International Symposium and Field Seminar on
Karst Waters & Environmental Impacts

Abstracts

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ON
KARST WATERS & ENVIRONMENTAL IMPACTS

September 10 - 20, 1995
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KEYNOTE PAPER

Legal aspects of karst areas and insurability

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Sensitive environmental impacts in karst settings are common and are more distinctive than those in other rock terrains. Human changes in karst hydrology regimes can trigger numerous legal activities where the effects of changes go beyond property boundaries. Regulatory procedures that are applicable in other rock terrains are not necessarily suitable for karst settings.

A predominant dependence on water from wells and springs in the numerous scattered karst regions of the world requires careful water and waste management policies that are closely related to legal issues. In contrast to the widespread abundant water supplies in the confined karst region of Florida and Georgia, USA, are the restricted and localized zones and springs in the common mature surface karst of many other regions. Both types of karst regions have complex legal implications involving hundreds of billions of dollars. Damages to karst water supplies can be permanent and costly.

Numerous lawsuits develop: (1) from lowering of water levels beneath wide areas in permeable karst settings and (2) from selective flow paths of subsurface water that are not easy to determine. Excessive withdrawal of water for municipal and industrial use may readily affect competitively the water supply in surrounding areas. Springs and well water are prone to contamination in water-table karst areas.

The risks of lawsuits are high near buildings and roads in sinkhole-prone areas, especially where water levels are lowered appreciably by pumping. Insurance policies against personal and property damages as a result of dynamic karst actions may be restrictive because of uncertainties resulting from human and natural actions related to water. Case histories of karst environmental problems need to be compiled and sorted so that probability assessments of future damaging actions can be considered and refined in a Bayesian framework. Skillful knowledge of karst hydrogeology is needed for legal activities and for applicable regulatory procedures.

Various environmental regulations that apply to all terrains are helpful in protecting acceptable karst settings; yet, local ordinances that are especially applicable to local conditions are proper. Some sensitive actions by humans in heavily populated karst areas will continue to keep karst problems at a high level. Vulnerability and sensitivity maps that express some cause and effect relations are needed for all karst settings.
The COST Action 65 "Hydrogeological Aspects of Groundwater Protection in Karstic Areas" is a joint scientific research project of 16 European countries (Austria, Belgium, Croatia, France, Germany, Hungary, Ireland, Italy, Malta, Portugal, Slovakia, Slovenia, Switzerland, Spain, Turkey and United Kingdom) in the domain of karst aquifer protection. In spite of the fact that from karst aquifers emerge huge amounts of high-quality potable water except in some European areas, mainly in Mediterranean and Alpine countries, the karst groundwater has not an adequately significant role in public water supply. A frequent reason for that phenomenon is a lower demand of potable water in karstic areas in comparison with alluvial lowlands where most of big urban and industrial consumers are situated. The extracted karst groundwater has to be conveyed rather costly to usually large distances. However, the alluvial aquifers have become over more polluted, mainly because of an intensive agriculture, but many urban and industrial sources of pollution should not be neglected as well. The actual interest of European countries is directed to the water supply from karstic, mainly mountainous areas where the present water quality and natural conditions guarantee the feasibility to maintain such quality in the future and to give high-quality water supply to a large portion of the European population.

Being conscious of that fact, the researchers of European countries, where the karstic aquifers have a large share in total reserves of potable water, have associated to solve the problem. They try, within the framework of the Commission of European Union, within its Cooperation in Science and Technology Actions (COST Actions), to help in solving possible problems. Within the COST Action 65 during the last five years, they have tried, through their individual and joint research work, to evaluate, firstly, the present cognitions on karst aquifers. After that, they have tried to improve national and international approaches and measures to improve the protection of those so precious resources for the present and future potable water supply. From the very beginning of this research action, numerous research pilot areas have been established in all participating countries and they represent various types of karst aquifers. Initial and annual national reports reveal the problems of groundwater protection and ways how particular countries deal with them.

During the research, ten joint working meetings were held, six of them were of a so-called regional type when the participating researchers visited the research pilot areas in eight countries (Croatia,
Ireland, Switzerland, Germany, Spain, France, Austria, Slovakia) and they were acknowledged with various hydrogeological and groundwater protection conditions. The joint research work was carried out within four working groups:

I. Character of karstic groundwater systems, lead by M. Bakalowicz, France
II. Exploration methods, lead by F. Zwahlen, Switzerland
III. Transport and processes, lead by C. Almeida, Portugal
IV. Regulations, lead by H. Hötzl, Germany

The research results are presented in a book divided in three parts:

I. Recommendations for karst aquifer protection
II. Results of joint research activity
III. National reports of 16 participating countries

We do believe that the research results of European experts gathered within the COST Action 65 will be valuable contribution for the groundwater protection of karstic terrains not only in Europe but also in the other karstic areas. A particular value of this action is that a large number of European hydrogeologists and related experts are closely associated within the COST organization and IAH. They are able to react jointly, if necessary, to solve problems that may appear in karstic areas as consequences of the present urban, industrial, traffic, and agricultural development. They may also help to the hydrogeologists and water management experts of other countries, those not included within the COST Action 65, to solve the discussed problems.

The results of the research within the COST Action 65 will be presented in an abridged form in the paper.

Karst groundwater protection: Hydrogeological criteria and recommended methodology

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Karst is first known as a landscape, with specific landforms and features, essentially developed in carbonate rocks. Karst areas are characterized by the absence of permanent surface flow and the presence of closed depressions, by the common occurrence of caves and, more generally, of underground passages where water flows or not, and by the occurrence of important springs. Therefore, karst should be defined as a surface landscape, but also as an underground landscape and an aquifer.

Karst aquifers present i) in their saturated zone, drains, flow paths hierarchized in a way similar to surface streams with high velocities and flow rates, where water residence time is short and waters do not mix very well; and storage areas, the so-called ex-to-drain systems, where water flows very slowly because of bad hydraulic connections with drains and where water residence time is much longer; ii) in their
infiltration zone, a disseminated infiltration all over the carbonate outcrop, a concentrated infiltration in a few sinking points collecting surface streams flowing on impermeable terrains and an epikarstic zone, a locally saturated zone near the surface.

The final result of karst processes is i) a hierarchization of flows and karst voids, ii) a high time variability of flow conditions and of water chemical contents. Consequently, it is not possible to define a karst aquifer by any Representative Elementary Volume (REV) like any aquifer; but the only whole karst system takes into account the drainage structure.

Contrarily to porous and fissured aquifers, karst aquifers show:

- various infiltration conditions (fast infiltration through streams into large joints, slow infiltration through two-phase flow into fine cracks, local and temporary storage in the epikarstic zone),
- an organized phreatic zone with drains of high hydraulic conductivity and large karstic cavities badly connected hydraulically to drains and strong hydraulic discontinuities.

Then, a karst system should be defined by its framework (geological conditions, boundaries), by its structure of underground flows both in infiltration and phreatic zones, by its functioning, which results on the state of development and of past conditions and by its evolution.

