A GIS-based Platform for Environmental and Water Resources Modeling

Kalypso Open Source

The Kalypso project encompasses a rich environment for environmental and water resources modeling. Workflow-based pre- and post-processing functions allow for preparing input data for computation modules and analyzing computational results in a GIS context. A precipitation-runoff model, a one-dimensional water surface profile model and a model for unsteady coupled 1D/2D flows for surface waters are distributed as freeware with Kalypso as well.

By Gernot Belger, Michael Haase, Thomas Jung and Kaj Lippert

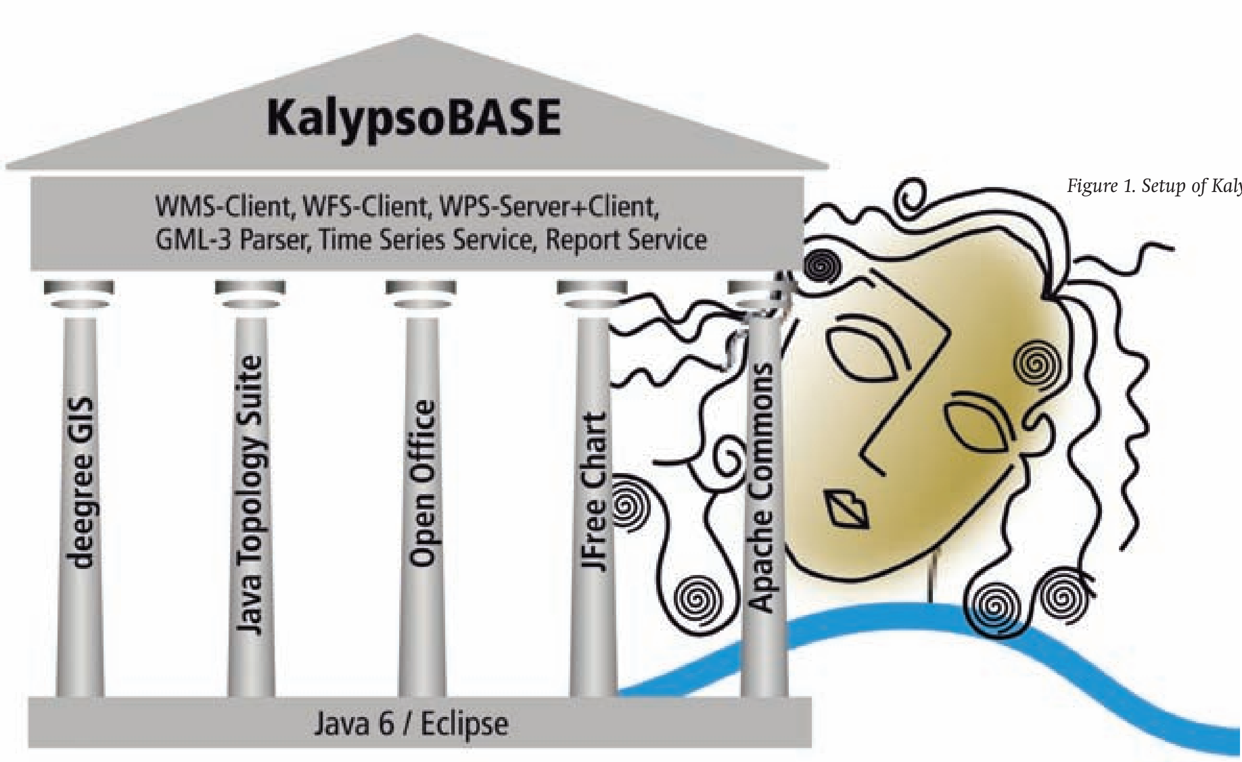

Figure 1. Setup of KalypsoBASE

Kalypso is a software product serving as a modeling environment in the field of water resources management, for example for developing flood defense concepts, flood hazard maps and flood risk maps. Kalypso is designed to be used by public associations, public authorities, universities and engineering companies engaged in the fields of water resource management as well as nature and landscape conservation. The software is developed in the context of an open source project and may therefore be used free of charge. It is licensed with the GNU LGPL (GNU Lesser General Public License) and can be downloaded from kalypso.sourceforge.net. Kalypso meets all relevant OGC (Open Geospatial Consortium) standards.

