Chapter 6
WP-D: Environmental Information System

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6.1 Motivation

The previous chapters gave detailed insight into the collection of environmental data
and the use of that data for purposes such as determining and improving water quality,
dealing with extreme weather events, or the planning of waste water management
systems. However, adequate visualisation techniques are required to communicate
the significance of this work and the consequences of research results to stakeholders
or laymen. In addition, sustainable management of water resources requires well-
engineered software solutions that can be operated by regional authorities and oper-
ating companies. To this end, the "Urban Catchments"-project includes the adaption
and adjustment of software frameworks for the region around Chao Lake. Section 6.2
demonstrates a WebGIS approach for an environmental information system for time-
series data from observation sites in Chaohu City to monitor water quality and hydro-

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logical parameters. In Sect. 6.3, a virtual geographic environment is introduced to present all available data sets for the Chao Lake catchment in one unified geographic context, such that the relevance and information for each data set are adequately visualised and the interaction with other data sets is coherently illustrated. It will become obvious that such software infrastructures are becoming essential to efficiently work with the large amount of heterogenous data collected within large-scale projects.

6.2 Environmental Information System Based on Online Measurements

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An important basis for the implementation of the Urban water resources management is the development and establishment of monitoring platforms for the sources of water pollution in connection with a powerful data management system. The resulting system consisting of hard- and software components at different levels is called Environmental Information System (EIS). Environmental Information Systems play an important role since they help to control, manage and reliably provide relevant data for the assessment of the existing environmental situation.

Environmental information systems are constructed in a decentralised manner and are hierarchically structured. They are modular in the target position and scalable to different dimensions (place, region, country) (Fig. 6.1). All important subsystems are covered especially when implementing environmental information systems for water balance - ground water and surface water, drinking water and waste water, households and industry. The data are associated with government information such as e.g. land registry details, properties and regulatory documents.

WISUTEC and AMC planned to implement the complete chain of an environmental information system together with all the partners based on modern technologies of the IoT (internet of things). In the "Urban Catchments"-project with Chinese partners, solutions at all levels were implemented.

Three groups of sensors are used for environmental information systems in the water and waste water area: sensors for water quality or quality parameters (temperature, conductivity, pH value, turbidity, concentration of contaminants, oxygen content, etc.), for hydrologic parameters (level, current speed, flowrate, etc.) and status parameters (camera, drop, energy supply, etc.). The selection and integration of the sensors takes place corresponding to the target position of monitoring and the local conditions (Fig. 6.2). A detailed overview on the parameters that can be measured in online operation is provided in Tables 6.1 and 6.2.
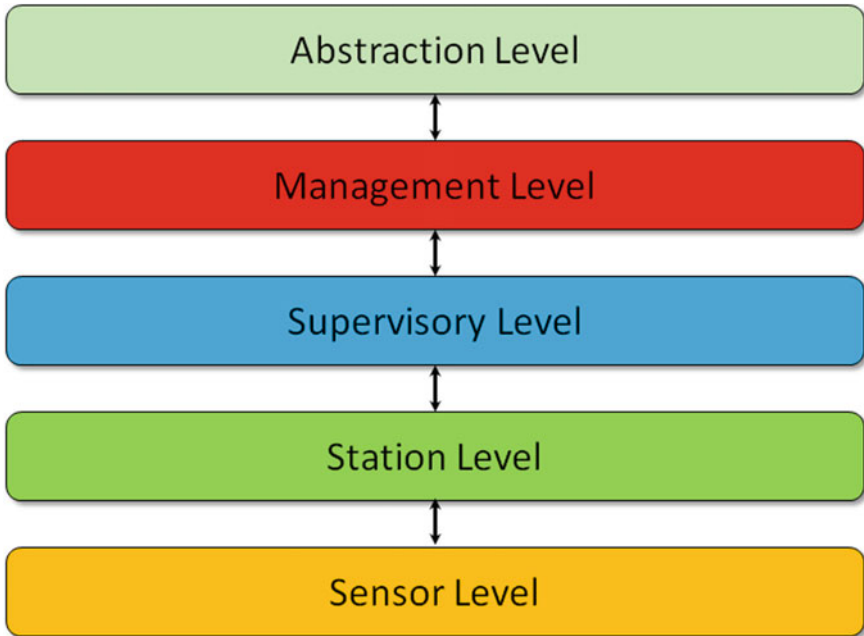
Fig. 6.1 Hierarchically structured environmental information system

Fig. 6.2 Sensors for environmental information systems

6.2.1 Station Level

The practical implementation of the measuring stations is carried out depending on the specific local conditions with respect to measuring conditions, energy supply, communication possibilities and safety. In addition to special solutions, three standard types of stations are built: mini stations, compact stations and modular stations

Table 6.1 Water quality parameters

Parameter	Description
Temp	Water temperature
pH	Potential of hydrogen
EC	Electrical conductivity
ORP	Oxidation reduction potential
Colour	Water colour
Turbidity	Water turbidity
TSS	Total suspended solids
BOD	Biological oxygen demand
COD	Chemical oxygen demand
BTX	Aromatic hydrocarbons (mixtures of benzene, toluene and 3 xylene isomers)
TOC	Total organic carbon
DOC	Dissolved organic carbon
AOC	Assimilable organic carbon
UV254	Water quality test parameter to detect organic matter in water and wastewater
NO_3-N	Nitrate as nitrogen (concentration is being reported as nitrogen only)
NO_2-N	Nitrite as nitrogen (concentration is being reported as nitrogen only)
NH_4-N	Ammonium as nitrogen (concentration is being reported as nitrogen only)
O_3	Ozone
O_2	Oxygen
H_2S	Hydrogen sulfide
K^+	Potassium ions
F^-	Fluor ions
ClO_2	Chlorine dioxide
CO_2	Carbon dioxide
H_2O_2	Hydrogen peroxide
$C_2H_4O_3$	Peracedic acid
FC/TC	Free/total chlorine