The exploitation and the protection of karst water resources must take into account the whole specific characters of karst aquifers. At first, because of widely opened voids, waters are not filtered. Secondly, the flow velocity is much faster in karst aquifer (from ten to several hundred meters per hour) than in any porous or fissured aquifer (commonly a few meters per day in alluvium). At last, surface flow sinkholes, which are direct access to drains, are points particularly sensitive to pollution. Then, self purification does not occur in karst and high velocity rates rapidly induce a pollution spreading far from the injection point. In karst, pollution may be attenuated only by a dilution effect.

In return, the high flow velocities in the karst drainage structure are responsible for a fast renewing of stored waters which efficiently removes the polluted waters. Nevertheless, because of their structure and of their high permeability in large voids, karst aquifers seem to be especially sensitive to permanent pollution, from agriculture for example. These characters should be taken into account for managing land surfaces, for defining protection zones of karst spring recharge areas.

Therefore, the recommended methodology should be focused on the determination of flow conditions inside the karstic aquifer and on the possible relations between land surface and groundwater. Some of the methods commonly used in porous or fissured aquifer hydrogeology are also useful in karst studies; but a great care must then be
taken. For instance, interpretation of pumping tests, especially in boreholes, may present some difficulties i) because the borehole may be not connected to the drainage structure (or its relative position is unknown), ii) mainly because the basic assumptions of pumping test modeling (e.g. Theis's assumptions) are unrealistic in karst. Then, a new way of interpreting pumping tests must be followed, as for other methods, like tracing tests.

A set of methods should be worked up for describing karst vulnerability. Geological and geophysical methods are devoted to define the framework. Geomorphology approach, like speleology and other direct approaches are involved in describing the (paleo) structure. Hydrodynamics, water geochemistry and artificial tracing deal with system functioning. Landscape analysis gives information about karst evolution. Finally, the whole information should be synthesized by a vulnerability map, the final document supporting the decisions for managing the karst land surface in order to protect the groundwater resources in quantity and in quality.

ENVIRONMENTAL IMPACTS AND LEGAL ASPECTS - I

Karst hydrogeology and environmental impacts of Pamukkale thermal springs

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Pamukkale travertine area is one of the world's most important natural heritages located in the West Anatolian geographical region of Turkey. It has partially overwhelmed the Roman City and the Necropolis of Hierapolis. Pamukkale 'cotton castle' is covered by the widespread natural, white travertines which are acquired immediately on deposition from hot spring waters.

Karst hydrogeological and environmental studies of the Pamukkale thermal springs were carried out within the program of Development and Conservation Projects implemented by the Ministry of Culture of Turkey. Definition of the physico-chemical characteristics of the hot waters, factors affecting the travertine deposition, the sources of pollution, delineation of protection areas and establishing the conservation strategy were the main objectives of this project. Geological and hydrogeological mapping, hydrological analyses, hydrochemical measurements and analyses, isotopic analyses and evaluations, dye tracing and pumping test were carried out in achieving these objectives.

Based on the results obtained from these studies, a new concrete canal system were constructed for hot water distribution onto the travertine area, and a conservation strategy was established.
Al Mokattam city karst problems
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Al Mokattam City has started its inauguration in the early sixties. The city is located on top of Al Mokattam Plateau which in turn bounds the eastern side of Cairo city including the suburbs of Nasr City, Al Maadi and Helwan. The plateau is comprised of highly dissected Middle and Upper Eocene formations including several rock units composed of intercalations of limestone, marl, and claystones.

Tectonic and non-tectonic displacements exist along the plateau and were mapped by several authors. Due to the successive tectonic events that occurred in this locality, the limestone and marly layers were affected by the network of fracture systems. The fracture systems aided in the development of the wide caves and caverns, and the infiltration of rainfall and leakage from the sewage systems along the plateau surface, penetrated deeply along the fractures, that widen them and aided in the separation of the limestone blocks.

Recent urbanization during the last 35 years contributed to the slumping of the separated blocks that caused a lot of damage to the unplanned urban communities established along the slopes of the plateau. In addition to this, the earthquake which had stricken Cairo on 12 October 1992 caused the release of these blocks and to roll along the slopes of Al Mokattam plateau. These enormous and heavy blocks falling during October 1993 in Naser and Al-Duweiqa squatter settlements and in the nearby slum areas, caused a sudden catastrophe to the inhabitants of these communities through the destruction of their houses and establishments.

Simple improvements in local building design in this locality would have prevented much of the damage and loss of life which did occur.

Main hydrogeological problems in the karstic aquifers of NE Bulgaria
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The area of Bulgaria bordered by the Rumania, the Black Sea, and Suha, and Batovo rivers covers approximately 4600 km². The area has at least two main carbonated aquifers that can be distinguished. The lower one is Valanginian in age and has a maximum thickness of that 400 m, and upper one, Sarmatian (Serravallian) in age has a thickness ranging from 0 to 250 m.

The climate of the region is semi-arid, with average annual rainfalls ranging from 440 mm in the eastern edge to 500 mm in the northwestern sector. The average annual temperature ranges from 10 to 14 °C.

Both aquifers have an independent behavior because of the existence of
a geometrically complex marly bed between them. The chemical character of the groundwater from the Valanginian aquifer varies depending on the sector, but it is always within the limits of potability. The thermal character of the groundwater is well recorded in the coastal fringe, where temperature is higher than 40 °C in some localities. The groundwater from the Serravallian carbonates characterized mainly as calcic bicarbonated and magnesic facies but in some localized areas sodic bicarbonated and sodic chloride types occur.

At the present, both system are exploited by several wells and derivations in the springs, the groundwater is used mainly for agriculture and urban supply. Locally a slight depletion of the Serravallian aquifer is noted because of the concentration of exploitations. This may be interpreted as a sign for the potential overexploitation of aquifers in the near future. Moreover, the risk of salt water intrusion is important if we take into account that in the coastal area the main pumping stations are located, in some areas, less than 1000 m from the coastline. In fact, the influence of salt water is evidenced in some coastal points by the existence of sodic chloride facies waters.

Likewise, the intensive agricultural activity in some areas is responsible for a noticeable increase in nitrate content in groundwater (more than 200 ppm determined in some wells). Evidences of this kind of pollution do not occur in the Vallanginian aquifer due to its deeper geological position. The lower aquifer is tapped by a series of artesian wells with thermal and sulphidric water which are located all along the coastal fringe. The discharge from these wells represent a waste of groundwater as they have no closing system.

The study of these two aquifers is being possible thanks to financial support given by the European Union through the project *Ecological Problems of Karst Water Caused by Overexploitation and Contamination* (CIPA - CT93 - 0139). Preliminary results of this research will be shown in the proposed paper.

**Environmental impacts of fly ash from coal fired power plants**

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The incombustible residue of coal called fly ash and constitutes around 15-45 % of the coal. Ash handling and collection systems in power plants may achieve collection efficiency of up to 99 %. Uncollectable fly ash is discharged into the atmosphere as particulate emissions causing air pollution and the collected fly ash and bottom ash may became hazardous waste. Karst system with their huge capacity is very attractive dump sites. However, hydraulic aspects of this hazardous waste deposition has to be evaluated and the fly ash must be characterized
carefully before discharge of particulates as waste material. Indian coal has a very high ash content and therefore represents an excellent case to study the environmental impacts of the fly ash.