The European Flood Directive (2007/60/EC) on the assessment and management of flood risks came into effect on November 2007. This directive requires Member States of the European Union to identify the river basins and associated coastal areas at risk of flooding by 2011, in a preliminary assessment. For such zones the Member States need to draw up flood risk maps by 2013 and establish flood risk management plans focused on prevention, protection and preparedness by 2015. The challenge to meet the required specifications of this directive is immense and demands the application of special software tools - such as Kalypso.

Technical Basis

KalypsoBASE is a framework for building Java-based "rich client" decision support and information systems. It resembles a Greek temple (see figure 1). The foundation of KalypsoBASE rests on the Java programming language which includes the corresponding Java virtual machine and the Eclipse (www.eclipse.org) development environment. The pillars in this analogy, among others, are the deegree GIS www.deegree.org, the Java Topology Suite www.vividsolutions.com/jts/jtshome.htm for processing geodata, the Open Office package www.openoffice.org, the JFreeChart www.jfree.org/jfreechart collection and the Apache Commons library commons. apache.org. On top rests the architrave and frieze, the latter carries the facets OGC WMS-Client, OGC WFS-Client, OGC WPS-Server and OGC WPS-Client, GML-3-Formats (for details about these services and formats please refer to the Open Geospatial Consortium, www.opengeospatial.org). These libraries are encapsulated by KalypsoBASE, which represents the tym-

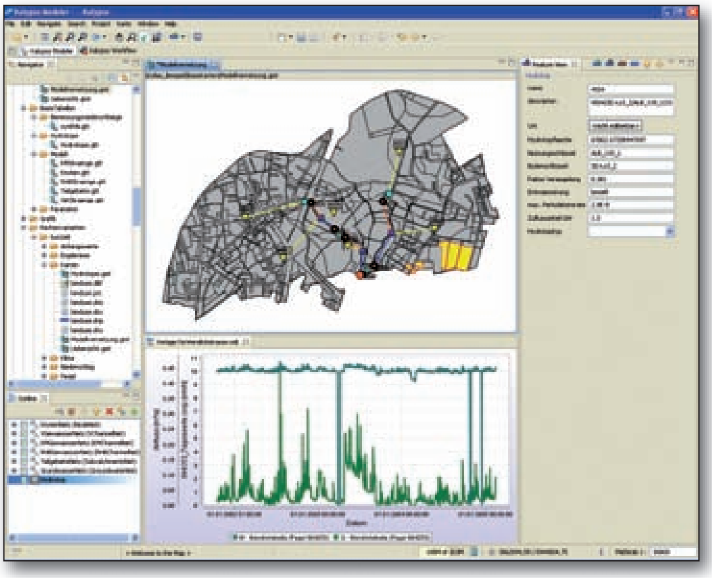

Figure 2. User interface of Kalypso Hydrology depicting a map of the river / creek network and assigned gauging data.

panum within the cornice of this temple.

Kalypso Modules

Kalypso Modules are based upon KalypsoBASE. At present, the following main modules are available as open source from the Kalypso Project:

- Kalypso Hydrology – A distributed rainfall-runoff model for simulating hydrological processes within a catchment
- Kalypso WSPM – A one-dimensional back-water surface profiling model for one-dimensional non-uniform steady fluvial flow
- Kalypso 1D/2D – A hybrid one- and two-dimensional Finite Element model for non-steady flow simulation of rivers and estuaries
- Kalypso Flood – A tool for visualizing flooded areas determined either by Kalypso WSPM or Kalypso 1D/2D
- Kalypso Risk – A tool for determining the expected annual damage and classifying flood prone areas into risk zones

Kalypso Hydrology, Kalypso WSPM and Kalypso 1D/2D are comprised of three parts: a data pre-processing component, a numerical processing component – the numerical processing software is available as freeware with the Kalypso Modules from the Institute of Hydraulic Engineering at the Technical University of Hamburg-Harburg (www.tu-harburg.de/wb/) - and a post-processing component for presenting and analyzing data obtained with the numerical processing component. Data can be easily shared between the different Kalypso Modules.

Kalypso Hydrology

Kalypso Hydrology is a software package for carrying out precipitation-runoff simulations. The model allows for simulating the entire land-based part of the water balance on the basis of a given time series. It transforms precipitation, potential evaporation and temperature input data into runoff output data, on the basis of predefined process parameters derived from physical spatial data, such as the distribution of soil types in a catchment.