Table 6.2 Hydrological parameters

Parameter	Description
Level	Water level
Velocity	Water stream velocity
Discharge	Water discharge
Pressure	Water pressure

which are respectively distinguished with respect to sample taking, water supply, size and energy supply (Fig. 6.3). Measuring stations are implemented in a stationary manner on the shore or bridge area, transportable as a measuring case or mobile (on boats). All communication methods are supported.
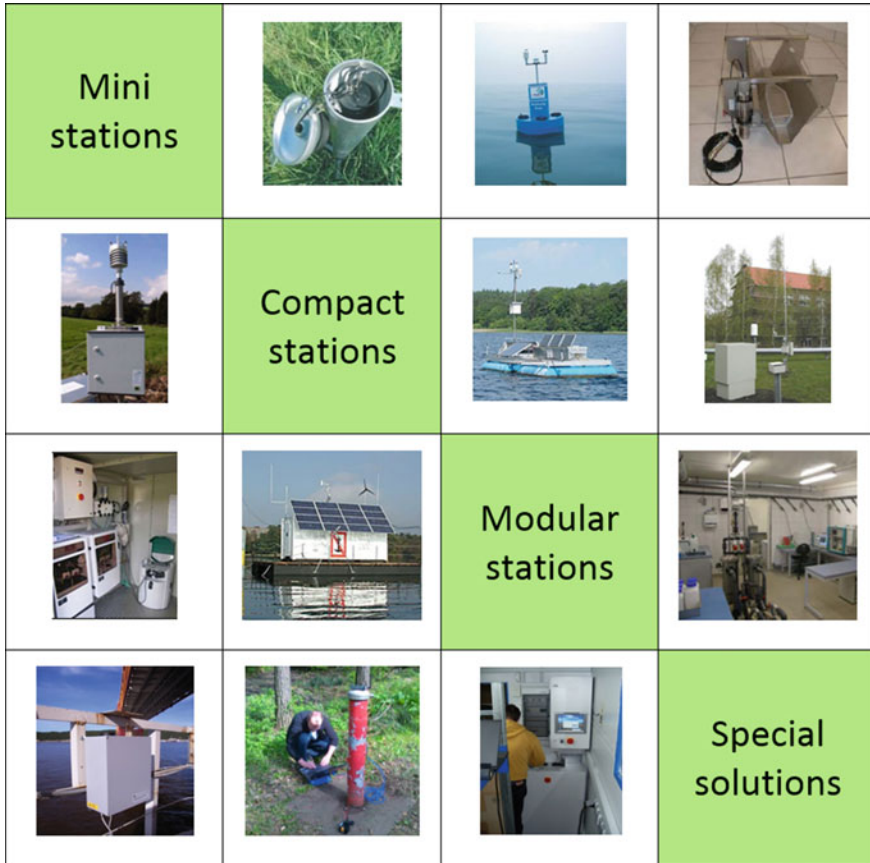
Fig. 6.3 Station level

6.2.2   Supervisory Level

A web-based solution is used as the software for the supervisory level (station supervisory system) which enables not only the monitoring of current operating statuses regarding safety, energy consumption, access rights and fault statuses, but can also execute control functions for pumps, valves and other actors. This station supervisory system (Fig. 6.4) ensures a largely maintenance-free operation and is capable of detecting faults, e.g. in pumps due to soiling in good time. Manual operation for function control on-site is also supported. All operating statuses, notifications and information on faults are recorded in a database and are available as historical data for evaluation. In the event of technical faults, notifications are actively generated.
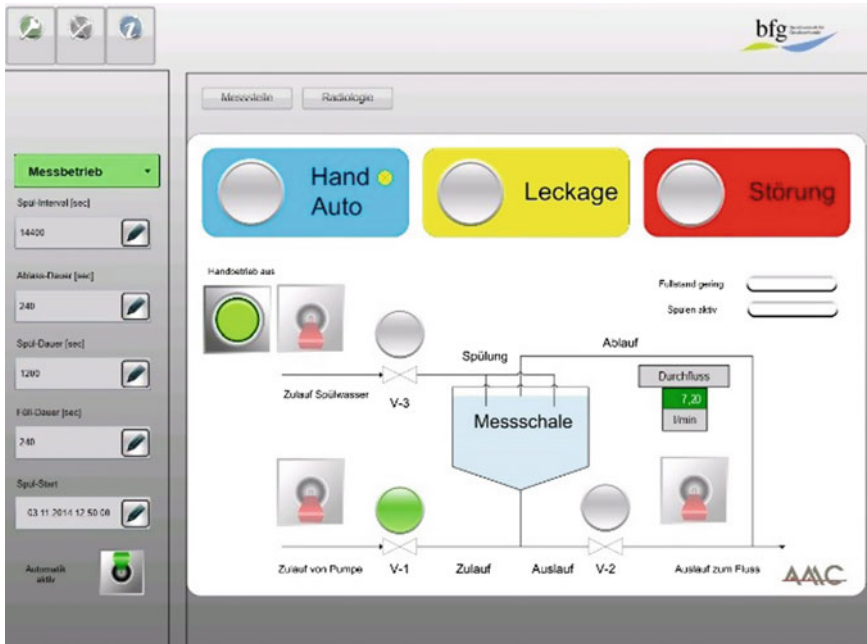
Fig. 6.4 Station supervisory system

6.2.3 Management Level

The software product, AL.VIS/Timeseries is used for the data centre of the EIS. The AL.VIS/Timeseries application is a network-based, multi-user information system for managing measurement networks and measured data in the form of time series data. It uses modern internet technologies to ensure you comprehensive access to your monitoring data. AL.VIS/Timeseries provides the user with all measured values from different areas in one system. A mobile component allows the measured data to be analysed online on smartphone or mobile device. AL.VIS/Timeseries has methods for importing data from different sources (process databases, data loggers, Excel tables), for quality assurance, research, analysis and exporting. The data-base model that is used is very flexible: additional measuring parameters or new measuring points can be easily added. The easy to use diagram function processes very long time series with thousands of measured values very quickly. AL.VIS/Timeseries is implemented in combination with web-GIS-components (Fig. 6.5).

