

## **Consolidated Scientific Report<sup>1</sup>**

### **Objectives**

The main natural resource researched in this Project was **groundwater**. The final objective of the Project was the development and application to two-case study areas in China of conceptual scientific tools and sound models including: (1) groundwater management policy and optimisation mathematical tools, (2) groundwater resources quantitative and qualitative databases and (3) groundwater vulnerability to pollution assessment and mapping. Further achievements included: (4) an enquire on the case-study region's water supply, wastewater and solid waste, including perspectives on (5) integrated approaches for sustainable development policies and (6) methodologies for minimising environmental impacts and for monitoring groundwater in landfill areas. All these were supported by the experience of the “**EU-PRC coastal groundwater**” team.

The research aimed the minimisation of environmental risks due to rapid economical growth of the Pearl River Delta region (Macau-Guangzhou-Hong-Kong region) and the Dalian Peninsula region. These two regions have very different climatic, hydrogeological and socio-economical characteristics.

The tasks developed in the Project were divided in several Work Packages. The first, *i.e.* WP1, was dedicated to the development of appropriated management mathematical models and practices towards the optimisation of the existing groundwater resources. This Work Package included: establishing the likely patterns in demand growth in the study areas; assessing resources based on available recharge data; examining the constraints which arise from water quality concerns and the onset of saline intrusion; exploring optimal abstraction policies which are related to particular levels of abstraction and the distribution of major demands; suggesting long term development strategies which allow the system to change in a way that converges on the optimal solution through a series of practical intermediate stages; establishing methodologies for operational control on a short term basis using the more appropriated models and graphical tools. The final outcome requires economic analysis to ensure that they are consistent with growth and development policies, which are external to the hydrogeologic system.

The second Work Package, *i.e.* WP2, was dedicated to the research of the intrinsic groundwater vulnerability to pollution, aiming the minimisation of environmental risks to groundwater. Some of the parameters are related to those evaluated in WP1. In WP2 the following parameters were analysed: quantitative and qualitative assessment of groundwater resources; groundwater use assessment (as described above); assessment of indexed vulnerability to pollution. Conceptually the data was subdivided in: steady parameters (*e.g.* hydraulic conductivity); and transient parameters (*e.g.* piezometry). To store information on groundwater, an hydrogeological data-base, the data-base INVENTOR\_PRC, was programmed and filled in for the selected coastal zones of China.

The third Work Package, *i.e.* WP3, was based on the partners experience related to the research of an integrated approach on sustainable development policies for water supply, wastewater and solid waste sectors, towards the protection of natural groundwater resources.

The fourth Work Package, *i.e.* WP4, was dedicated to the know-how transfer, not only from the EU towards China, but also, and we underline the relevance of this task, from China towards the EU, aiming the mastering by European researchers of the largely unknown environmental problems affecting rapid economic growing regions of Asia's DCs. Know-how transfer was therefore a major concern of this project. This was achieved thorough: (1) the exchange of scientific staff from China to Portugal and to the UK, (2) the exchange of scientific staff from Dalian to Guangzhou and vice-versa, and (3) the exchange of scientific staff from China to Macau and vice-versa.

In detail, the tasks scheduled for the 3 years of the project were divided in the following Work Packages:

Work Package WP1 *Management Policy and Optimisation Mathematical Tools*

WP1.1 - Establishing the likely patterns in demand growth in the study areas;

WP1.2 - Assessing data based on available recharge;

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<sup>1</sup> Written by Dr.-Ing. J.P. Lobo-Ferreira, Scientific Co-ordinator of Contract N. IC 18CT960048.

**EC-DGXII INCO-DC PROGRAMME 1996-1999 - Contract N. IC 18CT960048**  
**“Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks  
in Coastal Zones. EU - PRC Coastal Groundwater”**

WP1.3 - Examining the constraints which will arise from water quality concerns and the onset of saline intrusion;  
WP1.4 - Exploring optimal abstraction policies related to particular levels of abstraction and the distribution of major demands;  
WP1.5 - Suggesting long term development strategies which allow the system to change in a way that converges on the optimal solution through a series of practical intermediate stages;  
WP1.6 - Establishing methodologies for operational control on a short term basis using models and graphical tools which are appropriate;  
WP1.7 - The final outcomes requires economic analysis to ensure that they are consistent with growth and development policies, which are external to the hydrogeologic system.

**Work Package WP2 Resources Vulnerability Assessment and Risk Protection**

Task WP2.1 - Analysis of scale effects on conceptual models aiming the computation of resources and risks in the hydrogeology of coastal zones:

WP2.1.1 - analysis of the different types of hydrogeological systems of coastal zones, based on their genesis and age (*i.e.* ancient or recent, sedimentary, karst, etc.) and on their climatology;  
WP2.1.2 - selection, data gathering and analysis for the two different hydrogeology/ climatology regions of Pearl River Delta and Dalian Peninsula;  
WP2.1.3 - evaluation of the most appropriated working scale, compatible with the hydrogeology, climatology and the availability of information of the selected coastal zones.

Task WP2.2 - Characterisation of the hydrogeological types of the selected coastal zones and evaluation of their groundwater resources:

WP2.2.1 - characterisation of the hydrogeological systems;  
WP2.2.2 - evaluation of groundwater resources, both the renewable ones, *i.e.* the deep groundwater recharge, and the exploitable resources available in the hydrogeological systems. Development and calibration of a regional groundwater recharge model for the selected Chinese coastal zones;  
WP2.2.3 - assessment of groundwater uses, linked with Work Package WP1;  
WP2.2.4 - to define the relationship between the groundwater recharge and their genesis, related also to sea water of North Sea and Yellow Sea, for the Dalian Peninsula;  
WP2.2.5 - mapping in Geographical Information Systems (GIS) at the scale to be selected on WP2.1 of the hydrogeological systems and the potential mean regional groundwater recharge of the selected coastal zones;  
WP2.2.6 - programming the hydrogeological data-base INVENTOR\_PRC with the parameters to be gathered in the framework of the Project. The data is both on quantity and on quality values and is divided in the following items: locations of the wells; lithological profile of the wells; location of the screens; values on the piezometry; and values of major water elements evaluated in chemical analysis.

Task WP2.3 - Mapping of the groundwater vulnerability to pollution for both the Pearl River Delta and for the Dalian Peninsula regions.

WP2.3.1 - surveying the groundwater table depth of the aquifers of the two selected coastal regions;  
WP2.3.2 - determining the soil type and the lithological profile of the aquifers;  
WP2.3.3 - measuring the permeability or hydraulic conductivity and the variation of water content in aquifers by field pumping tests or water injecting tests;  
WP2.3.4 - to assess the topographical slope of the regions;  
WP2.3.5 - assessment of the values ranges (1 to 10) of each DRASTIC parameter, based on the local characteristics (higher values correspond to a higher vulnerability index; the values are obtained from tables that consider the correspondence between the local physical and hydrogeological characteristics and the DRASTIC parameter);  
WP2.3.6 - computation of the local index multiplying the DRASTIC value by its weight (each parameters has a pre-selected weighting value that reflects its relevance on the computation of the vulnerability; there are two sets of weighting values one for standard pollutants and the other for pesticides);  
WP2.3.7 - using a Geographical Information System the rating factors related to the DRASTIC model are being determined for both regions and the final evaluation of the groundwater pollution potential will be made.

Task WP2.4 - Development of conclusions and recommendations based on the knowledge gathered in the Project aiming the assessment and mapping of groundwater vulnerability to pollution of other coastal zones and inland regions of China.

#### Work Package WP3 *Regulations For Groundwater Risk Policies*

WP3.1 - Characterisation of the water supply, wastewater and solid waste sectors;

WP3.2 - Overall and sectorial diagnosis of the sectors;

WP3.3 - Identification of protection measures to be implemented in order to avoid contamination, considering the vulnerability of the different regions previously assessed and the risk posed by the existing infrastructures;

WP3.4 - Development of the tools required to implement the above-identified measures.

#### Work Package WP4 *Know-How Transfer*

WP4.1 - Co-ordination and know-how transfer from the EU to China;

WP4.2 - Exchange of scientific staff from China to the EU; know-how transfer from China to the EU; Exchange of scientific staff within China and from China to Macau and vice-versa;

WP4.3 - Organisation of regional scientific meetings in Guangzhou and Dalian;

WP4.4 - Organisation of international scientific meetings in Lisbon and in Macau.

## Activities

According to the Project Plan, during the lifetime of Project, *i.e.* Sept. 1996 - Dec. 1999, the accomplishments were the following:

- **Laboratório Nacional de Engenharia Civil, Departamento de Hidráulica, Grupo de Investigação de Águas Subterrâneas, established in Portugal (the Co-ordinator)**

Dr.-Ing. J.P. Lobo-Ferreira, Mr. Manuel de Oliveira, Dr. Teresa Leitão and Mrs. Maria José Henriques

Ministério do Equipamento Social

Laboratório Nacional de Engenharia Civil (LNEC)

Departamento de Hidráulica

Grupo de Investigação de Águas Subterrâneas

Laboratório Nacional de Engenharia Civil developed and applied new methodologies for the assessment of groundwater recharge in the framework of this Project. In order to apply this methodology use was made of the recorded daily values of piezometric levels in a well located near Tavira (Algarve, south of Portugal). Data was recorded with the groundwater level gauge belonging to the groundwater monitoring network of Direcção Regional do Ambiente e Recursos Naturais do Algarve (DRARN-Algarve; Regional Directorate of Environment and Natural Resources of Algarve) was used. Daily rainfall data came from a rain gauge station located in Tavira, about three kilometres north of the monitoring well. The lithologic log of the piezometer is characterised by the occurrence of limestone, dolomitic limestone, sand and clay (data from DRARN-Algarve). The detailed analysis was presented in the First Year Progress Report.

The method of **separation of total runoff** was tested in two Portuguese selected areas, one located in the *Alentejo* region, and another in the *Trás-os-Montes e Alto Douro* region. These regions are comparable with the selected areas of the Dalian Peninsula.

