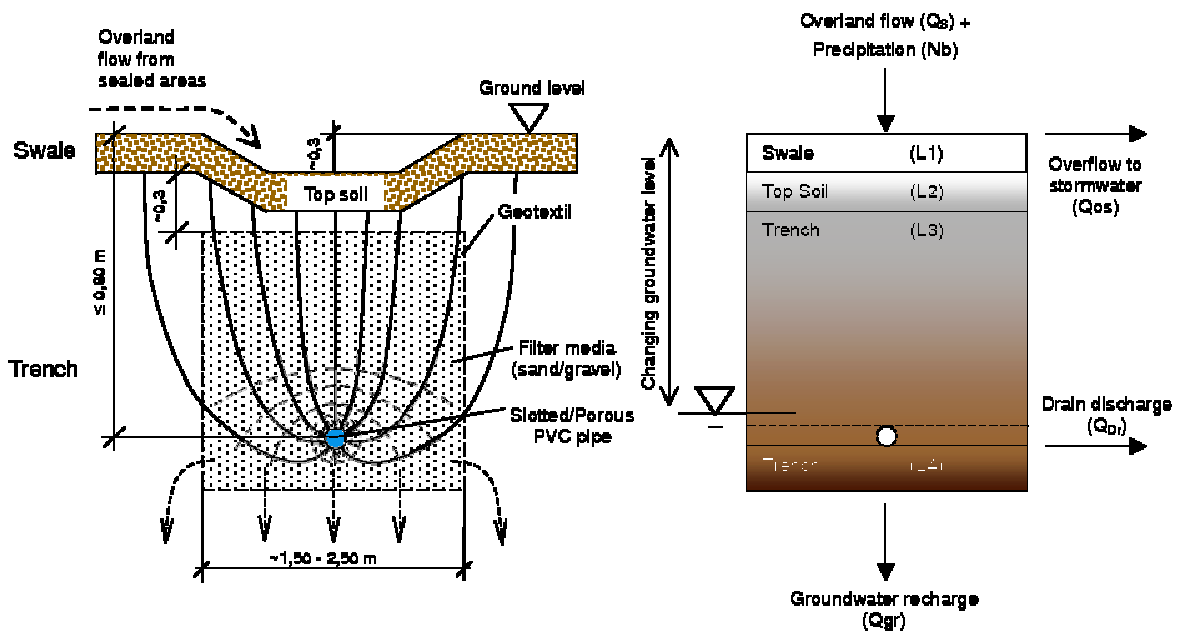


Fig. 1: Application of layer concept in a combined swale – filter drain

Saturation in the filter drain begins when at the bottom of the last layer L4 the potential percolation exceeds the infiltration capacity into groundwater. The flow into the drainpipe begins when the elevation of saturated soil zone reaches the bottom of the drainpipe. The flow in the drainpipe is often controlled through a valve at the outlet of the drainpipe in the way that the maximum drain flow from the developed areas does not exceed a given discharge into the stormwater network. Following the new German Water Act this discharge has to be limited that for a 100-year flood the overall flow in the river is not changed by the new urban development (100 % compensation requirement). This discharge is not known in advance but has to be found iteratively through the rainfall-runoff model.

The DSS-PC should support the user by an optimisation procedure in which this discharge is found by systematic variation and optimisation of the design parameters of the SUDS which are the volume of the filter drain and the pond as well as the maximum flow capacity  $q_{max}$  of the drainpipe. This parameter is a function of the diameter of the drainpipe and the pressure difference between the filter drain and the stormwater pipe. A precise calculation of the flow into the drain needs refined hydrodynamic modelling. In rainfall-runoff models simplifications are acceptable. A good approximation is to set the pressure gradient equal to the slope  $n$  of the drainpipe. Then  $q_{max}$  can be calculated on the basis of the Darcy-Weisbach and Colbrook-White formula for rough conditions:

$$q_{max} = 4 \log \left( \frac{3,71 \cdot D}{k_s} \right) \cdot \sqrt{2g \cdot \frac{D}{4} \cdot n \cdot \frac{\pi}{4} D^2} \quad (3)$$

with  $D$  = diameter of the drainpipe in [m] and  $k_s$ =equivalent sand roughness in [m].