- The software for management of monitoring data can be used in combination with software components for managing data of the river net incl. lakes
- Object-related information (cadastre) of various types
- Documents linked to objects or processes
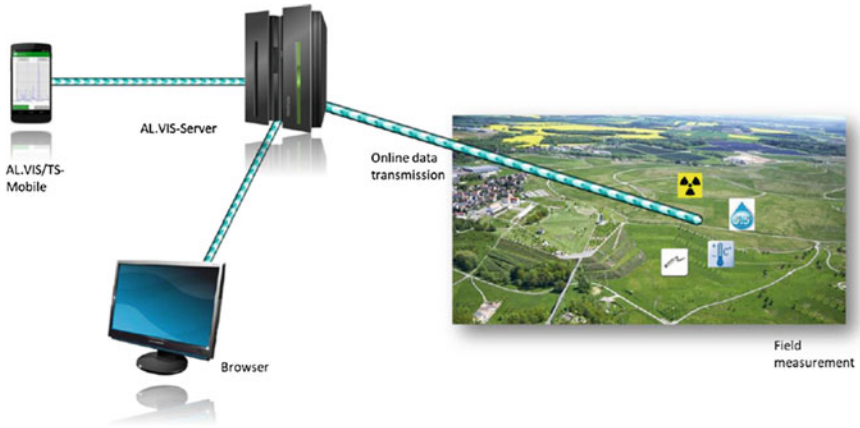- Survey data
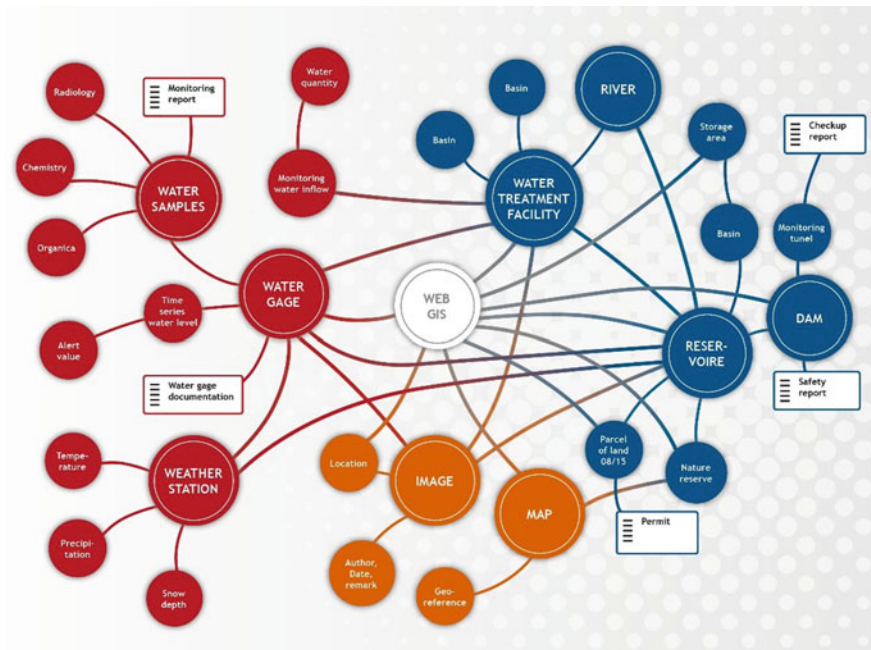
Fig. 6.5 AL.VIS/Timeseries application

Fig. 6.6 Different information categories and their interconnections of the "Urban Catchments"-project

- Topographical, hydrological or geological maps
- Images, maps, and aerial images

Bringing together all these data under one information system allows decision makers to manage remediation processes in an effective manner. The following figure illustrates the different information categories and their interconnections (Fig. 6.6). One important goal of the "Urban Catchments"-project was to demonstrate the possibility to manage all these data and information in the EIS.

6.3 Virtual Geographic Environment

Karsten Rink

6.3.1 Motivation

In recent years, there has been a considerable progress in the development and implementation of monitoring technologies. This includes both remote sensing (e.g. the Sentinel or LANDSAT satellite missions (Fletcher 2012; Wulder et al. 2016)) and in-situ measurements (e.g. sensor networks, climate stations). In combination with advances in specialised software frameworks such as Geographical Information Systems (GIS) or widely-used services such as Google Earth, the amount of available data for a given region of interest has increased substantially. A large variety of observed data sets can be employed in the Earth system modelling domain for environmental studies in general. Of particular interest for the "Urban Catchments"-project is the analysis and management of water resources. With 40% of chinese lakes being severely polluted and 80% of its lakes suffering from eutrophication (see Sect. 1.6 for details), the exploration and understanding of complex collections of heterogeneous data sets from affected regions becomes vitally important for studies aimed at understanding possible causes and devising schemes for remediation. The water from Chao Lake, specifically, is used for fishing, irrigation and obtaining drinking water. As has been shown in Sect. 1.5, harmful algal blooms (Chen and Liu 2014; Tang et al. 2006; Wang et al. 2008) and the lake and aquifer being contaminated with fertilisers, pesticide residues and heavy metals from mining (Li et al. 2013) are of great concern.

We created a Virtual Geographic Environment (VGE) specifically for the Chao Lake catchment, utilising a Virtual Reality environment for the presentation of geoscientific and environmental data. In recent years, VGEs have been regarded as a new generation of geographic analysis tools (Chen et al. 2013, 2015b; Lin et al. 2013a, b, 2015; Lü 2011) that can be employed for a wide range of applications. This includes water pollution analysis (Walther et al. 2014), geotechnical applications (Blöcher et al. 2015) or socio-economic studies (Koch et al. 2018). Such a system allows for

a combined presentation and assessment of geographic objects, such as lakes, river or sewer networks, groundwater information, etc. in combination with the results of process simulation software. Thus, VGEs can also help to predict trends and further pollution analysis (Chen et al. 2012; Lin et al. 2015) by combining observation data and modelling platforms using state-of-the art post-processing and visualisation algorithms (Helbig et al. 2014; Rink et al. 2014). Environmental Information Systems (EISs) can be embedded in VGEs to provide a realistic geographic context for a region of interest. Specifically required functionality can be added to the system, for instance so it may serve as an early warning system for drinking water supplies (see Sect. 6.2 for details).

6.3.2 Methodology

Virtual Geographic Environments provide a new and descriptive way to allow users to explore and evaluate complex collections of heterogeneous geoscientific data sets. Examples include remote sensing data, river networks, land use classes, climate data, and many more. By placing all data sets within an interactive 3D scene it becomes possible to see the correlation of data sets, the variation of certain variables in a region of interest or to highlight certain aspects of a given data set by employing established methods from visualisation sciences. In addition, numerical models and results from the simulation of (hydro-)geological processes and phenomena can also be displayed in the same context as the monitoring data.

By combining these different data sets using intuitive representations of the data, users will get a better understanding of the region of interest as well as the determining factors for phenomena or trends such as algal blooms, the accumulation of chemicals in soil and groundwater, or the effects of flooding during extreme weather events.

