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Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable D1.2.1 Report (Literature review)
Deliverable D1.2.2 Recommendation for study area
Deliverable D1.2.3 Recommendation on possible additional data requirements

An Overview of Existing Tools, Data Needs and Demo Cities

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SWITCH Document: An Overview of Existing Tools, Data Needs and Demo Cities
Deliverable reference: D-1-2-1, D-1-2-2 and D-1-2-3
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Audience This deliverable is targeted to those people who are interested in urban water modeling and decision support systems.
Purpose The purpose of this report is to provide an overview on the existing urban water modelling and decision support tools and the needs for basic data to enable modelling/KMDSS work and other work elements within the Work Package 1.2 Also, information with respect to the selection of two cities for demonstration purposes is given in this document.
Background Several modules are going to be developed (Theme 1) to provide modeling and decision support tools for integrated urban water management to be used by the Learning Alliance. Review of the existing urban water modelling and decision support tools would be a basis for selecting, analysing and designing the required tools to be developed for the Learning Alliances. The data need assessment and selections of demonstration cities are required to enable collection of data for the purpose in required quantity and quality and to enable demonstration of the applicability of the tools for divers problems.
Potential impact This overview provides awareness of the existing tools for urban water modeling and decision support.
Recommendations There is a need to improve current urban water modelling practices and to enhance functionalities of existing decision support systems.

Contents

1. Introduction

Integrated urban water management has emerged as an important concept for several reasons. First, there is the growing need to manage the urban water cycle on a global basis. Second, a range of alternative technologies to process different aspects of the urban water cycle are becoming available. Third, advances in urban hydroinformatics enable different phases of the entire cycle to be modelled and to use such models to optimise each phase locally and in the global context. In particular, the advances in urban hydroinformatics have made significant impacts on the development of new strategies for urban water management. The use of computer models pervades all aspects of water management, supporting wealth creation through products and services, contributing to many improvements in the quality of life. As a result, there is a growing increase in demands for better use, productivity, flexibility, robustness and quality of such modelling systems. This is leading in turn to new development paradigms and formalisms (Vojinovic and van Teeffelen, 2007; Abbott et al. 2006; Tumwesigye et al. 2005). Nowadays, the philosophy of integrated urban water management cannot be conceived without the use of hydroinformatics technologies. This is further supported by the fact that currently no serious investment decisions are being made without the use of computer models to evaluate various scenarios. In this context, computer modelling of the urban water cycle is aimed at understanding and predicting the behaviour and performance of the component and integrated systems so that the effective solutions to structural and operational problems can be derived and evaluated by the relevant stakeholders.

Every project involving stakeholder participation has, correspondingly, two sides: on the one side it has the visible and tangible *physical infrastructure* of steel, concrete, stone, and whatever other materials, as shaped by various machines and formed by computing and measuring activities, while on the other side it has an invisible and intangible *social infrastructure* sustained by the intentions, beliefs and codes of behaviour of people, most of whom are interested in, and some of whom are actively engaged in, *this same project*. This 'inner world' of the minds of socialised people requires means to transform the data, information and knowledge provided by the physical equipment into forms that these minds can easily assimilate, each after an own individual interest and ability. The organisation charged with constructing and subsequently operating the connection (i.e., knowledge-based decision-support system) must accordingly set up facilities for transforming the content provided by the equipment into forms that could be assimilated by the various stakeholders, each in its own special ways.

Therefore, the problem for those concerned with integrated urban water management is not only the complexity of the processes they are attempting to manage but also how to empower stakeholders to be able to meaningfully intervene in the decision making process. This highlights the need for an

appropriate knowledge-based decision-support system (KMDSS). The design of such a supporting system depends critically on the user and therefore must be based upon a sound philosophical and psychological foundation. In other words, an understanding of human cognitive processes in processes of developing the necessary judgmental inputs is critical.

An appropriate KMDSS thus needs to combine various aspects of human understanding, information communication and modelling systems such that these will be suitable for users who are not necessarily experts in modelling or data analysis, and to assist them in analysing the problems and in cooperating in developing suitable scenarios. Since our emphasis is on the safe and reliable management of urban water systems, there is a need to develop better tools that can generate a safe environment in which users can expect to achieve more reliable decisions (Ahmad and Price, 1998). In particular, the KMDSS discussed here needs to provide the framework for assessing relevant information, analysing the data, and making informed decisions with the widest range of modelling. Furthermore, such a system would need to allow the outcome of such scenario simulations to be compared, and eventually lead to advice on the optimal decision to be made.

The purpose of this report is to provide an overview on the existing urban water modelling and decision support tools. Exhaustive coverage of the existing literature for the purposes of this report was not possible at this point in time and since the review process will continue the content of this report will be updated. The report is structured as follows: the review of integrated modelling tools is provided in Chapter 2, whereas the review of knowledge-based decision support systems is provided in Chapter 3.

In addition to the review of literature, the needs for basic data to enable modelling/KMDSS work and other work elements within the Work Package 1.2 are outlined in Chapter 4. Finally, the selection of the two preferable cities where the use of models and knowledge-based systems will be demonstrated, is provided in Chapter 5.

2. Integrated Modelling Tools

The preliminary literature review has resulted in identifying the following five integrated modelling tools: *Hydro planner*, *Aquacycle, MikeUrban, CyberIntegrator* and *OpenMI – HarmonIT Data Exchange Protocol*.

2.1 Hydro Planner

Hydro Planner is developed to analyse the urban water system and to understand how water supply (i.e., water distribution), wastewater and storm water systems interact with each other and with natural water systems. It is built by adopting a systems approach to provide an automated method m explore interactions between components of the urban water system in terms of the water quantities and constituent flows at city and regional level under both natural influences and human influences within the urban water context. The systems approach allows seeing interrelationships rather than things, and seeing patterns of change rather than static 'snapshots' (Maheepala et al, 2005). An application of this systems approach to urban water system means consideration of the urban water system as a group of interacting, interrelated and interdependent components that form a complex and unified whole. It also means that changes happening in a particular system component may have an impact on other components, which may not be obvious or intended, but can cause a significant impact to the surrounding environment. In this way, understanding and where possible, internalising of these unintended impacts within the decision making process can improve the way in which urban water services are being provided in sustainability terms.

As explained by authors, the main purpose of Hydro Planner is to enable urban water planners and managers to adopt a systems approach for the assessment of physical interactions in an urban water system in terms of water quantity and quality. They refer to the ability to perform system-wide assessment which could help decision-makers to understand impacts of management and planning decisions. This is somewhat different from the concept adopted in the traditional urban water management practice in a way that the main focus is on the management of the constituent components in a rather fragmented manner. For example, fragmented management approach is adopted for water, wastewater and stormwater without giving much consideration to interrelationships between these three aspects of urban water cycle.

According to authors, practitioners could use Hydro Planner to assist development of regional water allocation, river management and urban water supply/demand and land development strategies. Therefore, Hydro Planner can be applied within such strategy development context to the following specific areas of analysis:

- Water availability analysis - to identify and quantify the temporal and spatial distribution of existing and potential water sources (e.g., surface water, storm water, wastewater, etc.),
- Water balance/allocation analysis - to link supply-side analysis with demand-side analysis on a daily, monthly or annual basis to understand the overall impacts of various supply and demand options on system yield and implications on health of waterways,
- Constituent balance analysis - to identify and quantify sources and sinks of constituents, and
- Flow and constituent routing analysis: that is, to understand transportation aspects of constituents. Such analysis might be required to identify reaches of waterways and rivers that are likely to be stressed.

The conceptual structure of Hydro Planner package consists of seven modules:

1. Catchment module - supports linking of models that can simulate constituent and runoff generation processes from supply catchments,
2. Water supply module – supports linking of models that can simulate behaviour of the bulk water supply system (i.e. water sources and major transfer system),
3. Consumption module - supports linking of models that can simulate urban water consumption,
4. Stormwater module - supports linking of models that can simulate storm water and associated constituent generation and routing processes through major drainage and waterway system,
5. Wastewater module - supports linking of models that can simulate wastewater and associated constituent generation and routing processes through major trunk sewer system,
6. Receiving water module – supports linking of models that can simulate constituent routing through a natural stream network and in-stream processes,
7. Integration module – provides a layer between the above six modules and the graphical user interface (GUI). This layer helps make the GUI independent of the particular models chosen within each of the modules. It also translates data representations form a general user input format into the structures specific for the individual component models. Furthermore, it provides functionality to support computation inputs to and outputs from modules to quantify interaction between systems components.

The current version of Hydro Planner software combines models of managed water releases and demand with a model of natural hydrology that provides a high temporal resolution and detailed simulation of water quantity and quality.

2.2 Aquacycle

Aquacycle was developed to provide a holistic view of an urban water system, allowing water supply, wastewater disposal, and stormwater to be considered as components within a single modelling framework (Mitchell et al, 2001). According to the author, the results to date indicate that the holistic approach of representing the flow of water through an urban area was possible. It essentially provides nothing more but a framework for assessing the potential for integrating stormwater and wastewater reuse options into the urban water system.

The software has been developed to assess the total quantity of water moving through the urban water cycle, and therefore, everything is expressed in daily time steps. There is no flow routing option within the model and as such is incapable of addressing any aspect of the flooding problems within a study area. Also, most of the critical urban hydrological processes such as wastewater overflows, inflow/infiltration, and exfiltration are not incorporated into the present version of Aquacycle. The lack of capabilities to address such important aspects is a major limitation of this software.

In summary, this conceptual urban water balance model (Aquacycle) has been developed to provide a picture of the available water quantity values within a city and for any further analysis this software would need to be substantially enhanced.

2.3 MIKEURBAN

MIKE URBAN is a GIS-based software system for the data management and modelling of surface runoff, flows, water quality and sediment transport in urban catchments and sewer systems. It provides a complete and effective working environment for sophisticated urban drainage and sewer engineering, including MOUSE and SWMM5 computational engines. MIKE URBAN CS can be applied as a modelling tool for the analysis (e.g., flooding, overflows, infiltration, etc.), design, management and operation of pipe networks with alternating free-surface and pressurized flows. The ability to link with GIS MIKE URBAN CS allows for an easy integration with external database systems. With MIKE URBAN it is possible to build advanced simulation models of urban drainage and wastewater collection system, all within a GIS environment. The main features of MIKE URBAN include:

- Fully integrated GIS and modelling environment powered by GIS technology from ESRI and the latest versions of industry standard simulation engines,
- Open architecture, OpenMI compliant,
- Includes all features to analyse various aspects of stormwater systems, sewer systems and water distribution systems in one integrated package ,

- Links with major GIS, CAD and asset management packages,
- It combines the best public domain and proprietary modelling engines into one integrated.

2.4 CyberIntegrator

In addition to the previously described software, which are aimed exclusively for addressing urban water problems, there is also a meta-workflow system designed for solving any complex scientific problems using heterogeneous tools which could also include those from urban environments. The meta-workflow is viewed as a framework that integrates heterogeneous workflow engines, software tools, data sites, hardware resources, organizational boundaries, and/or research domains. The architecture and implementation of a meta-workflow prototype called CyberIntegrator has been developed by the National Center for Supercomputing Applications (NCSA) at the University of Illinois, US. The need for CyberIntegrator comes from common geospatial information system (GIS) problems, where a number of on-going observatory and disaster planning efforts have to be supported by cyber-infrastructures being researched and developed at NCSA. Current meta-workflow architecture enables users:

- to browse registries of data, tools and computational resources,
- to create meta-workflows by example,
- to execute meta-workflows locally or remotely,
- to incorporate heterogeneous tools and link them transparently, and
- to provide recommendations about the usage of tools based on gathering and analysing provenance information.

The main contribution of the work carried out by NCSA is:

- in defining the meta-workflow concept focused on science requirements and
- in architecting technology and prototyping CyberIntegrator software.

The value of the CyberIntegrator software has been demonstrated by applying it to two classes of complex problems, such as data-driven analyses of multi-variable relationships from remote sensing data and Monte Carlo simulations of maximum amount of pollution that a water body can receive each day and still retain its uses.