The procedures of flood risk assessments are incorporated into a loop of scenario analysis, which includes further procedures for the decision making process (Fig. 2).

A spatial planner will not have the time and expertise to define the data model for a rainfall-runoff model or the hydraulic models. This work needs to be done by an expert with thorough hydrological and hydraulic background. The input and modeling interest of the spatial planner is confined on the

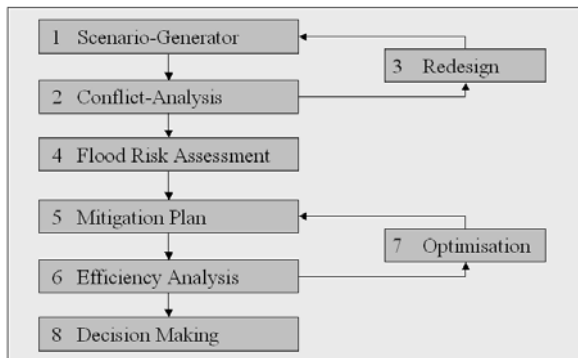


Fig. 2: Scenario-Analysis Loop within the DSS-PC

definition of the changes in the existing data models according to the planning intention. This must include the possibility to define mitigation measures to compensate the effect of planning on the hydrological cycle. They need to be defined and marked in a map. Thus the access to GIS-functionality is a prerequisite for the DSS-PC. Within the conflict analysis tool a spatial analysis of the planning intention defined in the scenario is carried out. It should contain Boolean functions, through which the overlapping of the planning domain with conflicting regions or functions of the landscape is detected. The intensity of conflict can be defined by a 5-step classification scheme ranging from knock-out to severe, moderate, little and no conflict. Within the conflict analysis tool a pre-qualification of the planning is offered which selects all areas with knockout criteria, indicating that the intended plan is not feasible and needs modification. In this case the DSS-PC refers back to the scenario generator requesting a redesign (Fig. 2). In step 4 the flood risk assessment of the final planning will be performed according to Tab. 1.

Within the efficiency analyzer the benefits of the mitigation measures defined in step 5 and the associated costs will be quantified. For evaluating the benefits the risk assessment tools of Tab. 1 determines the annual probable damage including the mitigation measures. The monetary cost-benefit evaluation compares the total costs (investment and operational costs expressed as annual costs) and the reduction in the annual probable damage. For being able to optimize the mitigation measures the costs should be defined as specific costs per unit or as cost functions. The non-monetary aspects can be analyzed by a Multi-Criteria Analysis (MCA). Based on a quantitative analysis (through scoring, weighting and ranking) the economic efficiency is compared with the distributive impact (e.g. environmental, social). In two stages the selected criteria (objectives or conflicts) are evaluated. Stage 1

scores the extent to which an objective has been achieved (e.g. the attenuation of the flood wave to predefined targets) or the severity of a conflict. In stage 2 the different impacts are normalized with weighting their scores. Within the optimization procedure the assortment of mitigation measures and their design parameters will be optimized through an iterative cycle between the efficiency analysis and the mitigation plan. Different optimization techniques are available (Stielau, 2005) out of which the shuffled-evolution-algorithm has been found to be very efficient.

## 2.2 Learning Program

Based on the didactic principle of Kolb/Fry, 1975 the learning process is divided in four steps which form together a closed learning circle, which can be repeated if necessary (Fig. 3). This principle has been applied and adapted to flood risk management in the *Learning Program* developed for spatial planners. In the first step, the participants are informed about the different aspects of flood, from the generation of flood, the transport and spreading of flood to the impact of floods.