The case-study in *Alentejo* was selected at Nisa stream watershed above Ponte de Panasco. The Nisa stream is an affluent of the left bank of Tagus river, near the border with Spain. The area of the watershed is 109.45 km<sup>2</sup>. Ponte de Panasco is at 320 m altitude and the highest point of the watershed is 940 m altitude. Lithologically, the basin is composed mainly of granite rocks or similar, with the exception of the NE boundary, in the Castelo de Vide mountain, where there are outcrops of arkoses and quartzites, and the SE edge where there are outcrops of schists. The granite rocks are cut with quartz dikes and faults that in some places condition the water flow. The case-study in *Trás-os-Montes e Alto Douro* region was selected at Zacarias stream, an affluent of the right bank of Douro river, located in the NE part of Portugal. Raingauge stations and a streamflow gauge station are available in this watershed. This streamflow gauge station is part of the National Institute of Water (INAG) net of streamflow gauge stations. Rain gauge stations belong to the INAG net and to the Institute of Meteorology (IM) net of rain gauge stations. The area of the watershed is 144.87 km<sup>2</sup>. Ponte Velha Capitão is at 200 m altitude and the highest point of the watershed is 1199 m altitude, in

the Bornes mountain, at the NW edge. Lithologically, the basin is composed mainly of schist, despite there are some outcrops of acid and basic metavulcanites in the E part of the basin. The results obtained allowed for the conclusions that the method, applied to these two Portuguese case studies, performed well. As it may exist some resemblance between these Portuguese watersheds and the Dalian peninsula conditions, this Portuguese case-study served as a mathematical modelling know-how gathering region to the Chinese Dalian case-study region.

Programming of the database Inventor\_PRC: The database on hydrogeology was named Inventor\_PRC. Inventor comes from Inventory, and PRC from People's Republic of China. The database is composed of 14 tables concerning different aspects of the inventoried water points, as may be seen in Table 1.

**Table 1 - General description of database INVENTOR\_PRC\_v1**

<b>Table</b>	<b>General description</b>
<b>LOCATION</b>	This table gives the position of the water point and some characteristics of the water point which do not change with time or depth.
<b>LITHOLOGY</b>	This table contains the lithological log of the well.
<b>CASING</b>	This table contains the depth and the diameter of the casing.
<b>SCREEN</b>	This table refers to the zones in the well where there is inflow of water to the well.
<b>SEAL</b>	This table contains the position of the isolation sections of the well and the isolating material.
<b>LEVEL</b>	This table contains the depth to the piezometric level. In the case of a spring (water point type 3) it can not be used.
<b>TEST</b>	This table refers to the values of a pumping test carried out in a well.
<b>AQUIFER</b>	This table contains the values that characterise the hydraulic properties of the aquifer.
<b>FIELDATA</b>	This table contains data about field measurements of some physico-chemical parameters.
<b>CHEMICS</b>	This table contains information about chemical analysis of water samples.
<b>TEXT</b>	This table allows for any text concerning observations or any information about the water point.
<b>AQUIFER DEFINITION</b>	This table gives information about the aquifer system and also about the position of the top and the bottom of the aquifer system
<b>ABSTRACTION</b>	This table contains information about measured discharge of natural springs or abstraction from the aquifer
<b>ABSTRACTION AVERAGE</b>	This table gives information about monthly average discharge of natural springs or monthly abstraction from the aquifer

Further Laboratório Nacional de Engenharia Civil (LNEC) developed and applied new methodologies for the automatic cartography of the groundwater vulnerability to pollution using the DRASTIC method. General procedures for the assignment of the indexes of the DRASTIC method were applied to several Portuguese regions. The programmes were written in Arc Macro Language (AML), the programming language of the ARC/INFO® environment. LNEC advised and helped DUT and SCUT to fulfil Work Package 2 tasks mentioned above.

The methodologies and the results obtained were presented to DGXII in the First, Second and Third Years Progress Reports, published in OLIVEIRA and LOBO-FERREIRA (1997), LOBO-FERREIRA (1997) and LOBO-FERREIRA (1998).

Concluded the know-how transfer of groundwater vulnerability assessment methodologies from LNEC to DUT and SCUT and the achievement of the sound results of Work Package 2 for the two case-study areas of Dalian Peninsula and Guangzhou Pearl River region, as reported in the Second Year Progress Report, during the period September 1998 to February 1999 LNEC researched an important topic of Work Package 3, aiming the minimisation of environmental impacts from landfills in groundwater, *i.e. the identification of protection measures to be implemented in order to avoid contamination, considering the vulnerability of the different regions previously assessed and the risk posed by the existing infrastructures.*

Towards the achievement of this topic LNEC reviewed methodologies for assessing the impact of sanitary landfills on groundwater. The methodology was then applied to two Portuguese landfill case-study areas. The results were presented in Guangzhou and Macau Workshops (*cf.* LEITÃO and LOBO-FERREIRA, 1999).

- **School of Civil Engineering - University of Birmingham, established in the United Kingdom**

Dr. Andrew Spink and Mr. Christopher R. Jackson  
University of Birmingham (UoB)  
School of Civil Engineering

During the Project UoB developed and applied most items of Work Package 1, dedicated to the Management policy and optimisation mathematical tool (lead by UoB, with the co-operation of DUT, SCUT, LECM and LNEC). The following may be considered as an executive summary of the major lines of activity completed by the School of Civil Engineering, University of Birmingham as part of this Project.

The work has involved the development of methodologies for the sustainable operational and strategic management of groundwater resources. These methodologies have been applied to the Guangzhou-Huadu basin and the Dalian Peninsula. A number of approaches must be employed to assess the size of a groundwater resource and risks to it (e.g. saltwater intrusion), in order to manage it sustainably. One approach is the use of models, which provide a means of advancing the understanding of an aquifer and of predicting its future behaviour. In this work a systems analysis approach has been employed, based on the use of models. Models are powerful tools for the management of an aquifer. Indeed, without models it is difficult to manage the Guangzhou-Huadu and Dalian aquifers sustainably and almost impossible to manage them optimally.

The objectives of the project for the University of Birmingham derive from the need for environmental management in general and water resource management in particular. Growing pressure on global water resources make the implementation of sustainable management strategies more urgent. However, groundwater presents a number of problems for management due to the way it occurs. Coastal aquifers present particular problems to hydrogeologists and water resource engineers as they are generally more vulnerable to contamination. This is discussed along with a description of saline intrusion. The overall objective of a management scheme should be the sustainability of the groundwater resource. Sustainability implies that the development of a resource now will not impair the ability of future generations to meet their own needs. Models offer significant benefits for the development of sustainable management policies and have been used to develop methodologies for the sound management of the groundwater resources in both study areas.

The development of the regional groundwater flow model in the Guangzhou-Huadu basin and Dalian study area is presented in a separated document, complementing this Final Report, *i.e.* JACKSON and SPINK (1999a).

A conceptual model of each aquifer was developed. In each case the boundaries and surface features of the study areas are defined along with an examination of the geology and hydrogeology. Water budgets are prepared through the detailed examination of climate data. This data has been collected by the Chinese partners or has been found on the Internet by the University of Birmingham. One of the inputs to the regional groundwater flow models is recharge. This is difficult to quantify and it is often only through the use of a number of methods that it is estimated accurately. A soil moisture balance model was developed for this purpose. This is a modification of the classic Penman-Grindley soil moisture balance model and can be applied to study areas, which experience high intensity rainfall. Estimates made using this model agree with those obtained through other methods. However, further work is required to increase confidence in the estimation of recharge. Data is limited in both study areas due to the lack of regulation and monitoring of hydrogeological variables. Consequently, the flow models do not currently reproduce the field behaviour adequately. Recommendations are made for further monitoring to improve the models and to enable them to be used for operational and strategic management. The models have highlighted the need for further work. In the Dalian region the lack of regulation is a serious problem. It has resulted in individual abstractors pumping solely according to their own needs and ignoring the sustainability of the global aquifer resource. The lack of regulation also results in a low level of monitoring, which makes it difficult to design sustainable abstraction policies. This must be addressed. Though the models require further work they indicate changes in the operation of the aquifers that provide significant benefits. For example, patterns of abstraction are identified with the model which reduce the amount of saline intrusion.

A decision-making framework was proposed that would help in the operational management and regulation of both the Guangzhou-Huadu and Dalian aquifers. This entails a regular review of the state

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of the aquifer using the model and prevents detrimental impacts. It requires the co-operation of both the water abstractors and regulators in a region.

In both study areas it is desirable to model features such as wells at the local scale. However, the aquifers are extensive and if the boundaries are to be based on physical boundaries the models cover a large area. This presents a series of problem to conventional models, which are inefficient in such situations. In response the model ZOOM2D has been developed which is capable of simulating wells at the scale of the borehole whilst still representing groundwater flow in the regional aquifer efficiently. This model forms the basis for the proposed decision making process. It employs state of the art technology and advances the Chinese partners' capabilities.

Optimisation models have been developed for both study areas. These minimise the cost of abstraction schemes subject to environmental constraints. In the Guangzhou-Huadu basin it is important to minimise drawdowns caused by pumping. In the Dalian study area a specified fresh water outflow at the coast must be maintained to prevent unacceptable saline intrusion. The application of the optimisation models has indicated acceptable patterns of abstraction though as they are based on the groundwater flow models they cannot provide optimal solutions. Therefore, it is apparent that the development of adequate groundwater flow models is crucial for both the short and long-term management of the resources.

A significant part of the project has been the transfer of knowledge between the partners. As part of this a number of visits between the participating organisations have taken place. The University of Birmingham has visited both LNEC and China to gain a better understanding of the study areas and to present the work developed in the project. Two researchers from SCUT and one from DUT have spent two months at the University of Birmingham to gain expertise in the field of groundwater modelling and optimisation. This will help SCUT and DUT to continue the work developed in the framework of this Project and to apply it to other study areas in China. To aid the dissemination of good modelling practice, the development of new groups of groundwater modellers and the application of groundwater models to sustainable management of groundwater resources an extensive set of training material has been prepared. This has been transferred to the Chinese partners. In addition to this material, manuals for all the models developed in this work are given in the appendices.