2.5 OpenMI – HarmonIT Data Exchange Protocol

OpenMI stands for Open Modelling Interface and Environment. It is being developed and implemented by the HarmonIT project, which is research project funded by the European Commission. It aims to deliver a standardised way to link water related computational models that run

parallel. It thus enables process interaction being represented more accurately, compared to sequential linkages.

A model application is the entire model software system that is installed in a computer. Normally a model application consist of many parts, the most common being the user interface, input files, the engine and output files. The engine is where the calculations take place. The user supplies information through the user interface upon which the user interface generates input files for the engine. The user can run the model simulation e.g. by pressing a button in the user interface, which will deploy the engine (see Figure 1). The engine will read the input files and perform calculations and finally the results are written to output files. When an engine has read its input files it becomes a model. In other words a model is an engine populated with data. A model can simulate the behaviour of a specific physical entity e.g. the River Rhine. If an engine can be instantiated separately and has a well-defined interface it becomes an engine component. An engine component populated with data is a model component. There are many variations of the model application pattern described above, but most important from the OpenMI perspective is the distinction between model application, engine, model, engine component, and model component.

Basically, a model can be regarded as an entity that can provide data and/or accept data. Most models receive data by reading input files and provide data by writing output files. However, the approach for OpenMI is to access the model directly at run time and not to use files for data exchange. In order to make this possible, the engine needs to be turned into an engine component and the engine component needs to implement an interface through which the data inside the component is accessible. OpenMI defines a standard interface that engine components must implement to become OpenMI compliant engine components. When an engine component implements this interface it becomes a linkable component. A similar pattern can be applied for databases or other kinds of data sources. By turning them into components and implementing the OpenMI interface they become linkable components that provide direct access to its data at run time.

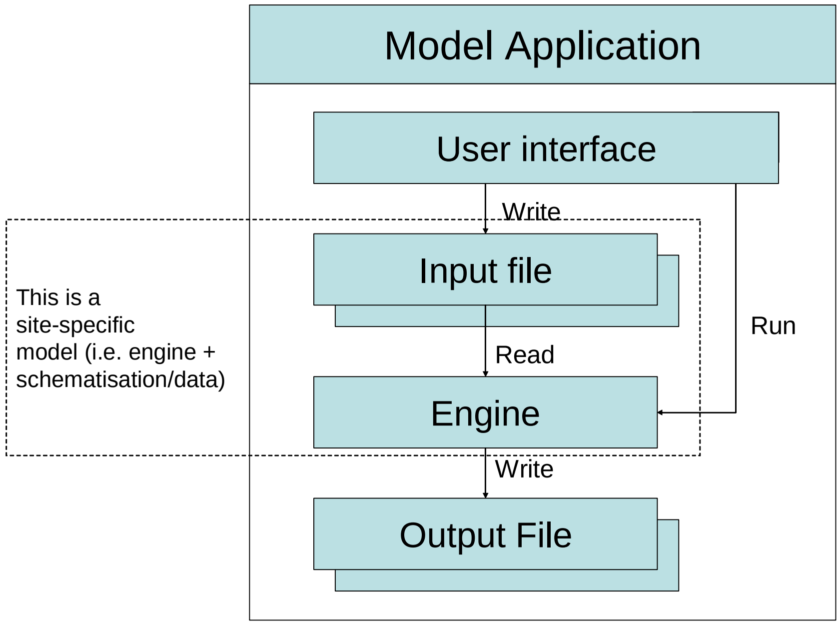


Figure 1: Model Application Pattern

[*Source*: adopted from (Gijsbers, 2004)]

OpenMI is based on the 'request & reply' mechanism (Gijsbers, 2004). OpenMI is a pull based pipe and filter architecture which consists of communicating components (source and target components) which exchange data in a predefined way and in a predefined format. OpenMI defines both the component interfaces as well as how the data is being exchanged. The components in OpenMI are called linkable components to indicate that it involves components that can be linked together.

From the data exchange perspective, OpenMI is a purely single-threaded architecture where an instance of a linkable component handles only one data request at a time before acting upon another request. Data exchange in the OpenMI-architecture is triggered by a component at the end of the component chain. Once triggered, components exchange data autonomously without any type of supervising authority. If necessary, components start their own computing process to produce the requested data. Only when output needs to converge to a certain criteria, a controlling component might need to be incorporated.

3. Knowledge Management and Decision Support Systems in Urban Water Management

The preliminary literature review has identified the following seven decision support systems: *WaterWare*, *NERC-ESRC Land use Programme (NELUP), WaterStrategyMan Decision Support System, Why, MULINO, Aquatool, DSS for Water Resources Planning Based on Environmental Balance.*

3.1 WaterWare

In 1995, a decision support system 'WaterWare' was developed with the primary aim to address the river basin planning activities. It has been designed to integrate the capabilities of GIS, database management system, modelling techniques, optimisation procedures and expert systems. The software system comprises of a set of standards to ensure compatibility, conventions, which provides consistency, shared tool for displaying result and common language for problem representation. The Pick-and-mix (modular) approach has been adopted to allow the required components to be selected and incorporated as part of the initial customisation of the system for particular river basin. This system has a capability to address a wide range of issues such as the limits of sustainable development, the impact of new environmental legislation, identification of new resources, etc. According to authors, the tool can be developed to assess environmental impacts of water-related developments and to formulate strategies for river and groundwater pollution control programs. The basic architecture of this system consists of the main menu (which is used to coordinate individual tasks), GIS, database, simulation model, optimisation model, expert system, data manipulation, friendly user interface and set of utility function. There are five simulation models in this system and their functionalities are shown in table 3.1.

Table 3.1 : WaterWare simulation models

Simulation model	Usage
GWP(2) flow and contaminant transport model - Groundwater pollution control	• Basic principle – conservation laws • Model the extent of pollution in terms of dispersion and at which rate is it occurring. • To arrive with the necessary information to reduce the level of contaminants in the aquifer
SWP(1) flow and pollutant transport model – Surface water pollution control	• Calculates the required treatment standard for each effluent discharge • Estimates the level of effluent treatment required to meet river water quality objectives
HPS(1) rainfall-runoff model – Hydrological	• Provides dynamic daily water balance for ungauged sub catchments

processes	• Assesses the impact of land use changes on runoff • Evaluates the effects of conjunctive use of surface and groundwater
IWD irrigation water demand – Demand forecasting component	• Provides demand forecasting
WRA(1) water resources assessment model	• Screening model to identify the best combination of source • Provides detailed simulation of a preferred option to verify its assumed performance

As a pilot project, this system has been implemented in the Thames basin. The result shows that WaterWare has a capability to address the range of issues that might need to be taken into account when planning new resources or maximising the use of existing ones.

3.2 NERC-ESRC Land use Programme (NELUP)

The NERC-ESRC Land use Programme (NELUP) has been developed to provide a quantitative description of the main economic and environmental impacts from rural land use changes at river basin scale. Its main utility can be divided into three sections, which are:

i. Description – To store and manage a wide variety of spatial temporal and relational data that describing the characteristic of river basin,
ii. Prediction – To establish the characteristics of river basin under a wide range of scenarios using a range of models
iii. Presentation – To provide concise, visual statements in graphical and tabular form of model results to illustrate the consequences of land use change.

This decision support system is constructed from three main elements. The main parts of this system are the mathematical models. There are three sets of models in this system namely, agricultural economics, ecological and hydrological. These models are used to identify the characteristics of a region under its present land use and to evaluate how these characteristics will respond to specific land use modification.

i. Agricultural Economics - It consists of two linear-programming models, which are a catchments level model and a farm level model. Catchments level model predicts the aggregated behaviour of a region by treating the area as a macro farm. According to authors, the advantage of this model is that it has a capability to account for a wide variation in agricultural activity that can exist across a region. The inputs are crop prices, agricultural subsidies and costs of materials. The output is a prediction of

changes in land use patterns and income across the region. The farm level model works similar as catchments level model. It is used to investigate the potential response of a particular type of farm to change in agricultural policy.

ii. Ecology - There are three types of models used to predict the distribution of various species within the landscape and the effects of environmental management on these distributions. First model is associative model used to predict the distribution of both plants and vertebrates. This model links the distribution of species to their known occurrence in particular land-cover type. The second model is Environmental Management Model (VEMM). This model takes the physical attributes of a particular area and it is designed to predict the likelihood of various species occurring for a range of management practice. The third type handles species such as birds and mammals which cannot be linked directly to individual land covers because they are highly mobile or their habitat require more than one land cover.

iii. Hydrology - There are two modelling systems within the hydrological component. First is NUARNO system that uses a conceptual and spatially aggregated modelling approach to describe the movement of water and contaminant at river basin scale. This system provides an overview of the catchments. Second model is called SHETRAN. This model uses a detailed physically based distributed modelling approach to provide more information about the hydrological system in finer resolution. This model has a capability to analyse small-scale problem in detail. Both models are based on baseline condition which can be defined either from agricultural-economic models or ecological models. Hydrological impact is assessed by a comparison of the prediction with the baseline conditions. The outputs can be viewed in different forms such as time series plots, distributed maps and water balance diagrams.

Second part is database. In this part, spatial data are stored in raster geographical information system (GRASS) while non-spatial data are stored in a relational database management system (ORACLE). There are various data types in this part: DEM, Satellite data (Landsat), soil data and meteorological data. These data are used as a basic data to all models. The Dem contains 50m digital elevation data derived from digitised contours of ordinance survey 1:50 000 maps. Its function is to serve as catchment boundaries, land capability map, elevation, topography and catchments slope for the models. The satellite image consists of 25 different land cover classes. This information is used to define the spatial pattern of land cover. The soils data consist of soil association map and soil series parameter data and it is used as important input for the derivation of the land capability maps and for defining the subsurface behaviour of the hydrological models. The meteorological data represent crucial input for hydrological models and are also used in economic models.

Finally, the graphical user interface provides the access to the system. It is used for displaying data and information within the DSS. It is capable of generating different land use change scenarios. The system is easy to use

and navigate. Help and information windows are available at all stage. Spatial data can be viewed in both two dimensions and three dimensions. Simple overlay can also be applied to two-dimensional maps. Summary information for any location within a displayed region is available by pointing and clicking on the appropriate location. The data can be also presented in the tabular as well as the bar chart format.

One of the aims of the system is to allow non-specialist users to have direct access to the model via graphical user interface. From the case study, it is shown that the process in the system can be done by relatively straightforward procedure. However, the complex issues relevant to land use planning require a specialist understanding of physical processes. From the overall impression, it seems that at present time the non-specialist users without assistance cannot use the NELUP DSS.

3.3 WaterStrategyMan Decision Support System

WaterStrategyMan Decision Support System (WSM DSS) has been developed within the WaterStrategyMan Project "Developing Strategies for Regulating and Managing Water Resources and Demand in Water Deficient Regions". This project is supported by the European Commission under the 5th Framework program. The decision support system is built within a GIS-based environment. Its aim is to assess the state of a water system in term of sources, usage, water cycle and environmental quality. In addition, this decision support system has a capability to evaluate the effects of actions on a basis of different scenario, alternative and policies.

According to authors, WSM DSS can model water conditions in a given area and it can be used to estimate how much water is needed to meet the existing and projected demand, to determine what interventions are necessary, and their cost. This system has a capability to provide indicators of performance for selected actions under potential availability and demand scenarios and to apply them to assess each and every scenario. The DSS is suitable to evaluate the water system under different conditions, to apply and test different alternative strategies, all within a framework for integrated water resources management. There are four main modules within this system:

i. Water availability module – aimed to estimate the amount of water that is available in a system and which needs to be allocated to the existing demand users
ii. Water demand module – aimed to generate hypothetical demand scenarios
iii. Water allocation module – aimed to simulate water distribution
iv. Evaluation module – aimed to facilitate the comparison of at least two alternatives for water management scheme which incorporate different

scenarios and/or strategic options. It provides the user with the ranking of schemes.