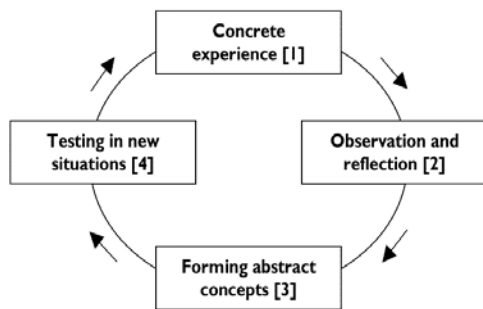


Fig. 3: Didactic concept of Kolb/Fry, 1975

In the second step, the participants have to reflect the information of the first phase in order to understand the mechanisms of flooding and the resulting risk. They learn to recognize the role of flood retention, spatial planning, risk awareness, preparedness and resiliency to reduce flood risks. In the third step, they have to develop general flood risk management strategies. In the last step they have to apply the new knowledge by developing flood risk management plans for their neighbourhood. A key element of this *Learning Program* is the providence of an animation centre, which creates virtual flooding situations by various flood symbols and animated flood situations. Emotional situations are created via haptic components, e.g. by sitting in a flood box or walking through a “forest” of water columns, creating a feeling of continuous water body (Fig. 4, Fig. 5). The flood animation centre is equipped with a GPS-sensor and a GIS-system on a laptop giving the user the possibility to fill the cylinders with a water height that corresponds to a flood probability taken from an existing geo-referenced hazard map. Additionally a haptic flood animation box supports the *Learning Program* in its intention to raise risk awareness. Movies of flood situations and a narrator who tells about his personal flood experiences complete the flood animation centre.



Fig. 4: Photo of the flood cylinder model



Fig. 5: Haptic Flood-Animation Box in Action

The knowledge to understand the complexity of flood formation in urban environments and the appropriate mitigation and adaptation strategy is extensive and requires intensive learning. As the learning process is dependent on the individual skills, an autodidactic learning approach seems to be the

appropriated learning strategy. Pasche/Kraus/Manojlovic, 2006 developed a corresponding learning concept making use of e-learning technology. It is composed of three different modules *Tutorial*, *Knowledge Base* and *Virtual Trainer*. In the *Tutorial* the content is structured in a logical way based on the needs of risk management: Mapping and Modelling Techniques, Risk Perception and Dissemination, and Decision Support and Water Management Systems. In the *Knowledge Base*, the user has

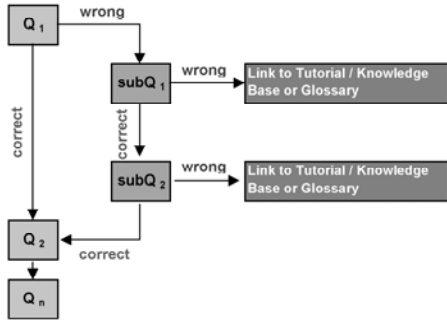


Fig. 6. Principle of the tree structure and a sequence from Virtual Trainer

the possibility to get precise and short answers to any relevant topics and results of the project by cross-referencing the content via key words or via trans-national experience and best practices in flood management. According to STONE, 2002 “The ability of the user to interact with and even control content is a primary benefit of *web-based training* and one of the primary reasons for its success as a delivery method.” This aspect is especially addressed in the *Virtual Trainer* where the user’s interaction is continuously requested in a questioning-answering procedure (Fig. 6). The user has to be active and gets a permanent feedback on his individual knowledge.

