Annual Report of the IGCP513
“ Karst Aquifers and Water Resources ”
China Working Group in 2007

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1. Major results of Project

Progresses of project IGCP513 achieved in the year 2007 could be summarized in line with the 4 objectives of the Project.

1) Relation of hydrology to the function and health of karst ecosystems;

Karst ecosystems are restrained by the karst environment, and especially by the karst geological setting. In karst regions, the main factors impacting plant growth are: (1) soil erosion extremely faster than soil formation, (2) suffering moisture-short in cyclicity owing to double-layer hydrogeological structure, and (3) deficiency or low availability of mineral elements in soils.

Cao Jianhua et al. studied the karst ecosystem of Guangxi Zhuang Autonomous Region constrained by geological setting: relationship between carbonate rock exposure and vegetation coverage. the percentage of exposed carbonate rocks, the arbor, bush, and grass covers were calculated for each county in Guangxi by using ArcView3.2. The results show there is significant negative correlation between arbor coverage and percentage of carbonate rock by the linear relation AC=-0.34PCR+33.75 with the correlation coefficient r=-0.75. A positive correlation can be fitted between shrub and grass coverage and percentage of carbonate rock by the linear relationship BC=0.25PCR-0.45, GC=0.03PCR+0.99 with the coefficient r=0.71 and 0.49, respectively.

Li Qiang studied the soil nutrient loss characteristics under different precipitation at the Nongla karst dynamic system monitoring site, Mashan county, Guangxi province, China. By monitoring the hydrochemical variation of local spring, the soil nutrient loss characteristics can be known under different precipitation. The result showed that the contents of K^+ and NO_3^- in Landiantang spring rapidly increased under different precipitation and the content of K^+ and NO_3^- in the spring had the positive correlation with the rainfall.According to the result, it can be known that the precipitation is the main factor that leads to the soil nutrient loss at karst area. Moreover, the content of NO_3^- in the spring had the different rule from K^+ and continued increase for a long time. The reason is that because of nitrogen mainly existing as NO_3^--N in the soil at karst area, the NO_3^- still can be lost for a long time undergoing eluviation, even when it stops raining.

Lu Yaoru et al. present the different ecosystems in main karst regions of both southern China and northern China. There are over 3,358 well-developed karst underground river systems with total discharge of about $420\times10^8 m^3$ in the main karst regions of southern China in the dry season. The exploitation rates are only 8%~15%. Over 100 larger karst spring systems in main karst regions of northern China covers the catchment area from 500 km^2 to over 4,000 km^2 each, of which the average discharge appears from about 1 m^3/s to 13 m^3/s, and the exploitation rates are 70%~80%. Some typical ecosystems in main karst regions in China were classified from six aspects: water environment, ecological features, materials and structures between parent rock and soil, bio-geological processes and karstification and related deposits. The qualitative evaluation of eco-geology and rocky desertification in karst regions should be based on the main karst ecological conditions and artificial impacts.

In karst areas, vegetation of different successions affects the soil environment, thus influencing soil microbial distribution. Shen Lina and Jiang Zhongcheng discussed microbial distribution and soil physical-chemical qualities of different succession in Nongla, Guangxi, China by the dilution plate counting method and soil essential analysis. The result showed bacteria was the dominant genus of soil microbe. Distribution of soil microbe varies obviously in different successions and soil depths. The number of soil microbe showed as A layer>B layer>C layer; compared microbe quantity in different successions, in A layer, the order is that tree layer>shrub layer>young tree layer>shrub and grass layer>grass layer; in B layer, the order is that shrub layer>young tree layer>tree layer>shrub and grass layer>grass layer.

2) Water supply in karst regions;

He Shiyi et al. (2007) calculate the natural reserves and recoverable reserves of Dalongdong Underground River Catchment, Xiangxi, Hunan by the methods of infiltration and runoff coefficient which enables us to give different coefficients according to the hydrogeological conditions and makes the results more suitable to the actual situation.

The natural runoff resources and natural reserves under the different frequency of precipitation are also calculated by the method of hydrological analysis, the results show that 2003 is the second low-water year. By methods of the statistic and hydrological dynamic analysis, the recoverable reserves under the condition of natural and factitious regulation, and the natural adjustment capacity of the system is calcualated respectively, the results indicate that the natural adjustment capacity is still smaller than capability of the estimated underground space. these results calculated by different methods，especially the recoverable reserves, have high reliability and comparability and provided the scientific data to the design of the planning reservoir.