Besides the main modules, there are some additional features, such as water quality algorithm and economic analysis, that can been included within the system. Water quality algorithm provides the users with estimation on how the concentration of a selected quality parameter may evolve during the simulation period under specific water demand, climatic conditions and allocation rules. The economic analysis in the system consists of a tentative implementation of the principle associated to the estimation of the full water cost and its components.

3.4 WHY

Recently developed tool WHY presents a prototype of a web-base watershed management spatial decision support system (SDSS). This system is built for hydrologic and water quality analysis. It is comprised of two main web systems and a HTML-based user interface including web-GIS functionality. In this system, the main physical model is L-THIA, which is a web application for estimating direst run-off and non point source pollution. This physical system is then integrated with Web-based hydrologic GIS (WHY) that consist of the real time watershed delineation capability, hydrologic data extraction function and a web GIS data publishing. There are six components in this system:

i. Online watershed delineation – Used to delineate a watershed boundary by the double seed array replacement scheme using an eight-flow direction matrix. This approach requires an outlet point and a flow direction grid as inputs. The watershed delineation capability has been developed in C language which is still very convenient for extensive manipulation of elevation grid data and very fast for number crunching.

ii. MapServer CGI - The MapServer web GIS tool is the CGI engine for developing the web GIS map user interface. It is an OpenSource development environment aimed for building spatially enabled internet applications. The CGI runs on the server side and provides a lightweight page for the client.

iii. Web-GIS interface - In Web-GIS interface, the layers are divided into background data and foreground data. The background data includes the shaded relief map, shadowed DEM, land use data and hydrological soil group data. The foreground data includes roads, railroad, rivers, county boundaries and 8 digit watershed boundaries. The Web-GIS interface also supports ancillary map graphics including a scale bar, legend, index map and a display control.

iv. Hydrologic data extraction and preparation – It is used to apply the results of watershed generation within the hydrologic analysis, a grid map clipping module for the basic data extraction of watershed characteristics involving land use, hydrologic soil group and natural resources conservation service curve number. The land use and hydrologic soil group map area are created right after the watershed delineation using this function.

v. Hydrologic model operation – Once the input data are prepared the user can start with model simulation. Optionally, users can edit L-THIA inputs generated by WHYGIS and prepare alternative land use change scenarios for evaluation. Then L-THIA runs on the web server and generates a series of tables, bar charts and pie charts for runoff and NPS pollution

vi. Soil map access - This capability allows users to identify the appropriate soil groups if they decide not to use the watershed delineation and data preparation module. The Internet GIS technology provided by MapServer CGI serves STATGO soil maps.

3.5 MULINO

MULINO is an acronym for MULti-sectoral, INtegrated and Operational DSS for sustainable use of water resource at a catchment scale. It integrates social, economic and environmental modelling tenuous with GIS capabilities and multi-criteria approach for water resources management. The core structure of this system is based on the Drivers- Pressure-State-Impact-Response (DPSIR) framework proposed and used by the European Environment Agency. The system aims to support the decision makers step by step along the decision process of decision making. It starts from the problem identification where the user is guided to select the best possible solution to solve the problems. There are main modules within the system:

i. In the Conceptual View - the Decision Maker (DM) is directly involved, being requested to define the water resource problem and to choose the decisional criteria which will be used to measure and evaluate the river basin status and the effectiveness of the action,
ii. In the Design View - the technician/engineer can address the problem formulated by the DM in order to find practical solutions that will constitute the set of possible options to be investigated,
iii. In the Choice View - the DM together with the technician/engineer assigns the weights to each and every options in order to define the most preferred one.

The entire decision process is based on DPSIR indicators and the cause-effect relationships that exist among them. Decision maker accesses a list of Drivers-Pressure-State indicators provided by the database and then chooses which are relevant to deal with water resource problem. In this way, the decision maker builds up the DPS chains in the Conceptual View of the interface.

There are two parts in The Design view. The first part is concerned with the creation and definition of an alternate option while in the other part, the user extracts the numerical values of the DPS indicators for each associated option by accessing the geo-referenced database through the GIS layers. The result is an Analysis Matrix with the status indices as rows and the different options as columns. This tool was applied to the Vela catchment and the following preferred options were identified:

i. EXCAV_MEO: excavation of a tributary, in order to increase the water retention time and as a consequence the potential self-purification effects for nutrient (N and P) discharges.
ii. DIV_CANDE: redirection of the discharge of an area (153ha) from the Vallio river into the Candellara canal that drains outside the lagoon.
iii. BUF_VALLIO: plantation of a wooden buffer strip along one of the main rivers of the catchment, the Vallio river, to improve the phyto-remediation effect.

In the Choice Phase, Decision- Maker evaluates the numerical values of the indicators and investigates which option is more effective. In this phase, the analysis matrix plays a very important role. The process starts with the standardisation procedure of all options using the so-called “Value Functions”. This process is carried out in order to make all options comparable. Then the indicators are assigned to each option with a weight. Finally the aggregated values are plotted on a graph and the best alternative can be chosen by the Decision-Maker. In order to test the robustness of the best option, the decision process could then be performed by different scenario features. Scenarios are defined by the social, environmental and socio-economic settings that determine the drivers and pressures and state of the basin.

3.6 Aquatool

The Universidad Politecnica de Valencia, Spain, has developed Aquatool and it is currently used and improved by several Spanish River Basin Agencies. It is a generalised decision support system for water resource planning and operational management at the watershed scale. The system has been used to manage Segura, Tagus and Jucar Rivers. The DSS contains two main modules: simulation module, and optimisation module. These modules are used for modelling of water flows in aquifers, risk assessment, analysis and reporting of results. According to authors, the components have been developed in different time steps and kept separate to make Aquatool highly flexible to work with and to make upgrades easily.

The modules can be accesses from a graphical user interface. The river basin representative can be shown over a geographical layer and can be imported from other GIS packages. The scheme’s elements include nodes with storage capacity such as lakes and reservoirs, diversions and junctions, natural

channels, aquifers, evaporation and infiltration losses. It also covers water users such as irrigated zones, municipal and industrial supply and hydroelectric plants. All these objects are available in a specific toolbar. When the users want to draw the system they have to select the elements from the toolbar and to click the location on the map where they want to place them. There is a list of all geo-referenced nodes and links placed on the map layer, which can be sorted alphabetically or by the element type. Once a particular element is selected within the list, window moves to the location of the element in the graphical representation.

The basin's elements are geo-referenced and their physical characteristics and operating rules can be inserted into the Aquatool database directly from the map layer loaded on the user interface. There are also certain variables that are used to define operating policies such as target as well as minimum and maximum volumes of reservoirs, inter-reservoirs relationship and priorities of use, minimum flow in rivers and flow requirements for hydroelectric plants, target water demand for each agricultural, industrial and domestic areas and their demand priorities that are used in the water allocation.

The simulation model, SIMGES simulates functioning of the system operations on a monthly basis. The model is built to address the allocation of surface water and groundwater and its effects on the entire basin. The model takes into account detailed relationships between the surface water source and aquifers and includes a broad spectrum of approaches for modelling of groundwater processes:

i. Aquifers with no discharge other than pumped water are represented as single cells in which mass balance calculation is performed;
ii. Aquifers with discharge through a spring, for which the flow is assumed to decline exponentially with storage until the storage level goes under the spring level;
iii. Aquifers hydraulically connected to one or two surface streams, conceptualised as rectangular, homogeneous aquifers for whom analytical solutions have been studied at the Universidad Politecnica de Valencia and later included in SIMGES;
iv. Distributed model of heterogeneous aquifers of irregular shape whose efficiency is strictly related to the possibility of using pre-processed data as input to SIMGES.

In Aquatool the optimisation module is called OPTIGES. The algorithm considers certain basin elements as selected by the user. These elements can be: nodes with and without storage capacity, channels, hydrological inflows, water demands and return flows. OPTIGES is based on the conservation of mass within the network of nodes and flows. It uses an iterative function that minimise the weighted sum of the water demand deficits and minimum flows by accounting for instance reservoirs' evaporation and return flows. Decision-Maker would typically assign the weights to the different users in the basin that can reflect the priorities of water use. The results from OPTIGES can be

plotted as a graph or a table to support the analysis and to make comparisons of different management solutions and operating rules.

SIMRISK is a module for risk assessment in real operational management of the system. It simulates the basin under several series of synthesised future hydrological inflows consistent with the initial conditions of the system and calculates the probability distribution function of water deficits, volumes of reservoirs, deficit in ecological flows and water quality indices. The Decision-Maker can use this module to analyse the results both in tabular and in graphical form and to evaluate the chosen operating rules and management options. In case that the estimated risks are too high to be assumed, decision maker can then decide to assign some restrictions to some or all of the basin water users and run again the risk assessment module. The degree of restriction depends on the user and can be the same for all demand nodes or specific to individual users. There is also a tool for water quality assessment of a river basin. It simulates the behaviour over the time horizon of pollutants' concentrations and calculates simplified water quality indices in each node and stream of the basin. Graphs, tables and report files that Graphical Analysis Module provides are used to support the decision maker to investigate decision variables' values resulting from simulations and optimisation. They can be also used to display hydrologic time series and parameters. The results are saved in the geo-referenced database and their corresponding plots and tables can be easily accessed and retrieved for each element of the basin schematisation by pointing the element of interest on the map.

In conclusion, Aquatool permits the simulation and comparison of different operating policies and hydrological data in order to analyse planning decisions and to determine tradeoffs between different hydrological scenarios. It also provides risk assessment and evaluation.

3.7 DSS for Water Resources Planning Based on Environmental Balance

A "Decision Support System for Water Resources Planning based on Environmental Balance" project funded by the Italian Cooperation is developed to build a methodological approach for sustainable water resources (WR) planning. The project started at the beginning of 1998 with a one-year long inception phase, while the implementation phase of the project ended in August 2001. The objectives of the Project are the development of:

i. A methodology for the integration of environmental and socio-economic aspects in the analysis of WR scenarios and development measures;
ii. A set of procedures, rules and relationships to facilitate the exchange of information among different organizations;
iii. An application to a representative case study;

iv. An integrated, open-architecture Decision Support System (DSS).

The project is developed around five basic functions:

i. The description of the water system including both the hydraulic and the environmental characteristics through a number of indicators;
ii. The assessment of the state of the system in terms of sources, usage, water cycles (paths), environmental quality;
iii. The forecasting of the evolution of the water system and environment on the basis of assumed or envisaged scenarios, technical alternatives and management policies;
iv. The evaluation of the effects of actions, by observing the results on the system forecast on the basis of different scenarios, alternatives and policies;
v. The consideration of local, national or international legal constraints and directives to be mapped and related to the geographical and administrative boundaries.

Within the integration of several data-processing modules and mathematical models the connection between the assessment and forecasting is provided. In order to accommodate mathematical models at different levels of aggregation and complexity an open and user friendly architecture was designed and adopted. The user through the GUI, which interacts with the Logical Co-ordination and Scheduling Unit (LCSU), activates the models. Inputs to models are prepared using a set of pre-processors (filters) of the LCU by collecting the DB data and GIS based geo-referencing. The same architecture is used backwards for storing and visualising the results. Storage in the DB is performed by means of post-processing filters, while the GUI helps the user in selecting, visualising and comparing results. Finally, the open structure of the system also allows for the use of external data and external models results. The scope of this DSS is to build EIA reports on the basis of several pressure and state indicators. Pressure indicators, among others, include:

i. Environmental: consumption of water/chemicals/energy by crop, region pollutants
ii. Loads to water bodies/fields changes of hydrological inflows pattern etc.;
iii. Economic: WR&Agro governmental investment costs, foreign, private investments GNP growth rate etc.;
iv. Socio-economic: Demographic growth rate

State indicators include: water flows, water quality, soils state (salinity, water logging); agro-sector employment; WR OMR expenditures and revenues; cost of water; value of agro production; agro export, import; economic efficiency by crop and region; economic efficiency of sectoral Development measures; sustainability of water use; all indicators of Quality of Life indices at different level of social, spatial and temporal aggregation.