### 3 IMPLEMENTATION AND APPLICATION

#### 3.1 The Software Concept of the DSS-PC

In connection with the Interreg IIIb project FLOWS the theoretical concept of the DSS-PC has been implemented into the software KALYPSO Enterprise, an Open Source software system for flood risk modelling (Pasche 2007, [www.kalypso.wb.tu-harburg.de](http://www.kalypso.wb.tu-harburg.de)). It is based on OGC-standards ([www.opengeospatial.org](http://www.opengeospatial.org)) and provides an Open GIS user interface for map-based data access and input. A Web Map Service (WMS) based on an implementation of the Open Source software *deegree* ([www.deegree.org](http://www.deegree.org)) provides access to GIS-data via Internet. The key frames of the user interface of the new DSS-PC are: map view, project (scenario) navigator, context view, theme organizer (map layer list) and the workflow browser (Fig. 7), which is the central control element of the DSS-PC. With this browser the user is guided through the tasks in the logical order of the planning and evaluation process given in Fig. 2. The scenario generator (task 1) needs the input from the planning documents. The DSS-PC supports the OGC conformal standard XPlanGML ([www.iai.fzk.de/projekte/geoinf/XPlanung/](http://www.iai.fzk.de/projekte/geoinf/XPlanung/)) for the import of digital maps (CAD or GIS maps) of planning tools and visualize them via SLD WMS service. In task 3 the planning parameters, which have an impact on the hydrological cycle are directly transferred into the input data files for the three modelling tools KALYPSO-Storm (rainfall-runoff model), KALYPSO-Flood (1- and 2-dimensional flow model) and KALYPSO-Risk (flood damage and risk assessment). In task 4 the impact of the development plan on the hydro-

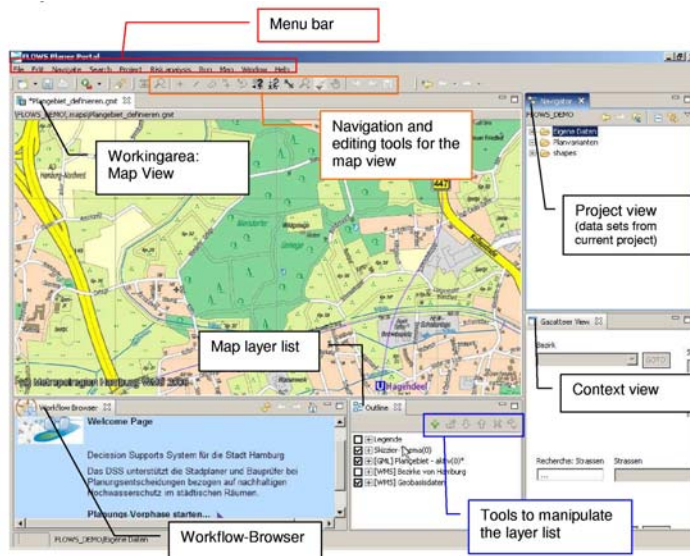


Fig. 7: User-Interface of the DSS-PC

logical cycle is quantified on the basis of the flood risk models and visualized for all relevant locations in the watercourse network through colouring an impact bar or through a flood hydrograph (Fig. 8), generated with a mouse-click at the impact bar. Within task 5, the user is requested to define mitigation measures. In the example given in Fig. 8 the user can choose between the three different options: restoration of pervious surface, retention ponds and SUDS.

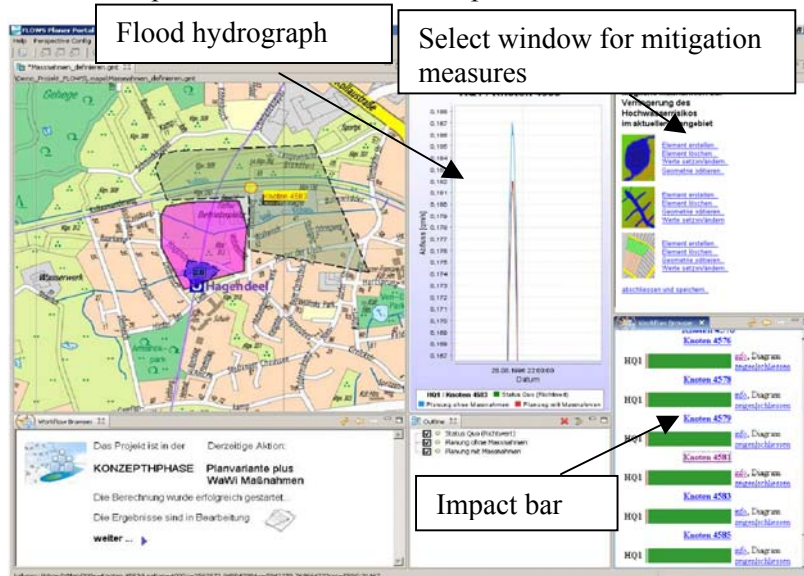


Fig. 8: Visualization of the efficiency of mitigation measures

As the DSS-PC only wants to support the decision process for an efficient mitigation plan and not the design of its measures the design-process within the DSS-PC is rough, making use of simple drawing functions, pictograms and requesting only the necessary input parameter for the modelling tools. They are automatically integrated in the input files of the models. Tasks 6 and 7 are executed automatically and gradually modify the design parameter in the iterative optimisation cycle to reach the predefined targets (e.g. full hydrological compensation, minimum

costs etc.), which will be presented in task 8, the decision making.