In this study particle morphology, size distribution, and chemical composition of fly ash from India have been studied using scanning electron microscope, image analysis, x-ray fluorescence, x-ray diffraction, x-ray microanalysis, and flame analysis techniques. Seven sets of fly ash samples from a power plant in India were obtained and studied under an electron microscope. Most of particles were observed to be spherical, with few distortions in large particles. A representative site was selected and samples were analyzed for size distribution using semi-automatic digital image analysis technique. The fly ash particles were analyzed and the size distribution in each sample set was compared by plotting histograms. The mean diameter of particles in each sample was also calculated. Chemical analysis showed that the fly ash is composed of mainly SiO₂, Al₂O₃, ferrous oxide with some minor components of CaO, MgO, K₂O, Na₂O, TiO₂, and some trace elements including As, Be, Cd, Cr, Co, Cu, Pb, Mo, Ni, Zn. It is observed that the concentrations of these trace elements increase with decreasing particle sizes.

Trace elements classified into three major groups and their enrichment mechanism is discussed. Most of these trace elements are toxic and releasing these particulates to soil, water, or karst system will contaminate the environment. If karst system is used as dump sites then ground water will be contaminated due to rapid water circulation and inability of self purification capacity of karst aquifer will create great risk for the future and certainly degrade the environment.

Environmental impact on the occurrence of groundwater in two different types of limestone terrains in Egypt

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The need for more water than is supplied by the River Nile for the agricultural expansion has led to evaluating the occurrence of groundwater in other non-traditional sources such as the limestones forming the Mediterranean rainy belt in the northwestern part of Egypt and the limestone plateau bordering the Nile Valley.

Vertical Electrical Sounding has been applied for this purpose to determine or evaluate the impact of the physical characteristics of the limestone, structural and climatic impacts on the storage of water in the limestone.

The results of this study revealed that in the Mediterranean littoral zone, where precipitation is available, the limestone is oolitic with primary porosity of 25% and in the absence of limiting geologic structure, groundwater with fair quality can be developed. However, the limestones
bordering the Nile Valley were determined to have no groundwater that infiltrated from the Nile, although secondary porosity in the form of fissures and caverns may be present. This is due to the compact nature of the limestone, presence of clay and shale intercalations, presence of faults and absence of precipitation. However, saline or brackish water may be present in some localities.

It is thus concluded that although the limestones surrounding the Nile Valley cover wide areas of the country, they are unfortunately not considered to be a potential for the groundwater development. The oolitic limestone present along the Mediterranean coastal areas are considered, more adequate groundwater source as long as withdrawal remains under accurate control based on the aquifer characteristics.

ENGINEERING AND ENVIRONMENTAL IMPACTS OF KARST

The impact of karstic features on mining hydrology and groundwater resource for Precambrian limestone in India

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Precambrian limestone is widely distributed in Indian subcontinent belonging to Vindhyan system. These limestone possess denudation due to varied action of local drainage, rainfall and groundwater ever large span of geological periods, leading to formation of karstic features. The karstic features are characterized with occurrence of karren, fluviokarst, sinkhole, spring, solution cavity, underground drainage and terra rossa among Vindhyan limestone of Rajasthan, Madhya Pradesh, Bihar States. An attempt has been made in this paper to classify these karstic features into young and mature category through selected case histories.

The impact of young category karstic features are Banjari (Bihar) and Senadih (Madhya Pradesh) are prone to mining hydrological hazards. These sites are traversed by perennial rivers, besides the occurrence of sinkhole, solution cavity, spring, and terra rossa. Both sites have cement grade limestone with varying degree of mining from large to small scale activity. The mining of karstic limestone exhibits hydrological problem due to high recharge capacity of strata, scanty vegetation, good rainfall, variation in size and location of solution cavity, overall fracture pattern. Banjari limestone mining produces karstic discharge at rate of 2200 kilo liter per hour since its inception due to large scale operation. Senadih limestone mining has not faced such hazard due its initial stage of mining under small scale activity.

The impact of mature category karstic features at Jedhpur (Rajasthan) and Rewa (Madhya Pradesh) have large groundwater resources. These are associated with large cavern due to underground drainage, karren, and
fluvio-karst. They are very promising confined aquifer with yield of 10 to 1000 kilo liter per hour without any significant drawdown.

Reservoirs in karst: Common watertightness problems
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In spite of serious investigations and large scale sealing treatment, a very few dam sites and reservoirs in the karst operate without any leakage. Some of reservoirs never been filled up (impounded). Some of them only partially filled by water, and some are dry and out of use.

Number of examples confirm that difficulties and failures commonly occurs during the first filling of reservoir. Very rare if can happen after many years of dam and reservoir operation.

The karst channels and open (karstified) cracks are source of problems. Naturally that features are plugged by clay and covered by alluvium and terra rossa. Some of them have been reactivated by water pressure, suffusion and air pressure effect. In many cases, it occurs as consequence of inadequate geological analysis and insufficient funds for investigations, but it is not a rule. Quantity of leakage vary from few hundreds of liters per second to 25-30 m³/s.

Practical solutions and rehabilitation treatment requires a lot of patience, close collaboration between experienced geologists and civil engineers, and adequate funds. But because of karst nature, the solutions are extremely complex. The hazard component can not be totally eliminated even in the case of investigation program increasing.

In this article a few examples are presented from different karst areas, typical for watertightness problems of reservoirs situated in karstified rock mass.

Geotechnical constraints and remediation in karst terrane
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Significant portions of the eastern United States are underlain by Paleozoic carbonate rocks. These solution-prone rocks often lie in scenic folded and faulted valleys, once prime farmland, but now under relentless development pressures. The problems posed by development in these areas are both structural and environmental in nature. As a result, groundwater contamination is as well as the provision of suitable support for structures of varying sizes and the related infrastructure, are of increased concern to owners, purchasers, and the regulatory community in these areas.

Conventional soil mechanics and foundation engineering investigation techniques are not adequate to develop a suitable understanding of a subsurface that contains, cavernous rock, soil voids, eroding soils, soft and weak soils underlying firm soils, soft vuggy rocks, highly weathered and open seams, the lack of filtering or absorption of contaminants.
entering the subsurface; large, in-place boulders; and an incredibly variable rock surface.

Planning an appropriate geotechnical investigation requires an understanding of both geology and civil engineering concepts in addition to economic realities. Appropriate investigative tools include: aerial photographs; satellite imagery; geologic mapping; site reconnaissance; rotary wash boring and drilling procedures; split, double tube coring devices; experienced inspectors and drillers; the monitoring of drilling water losses; and good fortune.