The system operates on the basis of selected scenarios and actions. Different hypotheses over a defined time span (10-20-30 years) using all the available data can be tested by the simulation models. At the end of the simulation process, the pressure and state indicators are then synthesised in order to offer an understandable report to the stakeholders.

4. Data Needs

In terms of the data needs, complexities and problems within the City area together with the purpose of the model will dictate different levels of accuracy. The quality of data has a direct implication on the reliability and confidence of model results. However, in some instances the data will have insignificant impact on the accuracy of the final model while in other instances these will be highly significant. In some cases, extensive surveys may be avoided by making the best use of all available data (i.e., by extrapolation/interpolation and best judgement). The balance between the need for precise data and taking the data with less accuracy will depend on the above mentioned factors and must be considered carefully.

Generally speaking, in order to apply any of the previously described models, the following data should be made available:

- Stormwater system data,
- Wastewater system data,
- Water distribution system data,
- Wastewater treatment data,
- Topographical data,
- Hydrometeorological, Hydological and geological catchment data,
- Population data,
- Groundwater data,
- Receiving environment data,
- City infrastructure data,
- Historical experience with the water related problems,
- Various town planning information,
- Any measurements or gauging data.

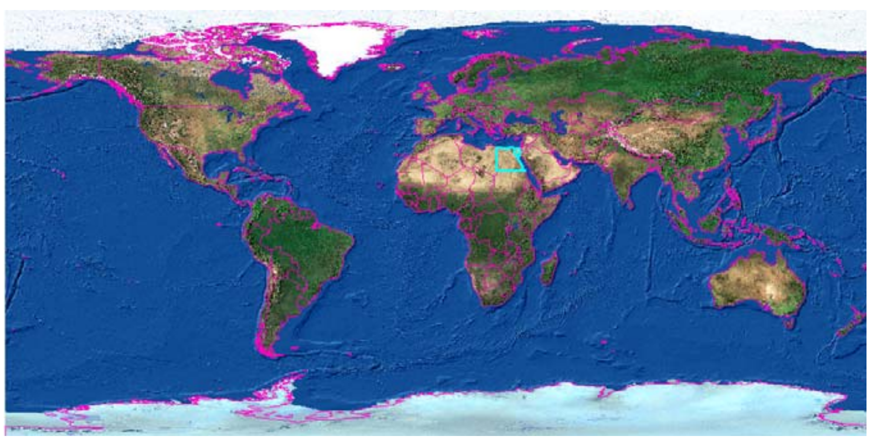
In addition to the above data, a filed inspection to the study area by the modellers is always very beneficial.

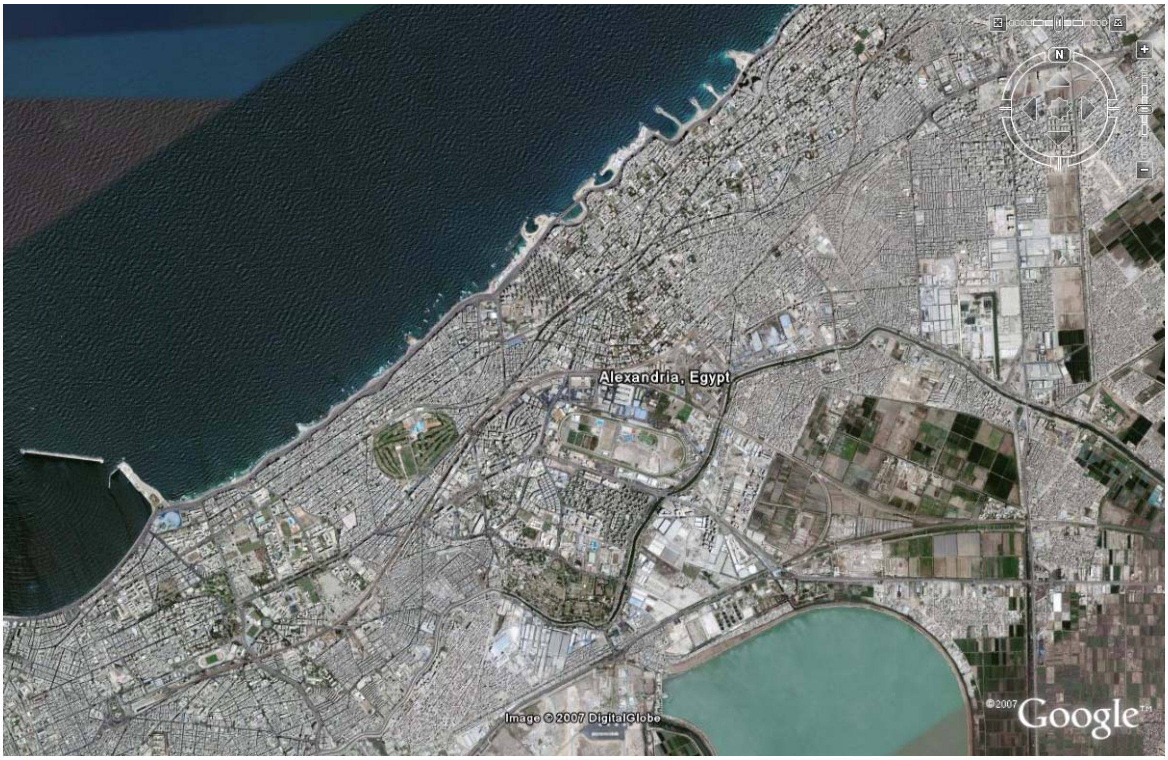
In case that the data is not available then the use of available literature, public questionnaire and interviews with local operators should be considered in order to set up the models.

5. Selection of the two representative demo cities

This section of the report starts with an overview of all nine CWITCH demo cities and ends with the recommendation to select the two representative cities where the functioning of the models and knowledge-based system will be demonstrated. An overview of problems of demo cities presented here is solely based on the review of SWITCH reports (http://www.switchurbanwater.eu) and therefore any possible misrepresentation that may appear will be due to the limited information available at this point in time.

5.1 Alexandria, Egypt





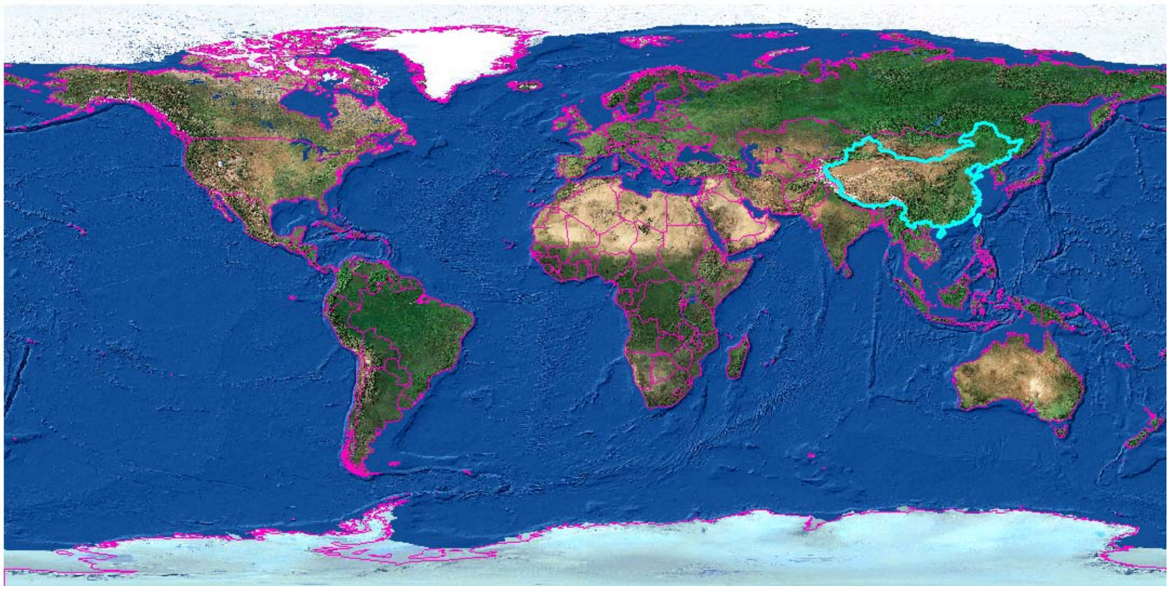
Background

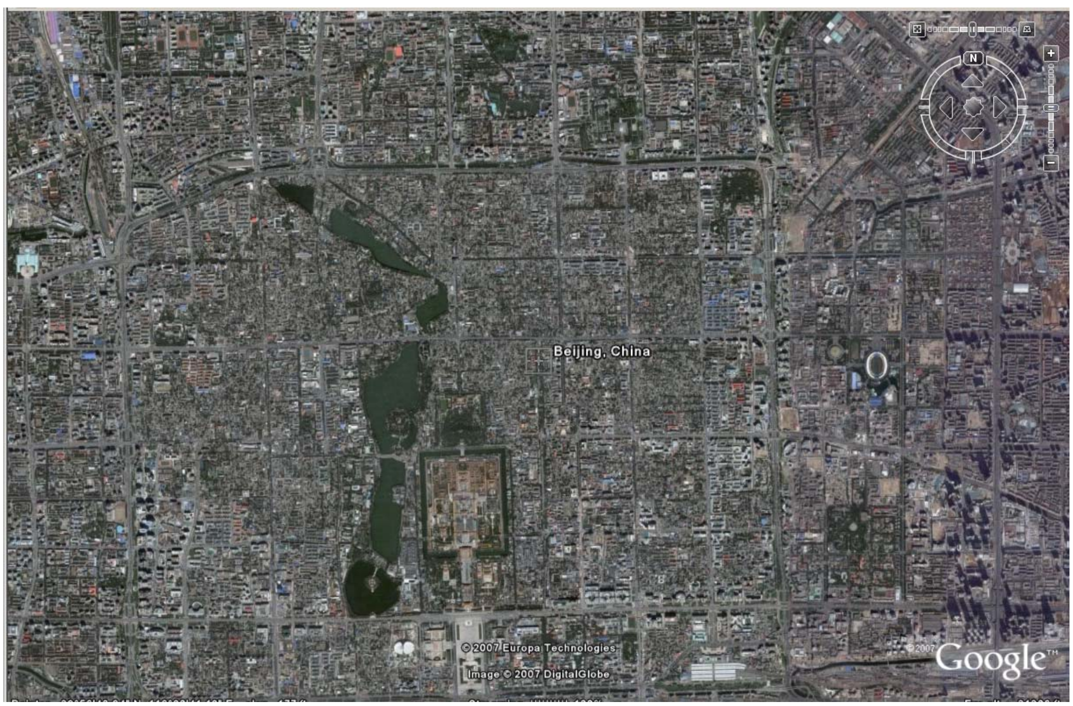
- Alexandria is a city with about 3.5 million inhabitants.
- The city is located on the Mediterranean coast and has an arid climate.