In this context the processes of snow storage, evapotranspiration, soil water storage, groundwater recharge, surface runoff, interflow (lateral water flows in the vadose zone), groundwater flow, and flow in rivers, creeks and open channels (wave translation) are modeled. In order to be able to analyze the water balance in the catchment in detail, the catchment is subdivided into subcatchments which in turn may be comprised of several distinct hydrological homogeneous areas (hydrotopes).

The setup and editing of the model is supported by a graphical user interface thereby making extensive use of built-in GIS-functions. Topological river/creek networks are defined as node-link-networks against the geographical background information. Simulation runs are controlled within this environment by the graphical user interfaces as well. The calculated runoff may be analyzed at any node of the node-link-networks by selecting a node with the mouse on the map.

Figure 2 depicts an example of the user interface of Kalypso Hydrology. On the left hand side within the Navigator different model-specific information items may be selected (e.g. maps, model scenarios) in a treelike view. Display characteristics of selected maps may be defined within the Outline view located below the Navigator. The selected map is displayed on the center upper part of the window. Commonly known means for navigating on the map and editing geometry features are of course provided as well. On the lower central part of the window time series for user selected nodes are presented. On the right hand side alpha-numeric model data may be edited and simulation runs controlled as well.

Tools are at hand for building flood forecasting centers on the basis of Kalypso Hydrology. Online precipitation and gauge runoff data may then be used to generate flood forecasts. This information will help emergency management services to coordinate their activities in order to save lives and assets as well as avoid environmental hazards. The public and decision makers are provided with up-to-date warning messages via a variety of pull and push services (e.g. web pages, teletext, SMS). The flood forecasting centers of the German states of Saxony and Saxony-Anhalt have been equipped with this software.

Kalypso WSPM

Kalypso WSPM (Water Surface Profiling Model) is a module for determining one-dimensional water surface profiles in near-natural creeks and rivers, e.g. for identifying inundated areas on the floodplain due to predefined creek / river flows on the basis of flood plain and river morphology. Flood plain and river cross sections are established on the basis of Digital Terrain Models (DTM) and morphologic river surveys. These cross sections are technically subdivided into a main channel with foreshores on the left and right hand side of the main channel. In addition, the hydraulic active area must be specified in order to define boundary conditions for the numerical computation.

The model allows for computing stationary non-uniform water surface profiles, optionally taking user selectable flow laws into account (Darcy-Weissbach or Gauckler-Manning-

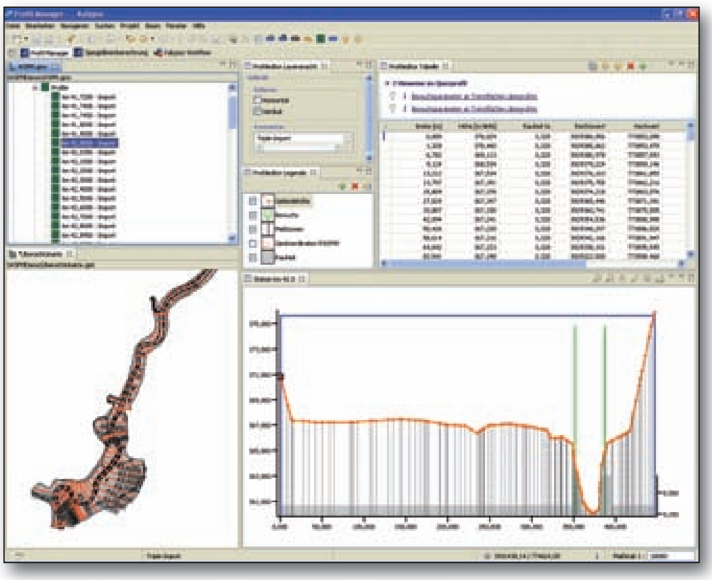

Figure 3. User interface of Kalypso WSPM depicting a map of a stretch of a river including assigned cross sections and a selected cross section in detail.