Foundation solutions available in the USA include: the relocation of the site or structure(s), piles or piers, preloading, reduced excavation, special design standards, dental concrete, and grouting. Grouting is often one of the most economical concepts, but requires an experienced field crew. Any foundation solution must be predicated upon a full understanding of the geologic conditions at the site, the nature of the development planned and the nature of the possible effects upon other activities in the site locale. Enlightened construction inspection is a necessity, with the ability to quickly offer alternate solutions to those originally planned.

Estimation of large scale transmissivity and leakage of a reservoir through karstic terrain using piezometric data: A case in Northern Greece

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The design of an earth dam in Northern Greece required the investigation of the potential leakages of the reservoir water through a portion of the slope covered by slightly karstified limestones.

A part of the reservoir area consists of carbonate formations (limestones and marbles) which were originally thought to be inclusions inside the otherwise watertight schists and ophiolites forming the greater region. The hydrogeological evaluation of the available data indicated that the carbonate formations are not isolated since (i) there are no springs at the interface of the limestones with the underlying schists inside the reservoir to discharge the rain water collected in the carbonate formations and (ii) the piezometric levels in the limestones-marbles indicate a flow towards an area about five kilometers away from the reservoir where springs with an appreciable discharge exist.

Despite the fact that the carbonate formations in the area are not isolated, it was considered necessary to estimate the amount of the potential leakage which might not be excessive since (i) the carbonate formations are only slightly karstified and (ii) the piezometric levels...
measured in the limestones did not appear to respond rapidly to the annual variation from the wet to the dry season, thus indicating a relatively slow discharge of the groundwater towards lower elevations, probably due to the geometrical features of the aquifer.

A computational model of the region was analyzed in order to estimate the potential leakage of reservoir water as a function of the water level in the reservoir. The macroscopic transmissivity of the limestones was estimated by analyzing the annual change of the piezometric levels in the limestones.

It was concluded that although the limestones and marbles are not watertight and some seepage of reservoir water should be anticipated, the calculated amount of the leakage was tolerable compared to the annual storage capacity of the reservoir.

Problems related to the regional water-level sinking in karstic aquifers caused by mining operations
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The bulk of the coal and bauxite bodies in the Transdanubian Range (Hungary) are laying on the Triassic karstic rocks or on fanglomerate-like permeable rock consisting of debris of dolomite. After the II. World War, the advance of mining production forced the operations to descend to a level deeply under the karstic water table. For security reasons, they had to dewater the surrounding rock masses, which created depression-cones around the mines and caused regional water-level sinking over vast areas. The affected karstic region is about 7000 km², the average decreasing of the water table is 20-30 meters.

As a consequence a big number of local water supply networks were damaged. Later they were substituted by regional systems based on the concentrated water-intake facilities belonging to the mines. Some great thermal springs, well known for ages and serving as balneological or recreational centers, also dried up, causing heavy reactions in the public opinion.

At the end of the eighties several mining sites were abandoned for economic reasons. The karstic watertable began to rise again and by the time the cavities of mining-operations are flooded. It is a danger that the remaining pollution - originating from the human activity and from the altered minerals- will appear in the regional water-supply systems. Methods to avoid this impending danger are treated.
RESEARCH METHODS

Implications from results of continuous in-situ-measurements of dissolved carbon dioxide in karst aquifers

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Carbonate hydrogeochemistry is seen as a tool for selective characterization of karst aquifers. In hydrogeological investigations of karst aquifers, for example, a number of hydrogeo-chemical methods offer the opportunity to use carbonate and carbon dioxide equilibria to characterize hydrodynamic processes. The calculation of saturation indices and solution equilibria with respect to predominant mineral phases (e.g., calcite, dolomite, gypsum) under ambient temperature/pressure conditions in natural waters of known ionic strength is made very easy by application of computer programs such as WATEQ, PHREEQE, etc. Generally the calculations are based on field-measurements of temperature, pH (as a primary variable), electrical conductivity and on laboratory analysis of the major constituents (calcium, magnesium, potassium, sodium, bicarbonate, chloride, nitrate, and sulfate). It is normally calculated instead as carbon dioxide partial pressure from given equilibrium equations because direct measurement of dissolved carbon dioxide is somewhat tedious. But the question is arising whether the calculated parameters are reliable or not.

Recently developed multiparameter field-devices, which measure continuously in situ temperature, pH and dissolved carbon dioxide, combined with appropriate data loggers, make it possible to compare the measured data with those of manually taken water samples, field measurements, and subsequent laboratory analyses.

The results derived from a case study show the sensitivity of the individual parameters on the accuracy and precision of their measurement. In particular it is shown that interpretative implications on hydrogeochemical processes depend very closely on measurement methodology.

The use of well logging for the study of karstic water resources in Maharlu basin

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Maharlu Karst Basin (MKB) is located in central part of Fars province, Iran (29°25'–29°55' N and 52°08'–52°40' E). Shiraz city is placed in the center of the basin and the great part of people drinking water obtained from 32 exploitation wells that drilled in carbonaceous formation around the city.

Tectonic activities, lithology, and climate play important role in the formation and development of karstic features. Different subsurface
geological techniques, particularly Well Logging, are usually used to explore karstic water resources. In order to find out distribution of karstic zones, karstic water resources and study hydrogeological parameters in the carbonate rocks, more than 40 piezometer, exploration wells and coring boreholes drilled in this rocks (Asmari-Jahrum formations). Various well logging methods include Electrical, Gamma, Neutron, Gamma Ray, Flowmetry, Fluid Resistivity, Temperature, and Caliper Loggings have been used to study the karstic water resources within carbonate rocks of MKB.

The results show that porosity, density, resistivity, and lithology of the rock formations in the Maharlu basin changes with depth. These changes are prominent in the dolomitic sections. The distribution of permeable interval, inflow and outflow zones within water wells indicates that karstification in Ghasr-e Ghomsheh, Kaftarak and Derak is more extensive compared to the other parts of the basin. The water tables within the basin matches fairly well with the karstic zones. Existence of semipermeable layers between karstic sections in some parts of the basin indicates early stage of tiered cave formation.

The application of geophysical methods for the analysis of subsurface karst structures

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The detection and analysis of subsurface karst structures, especially cavities, by exclusively geophysical surface methods is quite a difficult problem, since usually very few information about possible target depth, extension, and filling material is available.

Repeated surficial collapses in a "rauhwacke" formation, a cellular dolomite, in course of which there was also a fatal accident, were the occasion for systematical geophysical measurements in that karst region in some part of Southern Austria.

The actual aim was the evaluation of the optimal method or combination of methods to get a maximum of information about the karst features and least about the situation of possible subsidence zones. Therefore geoelectrical profiling, self-potential and mise-a-la-masse measurements, gravity and infrared - ground temperature measurements and electromagnetic methods in the low (EM 31 and 34 at < 10 kHz) as well as high frequency range (ground penetrating radar at 100 and 300 MHz) were applied on a 50 m x 100 m grid of a specific test area.