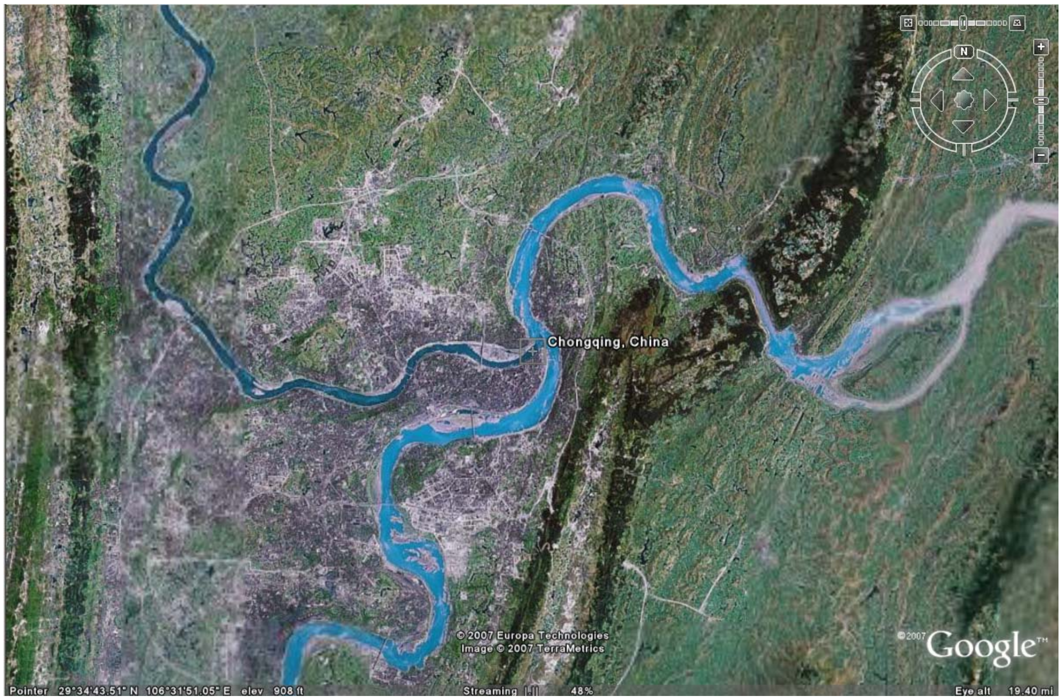
Summary of Problems

- Lack of sanitation services (low income),
- Industry waste,
- Conflict between agriculture, drinking and domestic water uses,
- Insufficient water resources to cover future demand,
- Water sources for agriculture
- Pollution due to untreated wastewater and poor solid waste management
- Management
    - Capacity building for planners, managers and implementers
    - Inclusive/participatory process management
    - Regulation and law enforcement
    - Stormwater management

5.2 Beijing and Chongqing, China







Beijing Background

- Population is about 14.5 million, out of which 3.2 million live in peri-urban districts and counties of the metropolitan area.
- Beijing covers an area of 16,808 sq. km and it is divided into 16 districts and 2 counties.
- Beijing's city includes 4 districts with about 87.1 sq. km and a high population density of 27506 persons/sq. km.
- Moderate continental climate and has an average annual rainfall of about 500mm. The temperature is in the range of -15-38 °C.

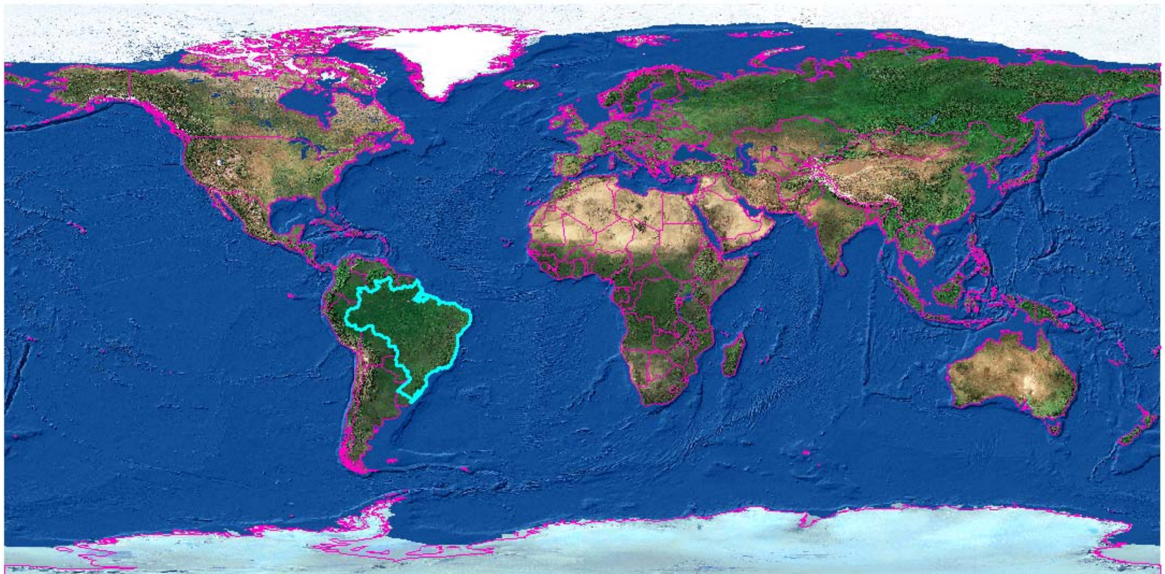
Chongqing Background

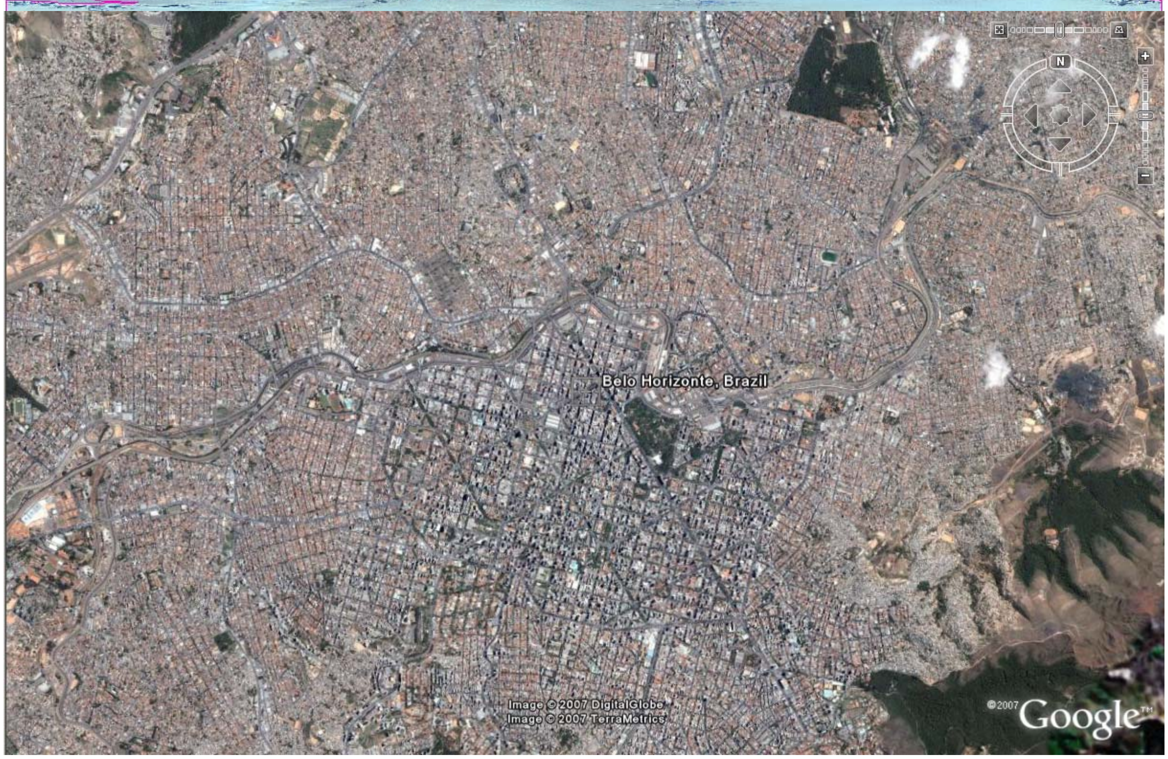
- Chongqing is located in the southwest of China and it has become the most important economic and cultural centre in the upriver of Yangtze River and Three Gorges Area in the last years.
- Population has doubled from a total of 15 million in 1995 to 31.1 million in 2003.

Summary of Problems

- Water resources
- Water demand – insufficient resources to meet future population and
- Water distribution – high in leakage rates
- Wastewater - less than 20% of wastewater is treated
- Infrastructures for sewage treatment is insufficient
- Lack of strategic and long term planning
- Environmental degradation
- Management
    - Lack of integrated policy – governance
    - Lack of integrated planning

5.3 Belo Horizonte, Brazil





Background

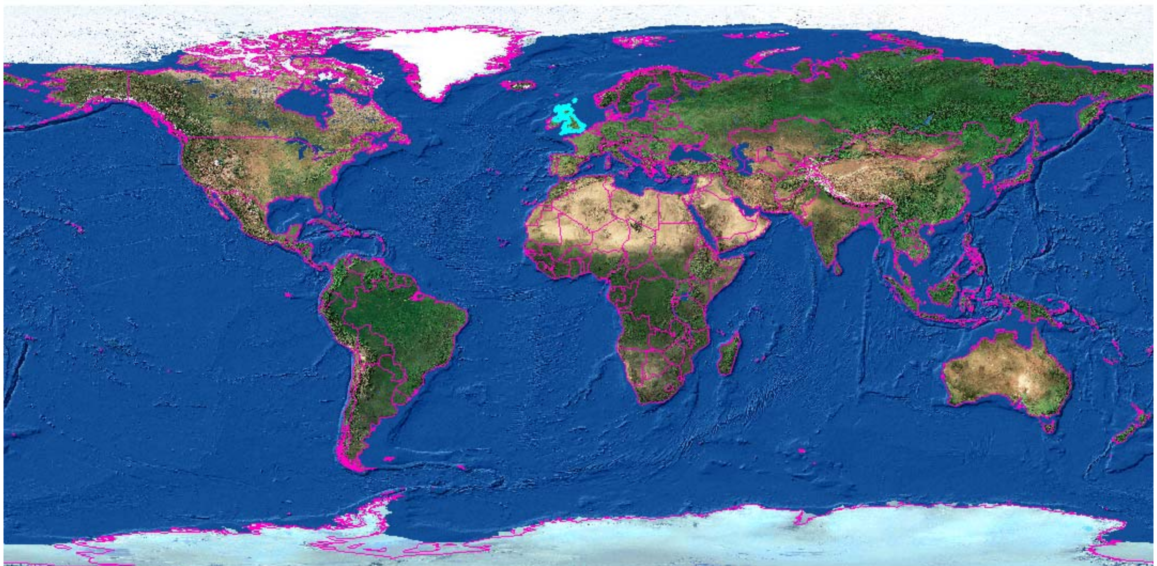
- The city is located at 20° South latitude and 44° West longitude and has an altitude of 750 to 1,300 metres. The total area of the municipality is 330 km^2.
- BH has 2.2 million inhabitants with a population density of 6,900 inhabitants/km^2

- Tropical highland weather predominates in this area, with an average yearly rainfall of 1,500 mm and an average yearly temperature of 21°C. The rainy season lasts from October to March, when 90% of the total yearly rainfall occurs.
- The water supply system (dinking water) connects to 99.7% of Belo Horizonte residents with an average supply rate of 286 litres per inhabitant/day.
- Surface sources predominate in the BH water supply system. The total water supply production capacity is 16.3 m^3/s, however, present demand in the Metropolitan Region of Belo Horizonte is for 11,9 m^3/s.
- About 92% of the population is connected to the wastewater sewerage system
- There are two relatively recent wastewater treatment plants in operation, the Arrudas WWTP and the Onça WWTP, with a total capacity to treat 4.0 m^3/s.