Wu Yuexia et al. tried to simulate the process of hydrological response to precipitation of a typical karst spring, Shuifang spring, with SWMM (Storm Water Management Model) developed by EPA (Environmental Protection Agency).

Abstraction of the model was developed based on field survey, including geology and geomorphology, hydrology, coverage of soil and vegetation, main directions of

surface and underground flowpaths, cave systems, depressions and swallow holes. The catchment area and connection between swallow holes and the spring were ascertained after two dye tracing tests, each with two injection points for each one with yellow-green tracer Fluorescein and purple-red Sulforhodamine B. Analysis of dye tracing results confirmed conduit flow between one of the sinkholes in the recharge area and the outlet of the drainage system – Shuifang spring. The spring catchment was divided into 7 sub-catchments with sinkholes as junctions to drainage surface water into underground, which were connected by conduits among them. Main parameters such as area, width, slope, permeable proportion, roughness of the sub-catchments, elevations of junctions, lengths, width, cross-section and roughness of conduits, porosity of aquifer, and coefficient of laminar groundwater flows into conduits through junctions and so on, are obtained under the observation, tests and analysis in ArcGIS.

SWMM gave a good report of simulated flow rate of the spring, compared with the observed data, with errors of 9.5% and 12% for calibration and validation, respectively. Results show that SWMM is applicable in simulating a karst aquifer with conduit flow system. In addition, the empirical SCS-CN (Curve Number) model was first used to evaluate infiltration and runoff in the model in domestic karst area. Infiltration tests were also done in the study area. It showed that infiltration rates are higher than that of a non-karst area.

3) Water-related environmental problems in karst regions;

Urbanization has been developing rapidly along with the blooming of the economy in China. In 1980s, the number of medium size cities increased from 180 to about 400, but in 2000, it was already 666, with 32 of them having population more than a million. The course will speed up in the next decades, because the government takes urbanization as one of the strategic measures for economic development, and to reduce the difference between developed and poor regions.

Yuan Daoxian discussed urban hydrogeology in karst regions of China in detail. For a sustainable development of cities in the karst regions of China, it is recommended: (1) to get a better understandings on the karst hydrological systems, and their difference in different parts of China (coastal, lowland, and plateau); (2) to take into account protecting scenic attractions, and ground stability while exploiting karst water resources; (3) to address properly the relationship between the land use planning and management and the protection of karst aquifers; (4) to carry out vulnerability assessment and mapping for karst aquifers.

China enjoys a broad expanse of karst, totalling 3,463,000 km^2, i.e. about one-third of its territory. Accordingly, many cities are underlain by karstic aquifers, including some important cities, such as Jinan, the capital city of Shandong province; Taiyuan, the capital city of Shanxi province; Kunming, the capital city of Yunnan province; and Guiyang, the capital city of Guizhou province. In addition to political, cultural and economic centers, the functions of the cities in the karst regions of China are various. Some cities are local industrial centers, such as Zunyi city in the north of Guizhou province, and Liuzhou city in the central part of Guangxi province. Most of

the medium and small size cities are based on local agriculture. Some of them enjoy special products, such as sugar cane (Guigang, Guangxi), tobacco (Mengzi, Yunnan), chili peppers (Qiubei, Yunnan), grapes and wine (Mile, Yunnan), and *Panax pseudo-ginseng var. notoginseng*, a species of medicinal herb (Wenshan, Yunnan). Many cities are related to the development of mineral deposits, such as cassiterite (Gejiu, Yunnan; Dachang, Guangxi), lead and zinc (Siding, Guangxi), bauxite (Pingguo, Guangxi), and coal industry, such as Jiaozuo, Henan province, and Zibo, Shandong province. On the other hand, a number of cities in the karst region are related on tourism, which enjoy particular karst features, such as Stone Forest (Lunan, Yunnan), tower karst, a type of tropical karst (Guilin, Guangxi), karst springs (Jinan, Shandong).

The exploitation of natural resources (water, land, mineral deposits, coal, and touristic attractions) benefits the urbanization of karst regions. But hydrogeological and environmental problems, even geological hazards may occur when there is an ignorance of scientific management, which need a good understanding on the karst hydrological system.