From the viewpoint of data management and visualisation, a number of conceptional and technical challenges have to be considered during the development of a multi-purpose Virtual Geographic Environment. For instance, each data set has to be visually represented in a way that is meaningful to a typical user. Such a representation can be either realistic or abstract. A basic example for a realistic model is shown in Fig. 6.7 where three data sets are required to create an instantly recognisable surface of the region of interest. In contrast, Fig. 6.14 shows an abstract representation that allows users to focus on the relevant variables stored within the data set.

However, the visualisation of data sets is a secondary challenge, a follow-up to the primary challenge of data storage. Data sets included in a VGE often have a highly heterogeneous nature, varying in area of interest, extent, projection, structure and many other parameters.

The inclusion of modelling data and simulation results in the system is of vital importance for an effective analysis of processes. Often, different scenarios and their effect on the environment need to be displayed such that stakeholders or researchers are supported in their decision making process and can predict and understand consequences of changes to the environment. Examples include predictions about
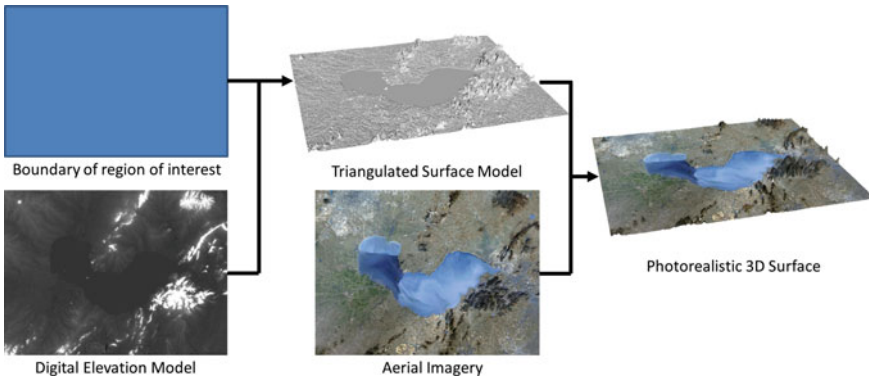
Fig. 6.7 Example of pre-processing steps necessary for the representation of 2D data sets in 3D space
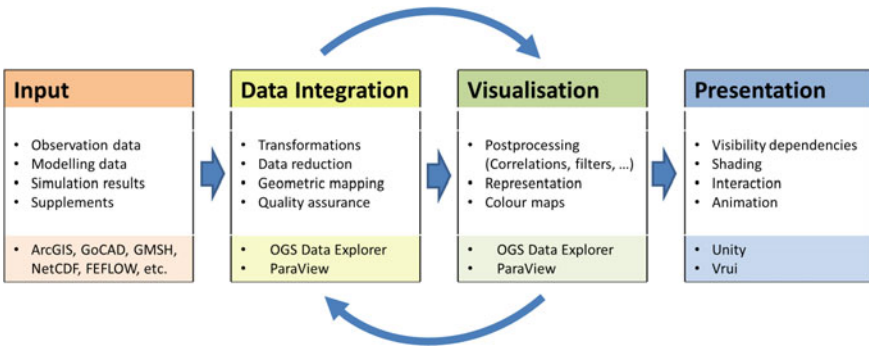
Fig. 6.8 Data integration workflow based on Helbig et al. (2017)

water management (e.g. short-term vs. long-term solutions) or waste water treatment (e.g. centralised vs. decentralised concepts). In addition to the challenges based on heterogeneity of the data, the inclusion of simulation requires the handling of (very) large data sets, the high number of parameters included, the transient structure of the data as well as the visualisation of uncertainty in simulated parameters.

To create a VGE that is not specifically tailored to one case study or region of interest requires flexible data structures and modular algorithms for storing, modifying and visualising data within the environment. This allows to use the same functionality for other case studies, even if these are focussed on different areas of application. The combination and parameterisation of these modules depend on the definition of a general workflows for data integration and visualisation (see Fig. 6.8) as well as flexible interfaces for connecting algorithms used within each of the steps within these workflows. The environmental information system as a whole is in turn embedded into a concept which provides a continuous data flow (Fig. 6.9) from the acquisition of data to the presentation of research results.
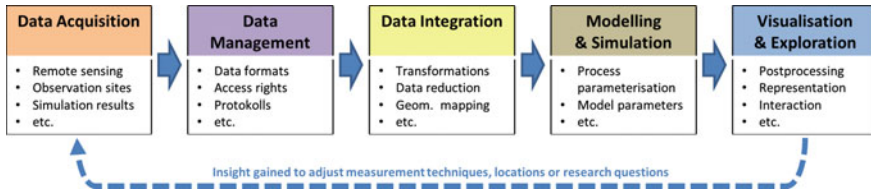
Fig. 6.9 Continuous modelling workflow concept based on Kolditz et al. (2012a)

6.3.3 Data Integration and Workflow

The import of all relevant data sets into a unified reference frame is handled by the OpenGeoSys Data Explorer (Rink et al. 2013). After the preprocessing stage, the integrated data sets are exported into the Unity engine (Goldstone 2011), which is used as the framework for the presented virtual geographic environment. The resulting applications can be used for presentations to audiences, such as stakeholders, researchers or the general public; but also for data exploration, discussions and verification of both input data and research results. Both programmes will be briefly introduced in the following.

OpenGeoSys Data Explorer

The Data Explorer is the graphical user interface to the platform-independent Open-GeoSys simulation software (Kolditz et al. 2012b). It is capable of importing and visualising measured data sets as well as simulation results. The framework already supports a large range of established file formats from the environmental sciences, incl. typical GIS formats (raster- or shapefiles), a variety of mesh generators for creating 3D objects, graphics formats and interfaces to a number of modelling and simulation frameworks. See Fig. 6.10 for an overview of currently supported file formats.

While OpenGeoSys is mostly used for the simulation of coupled Thermo-Hydro-Mechanical-Chemical (THMC) processes, the support of multi-purpose file formats such as VTK (Visualization Toolkit (Schroeder et al. 2006)) or NetCDF (Rew and Davis 1990) ensures that many simulation results from domains as diverse as continuum mechanics (e.g. OpenFOAM (Weller et al. 1998)), climate research (e.g. WRF (Michalakes et al. 2005)), lake and coastal research (e.g. GETM (Burchard and Bolding 2002)) or drainage network simulation (e.g. SWMM (Rossman 2014)) can be interpreted by the software. Measured or simulated parameter values (both static and transient) can be projected either on tessellated surfaces/volumes or geometric features.