Problems

- Water supply problems during the dry season
- Flooding problems
- Disruption of water supply because of natural hazards such as floods, fires and landslides
- Water quality problems due to catchment environmental degradation, emergence of pathogen occurrences, accidental contamination or operational failures
- Chronic pollution of receiving waters caused by the lack of sufficient wastewater treatment, inadequate capacities of wastewater interceptors, diffuse sources (urban, solid waste and erosion) and cross-connections (between sewer and stormwater)
- Malfunctioning of the wastewater system due to flooding and landslides
- Illegal occupation of low-lying (i.e., flood prone) areas by low income people (sanitation problem also)
- Lack of sound wastewater and stormwater planning policies
- Fast developments and increase of impermeable surface area place the continuous threat for more severe flooding
- Lack of maintenance
- Insufficient technologies
- High cost of structural measures
- Pollution due to urbanisation, mining and agriculture activities upstream
- Lack of integrated planning (stormwater and sanitation)
- Inadequate institutional arrangements
- Inadequate inter-municipal cooperation
- Inadequate public participation in the decision making process

5.4 Birmingham, United Kingdom



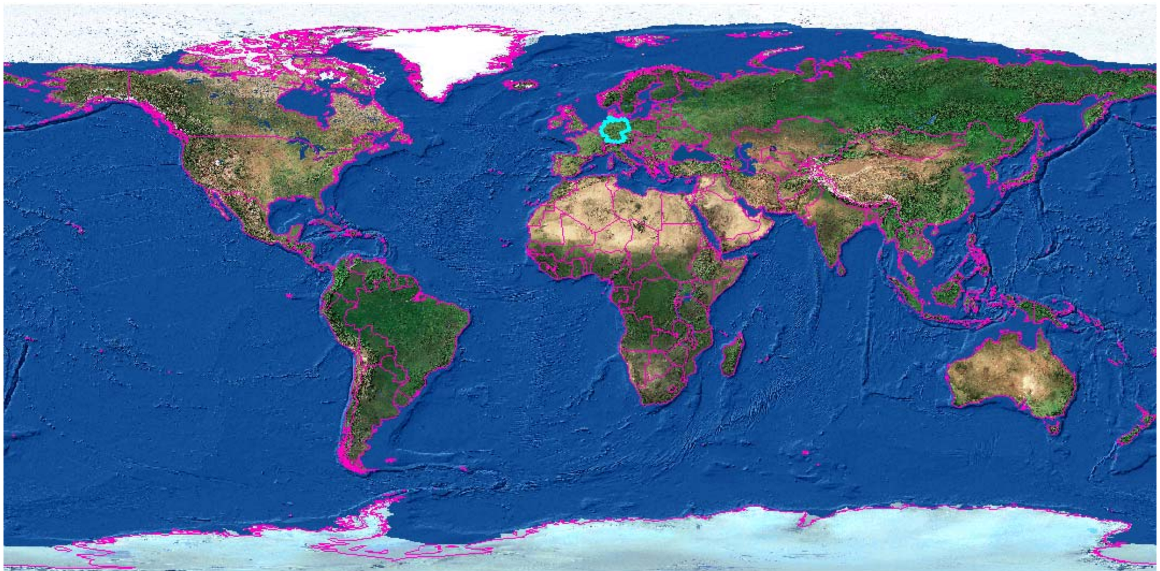
Background

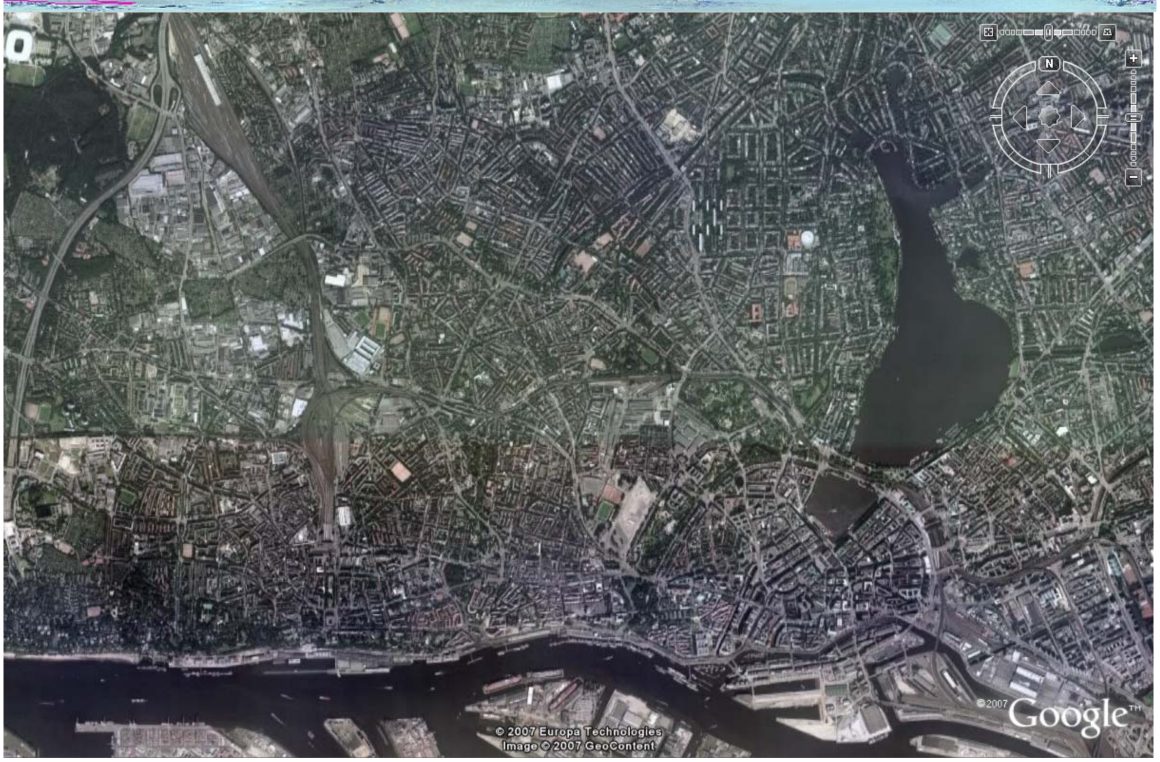
- Birmingham is a modern, diverse and multicultural society and sees itself as being the "second city" in the United Kingdom.
- The population of Birmingham is 1 million but it sits in the administrative region of the West Midlands and with the other adjoining municipal areas of Sandwell & Dudley, Wolverhampton, Walsall and Solihull accounts for almost 5 million inhabitants all told. The population density is 3,649 people per square km.
- The weather in Birmingham is quite temperate with average maximum temperatures in summer (July) being around 20^{o}C; and in winter (January) is around 4.5^{o}C

Summary of Problems

- Flooding
- Water Supply
- Water demand – increase in population causes rising demand on portable water
- Groundwater problems; pollution (organic & metal), increasing groundwater table affects subsurface infrastructures
- Water quality problems in the river
- Inadequate wastewater infrastructure

5.5 Hamburg, Germany





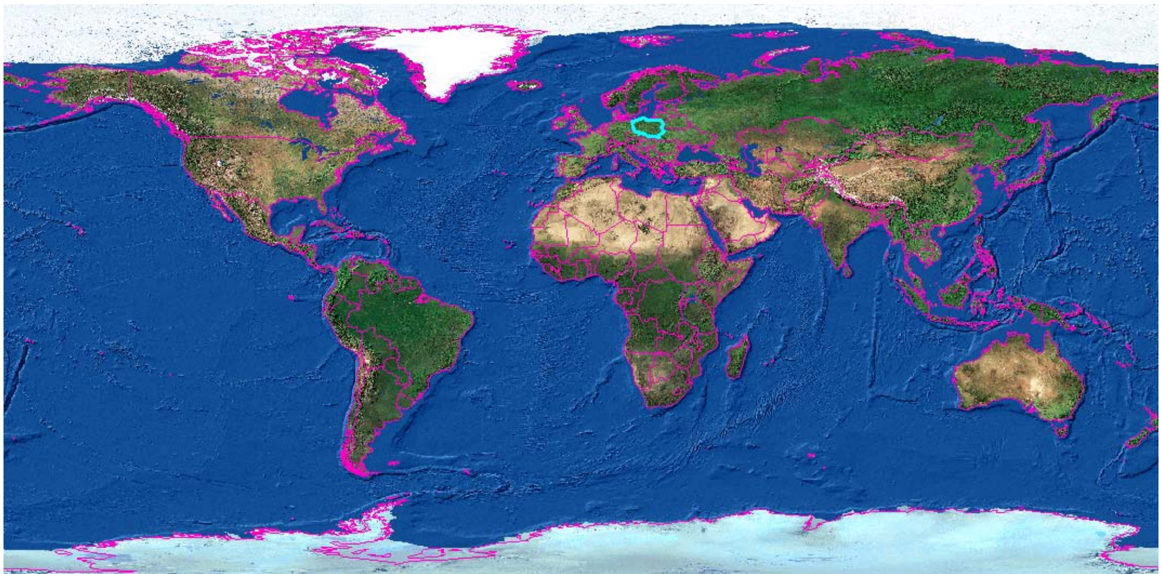
Background

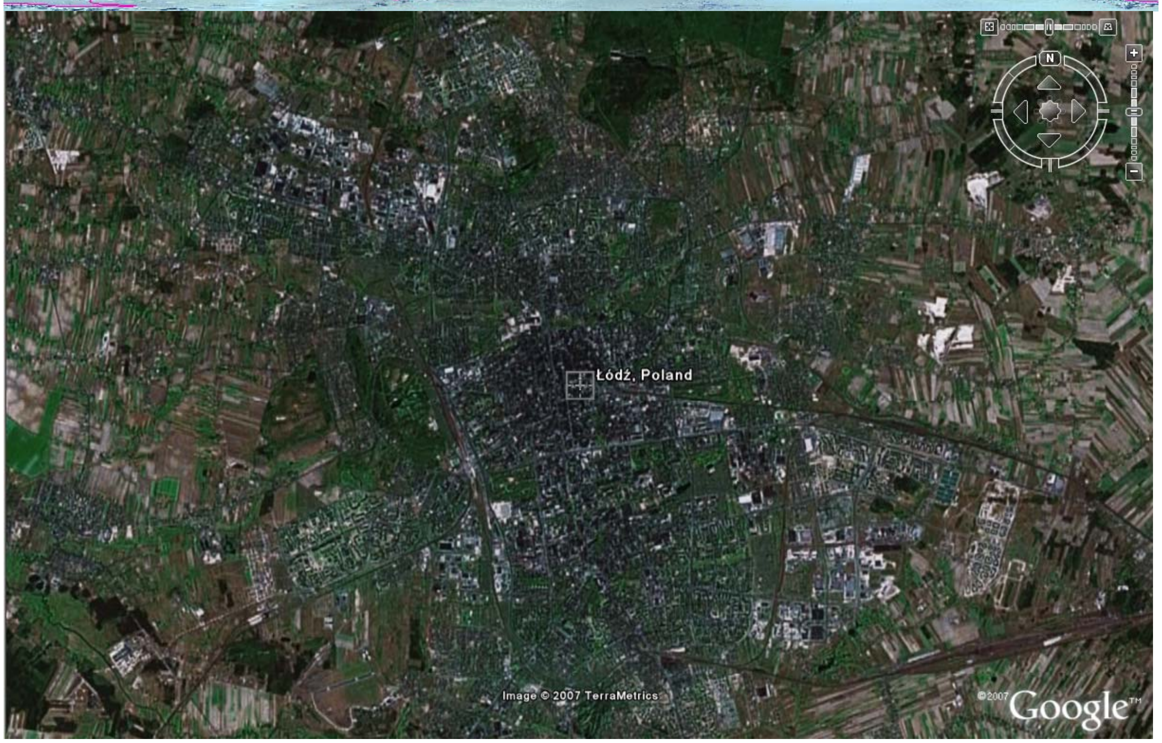
The city Hamburg has an increasing population and is one of the fastest growing cities in Germany. The expected population growths (60.000 people until 2020) and the expanding harbour evoke a predictable need for urban development. Related to this background the municipality Hamburg developed a model of qualitative and sustainable urban growth. The objectives were defined in the key concept 'Metropolis Hamburg – expanding city'. The urban development mainly takes place in the south of the city, in particular on the river island of Wilhelmsburg. The island will be scene of the international Building Exhibition (IBA) 2013 and the International Horticultural Exhibition 2013. Hamburg has a central water supply system with several wells sitting on city aquifers. Since the mid 1980th the average water consumption per capita was reduced. Despite of the increasing population, there is no shortage of drinking water expected in future. Hamburg has a sewerage system which connects over 99% of all inhabitants. The sewerage system is connected with a central sewage treatment plant and it ensures a progressive multi stage treatment of wastewater.