In coastal area, such as Dalian city, Liaoning province in northeast China, the extraction of groundwater from the Lower Paleozoic karst aquifers brought about sea water intrusion. In the lowland of eastern China, problems following overpumping from karst aquifers include drying up of karst springs, and karst collapses. For example, the Baotu spring and more than 70 other karst springs which used to flow out around downtown Jinan city, Shandong province with a total discharge of 300,000-350,000 m^3 per day stopped flowing in 1970s when the extraction from the Ordovician karst aquifer underlying the city was more than 270,000 m^3 per day, and brought problems to tourism. A karst collapse 9 m in diameter, and 5 m in visible depth happened in the railway station of Tai'an city, Shandong province, January 1979, right under the major railway between Beijing and Shanghai.

For cities in the plateau karst of Shanxi province in north China, and Yunnan-Guizhou provinces in southwest China, the most serious problem is the shortage of water, even with a general annual mean precipitation more than 1000 mm. The Cenozoic uplift and the development of underground drainage system made dry valley, and doline or polje the main karst landform of the region. The underground system drains away most of the rainfall and surface water. In the karst of southwest China, land and cities are usually distributed on denudation surfaces of different altitudes, which are dozens to hundreds meters higher above the local rivers and underground streams. Finding enough water sources to support the development of cities on the karst plateau is always a challenge. On the other hand, these cities are also frequented by flood and pollution problems. Cities in polje are often inundated when the relevant underground streams are not able to drain away excess water after a heavy storm. For example, Gejiu city in southeast Yunnan province, which provided most of the tin resources in China in 1950s, is located in a polje 1600 m asl. It was flooded in the rainy season of 1954, when water from the underground stream fed back through the swallow hole which used to drain surface water. Part of the polje has become a lake since the event. The Shuicheng city in western Guizhou province is

also in a polje 1800 m asl. It has developed on the bases of coal mining and steel manufactory. The industrial solid and liquid wastes have not only brought about environmental problems to the polje, but also polluted the underground hydrological systems downstream.

The influence of land use and land cover on ecological environments is a focus of global change research. Jia Yanan discussed the influence of land use change on karst water quality in Shuicheng basin,Guizhou, China. The industrial city of Shuicheng was chosen as a study site because the karst water quality around the city is deteriorating with land use and land cover change. The natural susceptibility of karst water system is an important factor leading to karst water pollution. But the change of land use and land cover is also a main factor according to the analysis of series data of the water quality and of land use change. So it is a good way to protect karst waters through rational planning and managing land use and land cover.

At present, rocky desertification is the most urgent ecological and environmental problem in southwest China, which has been paid attention to a high degree by Chinese governments and the relative scholars at home and abroad. The fragile karst ecosystem, which was formed by intensive karstification in southwest China, is the basement of the rocky desertification. However, the rocky desertification makes the ecological environments in karst areas of southwest China worse. There is not only a lack of water supplies and soils, but also frequent natural hazards, as well as low production capacity. So the local people have almost no conditions of production and life. About 17 million people are affected by the drinking water supply problem, and there are 88 state-grade poverty counties in Yunnan, Guizhou and Guangxi provinces(Jiang Zhongcheng).

Liu Hong reported the human impact on heilongtang spring, Kunming, China. Heilongtang Springs, 12 km north of downtown Kunming, is composed of three springs: Pearl spring, Qingshuitang and Hunshuitang. For a long time the springs have been a famous scenic site in Kunming city and a very important water source for the local drinking water supply and agricultural irrigation. Pearl spring and Qingshuitang spring are recharged by >20 km^2 Carboniferous-Permian karst aquifers with discharge of 82.78 L/s in the dry season and 368.5 L/s in the wet season in 1950s. With the urbanization of Kunming and environmental change in the recharge area, the quality and quantity of Heilongtang Springs has changed tremendously. Since the early 1960s, over 11,640 m^3/d of water has been exploited from the aquifer for the local water supply, which has caused the springs to run dry during the dry season and have increased turbidity during the rainy season. At present, there are still 11 pumping wells located within 1 km^2 of the springs. Hunshuitang is recharged by a basaltic aquifer with 3.75 L/s dry season discharge, which is getting dry during dry season with the water pumping for the park water supply. During October to December of 2000, Heilongtang Springs suffered a paroxysmal water pollution event, resulting in the death of *Sinocyclocheilus grahami*, an indigenous fish.

4) Aqueous geochemistry of karst aquifer/landscape systems.