As the results showed, the ground penetrating radar (GPR), the geoelectrical mise-a-la-masse and profiling methods were the most appropriate. The geoelectrical
profiling at different spacings (on 2 profiles) gave (pseudo) depth profiles of the specific electrical resistivity characterizing the water-table as well as certain high-resistivity regions up to a depth of ca. 6m. These anomalies correlate well with the anomalous structures in the radargrams and might be interpreted as air-filled cavities. A maximum of information concerning the depth and lateral position of anomalies was provided by the GPR. Based on those results a map of highly karstified zones of the test-area was drown.

Some problems encountered with the interpretation of the measured data will also be mentioned. They include the inherent ambiguity of the nature of the anomalies, strong external influences (e.g. vegetation, topography) and the corresponding lack of quantitative parameter determination. Concerning the mise-a-la-masse measurements a prospect on a corresponding research project aiming at the quantification of mise-a-la-masse results for hydrogeological and environmental topics will also be given.

**Groundwater - surface water exchange in the unconfined karstified Floridan aquifer, a view from inside the aquifer with implications for groundwater protection**

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Surface water that has intruded into the unconfined parts of the Floridan aquifer represents a significant component of the groundwater which discharges from the many springs in region where the aquifer is dissected by surface streams. A three year investigation of the Devil's Ear Cave System, an extensive saturated cave system in the Floridan aquifer which underlies a 1.5-km reach of the Santa Fe River in north-central Florida, revealed that there is an appreciable and rapid exchange of water between the river and the underlying aquifer. Natural tracers Radon-222 ($^{222}\text{Rn}$) and $\delta^{18}$O were used to quantify these exchanges. Cave diving was employed to collect water samples which were analyzed for tracer content and to observe water clarity and groundwater velocities within the saturated karst conduits as far as 1.2-km upstream of Devil's Ear spring.

The Santa Fe River drains the Northern Highlands province of north-central Florida where the Floridan aquifer is confined by the 25-m thick Hawthorne Formation, the presence of which precludes hydraulic connection between the river and the aquifer. However, downstream in the lowland provinces, the Hawthorne confining layer is eroded so that the Ocala Limestone is exposed at the surface. Here the Floridan aquifer is unconfined leaving the river and the aquifer in excellent hydraulic connection.

The direction of flow between the river and the aquifer is dependent primarily on where rainfall enters the total system. If precipitation is concentrated in the uplands, the
water accumulates in the Santa Fe River as overland flow and the flood pulse moves down the river onto the unconfined part of the aquifer. Consequently, even a small increase in river stage, as little as 1 m, produces a downward hydraulic gradient causing large amounts of river water to infiltrate into the underlying karst. This tannin stained surface water quickly enters caves developed under and parallel to the river resulting in dramatic water clarity reductions in the caves, a serious problem confronting cave divers. Under these conditions, as much as 50% of the $8 \text{ m}^3/\text{s}$ discharge from the Devil's Ear system can consist of surface water lost from the Santa Fe River.

Conversely, when precipitation is concentrated on the lowland regions where the Floridan aquifer is unconfined, the hydraulic head in the aquifer increases above that of the river resulting in upward flow from the aquifer to the river. The water in the cave clears as the tannin surface water from the Santa Fe River is flushed upward and out of the aquifer.

A 30-m thick section of saturated, karstified Ocala Limestone serves as the permeable layer separating the Santa Fe River and the huge conduits, up to 10-m in diameter, that comprise the Devil's Ear Cave System. Interconnected cavities within this layer contain water in storage that is displaced when either a downward or upward gradient develops in response to the different types of recharge pulses. The rate at which water moves through this layer is dependent on the magnitude and duration of the hydraulic head difference that develops between the river and the aquifer. Large floods originating in the highlands of the upper Santa Fe River are responsible for observed surface water intrusion into the aquifer in periods of as little as one day, based on water clarity reductions in the cave.

The findings of this study demonstrate the vulnerability of the unconfined sections of the Floridan aquifer to contamination from surface streams. During and after flood events, wholesale contamination of the major karstic conduits underlying the Santa Fe River can occur in as little as one day. Given this sensitive, it is clear that there is virtually no distinction between groundwater and surface water in this hydrologic system. This conclusion, however, is contrary to the current state regulations which segregate groundwater and surface water with regard to permissible levels of contaminants. State regulations allow higher levels of certain contaminants such as nitrates to be discharged to a river or stream than would be permissible in the Floridan aquifer. Based on the current distinction between ground and surface waters, state regulatory agencies permit the growing dairy and chicken farming industries to discharge large quantities of nitrate, ammonia, and soluble organic nitrogen species to surface streams. Because the hydrologic connection between the river and the aquifer has
not been acknowledged, the regulations permitting these discharges will directly contribute to legally unacceptable groundwater contamination of the Floridan aquifer. And in this light, similar problems will plague similar hydrologic environments elsewhere in the state.

**Heat as a natural tracer:**
**Characterization of a conduit network in a karst aquifer using temperature measurements of the spring water**
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Temperature variations in spring water have been recorded over more than six years with a resolution of 0.01 °C in the Gallusquelle karst spring (deep karst, Swabian Alb, SW. Germany). The temperature of the spring water is highly controlled by recharge events i.e., their intensities and magnitudes. Even during summer events, the recorded variations display only negative deviations, which are caused by the arrival of recharge water at the water table, cooler than the groundwater itself. The heat exchange with the rock in the karstified unsaturated zone, which is cooler than the phreatic zone because of the upward directed geothermal gradient, is responsible for the temperature difference between groundwater and recharge water. In order to have any significant deviation between the temperature of recharge water and groundwater, recharge water has to flow rapid enough in order to avoid temperature equilibration with the surrounding rock. Analyzing the spring water temperature time series for the controlling processes and the comparison with analytical models allows the distinction between the influence of the epikarst and the unsaturated zone (cooling of the recharge water) and the phreatic zone (heat convection and heat conduction). Effective parameters and geometries could be estimated for the solution channels of the karst unsaturated and saturated zone. The results were comparable with values, obtained from other measurement methods.

**The principles of search of karst, fracture and fracture-vein waters of the mountain folding zones**
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In arid zones, there is critical demand in fresh, low mineralized (1-3 g/l), but also in mineral and a thermal waters. In mountain folding zones are concentrated karst, fracture and fracture vein waters with great exploitational reserves. As compared with submontane plains hydrogeological conditions of mountain folding zones are poorly studied, where conditions of underground waters (UW) accumulation are different. By search and prospection of UW of the mountain folding zones traditional methods have not been used. For revealing water locations in karst, fractures, and vein of original
rocks in the mountain folding zones, it is necessary to study the role of tectonic fracturing and karst in hydrogeo-logical processes and diversity of its display on various levels of subsurface hydrosphere. One of modern hydrogeological principle question is clearing up the role of fractures and karst in formation and location of UW deposits. It is necessary to draw attention at following:

1. Hydrogeological zonation of area on the base of system analysis of materials of geological composition, aerial cosmic surveys, geo-physical and hydrogeological investigations, reveal watery tectonic fractures and karst locations.
2. Carrying out no research methods in potentially UW locations with various structural - facies conditions, clearing up the geotectonic peculiarity of deep fault zones and karst locations, the character of water bearing rocks, UW circulation, hydrodynamic and physical - mechanical parameters.
3. The influence of hydrodynamic factors at the flooding of watery locations (karst, fractures).
4. Working out research criteria of flooding and valuation the perspectivity of various fracture and karst types for prospecting and looking for UW.
5. Working out new technologies of drilling and testing to avoid the change for the worse water conductivity of tectonic fractures and physical-chemical component of UW.