Summary of Problems

- Groundwater issues
- Limited capacity of existing wastewater system
- Environmental impacts
- Flood risk caused by river Elbe and North Sea
- Fluvial flooding in the inland, caused by stormwater
- Potential of flood risk and high water danger due to climate change
- Pollution of surface water due to industries, agriculture and stormwater

5.6 Lodz, Poland





Background

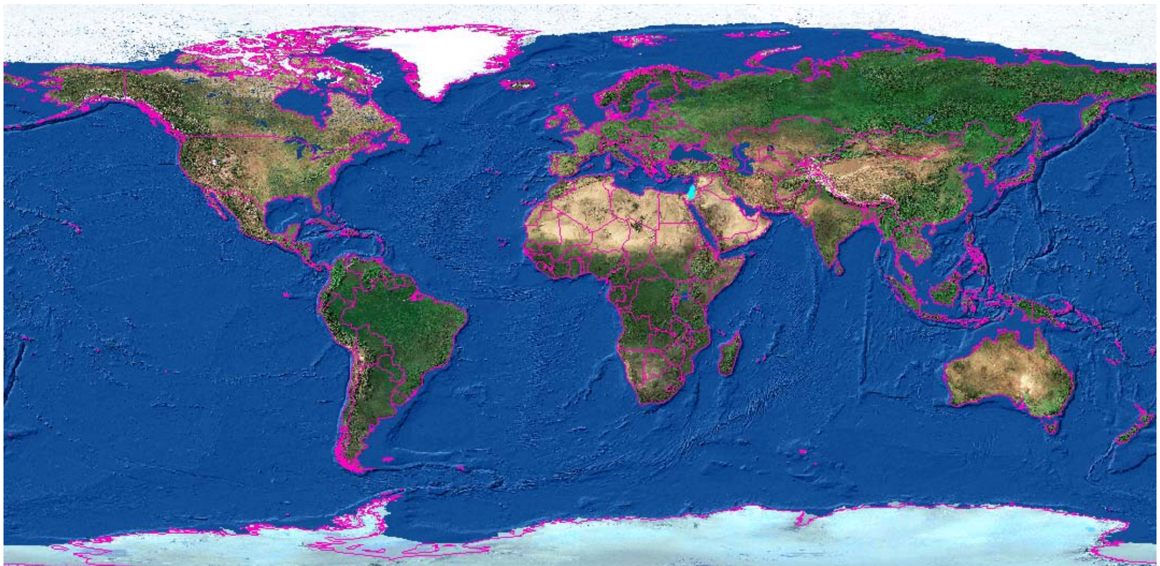
- The City of Lodz has about 800,000 inhabitants
- The city is located on a steep terrain between uplands and lowlands and the area rises from 180 m above sea level in its western part to 235 m in the East, on the first order watershed between the Vistula and Oder Rivers System (the two major basins in Poland).

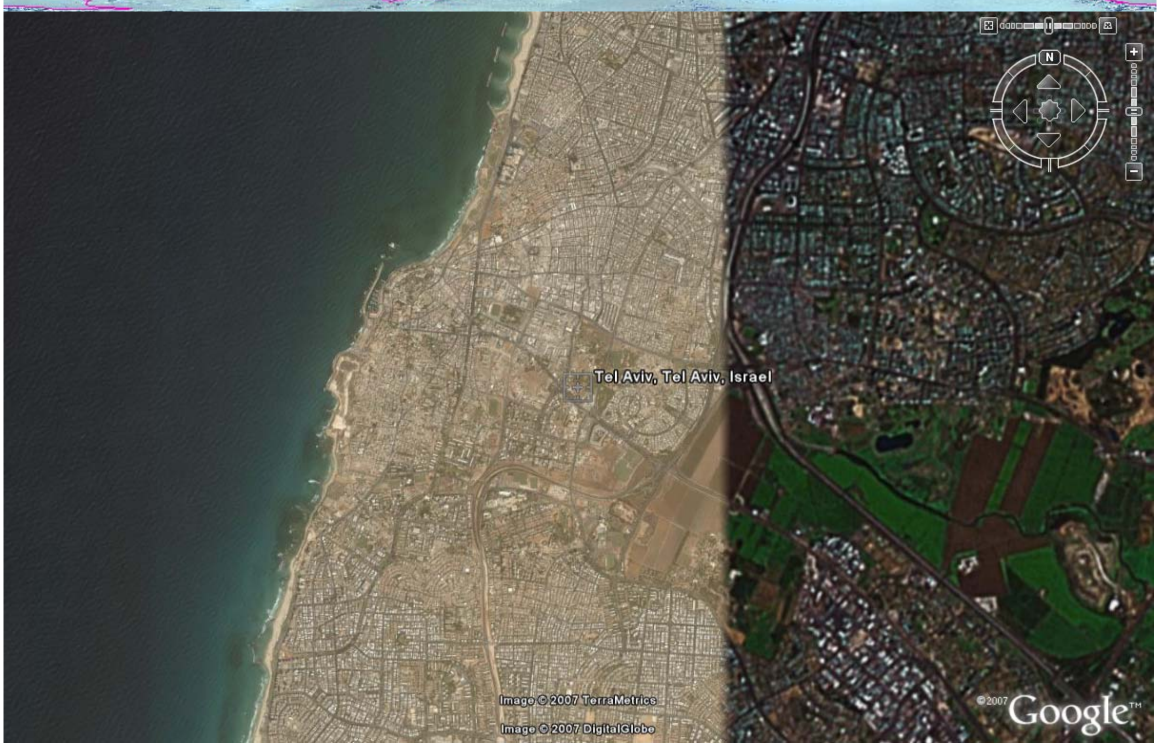
- The city area is divided into 18 catchments drained by small urban streams
- Lodz is equipped with a mixed drainage system – in general, about 80% of the population has access to the wastewater system.
- Growth projections for the city of Lodz predict possible decrease from 768,9 thousands in the year 2005 down to 605,1 thousands in 2030

Problems

- Inter basin transfer - location of the City on the first order watershed between the Vistula and Oder Rivers System requires inter-basin transfer of water from the water intakes at the Vistula catchment (Pilica River) to the disposal at the Oder catchment (Ner River)
- Decrease of water use in the last 20 years related to textile industry collapse - urbanisation of new areas
- Water treatment - treated sewage from the City is disposed into a small river (the Ner River) with natural flow of about 0.3 m3/s, and with the sewage outflow of 2.5 m3/s it exceeds the capacity of the sewage treatment system
- Sewage sludge utilization: the Group Wastewater Treatment Plant (GWWTP) produces 70,000 ton of sewage sludge, which causes additional economic and ecological issues
- City location and streams canalisation together with compacted and highly impermeable historical development of the city reduced water retentiveness in the landscape and capacity of streams. This particularly evidences during storm events, through increase in the flow peaks in the streams as well as the wastewater treatment systems
- City is located on the steep terrain between uplands and lowland areas in Poland resulting in high slope of stream channels 5-7 ‰
- Non-existence of big rivers – 18 small city streams (average Q < 1 m3 s-1), receiving stormwater
- The Ner river floodplain has been severely contaminated with heavy metals and organic compounds. During the last years, due to decrease of water consumption in the city, the average river flow and ground water level at floodplain decreased, resulting with mineralisation of cumulated organic matter in aerobic condition and in leaching heavy metals from the soil.
- Rivers degradation reduced also their capacity for self purification, deteriorating the quality of water, ecological stability of the ecosystems.

5.7 Tel Aviv, Israel





Background

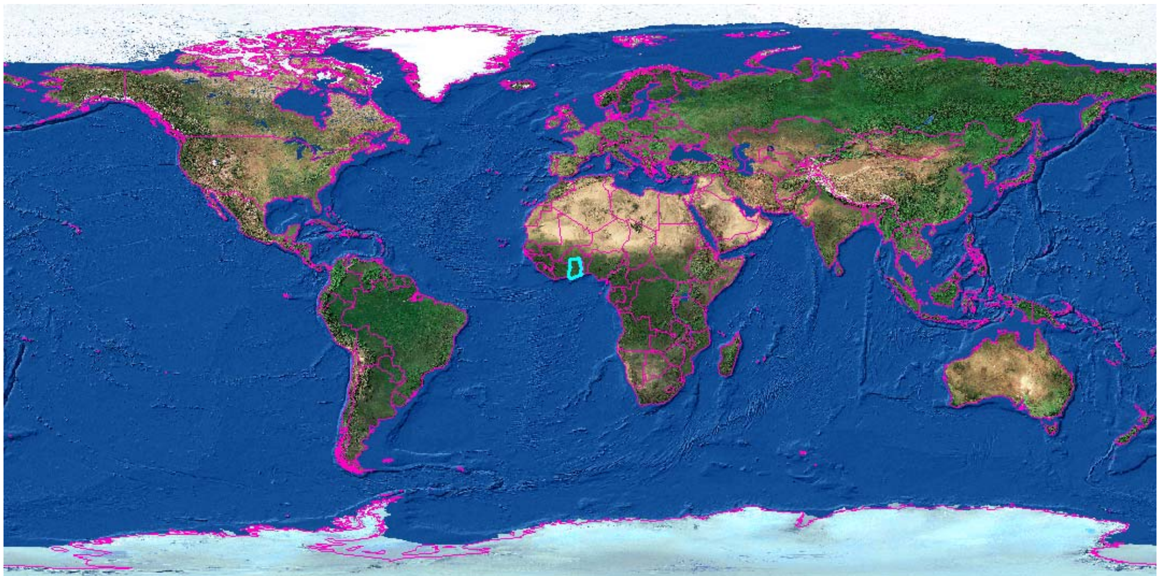
- Tel Aviv is the commercial centre of Israel with a population of over one million arriving to the city on each working day.
- Population estimated around 371,400 inhabitants for an area of municipal jurisdiction of 51.76 km^2 (area of dwelling 77.3 km^2) with a high population density (7200 persons/ km^2).

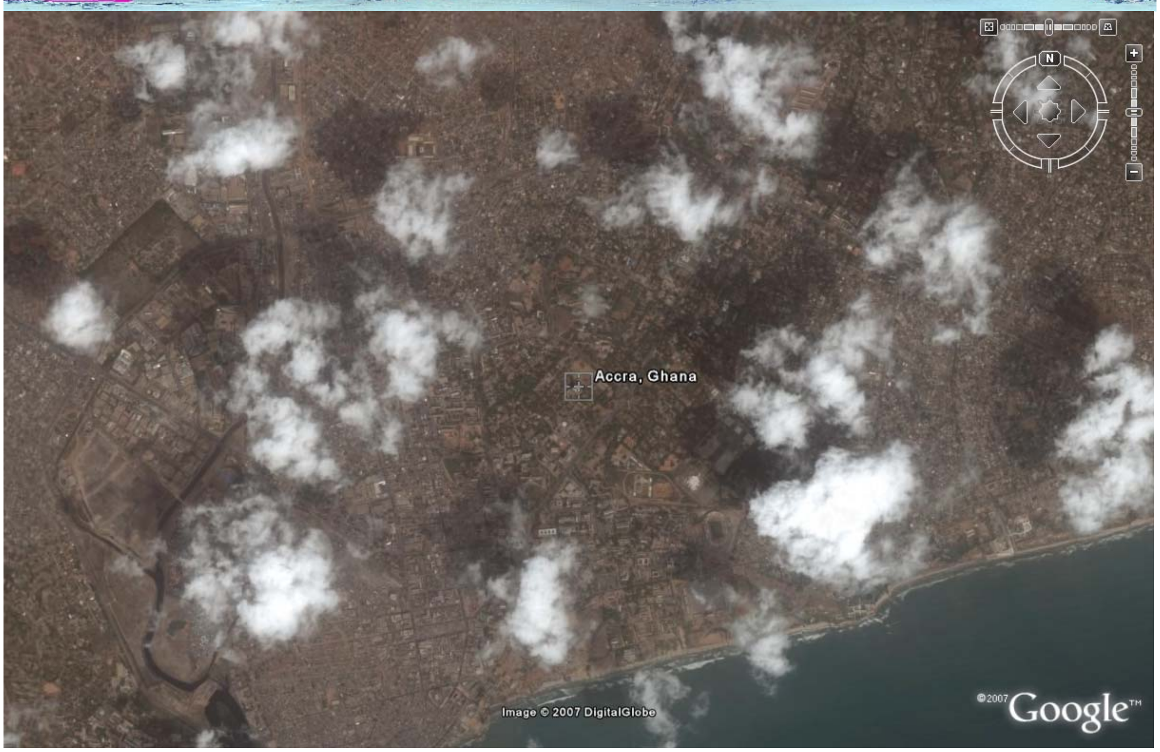
- The annual growth rate of the population is lately 2.2% with 150100 households (with a high percentage of single young people or single elderly people so that the average persons/household is 2.2).
- As a Mediterranean seashore town the climate in Tel-Aviv is mild (lowest daily average temperature (in January) is 9.6^{o}C and the highest average daily temperature (in August) is 30.2^{o}C while the average rainfall is 530 mm/year.
- The drinking water to the city is mainly supplied by Mekorot (41 MCMY or 90% of all the supply) and another 10% (around 5 MCMY) is supplied by local wells.
- The municipality also collects the wastewater by a pipe-line system (around 501 km) and pumps it to the WWTP through the central pipe-line (Reading-Rishon)
- EPAnet model for the distribution network is under development
- There are 24 municipalities which are connected to the central WWTP and around 2 million p.e. of wastes are treated.