Guo Fang et al. (2007) discussed the major ions in typical subterranean rivers

and their anthropogenic impacts in southwest karst areas, China. Subterranean rivers contain much of the groundwater in karst and supply many local people in southwest China. The quality of groundwater in subterranean rivers is of concern because of its sensitivity to anthropogenic activity. Groundwater samples in a rural catchment were collected at the discharge point, and the concentrations of major ions including potassium, sodium, calcium, magnesium, chloride, sulfate, nitrate and bicarbonate were analyzed in this study. Rainfall and discharge were also observed at the same time. It could be concluded from the data that the concentrations of sulfate and nitrate had a peak in the rainy season when the concentrations of sodium, calcium, magnesium and bicarbonate were low. The concentrations of potassium and chloride changed randomly throughout the year. The concentration of major ions in flood process was not completely controlled by discharge. Only the concentrations of nitrate and sulfate had obviously increased during the past two decades. It was believed that dilution, eluviation, karst erosion and anthropogenic activity can explain the ion variations and hence this study helps to understand environmental problem in karst.

Liu Zaihua et al.(2007) studied the seasonal, diurnal and storm-scale hydrochemical variations of typical epikarst springs in subtropical karst areas of SW China: Soil CO_2 and dilution effects. In this research two-year continuous pH, conductivity, temperature and water stage of the two typical epikarst springs, Nongla spring and Maolan spring (about 200 km apart) in subtropical karst areas of SW China were presented. Our primary study objective was to understand how karst systems respond hydrochemically to recharge at different time scales, and what the biogeochemical processes and controlling factors in the SW China epikarst environment are. A thermodynamic model was used to link the continuous data to monthly water quality data allowing the calculation of CO_2 partial pressures and calcite/ dolomite saturation levels on a continuous basis. Marked seasonal, diurnal and storm-scale variations were observed for pH, conductivity, CO_2 partial pressures and calcite/dolomite saturation indexes of the springs, indicating that both springs are dynamic and variable systems. However, the coefficients of variation of these hydrogeochemical features tends to be in the order of seasonal > storm-scale > diurnal. The seasonal and diurnal variations of these features (higher conductivity and lower pH in summer and at daytime; lower conductivity and higher pH in winter and at nighttime) tend to co-vary with temperature which influences the production of CO_2 in soils, thus being the driving force for the variations (soil CO_2 effect). The storm-scale fluctuations occur during the spring-summer rainy days due to the storm-events. Depending on the rainfall intensities, however, there are differences in magnitudes and direction of the variations of these features. At very high rainfall intensity, the dilution effect dominates the variations, characterized by the decrease in both conductivity and calcite/dolomite saturation of the springs, while soil CO_2 effect determines the variations at lower rainfall intensity, characterized by increase in CO_2 partial pressure and conductivity but decrease in pH and calcite/dolomite saturation. In a word, the hydrodynamic aspects together with hydrobiogeochemical characteristics need to be taken into account to correctly explain the hydrochemical variations of the epikarst springs. Results from the study demonstrate the need to

redesign hydrogeochemical sampling strategies for epikarst springs in karst areas with monsoon climate like SW China (i.e., with remarkable seasonal matching fluctuations in temperature, rainfall and vegetation).

Guo Fang et al. (2007) discuss the relation between land use and groundwater quality further, 131 water samples in Donghe catchment were collected and analyzed in the laboratory to determine K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, etc. Water temperature, pH and electric conductivity were measured in-situ. According to land-use type and pollution source, springs were divided into three types. It could be showed that the concentrations of K^+, Na^+, Cl^-, SO_4^{2-}, NO_3^-had a tendency of increase from the first type to the second type and to the third type, indicating that land use had a distinctly impact on groundwater quality. For the spatial distribution, concentrations of these ions were higher in the east, southeast and northwest parts, representing some springs had suffered from evident pollution. The land-use types in these regions were mostly paddy field, dry land and village, showing that springs here were easily affected by fertilizer and living waste. The two springs in Liuxinpo and Tongmuzhai respectively could show the impact of land use on water chemistry obviously. They had same geological condition but different land-use types, leading to difference in water chemistry. Although rural settlements and cultivated land had not made the groundwater undrinkable at present, the problem of rural drinking water safety should not be ignored at any time.