The resistivity method in karst media: Application to the Maciço Calcário Estremenho (Portugal)

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The resistivity method was used to detect void and/or partially filled caves in karst media. The data were achieved from field works in the "Maciço Calcário Estremenho" and from model simulations in an automated tank analog, using the pole - dipole and the dipole - dipole arrays. The automatic inversion of the data was performed considering the caves as empty bodies or bodies with a resistivity greater at least two orders of magnitude than the surrounding geological formations. The numerical results calculated with the two physical approaches are almost coinciding and are also very well correlated to those obtained for similar models both in the field or in the tank analog.

The resolution of the arrays was also analyzed in connection with the depth and the diameter of the caves.

The field data also provided the geometry of the circulation of the underground waters close to the "Almonda" cave.

About construing data of seismic radiosity between boreholes in karst rocks

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The usual interpretation of seismograms assumes the first entries
on them to be provoked by straight beams of seismic waves, ascertains, by a delay of these beams, only the presence of a big cavern between boreholes and lessens its real size by many times.

Caves in karst rocks are local objects of a small density. Therefore, the first signs of waves on a seismogram are provoked by waves surrounding a cave. They come before the waves spreading through the cave. The calculation of this peculiarity and the use of the Huygens principle permit to determine a place and sizes of a cave from a seismogram of radioscopy between boreholes by slanting beams.

Airborne remote sensing systems and usability at pollution research of karst water resources
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Remote Sensing studies have been going on by using both imagery obtained from sensor systems which are located on satellite platform produced for that purpose and aerial photographs supporting them, widely as an natural extension of existing space and computer age. Mentioned generalization is not only valid for world perspective but also for our country.

It can be clearly seen that, these studies have lots of deficiencies in operational considerations, when it is held by the point of view in near future developments. These deficiencies primarily in satellite imagery can be listed as follows:

a) Depending on abroad,
b) Difficulty of providing imagery for requested time and area,
c) Taking long time to provide of existing imagery,
d) Highly influencing from meteorological conditions,
e) Low level image resolution for some applications,
f) High cost.

Airborne Remote Sensing Systems are becoming more and more important, because they eliminate some of the above mentioned problems and reduce the minimum level some of the others.

In this study, it is aimed to explain technical features of airborne remote sensing systems, existing situation of project which was commenced by TUFUAB and usability of data from concerning systems for researching of pollution of karst water resources.

The study of engineering geophysics in karstic grounds and case studies
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The karstic cavities which effect engineering structures in a large scale could give unimportant results and its influence can be negligible, but its effect magnify by considering a smaller scale. The foundation of Antalya province, originally a karstic ground, made of travertines.

These travertines consist of solution cavities, caverns, joints, fractures, and alteration zones. The
determination of hidden cavities and structural features and engineering properties of the rock mass in the travertine grounds particularly identified by the use state-of-the-art geoelectrical and seismic from geophysical exploration methods.

Different case studies are given and interpreted by using seismic and geoelectrical methods, for the solution of foundation problems in the Antalya city grounds which consist of travertines, permissible bearing capacity of the ground and settlement of foundation and its elastic parameters for burden removal and determination of ground rippability. Also different case studies for features, which means fractures, faults and joints, solution cavities and caverns, alteration zones, swelling clay fillings, the position of groundwater.

Monitoring of sea water intrusion zone along the Mediterranean coast of Turkey by means of geophysical techniques

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High population density along the coastline creates problems related to the lack of reliable surface waters. The wide spread coastal aquifers are the main water resources to cover the demand in these areas. The coastal aquifers occur within highly karstified units and exhibit complex hydraulic systems.

The carbonate aquifers are highly effected by sea water intrusion either by natural processes or mismanagement of groundwater resources. Therefore, determining the depth of fresh water–salt water interface toward the inland becomes major concern. Temporal changes of the position of this interface control the amount of the groundwater that could be taken from these aquifers.

In this paper, the author discusses some of the typical sea water intrusion cases and geophysical methods applied to monitor and determine the expected saline water encroachment zone and its behavior during groundwater exploitation of coastal karst aquifers in Turkey. The present sea water intrusion problems take place in most of the provinces which are located along the Mediterranean coast of Turkey.

Geoelectrical investigation of Beşkonak head-reach tunnel

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In Turkey, one third of the surface is covered by the carbonate rocks of karstic properties and these karstic areas possess 50% of the hydroelectric energy potential of our country.

Beşkonak dam and hydroelectric power station is planned in Köprüçay basin which is located in the Western Taurids karst system. Problems
peculiar to karstic environments observed in these dam and reservoir site made the project infeasible.

Alternative to this project, it is planned to construct a dam on impervious units, to convey the water collected in the reservoir area by open canals and as a result to produce energy by making use of the natural flow of the water in a head-reach tunnel.

Since the head-reach tunnel route has such a topography that makes it impossible to apply investigation drillings and unemployment of the seismic refraction method because of the velocity problem. Vertical Electrical Sounding became the only solution in the problem of separation of conglomerate-flysch levels along the tunnel route.

Along the tunnel route, at the end of making Vertical Electrical Soundings at 55 points by using the Schlumberger Method, conglomerate-flysch levels were distinguished.

Satellite image analysis of structural fabric controlling groundwater flow in Southwestern Taurus karst region

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Digital analysis of remotely sensed imagery data can be used to help interpret regional structure, to aid in locating buried structures, and to map fractures. In regional syntheses, structural fabric of a terrane plays an important role in the regional fluid flow and, in this case regional direction of circulation. The most important and typical elements and geomorphologic forms related to karst terranes, such as those of sinkholes, dry valleys, karst poljes and springs are the results of fracturing and faulting.

This paper focuses on the specific, common practice of lineament analysis in groundwater resource exploration, and illustrates some of both the pitfalls and the power of remote sensing images for structural analysis in karst. Lineament analysis may focus attention on domain boundaries or zones of weakness, systems of close faults with similar strike, or large individual faults, which, in return, control the so called "concentrated underground flows" in karst terranes. Additionally, an attempt was made to show probable hydraulic connections may exist between the principal recharge, discharge, and transition areas based on both analyses of lineaments and thermal radiance band of Landsat Thematic Mapper.

The results of this research may help reveal regional hydrodynamic system and thus, pollution sensitive areas, where preventive measures need to be taken into consideration during the development of projects and environmental planning. The digital nature of the data will allow the results to be used as ready data for hydrological modeling of karst systems.
TRACING TECHNIQUES

The latest Paderborn tracing test (Northrhine Westphalia, FRG)

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Numerous tracing tests were performed in the Paderborn Cretaceous karst aquifer system over the past hundred years.