- **Dalian University of Technology, Environmental Engineering Institute - College of Chemical Engineering, established in P.R. China**

Prof. Zhou Jiti

Environmental Engineering Institute, Dalian University of Technology (DUT)

and

Dr. Qing Yang; Maotian Luan; Zhou Huicheng and Wang Guoli

Department of Civil Engineering, Dalian University of Technology

The study area is located on the Dalian Peninsula in the province of Liaoning. It lies at a latitude of 121°38' and longitude of 38°54'. To the west is the Bohai Sea and to the east the Yellow Sea. The city of Dalian is located in the centre of the region. This is an important industrial and economic port with a population of approximately 1.8 million. There has been extensive industrial development in the region and this is continuing rapidly. Thirty kilometres to the north of Dalian City is the *Dalian Economic and Technological Development Zone*, which covers an area of approximately 37 square kilometres. Since its inception, overseas investment in the development zone has exceeded US\$3.4 billion. Dalian harbour is now the third largest in China and is an important trading port for major oil, petrochemical, textile, electronic and shipbuilding industries. The Gross Domestic Product (GDP) of the region has risen from 52 billion Yuan in 1994 to approximately 230 billion Yuan in 1999. It is expected to be 510 billion Yuan by the year 2010.

Dalian district is approximately 12500km<sup>2</sup> in area. Its population in 1993 was 5.27 million with approximately 54% living in urban areas. Water demand for the district is approximately 1.7 million cubic metres per day. This is expected to rise by 50% by the year 2005. The demand is equivalent to approximately 330 litres per person per day and approximately 40% are supplied from groundwater.

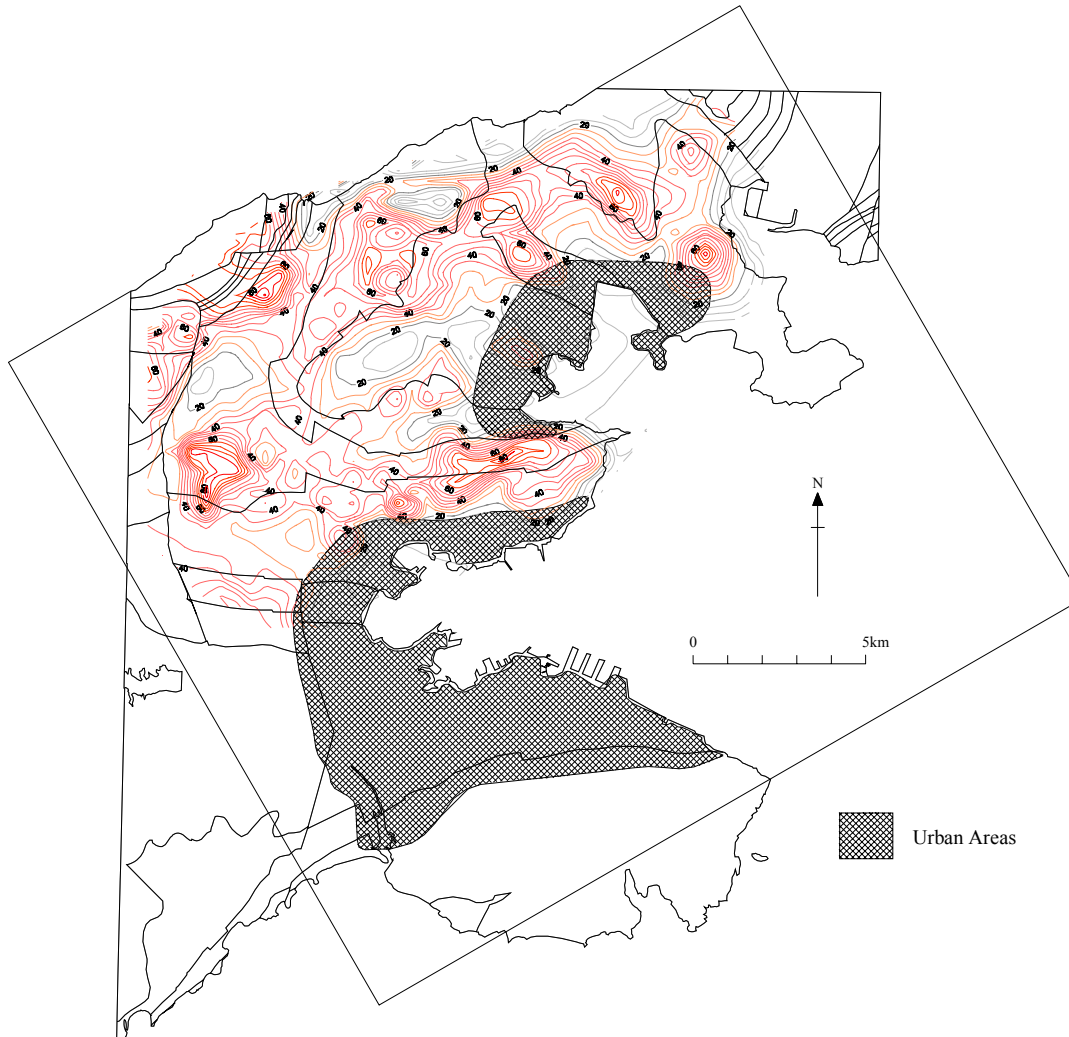
The study area, shown in more detail in Figure 1, extends 23.5 km from its south-west to the north-east limits and stretches 25 km south-east to north-west. It covers an area of approximately 250 km<sup>2</sup>. There are two urban areas in the region and the majority of the groundwater abstraction occurs in or

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near these centres of population. Central Dalian is the more southerly of these two developments and lies close to the harbour.

Dalian University of Technology (DUT) collected most of the necessary data on the Project's Dalian case-study area. The data included the following:

1. Basic information. This information shows the status of the aquifer in the area under research. Such as the thickness, the depth of aquifer at more than 400 spots.
2. All data required for assessing the DRASTIC index method: **D**epth to water table (D), **R**echarge (R), **A**quifer media (A), **S**oil media (S), **T**opography (T), **I**mpact of the vadose zone (I) and **H**ydraulic **C**onductivity of the aquifer (C).
3. Precipitation. Rainfall from 1990-6-15 to 1992-12-30. This data was divided in 24 calculation periods.
4. Evaporation. Data on evaporation in the above mentioned calculation periods.
5. Water table. Water level of 20 wells in the above mentioned calculation periods.
6. Agricultural abstraction. Abstraction of 117 wells for agricultural purpose in the above mentioned calculation periods.
7. Industry abstraction. Abstraction of 75 wells for Industrial purpose in the above mentioned calculation periods.
8. Pumping test data. Some information on 10 pumping test in study area was collected.
9. Some papers on water supply for Dalian City. These papers provide some valuable information on the policy-making for groundwater development of Dalian City.



**Figure 1 - The Dalian study area**

Further data collection: some other information on pumping tests. This was worked with Birmingham University during DUT partners visit to UK. This data helped in the process of modelling groundwater resources in the study area.

Data on river flow: It was impossible to collect this part of information because of no observation stations available.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relies on detailed information (as described above in input data) of the seven DRASTIC parameters. Based on the information described above, the maps of seven parameters of the DRASTIC indexes were generated using GIS ARC/INFO, during the mission of Dr. Yang Qing (DUT) to LNEC, Lisbon, held July, August and September 1998.

In the Third Year Progress Report (LOBO-FERREIRA, 1999) a paper entitled **Assessment Of Groundwater Drastic Vulnerability To Pollution Using GIS** was presented, written during the third year of the Project, aiming the presentation of the achievements on groundwater vulnerability modelling and the corresponding Dalian Peninsula application. The paper (*cf.* YANG, LUAN and LOBO-FERREIRA, 1999) was published in the Proceedings of EPSMESC VII International Conference on Enhancement and Promotion of Computational Methods in Engineering and Science, held in Macau, August 2-5, 1999.

Dr. Wang Guoli from DUT visited Birmingham University during two months from April 99 to June 99.

- **South China University of Technology, Environmental Science Institute, established in P.R. China**

Prof. Zhang Xiujuan, Dr. Yin Hua Wan and Dr. Xiangde Wang  
Environmental Science Institute  
South China University of Technology (SCUT)

The second study area, Figure 2, is centred on Huadu, a satellite city of Guangzhou, Guangdong Province, which is located approximately thirty kilometres to the south. It is contained within the Pearl River delta and thus there is an abundance of surface water. The area is developing rapidly and has been stated to have ‘potential for further development in the next decade’ (WAN *et al.*, 1998). Data collected by LECM as part of Work Package 3, for the characterisation of the water supply, wastewater and solid waste infrastructure, indicates that only 75% of the population were connected to a water supply network in 1998. However, a goal of the planned development is to have the entire region connected to the water supply network by the year 2000.

The study area, Figure 2, extends 36 km east to west and 30 kilometres north to south. Its population is approximately 660,000 of which 60% live in urban areas and 16% live in rural areas. The remainder is ‘semi-urban’ according to the data collected by LECM. The per capita water consumption within the area is between 100 and 200 litres per day though this is expected to rise due to industrialisation and an increase in the population. The population is rising by only 1.6% annually. It is the rapid industrialisation of the region, including the construction of a new Guangzhou airport near its eastern boundary, which is expected to have a greater effect on future water demand.

The majority of the study area is agricultural and is used for growing crops such as rice and bananas. Water supplies for these are derived directly from rainfall, the majority of which falls between April and August, and from the large surface water supplies of the Pearl River system. Though surface water is abundant, groundwater has been used for public supply due to its better quality. However, there have been problems with its withdrawal and the major part of the abstraction has recently ceased. This has been due to drawdowns at depth causing poor quality groundwater from the upper aquifer layers to leak vertically and contaminate wells. The quality of the groundwater in the upper layers is poor due to the application of agricultural chemicals.