In a pilot phase Kalypso Enterprise had been applied together with the Planner-Client module (DSS-PC) at the Ministry of Urban Development and Environment of the City of Hamburg. It was implemented on an own central server and integrated in the governmental intranet of the City of Hamburg. Parallel selected external consultants got access to the program. Both, the experts of the administration as well as the external consultants have been trained in the application of the software and attended with telephone support, regular meetings and updates for more than one year. Due to this close cooperation, the researchers received a good feedback, deficiencies in the user interface and software stability could be quickly detected and have been directly approached. In the meantime, Kalypso is an official information and decision support tool for the City of Hamburg. It has been already applied at 6 urban catchments and will be extended on all urban catchments and watercourses of the City in the next years to support the development of the flood risk management plan according to the EU Flood Directive and the new German Water Act. Already for these 6 catchments the approval of new urban development requires a hydrological impact assessment and the development of compensation measures on the basis of Kalypso Enterprise.

### 3.2 The Learning Program

The *Learning Program* has been implemented in a series of 4 workshops. The flood animation tools have been integrated in the first workshop, which addresses the experience of flood risk. Additionally, experts have explained different aspects of flood risk. In the second workshop experts from water authorities and universities explain the complexity of urban water cycle and the impact of urban planning on flood generation. For better understanding field trips to various locations of flood risk are recommended. In the third workshop the competence in defining efficient mitigation strategies for various tasks of spatial planning is fostered. In the final workshop the participants set up a real mitigation plan for a given urban development. This workshop series has been applied within the INTERREG IIIb project FLOWS at spatial planners, private stakeholders, and students of the spatial planning course of the Hamburg University of Technology. The animation elements created a “fun-effect”, rais-

ing the motivation of the participants. Even the local media and politicians were attracted by the life demonstration.

The Learning Program was complemented by the web-based learning tool Kalypso-INFORM (<http://flows.wb.tu-harburg.de>), which represents the implementation of the learning concept of Pasche/Kraus/Manojlovic, 2006. It was well accepted as an auto-didactic learning tool. Extensive use of infographics, short text blocks and a paging of the content instead of scrolling were evaluated as important factors for a good readability, quick understanding and good memory performance. In a perfect way for it addresses the experience of flood and creates emotional and haptic elements in the learning process.

#### 4 CONCLUSIONS

The *Learning Program* and the computer based DSS-PC have proved to be very efficient in building up the capacity of spatial planners to manage flood risk in their urban development plans. Through a user-friendly Open GIS-based software system, the spatial planners have been able to evaluate the impact of their planning on the hydrological cycle and to develop economic mitigation measures. Even sophisticated computer models have been applied successfully as long as the model of the status quo already exists. However, intensive training and support service has to come along with the introduction of this DSS. It should not restrict to the application of the DSS-PC but has to include the theoretical background of flood risk management and its application in urban planning which can be provided by the e-learning tool Kalypso-INFORM. The duration of the training can be sharply reduced by making use as it supports an auto-didactical learning at home.

The pilot application of the *Learning Program* in the City of Hamburg demonstrated that a successful capacity building of spatial planners has first to stimulate the motivation, which can be accomplished with emotional learning elements as the flood animation centre. But the effort to organize the workshop series of the Learning Program is high. They require extensive preparation and mentoring. Definitely capacity building of spatial planners requires considerable resources which needs a paradigm change in the administration from an infrastructure oriented investment policy to a more qualification oriented social management plan.

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