2. Scientific activities

Members from China national working group of IGCP513 are involved in 2 activities in 2007. One is the international conference on Karst Hydrogeology and Ecosystems which was held at Western Kentucky University and Mammoth Cave National Park, Bowling Green, Kentucky, USA on 13-19 August, 2007, as a joint meeting of the karst IGCP project, the Karst Commissions of the International Geographical Union (IGU) and IAH, and the Commission on the Hydrogeology and Speleogenesis of Karst Aquifers of the International Union of Speleology (IUS).

The other is karst hydrogeology workshop on 8-14 October 2007 in Southwest University, Chongqing, China.

1) Bowling Green：13-19 Aug. 2007

The conference was organized by the Hoffman Institute, Western Kentucky University and the Karst Commissions of the International Geographical Union (IGU) and IAH, and the Commission on the Hydrogeology and Speleogenesis of Karst Aquifers of the International Union of Speleology (IUS). The theme is karst geomorphology, ecosystem health and karst water resources. The conference was held at Western Kentucky University in Bowling Green, Kentucky, August 13, 14, and 15, 2007, followed by a four-day field trip (August 16-19) to the karst of the Cumberland Plateau and southern Appalachian Mountains of Kentucky and Tennessee. This is a region of stable, humid subtropical plateau karst with many of the finest caves of the eastern United States, and many karst water issues with regard to geomorphology,

ecology, and human water supply.

August 13 is for business meetings of the four groups, followed by a plenary session, followed by two days of technical sessions. This meeting follows successful meetings of IGCP 379 in 1998 and IGCP 449 in 2003, in collaboration with the other karst commissions.

More than 70 participants from 8 countries (USA, UK, China, Switzerland, Korea, Peru, Belgium and Slovenia) attend the meeting, in which 13 from China(Beijing University, Tongji University, Southwest University, Yunan University and Institute of Karst Geology, CAGS). 32 papers(9 from China)were presented in different sessions, including karst hydrogeology and underground dye tracing technology, karst ecosystem, GIS and hydrology modeling, karst and climate and human activities.

Moreover, 3 postgraduate students(1 from Karst Dynamics Laboratory, Guilin; 2 from School of Geographical Sciences, Southwest University, Chongqing) visited the field experimental site near Mammoth Cave, Bowling Green on 20-22 August after the meeting with several colleagues from Hoffman Environmental Institute, Department of Geology and Geography, Western Kentucky University.

2)Paris, France：3-10 Oct. 2007

IGCP513 co-leader Prof. Yuan Daoxian and Dr. Zhang Cheng from Institute of Karst geology, CAGS attended the UNESCO 177 Executive Board (provisional item 13) on 3-10 October 2007 in Paris, France, i.e. the proposal of the government of the People's Republic of China to establish the International Research Centre on karst (IRCK) in Guilin, China, under the auspices of UNESCO. After having received a more detailed proposal, the 35th session of the IGCP Scientific Board in February 2007, adopted Resolution IGCP/35-1, welcoming the establishment of the Centre. Therefore, under the framework of IGCP and requested by Dr. Robert Missotten, secretariat for China working group of IGCP513 prepared the necessary documentation to be submitted to UNESCO's governing bodies with assistance of China National Committee for IGCP and China Permanent Delegation for UNESCO, that is, a report by the Director-General assessing the feasibility of the proposal, supplemented by Annexes containing the draft agreement between UNESCO and the government of China concerning the proposed centre. The 177 Execitive Board (FA and PX) approved the report proposed by Director-General on the feasibility assessment for the establishment and functioning of the IRCK in Guilin, China and adopted the document 177EX/13, and recommends to the General Conference at its 34th session to approve the establishment of the International Research Centre on karst in Guilin, China, as a Centre under the auspices of UNESCO (category 2) and to authorize the Director General to sign the Agreement presented in Annex II of document 177EX/13.

3) Southwest University, Chongqing:：8-14 Oct. 2007

Chongqing karst hydrogeology workshop at Southwest University was

co-organized by China working group of IGCP513, School of Geographical Sciences and Karst Dynamics Laboratory, MLR joint with China Environmental Health Project(CEHP). 11 faculty (mainly from USA, such as Western Kentucky University, the Pennsylvania State University), and more than 80 participants from Southwest University, Karst Dynamics Laboratory, MLR, Guizhou Normal University, Sichuan Normal University, Guilin College of Technology attend the workshop. Dr. Chris Groves made a description of CEHP(history and goals) and the framework for karst water quality investigations; 2 key presentations entitled on karst and related water resources problems of southwest China, Geomorphology and karst hydrology introduction respectively were given by Prof. Yuan Daoxian and Prof. William White. 7 other sessions also were presented during the workshop, including carbonate geochemistry, karst water flow monitoring, statistical analysis, water quality (contaminations, method of analysis, remediation), groundwater sensitivity mapping/land use mapping, social science aspects related to rural development. Field trip was organized on 10 Oct. and 14 Oct., including placement and collect of receptors, dye injection, data analysis and interpretation.