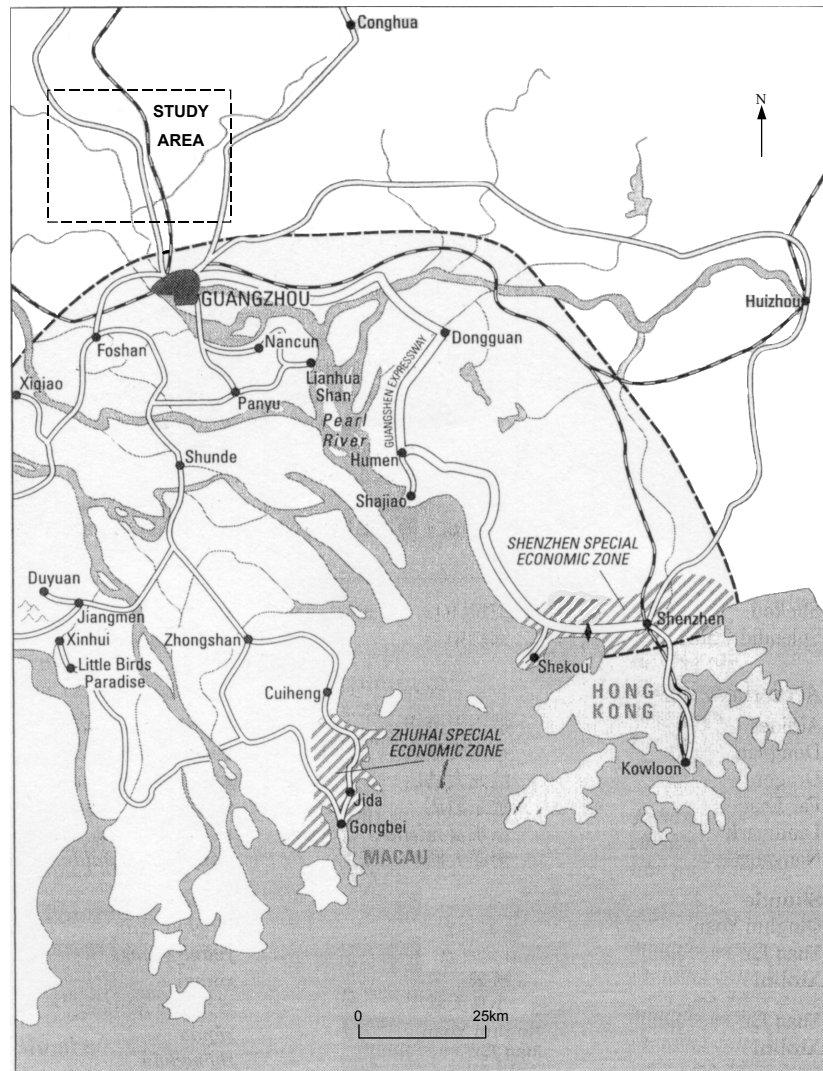
SCUT performed data collection according to the requirements set by LNEC and UoB, as previously mentioned for DUT. The data collected was stored in database INVENTOR\_PRC. Based on the information collected, the maps of the seven DRASTIC parameters as well as the final standard DRASTIC map and the final pesticide DRASTIC map, were generated using GIS ARC/INFO, during the mission of Dr. Yin Hua Wan (SCUT) to LNEC, Lisbon, from July to September 1998.



In the Second Year Progress Report (LOBO-FERREIRA, 1998) a paper entitled **Assessment of Groundwater Vulnerability to Pollution using the DRASTIC Method: A Case Study of Guangzhou-Huaxian Basin** was presented, written during the second year of the Project, aiming the presentation of the achievements on groundwater vulnerability modelling and the corresponding Guangzhou-Huaxian Basin application. The paper (cf. WAN, WANG, ZHANG, LOBO-FERREIRA and OLIVEIRA, 1999) was presented to the International Workshop held in Guangzhou, China, August 1999, and to the "Seminário sobre Águas Subterrâneas" held in Lisbon, Portugal, Dec. 1999.

Another groundwater topic researched by SCUT was **groundwater flow modelling**. This objective was thoroughly addressed during the two-month stay of Dr. Yin Hua Wan and Dr. Xiangde Wang of SCUT in Birmingham University from April to June 1999.

SCUT also co-organised with LNEC and LECM the Workshops held in Guangzhou and in Macau, during August 1999.



**Figure 2 - The Guangzhou study area**

- **Laboratório de Engenharia Civil de Macau, Hydraulics Division, Training, Documentation and Information Department, established in Macau, with the co-operation of Laboratório Nacional de Engenharia Civil, Departamento de Hidráulica, Núcleo de Engenharia Sanitária, established in Portugal**

Eng. Manuel Catarino (Former President of LECM), Eng. Luís Lamas (President of LECM), and Eng. Orlando Botelho (Head of the Department for Quality and Standardisation - Division for Sanitary Engineering)

Laboratório de Engenharia Civil de Macau (LECM)

and

Eng. Jaime Melo Baptista (Head of the Hydraulics Department)

Eng<sup>a</sup> Rafaela Matos (Head of the Sanitary Engineering Division - NES)

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Laboratório Nacional de Engenharia Civil

Departamento de Hidráulica

As mentioned in the Second Year Progress Report, Laboratório de Engenharia Civil de Macau (*i.e.* Partner 5), worked in WP3 - Sustainable Development Policies For Water Supply, Wastewater & Solid Waste Sectors - by the establishment of an agreement with the Sanitary Engineering Division of LNEC (*i.e.* Partner 1) towards the development of a study on **An Integrated Approach on Sustainable Development Policies for Water Supply, Wastewater and Solid Waste**. The activity developed was related to WP 3.2 Global and Sectorial Diagnosis of the Sector: Development of a global and sectorial diagnosis of the sector situation, based on the information gathered in the preliminary phase (3.1). Also WP 3.3 Identification of the Measures to be implemented was addressed. Based on the main issues coming from the diagnosis of the existing situation (WP 3.2) described in the Second Year Progress Report (Sept. 97 to August 98) LECM and the Sanitary Engineering Division of LNEC concluded the conceptual identification and the systematization of the necessary measures that need to be implemented, from very different nature and covering several technical and operational aspects (planning, design, construction, operation and rehabilitation), normative, economical and financial and, eventually, organisative and institutional.

The general scheme of the activities developed in Work Package WP3 can be visualised in Figure 3.

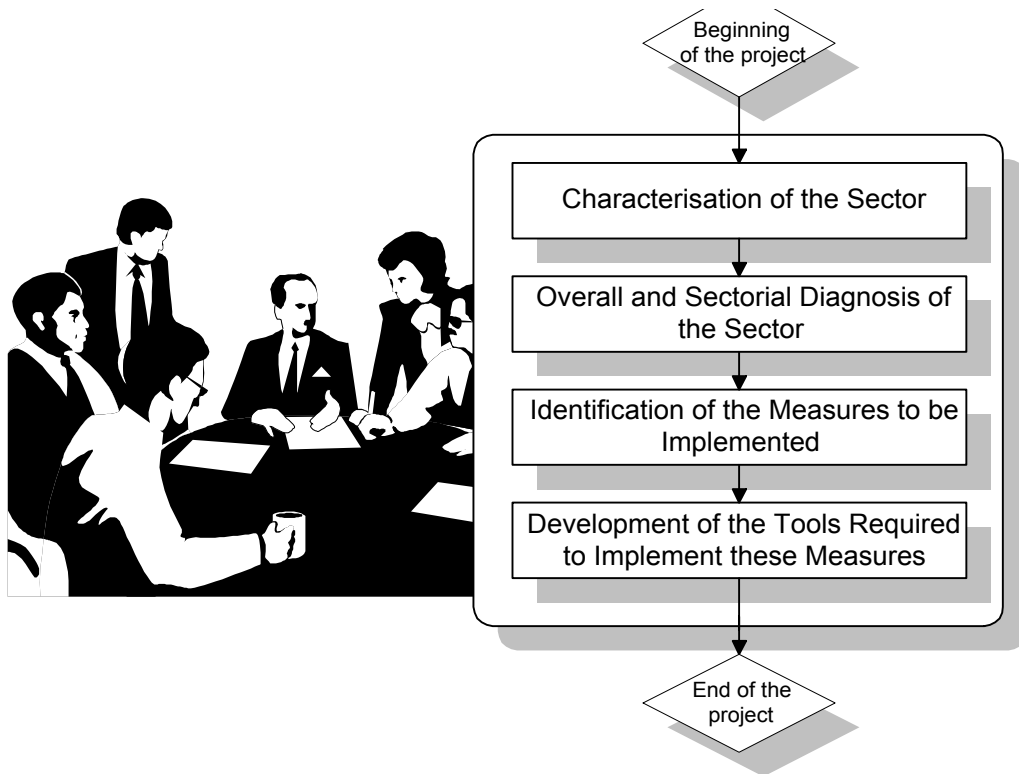
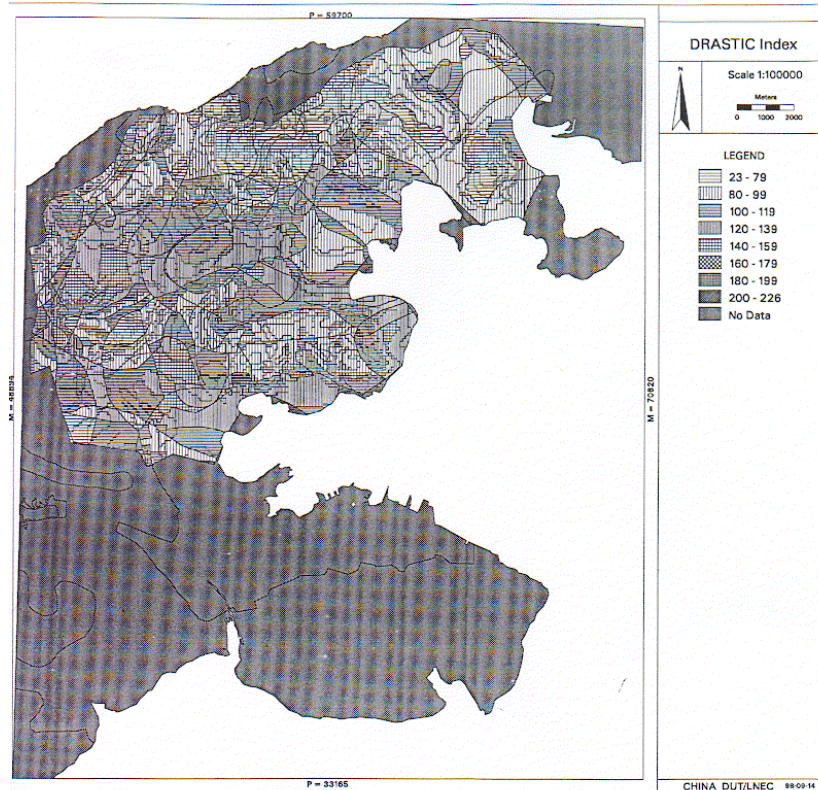