Unity engine

Unity is a cross-platform game engine, developed for the creation of computer games for personal computers and mobile devices. The software is available for free and
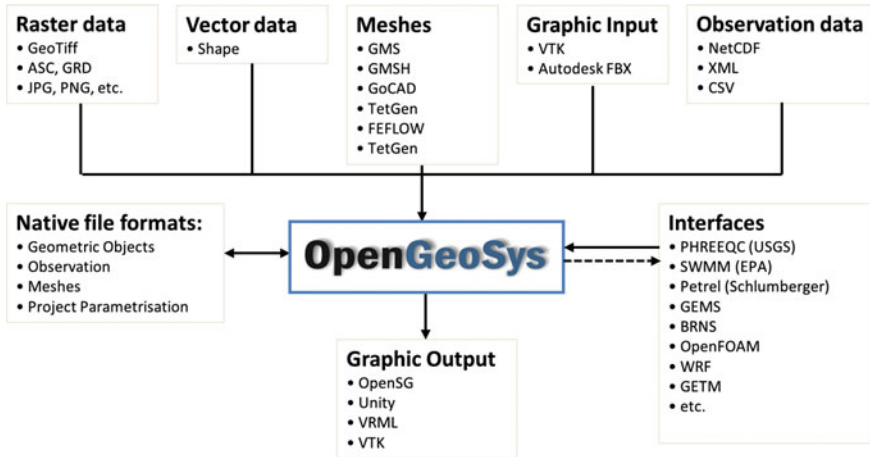
Fig. 6.10 Supported file formats for the OpenGeoSys framework. Due to the wide range of supported formats, interfacing with other simulation software is simple if an established format is supported. For instance, due to support of the NetCDF format, the integration of data from models such as the Weather Research & Forecast Model (WRF) used for climate simulations or the General Estuarine Transport Model (GETM) used for studies of lakes or coastal regions becomes straightforward

offers a wide range of features for displaying static and dynamic graphics in both 2D and 3D. Unity provides an interactive and extendable GUI that can be customised by users for creating certain types of applications. Dragging and dropping is supported for all types of Unity objects and it is possible to select, view and transform all data sets after import. Likewise, animation and interactive functionality can be instantly tested within the software without explicitly building an application. The software is extendable via the C# programming language, has a very large user base and a wide range of tutorials is available on the internet. Once functionality has been integrated, it is available within the Unity GUI and can subsequently be used to create new applications with that same set of methods.

Within the presented workflow, Unity is used in combination with the MiddleVR plug-in (MiddleVR Developers 2017). That way, a large range of technical challenges are automatically handled when building applications. This includes a wide range of rendering backends such as various operation systems for personal computers, web-applications, virtual reality (VR) environments or head-mounted displays; but also the required input devices for such environments, tracking of users in VR, or the support of various stereoscopic display modes.

Workflow

A typical workflow for integrating a new geoscientific data set into an existing virtual environment usually includes the following steps:

1. Import data set into Data Explorer framework
2. Create meaningful representations of the data set in 3D space
3. Detect inconsistencies between data sets (both visually and algorithmically)
4. If necessary, modify data set by adding missing information (such as elevation on 2D data, mapping of simulation results onto 3D objects, etc.) or correcting inconsistent or false information (e.g. topological incorrect surfaces, NaN values, etc.)
5. Present data in a meaningful fashion (e.g. choose adequate colours, apply textures, select glyphs or colour lookup tables for parameters of data points, etc.)
6. Add interaction methods to guide users to data set (camera paths, viewpoints, animations, etc.)

Steps 1–4 are usually performed using the OpenGeoSys Data Explorer. Once all data sets have been pre-processed, they are added to a scene generated within the Unity framework. Depending on structure and interpretation of each original data set, step 5 of our workflow may require algorithms implemented either in OpenGeoSys or in Unity. Step 6 is executed exclusively in Unity.

Being a game engine, the visualisation of environmental data sets is not a focus of the Unity framework. However, a lot of the functionality required for a VGE is already implemented in the software. This includes the the movement in 3D space, tracking of the user and the functionality to display and interact with complex objects. In addition, the framework is well-documented and easily extendable. We have developed a number of specific methods for importing and displaying geoscientific data sets, circumventing some of the limitations of the Unity engine. Geoscientific data sets are usually represented by objects that are larger then typical objects used in computer games and they rely more on a precise representation. Where computer games rely on automatically generated surfaces or roughly modelled objects that are displayed using computer graphics methods such as bump mapping or MIP mapping, geoscientific data has usually been exactly measured and does not contain repeatable features. We implemented algorithms for importing and visualising typical environmental data sets within Unity and added methods to deal with large data sets. Examples for such algorithms include the subdivision and use of very large textures (e.g. remote sensing imagery) or the automatic translation and scaling routines to convert the often very large coordinates from regional geographic projections into a small, scaled coordinate system typically used for scenes in graphics applications. Other application-specific issues include the use of modified shaders, e.g. for mapping pre-selected colour arrays on objects based on simulated parameters at varying time steps. For a more in-depth technical description the interested reader is referred to the article by Rink et al. (2017).

The Unity scene containing relevant data sets can be built as an executable file for a variety of target architectures, including virtual reality environments such as stereoscopic video walls or head-mounted displays (Oculus Rift, HTC Vive, etc.), but also for regular desktop computers. Users can navigate within the geographic environment with typical interaction devices. Besides keyboard and mouse this also includes typical VR interaction devices such as flysticks or gamepads. To make the

Fig. 6.11 The environmental information system for Chao Lake, displayed on the video wall in a Virtual Reality environment

framework easy to handle for inexperienced users, a number of features have been added for navigation and interaction:

- predefined viewpoints of relevant regions or data sets within the scene, such that users need not navigate the scene themselves and have pointers to regions of interest,
- the definition of camera paths along interesting features or gradients of natural or simulated parameters,
- picking objects to access supplemental content such as diagrams, photos, movies or webpages that give additional context to the currently viewed object or region,
- a simple animation interface to start, pause or step through time-variant content such as the time steps of simulation or remote sensing data, different scenarios, or predefined transformation of the data
- toggling of data sets or groups of data sets and adjusting their transparency to be able to focus on interesting aspects or compare data sets.