Summary of Problems

- Regular water supply to the city during dry seasons in semi-arid conditions.
- Expanding water and future effluent desalination projects
- Municipal water reuses including grey water and resulting dual systems operations, in addition to agricultural irrigation in the periphery.
- Change in wastewater and effluent treatment trends due to rapid urbanisation
- Insufficient equipment in wastewater and effluent treatment to respond to climate and demographic changes
- Flooding
- Industry-related pollution
- Groundwater issues

5.8 Accra, Ghana





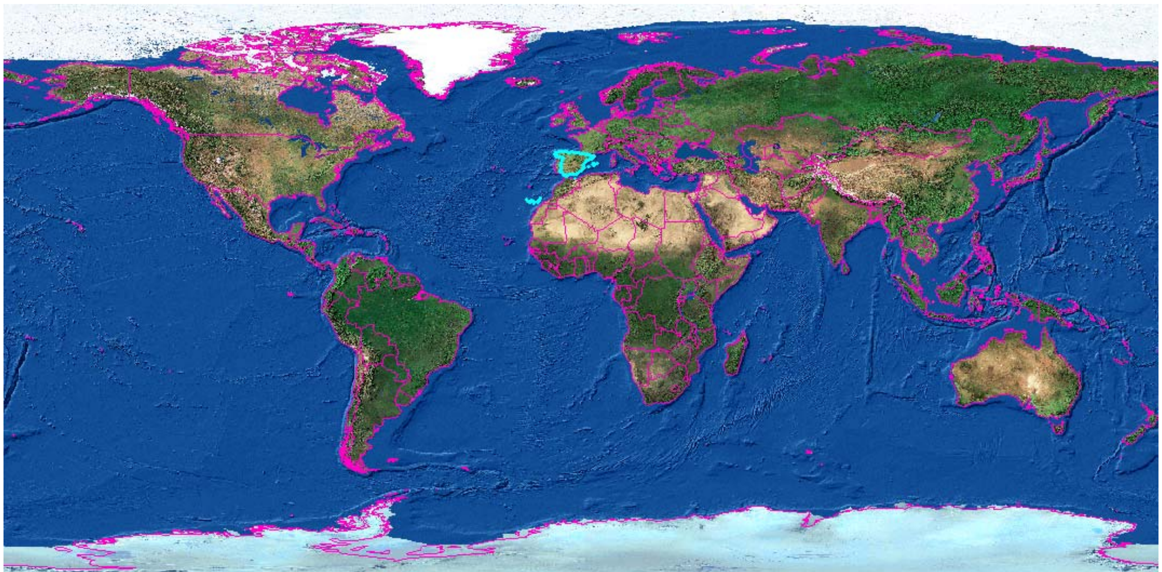
Background

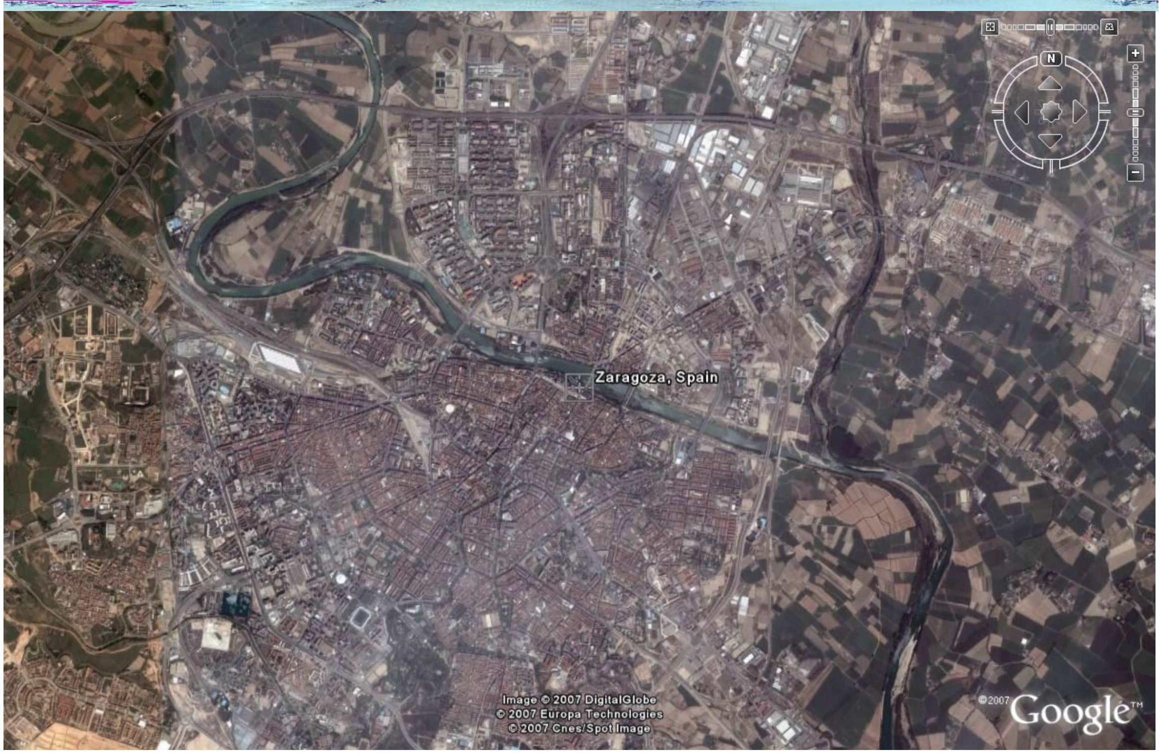
- Accra has a current population of about 2 million. It is the most populated and the fast growing metropolis in Ghana with an annual growth rate of 4.3 % (National Population Census, 2000).
- The production levels of GWCL do not meet the demands of the city and therefore most suburbs of Accra such as Adenta and newly developed areas are not connected to the distribution networks. Those connected to distribution networks are not supplied daily.
- Less than 5% of the households in Accra are connected to pipe sewerage systems, while 21 % use flood drains (gutters) as open sewerage that ends up in nearby urban water bodies.
- Most of urban drains are not adequate and investigation shows that some households are without adequate sanitation facilities.
- Presently, a large modern biological treatment plant is in operation. However this plant handles about 8% of Accra's inner city wastewater from domestic and industrial sources. There are about three other smaller treatment plants scattered in the city.
- About 10% of Accra's wastewater is collected for some form of treatment. The other percentage of wastewater is discharged untreated to open drains, wetlands and natural channels that finally discharge into the Odaw river, Korle lagoon or the sea.

Summary of Problems

- Water distribution network is limited but existent.
- The water supply is also from secondary sources. This means the urban poor who are not connected to the GWCL network need to pay more for the same quantity of water supplied.
- GWCL is losing a lot of water and consequently money due to poor condition of the pipes and illegal connections.
- Lack of access to safe water and sanitation especially in poor areas
- Polluted wastewater use in agriculture
- Flooding due to poor drainage and blockages (solid waste problem)
- Pollution of water bodies due to inadequate treatment and poor sanitation

5.9 Zaragoza, Spain

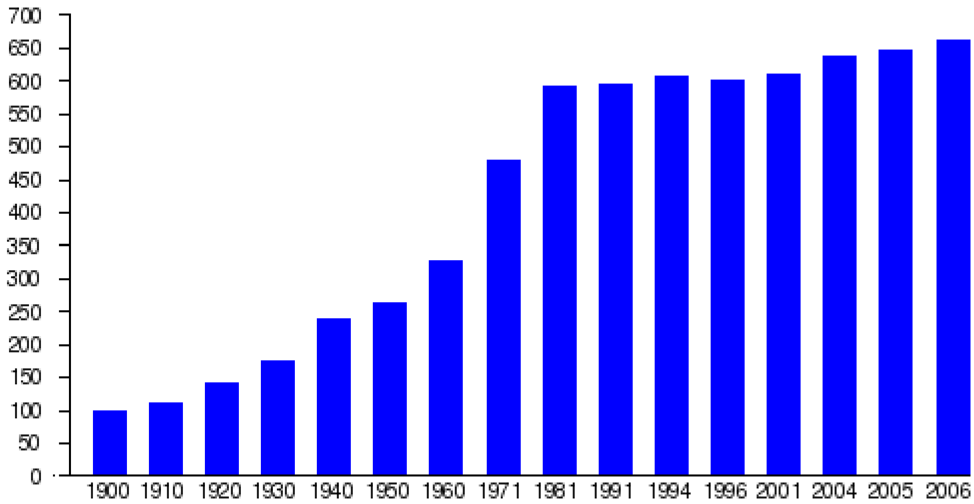




Background

- Situated on the river Ebro and its tributaries, the *Huerva* and *Gállego*, near the centre of the region, in a great valley with a variety of landscapes, ranging from desert (*Los Monegros*) to thick forest, meadows and mountains.
- According to 2006 data from the Zaragoza council, the population of the city of Zaragoza was 660.895, ranking fifth in Spain. The

population of the metropolitan area was estimated in 2006 at 833.455 inhabitants.



Zaragoza population expansion from 1900 to 2006

Summary of Problems

- The major problem in Zaragoza is water scarcity for domestic, industrial and agricultural use.
- Drinking water quality is also the problem
- Industrial pollution
- Inadequate Management and Institutional arrangements

Table 1: Summary of problems in SWITCH demo cities (the circles represent current problem areas).

	Water Supply								Wastewater					Stormwater					
	Resource			Demand				Dist.	Sewer		Treatment	Rec. Env		Flooding		Surface Deg.			Groundwater Deg.
	SW	GW	NC	D	I	A	T		D	I		SW	GW	Urb.	Riv.	P	R	E	
Accra	o	o	o	o					o		o	o		o					
Alexandria			o	o		o			o	o									
Beijing & Chongqing	o	o	o	o				o			o	o	o						
Belo Horizonte	o	o							o		o			o		o	o		
Birmingham	o	o		o					o		o			o	o				o
Hamburg									o			o	o	o	o	o	o		
Lodz				o							o			o	o	o			
Tel Aviv	o		o					o			o	o		o					
Zaragoza			o	o	o	o				o									

Dist	Distribution
Deg.	Degradation
SW	Surface water
GW	Groundwater
NC	Non conventional
D	Domestic
I	Industry
T	Tourist
Rec. Env.	Receiving environment
Urb.	Urban
Riv	River
P	Pollution
R	Runoff
E	Ecosystem
A	Agriculture

5.10 Selection of representative cities

Considering the scope of modelling and KMDSS work, during the February 2007 workshop, it was decided to select two representative cities for demonstration activities of WP1.2. In order to have a diversity of problems for demonstration purposes, it was suggested to search for the two cities which have a large differences between each other, and where one would be from the so-called 'developing environment', and the other form the so-called 'developed environment'.

From the analysis of all demo cities (based on the available information) and with respect to the diversity of problems, geographic position, climate conditions, and availability of local support by city operators, the selection of appropriate cities has resulted in the preference to Birmingham (being a European city) and Belo Horizonte (as a typical South American city).

6. References

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