Figure 3 - General overview of the issues raised during the project on WP3

## Results achieved

- Assessment of the hydrogeological characteristics of the two case-study regions in China, storage of the information gathered in a database specially programmed for the Project (named INVENTOR\_PRC) and computation of the DRASTIC groundwater vulnerability to pollution indexes, including the assessment of information related to the seven DRASTIC parameters. Based on this information, the maps of seven parameters of the DRASTIC indexes were generated using GIS ARC/INFO. Specific descriptions on how to use GIS to obtain each index were outlined, centring around each DRASTIC parameter.
- The DRASTIC index method was successfully used by DUT and LNEC to evaluate the vulnerability to pollution of the unconfined aquifer of Dalian peninsula, P.R.China, based on the assessment of the hydrogeological conditions using GIS ARC/INFO, *cf.* Figure 4. In the Third Year Progress Report a paper entitled **Assessment Of Groundwater Drastic Vulnerability To Pollution Using GIS** was presented, aiming the presentation of the achievements on groundwater vulnerability modelling and the corresponding Dalian Peninsula application. This paper was published in the Proceedings of *EPSMESC VII International Conference on Enhancement and Promotion of Computational Methods in Engineering and Science*, held in Macau, August 1999.
- The groundwater model grid for the Dalian study area was shown in the Third Year Progress Report. The grid boundaries, which encompass the region for which data has been collected, have been located to coincide with physical boundaries where possible, *cf.* Figure 1. The model has been extended beyond the coast to allow leakage between the aquifer and the sea. Due to the unreliability of the abstraction data and the fact that the water level data is significantly affected by abstraction, matching modelled and historic heads is neither feasible nor appropriate. The difficulty in model 'calibration' is predominantly due to considerations of data quality, particularly with regard to recharge and abstraction. Furthermore, sensitivity analysis should follow calibration to provide an understanding of the important features of the system, the relative effects of parameter variation on the system and to identify any weaknesses in the model or input data. Initially, sensitivity analysis has involved investigating the effect of parameter variation on the regional groundwater levels, stream-flows and freshwater outflows at the coast. As a starting point abstraction has been neglected. This allows an examination of the groundwater system under natural conditions and removes the complicated effect of abstraction, the data for which appears unreliable. However, sensitivity analysis involving groundwater abstraction has begun and we suggest it to be continued, even after the conclusion of the Project. Sensitivity analyses of the soil moisture balance and groundwater models has led to an estimate of average groundwater recharge of 0.44 mm/d. This gives 110 MI/d of water entering the aquifer in the study area. As the average abstraction for the area is approximately 61 MI/d this is equivalent to 55% of the recharge. This is close to the figure quoted by DUT in the second year report of 57%. However, the groundwater model is sensitive to recharge and estimates are difficult to verify as groundwater levels are significantly affected by abstraction.
- It was difficult to compare the model runs directly with the collected data because abstraction is not included in the model. Therefore a set of simulations have been carried out which do include abstraction. The abstraction is varied as a percentage of the total recharge and the volume of saline water drawn into the aquifer is calculated. The average saline concentration of the abstracted groundwater is estimated by assuming that either the saline water arrives at all the abstraction wells or at just the 30 coastal wells. Two simulations were run for each scenario, first with the abstraction distributed in a pattern similar to the available data and secondly with a uniform distribution between the 165 wells. The model transmissivity is 100 m<sup>2</sup>/d and the long-term recharge is 0.43 mm/d. The results of the simulations are presented in an annex to this Final Report, *i.e.* in JACKSON and SPINK (1999a). The most obvious result is that if pumping is uniformly distributed between the wells the volume of saline water drawn into the aquifer is significantly reduced. Simulated TDS concentrations in the wells are approximately 10 times lower when the abstraction is uniformly distributed. With the historic abstraction of 60.75 MI/d distributed as in the field, the TDS concentrations range from 1.9 and 13.0 g/l. The simulated groundwater head contours for this model are shown in Figure 5.
- As for the Dalian case-study area, the DRASTIC index method was also successfully applied to evaluate the vulnerability to pollution of the unconfined aquifer of Guangzhou-Huaxian Basin. In the Second Year Progress Report a paper entitled **Assessment of Groundwater Vulnerability to**

**Pollution using the DRASTIC Method: A Case Study of Guangzhou-Huaxian Basin** was presented. This paper was presented to the International Workshop held in Guangzhou, China, August 1999, and to the "Seminário sobre Águas Subterrâneas" held in Lisbon, Portugal, Dec. 1999. In Figure 6 the DRASTIC groundwater vulnerability to pollution map of the Guangzhou-Huaxian Basin is presented.

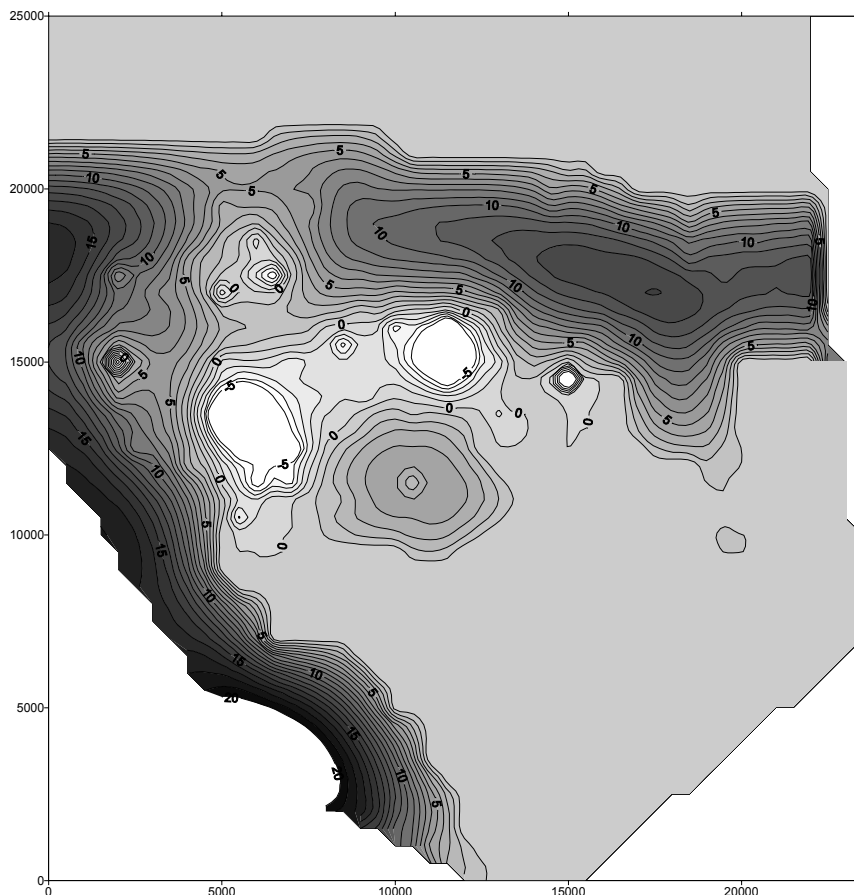


**Figure 4 - Dalian peninsula study-area map of DRASTIC groundwater vulnerability to pollution**

- The groundwater model grid for the Guangzhou study area was shown in the Third Year Progress Report (LOBO-FERREIRA, 1999). Due to the lack of geological data on vertical sections the aquifer was modelled as a closed system. Boundaries have been based on geological features where possible, for example the granite outcrop in the north, but some have been determined from assumed groundwater flow patterns.
- Groundwater flow patterns have been extrapolated to certain regions, as data coverage is incomplete. The only route for groundwater to leave the system is through the river network, which is modelled as a leakage process. Initial sensitivity analysis has been carried out on the model and we suggest it to be continued, even after the conclusion of the Project. Similar regional groundwater head profiles can be simulated with models that have different parameters. Determining how much recharge enters the aquifer system is therefore an important task. Sensitivity analysis applied to the recharge model indicates that 0.6 mm/d is probably an underestimate of recharge. With this recharge rate, a transmissivity of approximately 3000 m<sup>3</sup>/d is required to produce modelled heads that approach those observed in the field. This transmissivity is twice that calculated from pumping test analysis. As groundwater heads are not significantly affected by groundwater abstraction a comparison between groundwater level and recharge has been made.
- A paper on **Local Grid Refinement using Object-Oriented Programming**, specially prepared for the Project's August 99 Workshop held in Macau was presented in Annex 2 of the Third Year Report (cf. JACKSON and SPINK, 1999b). The flexibility of the new modelling approach, a finite difference grid of a Guangzhou-Huadu basin model using ZOOM2D, is shown in JACKSON and SPINK (1999a). Figure 7 shows the whole model domain. In JACKSON and SPINK (1999a) two aspects of the use of regional groundwater models in the operational management of aquifers are

addressed. An example of a decision-making framework for the management of short-term groundwater abstraction is presented. Such a framework would help significantly in the regulation of the Guangzhou-Huadu and Dalian aquifers. Whilst it is formulated as a rigid set of steps the method is flexible enough to prevent detrimental environmental impacts on the aquifer. This arises because the procedure requires a regular review of the state of the aquifer. There is a particular need for such a framework in the Dalian region because groundwater is a critical resource. Unmanaged abstraction will continue to degrade the quality of the groundwater. This is occurring now (Personal Communication, Zhou Jiti, 1999), and it is thus imperative to develop a similar management strategy. If this is not carried out other water resources may have to be located and developed. A model has been developed which can be used as the basis for such a decision-making framework. The new model overcomes many limitations of conventional models when small-scale features have to be represented accurately. ZOOM2D is capable of modelling wells at the scale of the borehole whilst still simulating groundwater flow in a regional aquifer efficiently. This is required in both regions. In the Guangzhou-Huadu study area well drawdowns must be modelled in detail to represent accurately the vertical leakage of contaminated groundwater in the upper Quaternary deposits. In the Dalian study area a dense mesh is required to represent abstraction and the distribution of saline intrusion accurately. These tasks are easily performed with the new model, which represents a state of the art technology.

- Presentation of two lectures in DUT by Chris Jackson (UoB) on *"The Application of Simulation-Optimisation Models to Coastal Groundwater Management"* and *"Data Requirements for Groundwater Modelling. A case study"* and of another two lectures by Manuel Oliveira (LNEC) on *"Groundwater Recharge Assessment Methodologies"* and *"Groundwater Vulnerability Mapping using Geographical Information System (GIS)"*, during their mission to Dalian held January 1998.