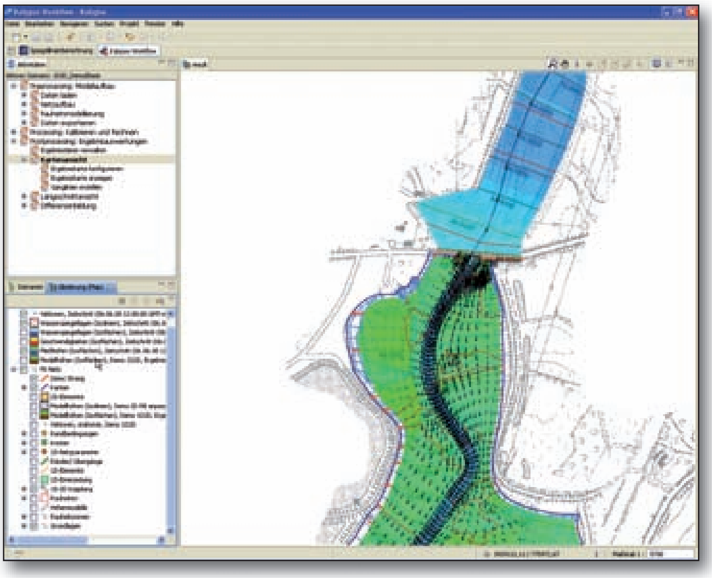

Figure 4. User Interface of Kalypso 1D/2D depicting simulation results – flow velocities and flow depths – against the background of a transition between a one- and two-dimensionally modeled project area.

Strickler). Fouling roughness is accounted for by the approach of Pasche and Linder. The effects on the flow regimes of intersecting bridges and weirs are taken into account by the software.

Figure 3 depicts an example of the Kalypso WSPM user interface for analyzing cross sections. All cross sections are listed with regard to the station of the intersection of the cross sections with the creek / river branches in a tree-like view on the upper left side of window. On the lower left side of the window a map depicts the location of the cross sections. The selected cross section is presented to the user in a diagram on the right hand side of the window. The numeric properties of this cross section are contained in a spreadsheet-like view on the upper right side of the window. The user may either edit the cross section data in the diagram view by using mouse functions or in the spreadsheet. Roughness and fouling zones can be automatically assigned to cross sections by integrated GIS functions (intersection).

Geographic data may be imported and exported in ESRI Shape and Grid formats. Web Map Services can be integrated as background information on demand. An interface to Kalypso Flood is provided in order to revise inundation areas. In order to account for comparisons of different model scenarios (e.g. for analyzing the effects of nature-oriented flood protection measures by relocating dykes on the flood plain upstream on flood patterns of densely populated areas, downstream of a selected river / creek) calculation results are automatically stored in the background for further analysis.

Kalypso 1D/2D

Kalypso 1D/2D allows for computing water surface profiles for the unsteady flow of surface waters. The study area may either be discretized by a two-dimensional mesh of finite elements or a one-dimensional string of nodes. As a special feature of this module, one- and two-dimensional modeled areas may be linked into a single hydraulic model (see figure 4). No limits exist with regard to the number of transitions between one- and two-dimensiona-modeled river / creek stretches. The program's nucleus is based upon the well known RMA 10S by Prof. Ian King of Resource Management Associates and has been further enhanced by the Technical University of Hamburg-Harburg. The mathematical basis of the computation module is formed by the St. Venant equations and the depth-averaged shallow water equations. The computation module is based on the finite element method (FEM).

The computation module allows for optionally selecting either the flow-laws of Darcy-Weisbach or Gauckler-Manning-Strickler. Fouling roughness is also accounted for. Wetting and drying algorithms are integrated in the two-dimensional modeling approach for determining spatial transitions for unsteady flow conditions. The software is capable of handling subcritical as well as supercritical flow conditions during simulation. Various turbulence models are implemented in the software, e.g. constant eddy viscosity, soil surface induced turbulence model, Prandtl's mixing length concept and Smagorinsky's model.

Kalypso 1D/2D allows for cost efficient hydraulic analysis of long river stretches in big catchment areas. Depending on the local complexity of the hydraulic processes and the required accuracy of the results, either the one- or two-dimensional approach can be selected for modeling the particular stretch of river / creek. For example, straight stretches of rivers confined by mainly agricultural or forested areas can be modeled extremely well with the one-dimen-