Previous tests were restricted to the open karst system of the Paderborn High Plateau, with sinkholes within stream beds used as injection points and the Pader springs were sampled as discharge points to prove the tracer's re-appearance and to calculate travel times. Recently, the confined system from which deep karst groundwater is being abstracted for drinking and industrial purposes, was included in the testing activities. Results of the latest test in July 1994 are presented. Chemical tracers, namely lithium chloride (30 kg) were applied for the first time besides uranine. LiCl proved to be a very suitable tracer, especially within groundwater protection areas where dyes are to be avoided.

The following advantages are to be emphasized:

- analysis without interference with fluorescence dyes
- because of the small lithium ion radius there are hardly any interactions to be expected with the aquifer
- Li can be used and analyzed without problems even in acid groundwaters and humic acid-rich groundwaters
- Lithium ions are invisible
- Lithium ions are proved to be physiologically harmless even at such expected high concentrations
- Lithium chloride is a rather cheap tracer although only 16% of LiCl is to be analyzed as Li.

Transition curves of the both lithium and uranine are to be discussed along with hydraulic data representing the actual state of the system when the test was conducted.

Tracing techniques and hydrodynamique analysis in the karst

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Recent developments in applying tracing techniques in different karstic systems indicate that informations obtained are of restricted value as far hydrodynamical transport models are concerned. In the Dinaric and Carpathian-Balkan karsts was studied for two hydraulic flows by use of several tracers experiments. The tracers used were injected instantaneously and simultaneously in the flowing channels which were known up to this date. Their restitution was followed at the principal outlets of the karstic system. The interpretation of experimental results has allowed to specify the mass transfer made in this karst. This is particularly true regarding stable hydrodynamical
regime (stationary) during the tracing procedure which rarely may be provided in field. However, it is important to note that careful investigation of the DTRT curve (Distribution of Tracer Retaining Time) may give certain very important characteristics of given HKS (Hydrogeological Karst System), particularly concerning it's transmissivity, and storage capacity properties. This is of a high importance in hydrogeological studies of groundwater pollution.

Tracing techniques using artificial tracers should be combined with natural tracers such as temperature, chemical properties of water, and water mass flux, etc. Those natural tracers are complementary with tracing techniques using artificial tracers and may significantly improve reliability in overall data interpretation.

Stochastic modeling of single well tracer data in fractured rock

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There are many downhole methods that provide excellent assessment of rock and fracture flow characteristics immediately surrounding the well. Among them are single well tracer techniques which employ the use of short-lived radionuclides for dilution, direction and slug logging of natural or artificially induced inhole flow which is related to the hydraulic conductivity of the water bearing units open to the well. The nuclear tracer logs have been used at different discharge and recharge conditions in open and cased boreholes in the Swabian and Franconian Jura (Germany), where the measurements and their interpretation were en-countered in problems of safe yield, delineation of protection zones and well construction.

Stochastic modeling was applied in order to assess the uniformity of conditions of the localized data and their correlation between holes over a large area of the generally anisotropic fractured aquifers. The statistical approach is analyzing the localized hydraulic conductivities as a process by which the variance of the medium conductivity is produced mainly proportional to aquifers dispersivity. The parameter to be evaluated is the correlation scale between the localized conductivities which can be estimated by variogram analysis. The analysis is made with a computer code which lets variance and correlation scale float and compares experimental with model variograms.

The results of the stochastic analyses mirror the different types of porosity which may exist within the rock. In conditions of fracture flow where the interfraction spacings are small in comparison with the scale of the system and which may be treated as an equivalent porous media and described by Darcy's law under certain conditions the stochastic approach produces aquifers dispersivity scale dependent and
reaching an asymptotic value of some hundred meters. In conditions of flow within large cavernous systems which may be treated as pipe or open channel flow or by analytical models such as flow between parallel plates apparently the computational efficiency does not enable to account for errors in including elements of higher dimensions than the overall model.

**Guidelines for the quantity of dye needed for quantitative tracing to springs in carbonate rocks**

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There have been various estimates of the quantity of dye needed for a successful groundwater trace. However, rule of thumb methods often prevail, and there is a common belief that the quantity of dye needed is not predictable.

Dye injected into wells or sinking streams is subject to advection, dilution, dispersion and adsorption. Advection, dilution and dispersion are relatively straightforward to quantify, while adsorption is the most difficult parameter to predict. However, dye recoveries in quantitative tracer tests are commonly >25%. This suggests that the quantity of dye needed in a trace should be able to be estimated within an order of magnitude.

Data from more than 100 quantitative tracer tests were examined to determine if a statistically significant equation could be determined. The tests included a wide range of spring discharges (0.002-47 m\(^3\)/s), distances (30 m - 30 km) and mass of dye used (<1 g - >50 kg). Tests with slow velocities often have poor tracer recoveries, so the few tests with peak velocities <0.005 m/s or recoveries <25% were rejected. The pertinent variables that were tested were spring discharge, distance, velocity, mass of dye injected, peak recovery, and time from injection to peak recovery.

It was found that the most useful equation predicts peak dye concentration as a function of spring discharge and distance traced. Use of the equation gives a high probability of successful sub-visual detection of dye in water samples, and thus solves one of the major problems of tracer testing.

**Interpretation of tracer experiments in the Danube-Aach system (Western Swabian Alb, Germany) with analytical models**

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The karstified region of the Swabian Alb is located in South-West Germany. The Upper Danube river crosses this region from the west to the east. For about 150 days per year the river loses its water completely. About 12 km south of the main water
loss the largest spring of Germany, the Aachspring, is located. Due of this remarkability (the water loss of the Danube and the extremely large spring), the Danube - Aach - system is a research area for a long time. Since 1869, many tracer experiments will be carried out there, the first quantitative one was already performed in 1877.

In the frame of a research project, these experiments will be new analyzed. For that purpose, the experiments were interpreted with two analytical models. The first model was an extended dispersion model and the second one a double-porosity model. A computer program ("Traci for Windows") was developed for this investigations. This program is especially suitable for the interpretation of tracer experiments in karst. Based on the modeling of the tracer experiments a new water balance for the Danube - Aach - System will be prepared.

The investigations show that the analytical solutions will be qualified for the interpretations of tracer experiments in karst. In the Danube - Aach - System could be find out, that the extended dispersion was suitable for the main flow path with its high water flow velocities. For the other flow paths the calculations would be carried out with the double-porosity-model. For comparing these two models, the results of tracer experiments from other karstified regions were used.

Karst aquifer regionalization in the Basque country (Northern Spain)
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Carbonated formations, Jurassic, Cretaceous and Tertiary, are the most important aquifers in Basque Country. Their main geological, hydrochemical and hydrodynamical features are summarized in this paper, from a viewpoint of the regionalization. A basical typology of the aquifer is set taking into account the examination of their global responses. Regional data are provided.