This functionality is accessible via a menu defined as on overlay in the 3D scene. The menu can be toggled via the interaction device to be visible/invisible and it can be moved across the view plane so it doesn't occlude interesting data. While it is possible to navigate freely in 3D space, experience has shown that most users prefer to access predefined points of view and interaction via a menu, similar to desktop applications. Figure 6.11 shows an example of a VGE based on case study of the Chao Lake in China, described in detail in the following section. The 3D visualisation is linked to time-series data measured from climate stations in the region and contains GIS data and simulation results as well as supplemental material such as pictures or diagrams. This facilitates a powerful combination of monitoring data and simulation results in one coherent, spatially arranged visualisation.
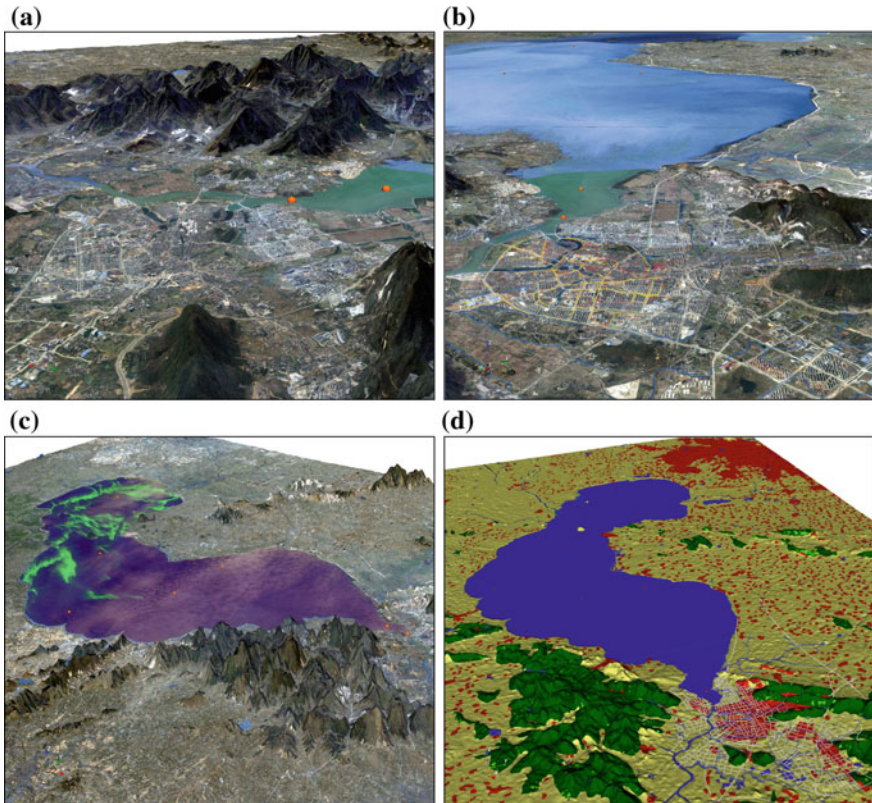
Fig. 6.12 Visualisation of the Chao Lake VGE. (**a**) Super-elevated terrain of Chaohu City from the north with aerial image texture. Buoys within the lake are marked in orange. (**b**) View of Chaohu City from the east with sewage network superimposed on the surface. Note the fine resolution of the texture within the city compared to the rougher texture in the background. (**c**) Super-elevated view of Chao Lake from the southwest. Mapped on the lake surface is a LANDSAT 8 image showing algal bloom in summer. (**d**) View of land use information in the Chao Lake region. Chaohu City is located in the lower left corner, road- and river network are mapped onto the terrain surface

6.3.4 Application Prototype

A Virtual Geographic Environment for the area around Chao Lake in China (see Fig. 6.12) has been set up as a prototype for the international project "Managing Water Resources for Urban Catchments" (Dohmann et al. 2016). The focus within this prototype is Chaohu, a city with a population of almost one million people, located on the eastern shore of Chao Lake within the Anhui Province in Eastern China. With a surface area of $720 km^2$ Chao Lake is the fifth-largest freshwater lake in China. Due to eutrophication and silting, the lake has become one of the most polluted lakes in China in recent years (Chen et al. 2015a) which causes a number of problems for cities located at or near the lake, as the population uses the lake

for fishing, irrigation and obtaining drinking water. Project partners from China and Germany are working together with the goal to analyse and improve the current situation at different stages of the fresh- and sewage water treatment workflow.

The purpose of the Virtual Geographic Environment for this region is to show the current situation in and around the lake, including risk factors such as algae or pesticide concentration. While the data collection is still ongoing, more than 30 data sets have been collected and processed into an immersive 3D scene to give users an impression of the region. Examples include digital elevation models (Tachikawa et al. 2011), a land cover map (Chen et al. 2015c), the bathymetry of Chao Lake, aerial imagery (Google Earth 2016), water bodies for the region of interest surrounding Chao Lake (OpenStreetMap contributors 2016) as well as detailed data on water and sewage networks within Chaohu City (Liao et al. 2016), etc. For a comprehensive overview, see Table 6.3.

In addition, results of transient simulation of processes have also been integrated into the system (see Table 6.4). A combined visualisation of monitoring and modelling data will support both stakeholders and researchers in their understanding and analysis of the complex coupled processes related to the pollution and management of water resources. In particular, a simulation of the drainage pipeline system for storm- and sewage water within the Chaohu City during rain events allows for an estimation of run-off times, the distribution of pollutants as well as the risk of flooding within the city (see Figs. 6.13 and 6.14). The implementation of the complex groundwater system model of the lake catchment shows the interaction with Chao Lake and the distribution of the algae toxin Microcystin (see Chap. 7). Finally, preliminary results of a lake simulation (Fig. 6.15) show temporal variation of temperature, evapotranspiration, etc. Similar to observation data, these simulation results can be explored in context with all the other data sets, with the additional benefit of user-controlled animation of the temporal variance of simulated parameters.