4) Investigations in Yunnan and Guilin, China

Benefited from the implementation of IGCP513, two bilateral cooperation projects (Sino-USA and Sino-Switzerland) were carried out continuously in the year 2007.

One is Sino- Switzerland student-exchange project started from August last year., which focused on groundwater tracing test and vulnerability mapping. Dr. Nico Goldscheider from Neuchâtel Hydrogeological Centre, Neuchâtel University, Switzerland, and his student Vu Thi Minh Nguyet from Research Institute of Geology and Mineral Resources (RIGMR), Hanoi, Vietnam visited Guilin (Karst Dynamics laboratory, MLR) on 15-19 October 2007, and gave 2 lectures on karst groundwater quality /microbiology and new method for aquifer vulnerability mapping. They also visited the Maocun and Yaji experiment sites near Guilin and had an on-site discussion with Chinese colleagues on dye tracing test that was carried out during the last co-investigation, as well as other discussions concerning several aspects of cooperation between two institutions, including the way involved in the project 513, student exchange plan, feasibility to develop a new vulnerability mapping approach widely used for karst erea around the world.

Another is Sino-USA project, a part of AID(USA Agency of International Development) China Environmental Health Project, started from October last year. The major emphasis of this work is US-Chinese University collaboration in developing solutions to public health challenges in China, and in the efforts on the Project related to water resources. In year 2007 it focused on the cave expedition and groundwater resource investigation and dye-tracing test in Mengzi Basin, Yunnan Province, China. A co-expedition was carried out in the above-mentioned region on 28 Feb. to 18 march 2007, 16 people from USA(8), China Southwest University(6) and Karst Dynamics Laboratory(2), MLR were involved in the co-expedition.

3. Work plan of year 2008

(1) Carry out Sino-USA and Sino-Switzerland cooperation projects continuously.
(2) Combination with China Geological Survey Project: study on key geo-environmental problems and their countermeasure, to investigate the typical underground rivers in southwest China karst areas, including the distribution features, water quality and quantity variations during the past 2 decades and their controlling factors, contamination and its relationship with human activities, et al. underground river database will be established and aquifer vulnerability mapping will be carried out in typical underground river basins of southwest China in the year 2008.
(3) Take part in IGCP513 working group meeting at the annual Geological Society of America meeting on 28-31 October 2008 in Denver, Colorado, USA.
(4) Organizing the national working group meeting scheduled in October 2008 in Guilin Institute of Karst Geology, CAGS.

4. List of important publications

(1) Guo Fang, et.al.. 2007. Major ions in typical subterranean rivers and their anthropogenic impacts in southwest karst areas China.Environmental Geology. 53(3): 533 - 541
(2) Guo Fang, Jiang Guanghui, Xia Qing et al. 2007. Hydro-chemical variation of karst groundwater under the impact of land use in Donghe catchment, Hunan. Carsologica Sinica. 26(3): 212-218
(3) He Shiyi1, Zhou Jingzhong, Zeng Feiyue. 2007. Assessment on the Karst Water Resources of Dalongdong Underground River Catchment, Xiangxi, Hunan. Hydrogeology & Enginering Geology. 34(5): 33-36
(4) Liu Zaihua,Li Qiang, Sun Hailong,et.al.2007. Seasonal, diurnal and storm-scale hydrochemical variations of typical epikarst springs in subtropical karst areas of SW China: Soil CO_2 and dilution effects. Journal of Hydrology. 337: 207–223
(5) Yuan Daoxian. 2006. The Development of Modern Karstology in China. Geological Review. 52(6): 733~736
(6) Zhang Cheng, Jiang Yongjun, Lian Yanqing, et.al. 2007. Rainfall runoff simulation of a typical karst fengcong depression system using SWMM model. Hydrogeology & Enginering Geology. 34(3): 10-14