**Figure 5 - Simulated groundwater head contours with historically distributed abstraction (60.75 Ml/d)**

- Further scientific know-how exchange achievements: (1) a document presented in the Third Year Progress Report entitled ***Methodologies For Minimizing Environmental Impacts And For Monitoring Groundwater In Landfills*** was developed by LNEC during the third year of



the Project, aiming the presentation of requirements for groundwater quantity and quality monitoring on and around landfill areas; (2) a document presented in the Third Year Progress Report entitled Selected Overheads of the Conference presented by LNEC in Guangzhou and in Macau on **Storage of Groundwater Information for Use in Groundwater Models, Geographical Information Systems and as a Management Tool: <Inventor\_Prc.Mdb> Database.**

- Workshop and Scientific meeting co-organisation: SCUT and LECM co-organised with LNEC the Workshops held in Guangzhou and in Macau, during August 1999. In the Third Year Progress Report the Announcement of Guangzhou and Macau Workshops was presented. LNEC organised with the Portuguese Water Resources Association a Scientific meeting on the achievements of this Project, held in the framework of the "Seminário sobre Águas Subterrâneas", in Lisbon, Dec. 1999.

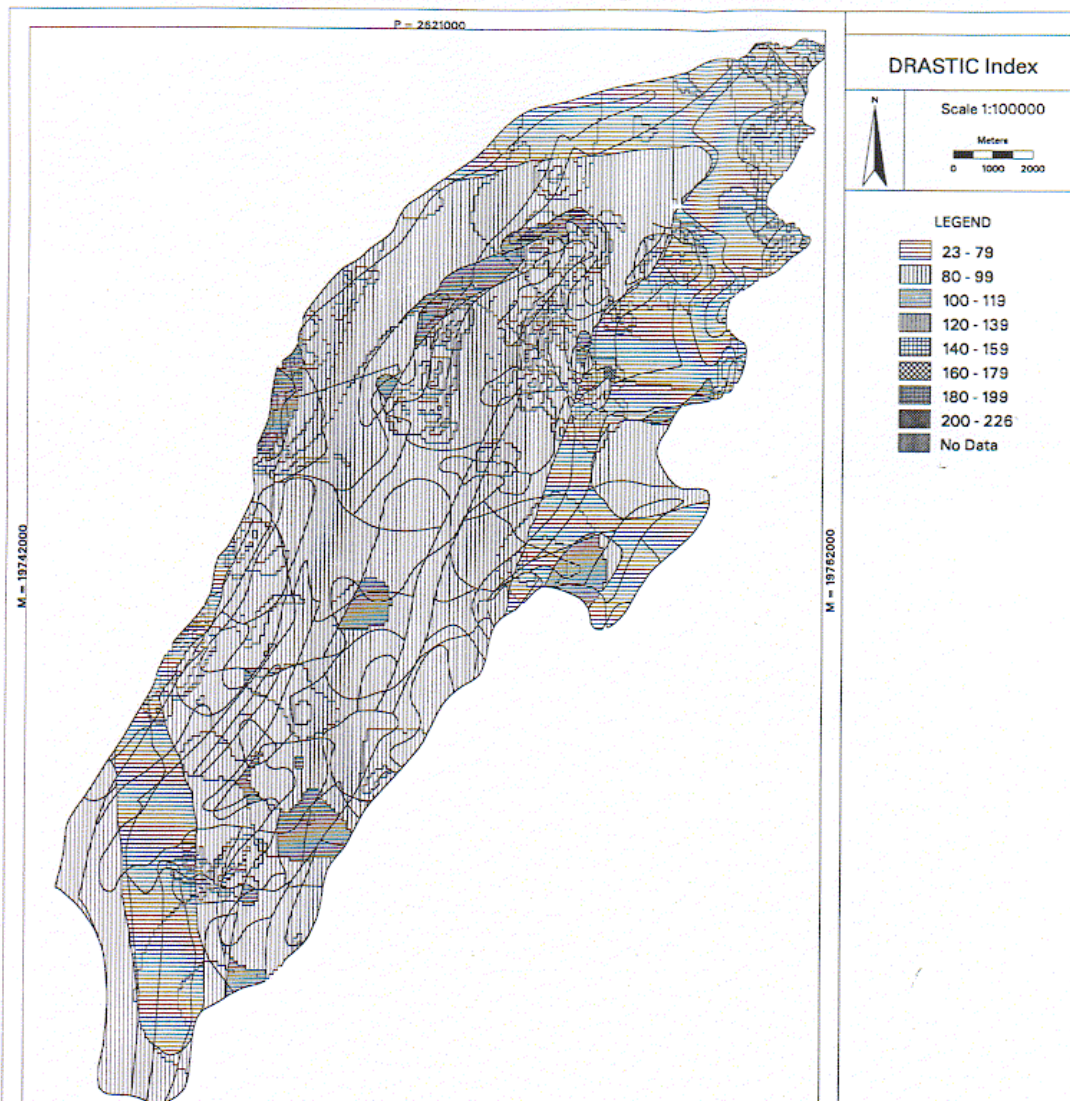


Figure 6 - The Guangzhou-Huaxian Basin map of DRASTIC groundwater vulnerability to pollution

- In the Third Year Progress Report the team presented a *Draft Contribution For Discussion* (i.e. with the Project's Chinese and Macau Partners SCUT, DUT, LECM, as well as Guangdong's Province National Environmental Protection Agency, NEPA) based on Selected Overheads of two Conferences held LNEC in Guangzhou and in Macau on **Sustainable Development Policies For The Water Supply, Wastewater And Solid Waste: An Integrated Approach for Groundwater Pollution Control and a Better Environment.** The *Draft Contribution For Discussion* describes

the conceptualisation and achievements of WP3 tasks. The detailed overview of the task raised during the Project may be seen in Figure 8.

## Application of results

The methodological and scientific achievements of the Project were carried out based on the models calibrated in case-study areas of the UK (by UoB for Work Package 1) and of Portugal (by LNEC for Work Package 2). These achievements were afterwards applied to the two case-study regions of China, *i.e.* Dalian and Guangzhou.

Dalian is the one of fastest developing city of China and has high potential for future development in the next decade. Based on the programme of Dalian industrial and economic development, a GDP of 230 billion yuan will be reached in 2000, a GDP of 507.2 billion yuan will be reached in 2010. At the same time, the demand for water of Dalian will be of greater growth rate. The water demand of Dalian City will be 623.42 million cubic meters in 2000, and it will be 935.2 million cubic meters in 2005.

As an important opening city of China, Dalian is short of water resources. The natural water resources per person is only 334 cubic meters annually. This value is about 12.4 percent of average of the whole China. Groundwater represents about 19.34% of the total volume of water resources used in Dalian peninsula for domestic, industrial and agricultural purposes. Due to the artificial pollution in some extent and saline intrusion, the groundwater of the area is heavily contaminated with for example carbonic acid and chloride. The deterioration of groundwater quality gets serious. It represents therefore a strategic resource whose management and protection, both from quantitative and from qualitative points of view, should be appropriately considered at high level.

Pollution problems have led to a growing public awareness of the environment during the recent years. Groundwater pollution is of particular concern, as large quantities of drinking water are supplied by groundwater abstraction. Due to the growing industrialisation and the growing waste problem as a consequence, more and more problems with groundwater are arising.

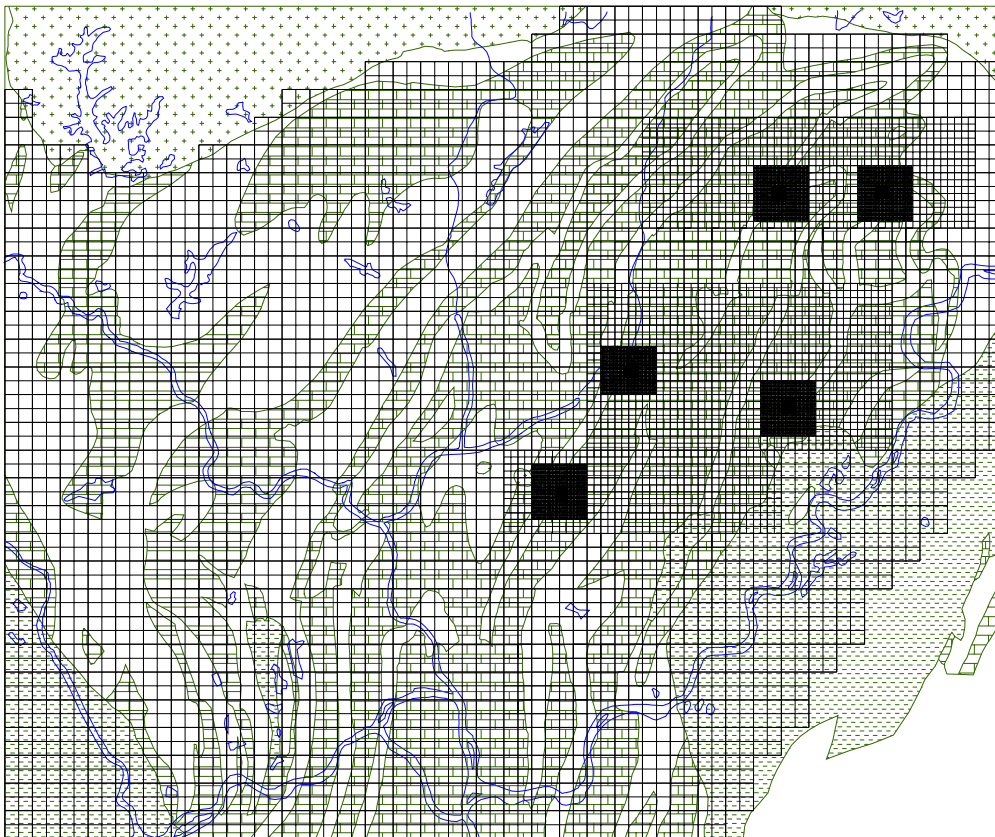


Figure 7 - SCUT study area refined mesh

The results achieved in this Project helped the identification of areas, which are more or less vulnerable than others. This delineation allows administrators to direct their resources to those more vulnerable areas where it is more critical to manage the limited resources in a wisely way. Therefore, the assessment of vulnerability to pollution of Dalian Peninsula is important to determine feasible strategies to protect the groundwater and prevent the pollution of groundwater in the future. Also it can help to mitigate some of the problems which have been created in the past. Because prevention is the key to ensure that future practices do not result in groundwater contamination, it is now more important than ever to use planning and management tools to help recognise the places where certain activities pose a higher risk to the very limited groundwater resources of Dalian peninsula.