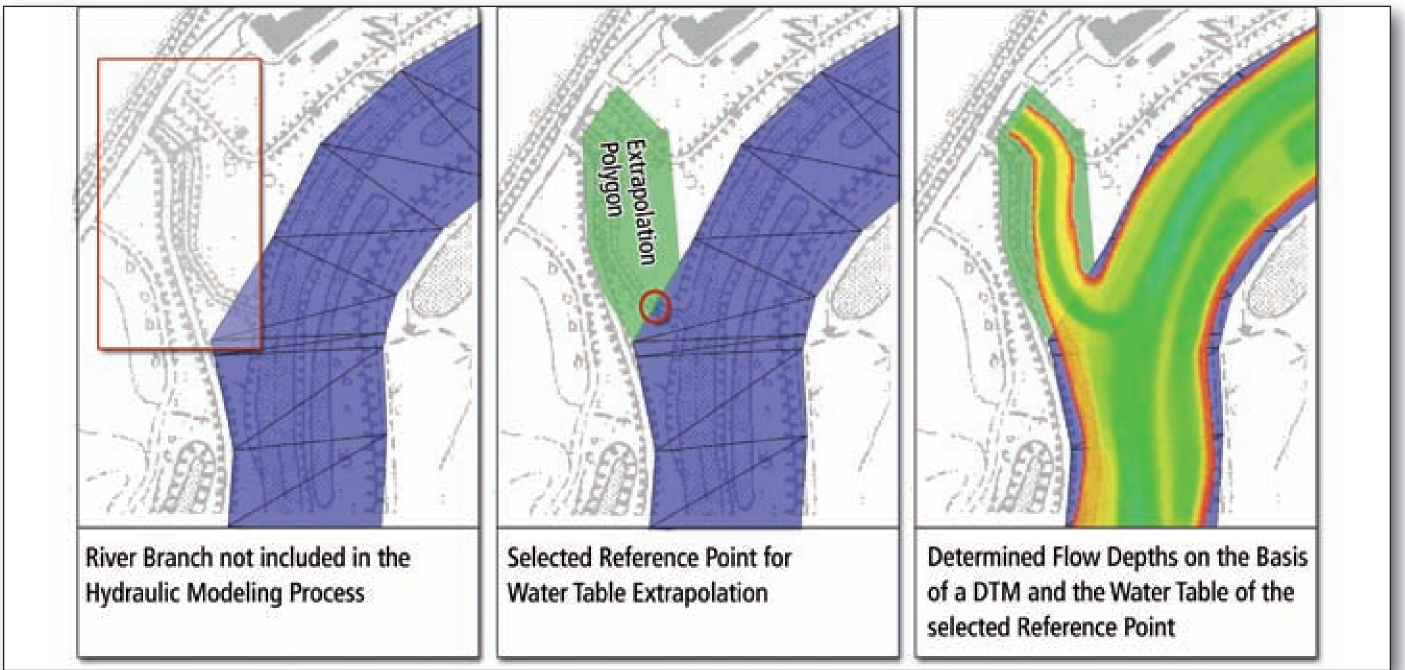

Figure 5. Manual extrapolation of inundation areas with Kalypso Flood - workflow from left to right.

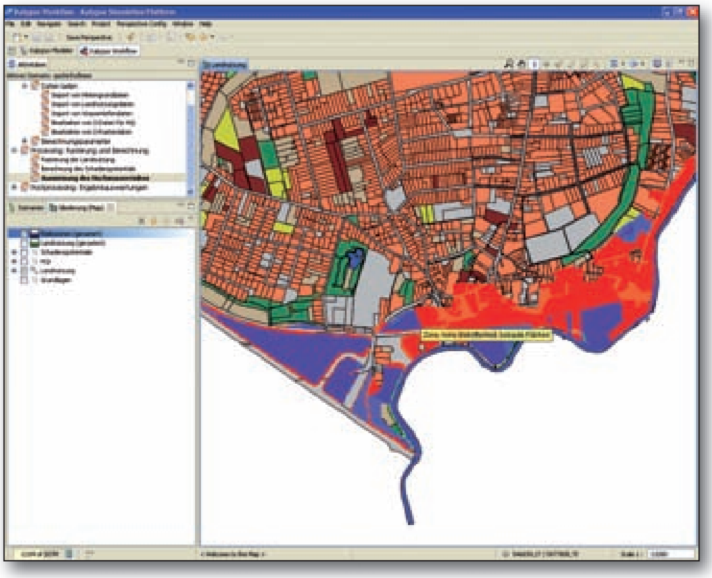

Figure 6. User interface of Kalypso Risk depicting an example of a risk zone mapping against the background of land use.