Our extensions of the Unity framework mentioned in the previous section are particularly useful for this case study. The overall region around Chao Lake integrated into the VGE has a size of over $5000 \, \text{km}^2$. We have created a surface representation consisting of roughly 200,000 triangles with a maximum edge length of 250 m. The corresponding aerial imagery from Google (Google Earth 2016) and LANDSAT (Wulder et al. 2016) (see Fig. 6.12c) have a pixel size of roughly 12.5 m. The combination of those data sets results in a detailed visualisation of the surface data despite not incorporating advanced methods such as bump mapping (see Fig. 6.7 for a schematic of creating the textured terrain surface). However, the regions of interest for domain scientists are usually much smaller. For instance, for Chaohu City we built a refined surface representation with image data at much higher resolution. With a size of less than $100 \, \text{km}^2$, this more detailed surface still consists of over 300,000 triangles with a maximum edge length of 10 m. The aerial imagery has a pixel size of less than 3 m. This fine resolution is necessary to maintain a useful representation of the area because users are expected to zoom in very close to the surface. Also, integrating very detailed data sets such as the drainage system for the city (with a sub-metre resolution) requires similarly refined corresponding data for a visual assessment of the relation of data sets to each other. Our extensions to the

Table 6.3 Observation-based data sets included in the environmental information system

Data type	Geospatial context	Data
Remote sensing data	Chao Lake catchment	ASTER Global Digital Elevation Model
		Google Earth aerial imagery
		LANDSAT8 imagery
		GLOBELAND30 land use data
	Chao Lake	Bathymetry
	Chaohu City	High resolution digital elevation model
		High resolution airial imagery
Vector data	Chao Lake	Catchment boundary
		OpenStreetMap data (waterbodies, roads, etc.)
		Lake boundary
		Buoy network
	Chaohu City	River network
		Roads
		Sewage network (Sewage pipelines, stormwater pipelines, outlets, etc.)
		Land development plan
	Shuagqiao He catchment	River and tributaries
		Subcatchments
Time-series data	Hefei City	Climate data 1952–2016 (Temperature, Precipitation, etc.)
	Chao Lake	Test buoy measurements
Supplemental data	Chao Lake	Photos
	Chaohu City	Traffic monitoring imagery
	Chaohu City water treatment plant	Photos
		Biomonitoring video
	Shuagqiao He catchment	Photos

Table 6.4 Model-based data sets included in the environmental information system

| Software	Geospatial context	Data
OpenGeoSys	Chao Lake catchment	Structural model
		Groundwater head
		Groundwater flow direction
GETM	Chao Lake	Evaporation
		Heat flux
SWMM	Shuagqiao He catchment	Pollutant concentration
	Chaohu City	Sewage network
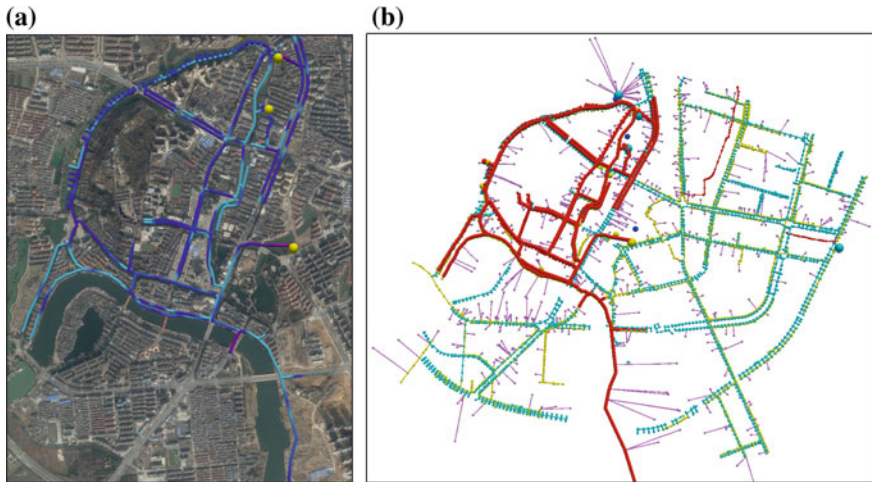
Fig. 6.13 Simulation of the Chaohu City sewage network using the Storm Water Management System (SWMM) (Rossman 2014). (**a**) SWMM Model within geographical context of Chaohu City. (**b**) Overlap of SWMM Model (in red) with the Chaohu City sewage network. All sewage data and simulation results have been provided by our project partners from Tongji University, Shanghai, China. SWMM output has then been imported into OpenGeoSys data structures for visualisation

Unity-framework allow to automatically choose to display the correct surface based on the position of the user. There will be automatic cross-fading between data sets when viewpoint within the city are selected from outside and vice versa.

When creating the VGE, data sets can be selected into groups, which is vital for a case study like this with many small data sets being part of a bigger picture. Both visibility and transparency can be adjusted simultaneously for all sets within each group, thus avoiding time-consuming selection or deselection of data sets. As an example, the case study contains 15 data sets contributing to the drainage pipeline system of Chaohu City (pipes, outlets, treatment plants, etc., see Fig. 6.16). Changing the status of each of these separately would not be viable during live presentations.

A number of dynamic data sets require the display of animations based on user input. For instance, time series of LANDSAT images of Chao Lake (Fig. 6.12c) visualises the annual algae growth. Likewise, results of transient simulations show the flow of groundwater, or the temporal distribution of pollutants within the sewage network, lake, or groundwater system. Especially the simulation of short term events, such as flooding, requires a very fine temporal resolution, often resulting in thousands of time steps. The example shown in Fig. 6.14 is taken from a simulation consisting of approximately 5000 time steps at an interval of five minutes.

While the virtual geographic environment of Chao Lake can be explored on a wide range of devices, as previously mentioned, it has been originally designed for use in a virtual reality environment using a 6×3 m video wall with additional projections at the sides and the floor where user position is tracked using infrared cameras (Bilke et al. 2014). Scientists from various research domains and stakeholders from the
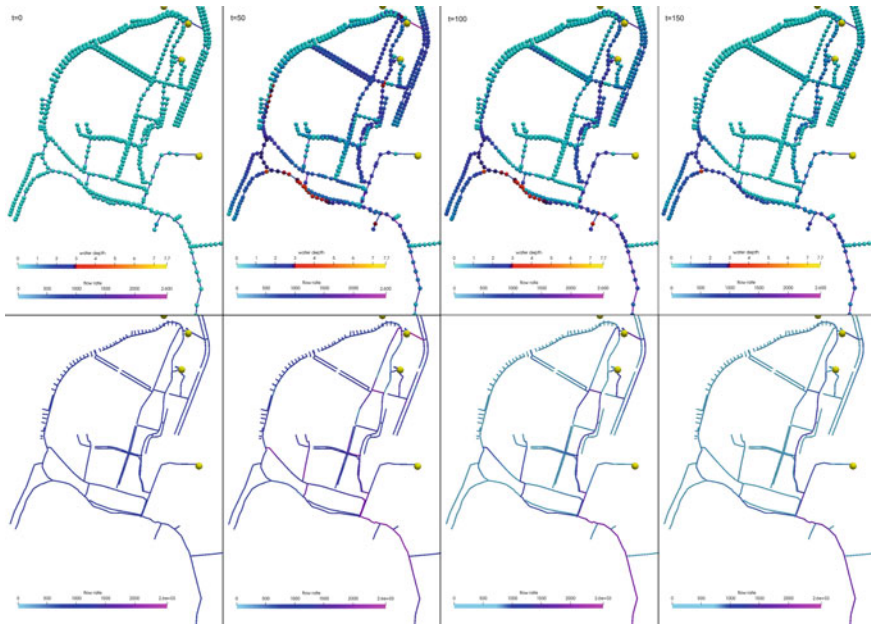
Fig. 6.14 Visualisation of a SWMM simulation of the Chaohu City sewage network during a rain event. Shown are the water depth (top line of the legend) with a range of 0–5 m and the flow rate (bottom line of the legend) of about 500 to 2000 m^3/s. With increased flow rate, water depth is critically increasing in certain parts of the network. Even after the flow rate has decreased again, it takes a long time for the water levels to reach normal levels again. The simulation results have been created by our project partners at Tongji University