The formulation of an optimisation algorithm was applied to the Dalian Peninsula. There is no constraint placed on the river flows. Whilst maintaining a minimum river flow is often important, the most serious consideration in the Dalian region is to prevent saline intrusion. Currently, because of poorly managed abstraction, the rivers are often dry. However, this is not serious when compared to the need for sustainable groundwater resource management. The optimisation objective researched in Dalian's case study was the minimisation of the cost of transporting water from the wells to the demand centre.

For similar reasons to those in the Guangzhou-Huadu basin study, the groundwater flow model of the Dalian aquifer does not yet reproduce the field behaviour adequately. This is due to limitations in the hydrogeological data and the lack of historic water level data against which to compare the simulated model output. Consequently, the results from the optimisation model, which is linked to the simulation model, cannot provide optimal patterns of abstraction on which to base real management strategies at this stage. However, whilst the examples in this Project are presented to illustrate the application of the optimisation model, they do show that saline intrusion can be reduced significantly by redistributing the abstraction.

The simulated groundwater heads based on the optimised patterns of pumping are shown in JACKSON and SPINK (1999a). The simulated groundwater heads based on the current abstraction pattern are shown in Figure 5. This shows the large cones of depression around the major abstraction wells located close to the coast. The largest of these drawdowns is caused by a dominant single well abstracting approximately 4.5 Ml/d. This pumping rate is certainly too great for a single well close to the coast. The simulated groundwater heads based on the optimised pumping patterns show a significant difference from the historic groundwater levels. The optimisation redistributes the abstraction wells relatively uniformly over the study area. As each well has been constrained to pump at the same rate, no major cones of depressions are produced. This does not have to be the case and pumping rates can be optimised by the program. In addition, certain wells can be fixed and a subset of the wells optimised if required. Thus the optimisation model is flexible enough to examine a number of scenarios based on decisions made by planners and water resource engineers.

## **Problems encountered**

No significant scientific and methodological problems have been encountered during the project, which could not be overcome by discussion and know-how exchange among the partners.

Major problems, related to data gathering and availability, could be successfully overcome by the end of 1997 and/or during the beginning of 1998, after fruitful contacts established between DUT and SCUT with local and regional authorities in Dalian and Guangzhou.

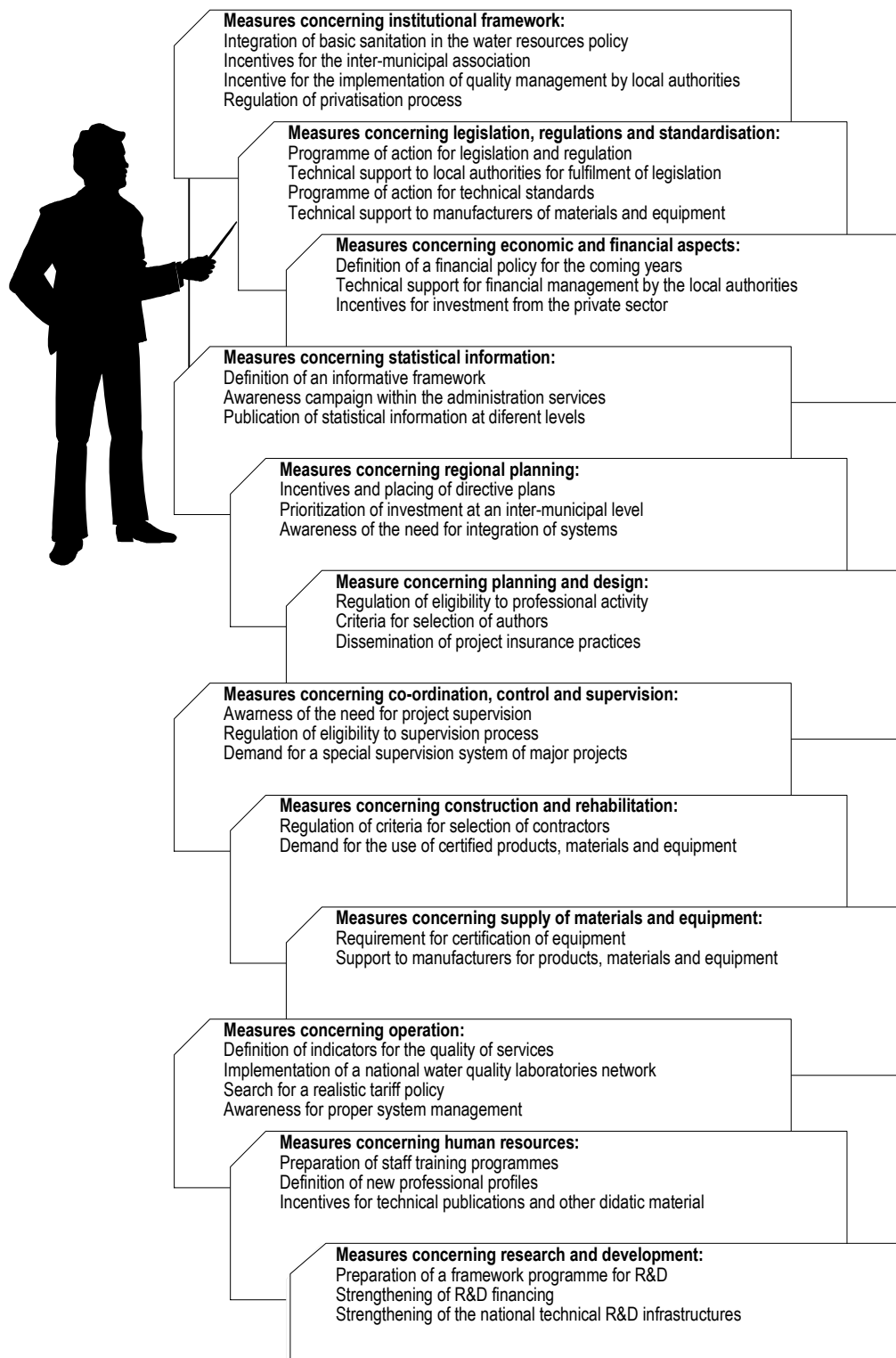
## **Technology implementation plan**

Two workshops and a scientific meeting were co-organised by the EU and the Asian partners: a three days regional Workshop held in Guangzhou, August 1999, a one day international workshop held in Macau, August 1999, and a scientific one day meeting held in Lisbon, Dec. 1999. Aiming the know-how transfer necessary for regional Chinese implementation of the results achieved during the Project, invited participants to the Guangzhou Workshop were selected from the *end-user* Guangdong's Province National Environmental Protection Agency (NEPA).

The results addressed in this Project can also be used by the Dalian authorities to protect and manage groundwater resources in the next years in a rational way.



**EC-DGXII INCO-DC PROGRAMME 1996-1999 - Contract N. IC 18CT960048**  
**“Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. EU - PRC Coastal Groundwater”**



**Figure 8 - Detailed overview of the issues raised during the project on WP3**

## **Publications and papers**

- 1) OLIVEIRA, M. M and LOBO-FERREIRA, J. P. (1997, in First Year Progress Report) - "Development of Methodologies for the Assessment and Management of Groundwater Resources

**EC-DGXII INCO-DC PROGRAMME 1996-1999 - Contract N. IC 18CT960048**  
***“Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. EU - PRC Coastal Groundwater”***

and Risks in Coastal Zones. LNEC Contribution for the 1st Year Progress Report". Lisboa, LNEC, Relatório 224/97-GIAS.

- 2) LOBO-FERREIRA, J. P. (1997) - "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. 1st Year Progress Report: September 1, 1996 to August 31, 1997 - EC-DGXII, INCO-DC Contract No. IC 18CT960048". Lisboa, LNEC, Relatório 233/97-GIAS.
- 3) JACKSON and SPINK (1997, in First Year Progress Report) - "Interim report of work package WP1. Management policy and optimisation mathematical tools". The University of Birmingham, School of Civil Engineering, August 1997.
- 4) OLIVEIRA, M.M. and LOBO-FERREIRA, J.P. (1998) - "Cartografia Automática da Vulnerabilidade de Aquíferos com Base na Aplicação do Método DRASTIC". Comunicação apresentada ao 4º Congresso da Água, organizado pela APRH, Lisboa, Março de 1998.
- 5) LOBO-FERREIRA, J.P. (1998) - "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. 2nd Year Progress Report: September 1, 1997 to August 31, 1998 - EC-DGXII, INCO-DC Contract N° IC 18CT960048". Lisboa, LNEC, Relatório 275/98 - GIAS.
- 6) OLIVEIRA, M. M and LOBO-FERREIRA, J. P. (1998, in Second Year Progress Report) - "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. LNEC Contribution for the 2nd Year Progress Report". Lisboa, LNEC, Relatório 276/98-GIAS.
- 7) JACKSON and SPINK (1998, in Second Year Progress Report) - "Development of methodologies for the assessment and management of groundwater resources and risks in coastal groundwater. Second year report". The University of Birmingham, School of Civil Engineering, September 1998.
- 8) LOBO-FERREIRA, J.P. (1998a, in Third Year Progress Report) - "Development of Methodologies for the Assessment and Management of Groundwater Resources in Coastal Zones", in LOBO-FERREIRA, J.P. and TILAK-VIEGAS, F.J. (Ed.) (1999) - "Proceedings of the S&T Co-operation with Asia in the Area of Sustainable Management of Natural Resources". A Co-ordination Meeting, China 1998. Beijing, P. R. China, Nov. 24-27, 1998. Lisboa, LNEC, CD-ROM.
- 9) YANG, Q., LUAN, M., LOBO-FERREIRA, J.P. (1999, in Third Year Progress Report) - "Assessment of Groundwater DRASTIC Vulnerability to Pollution using GIS", in Proceedings of the "International Conference on Enhancement and Promotion of Computational Methods in Engineering and Science (EPMESC VII)", held in Macau, 2-5 August, 1999, Edited by BENTO, J., ARANTES e OLIVEIRA, E. and PEREIRA, E. (1999), Elsevier, Amsterdam.
- 10) LEITÃO, T.E. and LOBO-FERREIRA, J.P. (1999, in Third Year Progress Report) - "Methodologies for Minimising Environmental Impacts and for Monitoring Groundwater In Landfill Areas". Paper presented to the International Workshop of the Project "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. EU - PRC Coastal Groundwater", organised by LNEC, LECM and SCUT, in Guangzhou, PR China, August 2-4, 1999, in Macau, August 5, 1999, and to the "Seminário sobre Águas Subterrâneas", organised by the Portuguese Water Resources Association (APRH), in Lisbon, Portugal, Dec. 15-17, 1999.
- 11) LOBO-FERREIRA, J.P. (1999) - "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. 3rd Year Progress Report: September 1, 1998 to August 31, 1999 - EC-DGXII, INCO-DC Contract N° IC 18CT960048". Lisboa, LNEC.
- 12) WAN, Yinhua, WANG, Xiangde, ZHANG, Xiujuan, LOBO-FERREIRA, J.P. and OLIVEIRA, M. (1999, in Second Year Progress Report) - "Assessment of Groundwater Vulnerability to Pollution using the DRASTIC Method: The Case Study of Guangzhou-Huaxian Basin, P.R. China". Paper presented to the International Workshop of the Project "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. EU - PRC Coastal Groundwater", organised by LNEC, LECM and SCUT, in Guangzhou, PR China, August 2-4, 1999, and to the "Seminário sobre Águas Subterrâneas", organised by the Portuguese Water Resources Association (APRH), in Lisbon, Portugal, Dec. 15-17, 1999.