sional approach, with good results. On the other hand, urban areas with high vulnerabilities will need to be modeled in a more detailed manner by using the two-dimensional approach. Both approaches may be linked into a single hydraulic model. Choosing the unsteady flow simulating option of the computation module allows for taking hydrodynamic effects of the flood wave propagation into account. Thus, the effects of flood plain retention can be modeled with a high degree of accuracy. The latter is commonly neglected in steady state flow calculations. The resulting inundation areas of extreme flows may therefore be smaller using this option and thus flood protection schemes designed on the basis of these simulations may save money to the taxpayer.
The module is equipped with powerful pre- and post-processing functions which are integrated in the graphical user interface. The user interface is based on the idea of workflow management and has been designed and implemented according to modern principles. The entire process of setting up a hydraulic model and analyzing model results is implemented in a workflow-driven manner, thus the user is provided the utmost assistance in handling the system. The user is interacting with the modeling software on a background of available spatial information, e.g. maps supplied for the study area by a Web Map Service.
A finite element mesh generator for river channels, based on cross sections as well as methods for generating and refining the finite element mesh (e.g. on the floodplains), is implemented in the system. Finite element nodal points are automatically assigned elevations on the basis of a digital terrain model e.g. derived from airborne laser scanner data. Common data interfaces are supported by the software for this purpose (e.g. ESRI ASCII Grid format). Land use data may be utilized for assigning roughness values to the finite elements by intersecting the land use layer with the finite element mesh layer. Results from the computation module may be automatically processed into, for instance, flow vector maps, inundation isolines and flow speed isolines presented against a background of topographic maps. Hydrographs which are generated by the computation module for all nodal points of the finite element mesh can be displayed for user selected locations in time-series plots. Last but not least, the user may define arbitrary cross sections for display in a separate cross sectional view, including water tables and ground surface.

Kalypso Flood

Kalypso Flood is a post-processing module for determining and displaying inundated areas and flow depths on the basis of digital terrain model data and water surface profiles. Kalypso Flood works with ESRI ASCII Grid formatted data with arbitrary spatial resolution.
During data processing every cell of the digital terrain model is assigned a water surface profile value from the water surface profile data. By determining the difference in these values flow depths for every grid cell are calculated. This results in a flow depth grid inheriting the cell size and spatial resolution from the digital terrain model being used. Water profile data are directly imported from Kalypso WSPM and Kalypso 1D/2D. Water profile data from other sources may be imported in ESRI Shape format. Kalypso Flood allows merging of different model results into a single result set, thus providing a means for combining separately computed model segments for further processing. The result of these computations is also used in Kalypso Risk for determining damage potential and risk maps. Data from Kalypso Flood may be exported in ESRI ASCII Grid format for further processing with other software.
Furthermore, Kalypso Flood provides a means for manual data editing. For example, clip and extrapolation areas may be defined in order to exclude areas from intersection processes or to assign water level data to areas with no water level data for determining overall inundated areas. Figure 5 depicts the workflow for extrapolating flow depths into a side river branch which has not been included in the hydraulic modeling process.

Kalypso Risk

Kalypso Risk complements the post-processing palette of Kalypso with a module for determining flood risks along the course of rivers. On the basis of land use data and flow depths, the module provides a means for determining damage potentials and yearly expected damage values as well as allocating risk zones. For determining annually expected damage values, flow depth data from a variety of flood events corresponding to different return intervals are required.
Land use data are imported as Shape data into Kalypso Risk. Flow depths are imported as raster data in ESRI ASCII Grid format. Efficient management tools for carrying out these tasks are provided in the Kalypso Risk user interface. Annual expected damage values are computed based upon a mesoscale approach for monetary values (specific asset allocations to land use categories) and user selected stage-damage function, which determine the relationship between water depth and structure damage. The user of Kalypso Risk can choose between working with specific asset values and stage-damage functions defined by him or herself, or applying existing material, e.g. from the International Commission for the Protection of the Rhine (IKSR) or the International Commission for the Protection of the Elbe River (IKSE). Annual expected damage values are of particular interest in evaluation processes of planned flood protection schemes, e.g. for carrying out cost-benefit analysis.
Flood risk zones are derived from specific annually expected damage values [¤/a/m]. Six risk zone categories may be differentiated with Kalypso Risk taking only the land use categories “settlement areas” and “unsettled areas” into account; a differentiation between “highly affected”, “medium affected” and “little affected” is possible. The user interface offers a means for defining and editing limiting values for these categories. Figure 6 depicts an example for a risk zone classification of a settled area close to a meandering river (southern boundary in figure 6).

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Have a look at: kalypso.sourceforge.net and nofdpidss.sourceforge.net