German and Chinese Ministry of Science have participated in presentations and the response has been very positive. Complex contexts and interrelation of data sets are easy to understand even for users without a hydrogeological background and participants are often able to point out correlations or inconsistencies that would not have been visible within established software solutions, such as geographic information systems. While the VGE is still in a prototype stage, we hope to acquire more detailed data for the region in the future and extend the functionality offered by the system to import and display an even wider range of information and interaction.

6.3.5   Conclusions and Outlook

The presented work shows a generic framework for the development of Virtual Geographic Environments for Environmental Information Systems. This framework has been demonstrated for a case study of water resources management in the catchment of Chao Lake in the Anhui Province of China. All relevant types of data for water
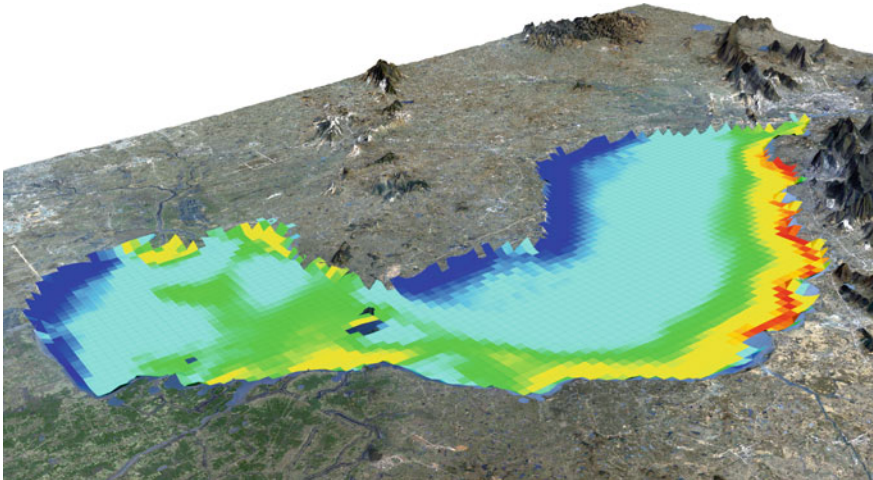
Fig. 6.15 Embedded simulation of Chao Lake into 3D geographical scene. To enhance the existing topography of the region, the underlying DEM has been super-elevated by factor 5 and texturised using an airal image of the region. With a maximum depth of 5 m, Chao Lake is extremely shallow for a lake of its size. The depicted bathymetry has been super-elevated by factor 200 to give a sense of its 3D surface. Mapped on the lake surface is the result of preliminary simulation of evapotranspiration using the General Estuarine Transport Model (GETM) (Burchard and Bolding 2002)
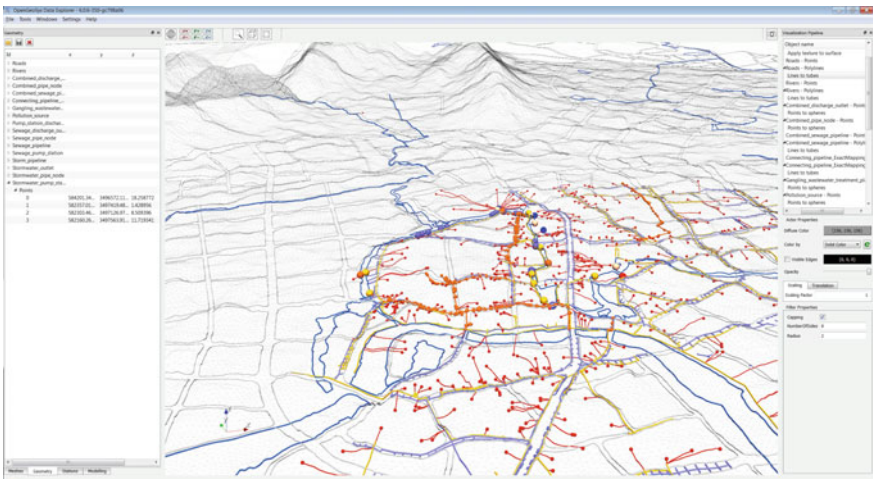
Fig. 6.16 Pre-processing of data sets. Depicted is the OpenGeoSys Data Explorer interface while integrating the drainage pipeline system in Chaohu City into the existing scene. The terrain surface mesh is semi-transparent visible in the background for reference as well as the road- (grey) and river network (blue). Fifteen data sets related to the drainage system have been loaded, mapped and assigned colours according to their function (e.g. violet data represents storm pipeline infrastructure, yellow signifies sewage infrastructure, etc.)

resources management that we are aware of have been integrated into the VGE with the help of both the OGS Data Explorer and the Unity game engine.

The presented VGE provides novelty in two directions: Firstly, static and dynamic data from both remote sensing and process modelling, can be integrated, explored and compared within the context of the VGE. Secondly, the framework allows for data integration at different spatial and temporal resolution, permitting to focus on specific regions of interest within a scene. The modular approach of the framework also allows to easily update existing data sets or add new data to an existing VGE.

Future activities are related to completing the data integration concept for all aquatic compartments (e.g. soil and groundwater systems) and to apply the framework to similar case studies within the Yangtze River Basin, such as the Poyang Lake or Tai Lake catchments. These case studies are also part of the "Research Centre for Environmental Information Science" (RCEIS - www.ufz.de/rceis).

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