- 13) WAN, Yinhua, WANG, Ming, WANG, Xiangde, ZHU, Bin and ZHANG, Xiujuan (1999, in The Final Report) - "An Introduction to Groundwater Flow Modelling". Paper presented to the International Workshop of the Project "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. EU - PRC Coastal Groundwater", organised by LNEC, LECM and SCUT, in Guangzhou, PR China, August 2-4, 1999.
- 14) JACKSON, C.R. and SPINK, A.E.F. (1999a, in The Final Report) - "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones". Contribution to the Final Year Report of The University of Birmingham, School of Civil Engineering, November 1999.
- 15) JACKSON, C.R. and SPINK, A.E.F. (1999b, in Third Year Progress Report) - "Local grid refinement using object oriented programming". Paper presented to the International Workshop of the Project "Development of Methodologies for the Assessment and Management of Groundwater Resources and Risks in Coastal Zones. EU - PRC Coastal Groundwater", organised by LNEC and LECM, in Macau, August 5, 1999, and to the "Seminário sobre Águas Subterrâneas", organised by the Portuguese Water Resources Association (APRH), in Lisbon, Portugal, Dec. 15-17, 1999.

## Travel and Visits

- The Scientific Co-ordinator of the Project, Dr.-Ing. J.P. Lobo-Ferreira, visited all partner institutions and the CE-DGXII INCO-DC Unit in 1996:
  1. Visit to LECM, Macau: May 17, 18 and 29, 1996.
  2. Visit to SCUT, Guangzhou, PRC: May 20, 21 and 22, 1996.
  3. Visit to DUT, Dalian, PRC: May 22 to 26 May, 1996.
  4. Visit to UoB, Birmingham, UK: June 4 and 5, 1996.
  5. Visit to EC-DGXII, INCO-DC Programme, Brussels: December 10, 1996.
- Mission to Guangzhou and Macau, June 1997, by Eng<sup>a</sup> Maria Rafaela Matos of LNEC/NES (WP3)
- Mission to EC-DGXII, Brussels, held October 10, 1997, by Dr. J.P. Lobo-Ferreira with the aim of presenting and describing in detail to the INCO-DC Programme Co-ordination (Dr. Tilak Viegas) the First Year Progress Report of the Project.
- Mission of Mr. Christopher R. Jackson (UoB, United Kingdom) to LNEC, Lisbon, during January 1998.
- Mission of Mr. Manuel M. Oliveira (LNEC, Portugal) and of Mr. Christopher R. Jackson (UoB, United Kingdom) to the P.R. of China, Dalian (DUT) and Guangzhou (SCUT), held January 18th to 24th, 1998. In the Annex of the Progress Report of the 1st Semester of the 2nd Year a detailed description of this mission was presented.
- Mission of Dr. J.P.Lobo-Ferreira (LNEC, Portugal) to the P.R. of China, Pearl River region (SCUT) during April 1998.
- Mission of Dr. J.P.Lobo-Ferreira (LNEC, Portugal) to the P.R. of China, Dalian Peninsula (DUT) during July 1998.
- Dr. Yang Qing (DUT) mission to LNEC, Lisbon, during July, August and September 1998.
- Dr. Wan Hin Hua (SCUT) mission to LNEC, Lisbon, during July, August and September 1998.
- Mission of Mr. Christopher R. Jackson (UoB) to LNEC, Lisbon, during September 1998.
- Meeting of the INCO-DC Programme Co-ordination (Dr. Tilak Viegas) with Dr. J.P. Lobo-Ferreira (LNEC) and Prof. Jiti Zhou (DUT) in Beijing, P. R. China, November 1998.
- Dr. Wang Guoli from DUT, along with Dr. Wan Hin Hua and Dr. Xiangde Wang from SCUT visited Birmingham University during two months from April 99 to June 99.
- Mission of Dr. Lobo-Ferreira, Mr. Manuel Oliveira, Dr. Teresa Leitão (all LNEC), Mr. Mr. Christopher R. Jackson (UoB), Prof. Jiti Zhou, Dr. Yang Qing, Dr. Wang Guoli (all DUT) to Guangzhou in August 1999.
- Mission of Dr. Lobo-Ferreira, Mr. Manuel Oliveira, Dr. Teresa Leitão (all LNEC), Mr. Mr. Christopher R. Jackson (UOB), Dr. Yang Qing (DUT) to Macau in August 1999.
- Missions of Dr. Andrew Spink (UoB) and of Dr. Wan Hin Yua (SCUT) to Lisbon, Dec.1999.

## Conclusions

The characteristics of hydrogeology and groundwater resources of Dalian Peninsula were researched in this Project and an assessment of groundwater vulnerability to pollution of the aquifers in a selected case study area of Dalian Peninsula was evaluated both for fertilisers and for pesticides based on the

DRASTIC index method. Based on the information collected and stored in the database INVENTOR\_PRC, specially programmed for this Project, and in GIS, the DRASTIC index was calculated. Figure 4 shows the standard vulnerability to pollution map of Dalian peninsula's unconfined aquifer. It may be observed that the standard DRASTIC index ranges from 55 to 161, therefore indicating that the standard vulnerability of the aquifer is *“low to medium vulnerability”*. These values just have a relative meaning as the DRASTIC index provides only a relative evaluation tool and is not designed to provide absolute answers. For example, DRASTIC does not reflect the suitability of a site for waste disposal or land use activities. The suitability of a waste disposal site is based not only on the groundwater pollution potential of an area, but also on other design criteria. DRASTIC provides the user with a measure of relative groundwater vulnerability to pollution and therefore, may be one of many criteria used in selecting decisions, but should not be the sole criteria. Although DRASTIC cannot be used to identify areas where pollution has occurred, it may be usable to focus clean-up efforts in those areas with the highest vulnerability to pollution potential.

In SCUT case study area, both the standard DRASTIC and pesticide DRASTIC method were applied to the confined aquifer and the final DRASTIC aquifer vulnerability maps were produced based on the information collected and stored in the data-base INVENTOR\_PRC. It was found that the index evaluated ranges from 41 to 109 using the DRASTIC mapping programme developed by LNEC. Figure 6 shows the mapping of groundwater vulnerability using the standard DRASTIC index method. As it may be seen in this map, the highest assessed value is far from the potential maximum of 226. Therefore, the confined aquifers in the case study area can be considered to have a relatively *“low vulnerability”*. For the case of pesticide DRASTIC vulnerability assessment, the index evaluated ranges from 63 to 148. The DRASTIC index of most of the study area is in the range of 105-129, only half of the potential maximum of 256. Therefore, the confined aquifers in the case study area can also be considered to have relatively *“low vulnerability”* when pesticide DRASTIC vulnerability assessment is applied. These results also suggest that the quality of groundwater in confined aquifers should be good, which is in agreement with the analytical results of the groundwater quality in the case study area.

Based on the expertise gathered during this Project, it is the opinion of the partnership that it is appropriate, with the hydrogeological data usually available in China, the application of DRASTIC groundwater vulnerability to pollution assessment to coastal and inland regions of China.

The Project also involved the development of methodologies for the sustainable operational and strategic management of groundwater resources. These methodologies have been applied to the Guangzhou-Huadu basin and the Dalian Peninsula. A number of approaches will have to be further employed in next years to assess the dimension of groundwater resources and risks to it (e.g. saltwater intrusion), in order to manage its sustainably. One approach is the use of models, which provide a means of advancing the understanding of an aquifer and of predicting its future behaviour. In this Project a systems analysis approach has been employed, based on the use of models. Models are powerful tools for the management of an aquifer. Indeed, without models it is difficult to manage the Guangzhou-Huadu and Dalian aquifers sustainably and almost impossible to manage them optimally.

Aiming the know-how transfer, necessary for regional Chinese implementation of the results achieved in the Project, invited participants to the Guangzhou Workshop were selected from the *end-user* Guangdong's Province National Environmental Protection Agency (NEPA). The Dalian authorities (to protect and manage groundwater resources in the next years in a rational way) were also invited to use the results achieved in this Project.

The outcome of DUT and SCUT teams, including the very successful missions to Portugal, held during 1998, and to the UK, held during 1999, have made this INCO-DC project a very rewarding and interesting one to the co-ordinator (LNEC) and to EU (UoB) and Macau (LECM) partners. These missions were of paramount importance for DUT and SCUT to gain expertise in the fields of groundwater vulnerability assessment, hydrogeological database programming, modelling and optimisation. This may help SCUT and DUT to continue their work, applying the know-how gathered in the framework of this Project to other study areas of China. The written acknowledgements received by the Co-ordinator (LNEC) from the Chinese partners (DUT and SCUT) on the successfully application of the researched methodologies to the case studies of Dalian and Guangzhou, indeed make this Project a *“success story”*.