In general, waters shows a mineralization less than 450 mg/l. Both the very karstified and little karstified carbonated aquifers present a small temporal variability, although they show a logically different degree of mineralization. In the intermediate karstified aquifers different hydrochemical families appear which are to be related to the hydrodynamic behavior. In some cases, water pollution is very important due to the inadequate location of toxic wastes disposal sites.

Analysis of the time series, discharge in springs and daily rainfall, by using correlatory and spectral analysis, let us establish a typology according to the different inertial effect, from very quick response aquifers, Early Cretaceous ones mainly, to very slow response aquifers. Although there is no a direct relation between the exploitation interest and the type of carbonated formation, due to the
decisive influence the local factors, geology related ones mainly, have in the development of the karstic drainage.

Finally, the detailed analysis of the tracer breakthrough curves, combined with the geological, hydrogeological and hydrochemical information, has provided a valid structural model (rapid circulation subsystem and fissured subsystem) of some aquifers. Lithium tracer shows excellent recovery rates as opposed to fluorescein and iodide which have offered less satisfactory results.

**HYDROCHEMISTRY**

**Seasonal fluctuations and trends in the hydrochemical background of karst waters in some regions in Bulgaria**

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The present study aims to develop methodology and way of presentation of results in the evaluation of fluctuations of the main parameters of the hydrochemical background of karst waters using the Bistretz karst spring in the North-West Bulgaria as an example. Based on historical hydrological and hydrochemical information (monthly values for eleven years period), a method for evaluation and analysis of the seasonal fluctuations and trends are outlined. The region investigated is chosen as a typical one in an area not significantly affected by antropogenic factors and thus being suitable for evaluating and analyzing the background parameters. Conclusions derived, clarify the hydrochemical characteristics of the region investigated and give information about the application of the method in solving other similar problems.

**The governing factors of the physical and hydrochemical characteristics of karst springs**

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The physico-chemical characteristics of karstic springs is not a sole function of flow path in the carbonate rock masses. A number of other parameters including the type of precipitation, vegetation cover, morphology of the exposed area, and hydrochemistry of the infiltrating water into the karst system also have their own contribution.

In the present study, the Gar and the Barm Firuz Mountains are chosen to determine the governing factors of the physical and hydrochemical characteristics of karst springs. Geological, hydrochemical and tracer analysis data reveal that the drainage area of Sheshpeer aquifer comprises the whole of the Barm Firuz Mount and the northern flank of the Gar Mount. The following measurements were carried out.

1. Variation of discharge as a function of time. Temperature, electrical conductivity and pH of the inflow into six sinkholes.
2. Electrical conductivity, pH and temperature of water at the surface and 40 centimeters inside soil cover

3. Major ions, temperature, electrical conductivity and pH of the precipitation, fresh and accumulated snow and the inflow of the sinkholes

4. Infiltration parameters of the soil and the carbonate exposures by double ring method

5. Discharge, major ions, temperature and electrical conductivity of the water was measured every twenty days for a period of three years.

The results indicate that the physicochemical characteristics of the inflow systems changes with time. In advanced karst systems where the dissolution channels are large and the flow is turbulent, the characteristics of the outflow system (springs) is influenced by the inflow one; while in undeveloped karst systems where the type of flow is diffused, the hydrochemical properties of the discharging spring is mainly controlled by the aquifer.

**The influence of CO₂-conversion on the dissolution kinetics of limestone and its consequences to the safety of dam sites**

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In a recent book [1], A. N. James claims the possibility to predict endangerment of dam sites caused by CO₂ containing aggressive water seeping through fissures in the underlying limestone and enlarging them by dissolution. A. N. Palmer [2] and W. Dreybrodt [3] also concluded that karstification might endanger hydraulic structures. A critical condition for the safety of a dam was formulated [3] by $2.6 \times 10^5 > a^3 i c_{eq}/k_1 l$, where $a$ is the width of the fissure, $l$ its length in cm and $i$ the hydraulic gradient, $k$ (mole/(cm²s)) and $c_{eq}$ (mole/cm³) determine the dissolution rate far from equilibrium, given by $R = k (1 - c/c_{eq})$. The value of $k$, therefore, is of crucial importance. For natural conditions $a \sim 10^2$ cm, and dissolution proceeds in a system closed to CO₂. In such cases D. Buhmann and W. Dreybrodt [4] have shown theoretically that the value of $k$ is determined by the slow conversion of $\text{CO}_2 \rightarrow \text{H}^+ + \text{HCO}_3^-$ and depends on the ratio $r = V/F$; $V$ is the volume of the water and $F$ the surface of the dissolving limestone. To verify these predictions we have performed batch experiments to measure $k$ for $r$-values of 0.4 cm and 0.04 cm under chemical conditions similar to nature. The results clearly demonstrate the influence of CO₂ conversion, showing a significant decrease of $k$ with decreasing $r$. The $k$ value for $r = 0.01$ cm corresponding to joint widths of $2 \times 10^{-2}$ cm inferred from these data yields $k = 5 \times 10^{-11}$ mole/(cm²s) in comparison to a value of $4 \times 10^{-10}$ suggested by James [1]. In consequence of the safety criteria above a dam site predicted to be safe with the higher $k$ value of $4 \times 10^{-4}$ could fail in nature.

[1] Soluble Materials in Civil Engineering, Ellis Horwood, London,
Monochemical assessment of Umm Er Radhuma karstic aquifer in the eastern part of Saudi Arabia

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Hydrochemical behaviors of a karstic aquifer help to identify groundwater quality types within the extensive area of the reservoir. Classical bar, pie, trilinear, and Durov diagrams are used extensively in the literature for such a purpose. However, in this research new techniques and procedures such as area-concentration, frequency-concentration, ion-concentration percentage-frequency relationships are developed in the form of various charts for the identification of zonations and saturations of the groundwater in terms of various chemical constituents. Furthermore, relative frequency-electrical conductivity and total dissolved solid relationships are obtained based on whether the groundwater is of sodium chloride, calcium chloride, calcium chloride or mixture of two types. Last but not the least, chemical equilibrium studies led to ionic strength = total dissolved solids = electrical conductivity relationships as well as the activity coefficient charts for major ions and cations. All of these techniques can be used in groundwater studies in any part of the world.

The hydrochemical characteristics of the Umm Er Radhuma aquifer were investigated by the aforementioned new and classical techniques. The results indicated that the major groundwater types are sodium chloride and calcium sulfate. Umm Er Radhuma groundwater is saturated with respect to calcite but unsaturated for anhydrite in the northern part of the study area.

Hydrogeochemistry and karstification in the Cienaga de Zapata aquifer (Matanzas, Cuba)

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The area of La Cienaga de Zapata and its surroundings occupy some 4500 km², composed of gently tilting Miocene, Pliocene, and Quaternary materials which are somewhat fractured and intensely karstified. In the recent geological history of the sector, the sea level has fluctuated, thereby strongly favoring the karstification processes. At the same time, the central part of the marsh (Cienaga), depressed by tectonic events and/or by karstification, became the discharge point for local flow systems of the aquifer, encouraging the accumulations of peat exceeding 10 m in places. This accumulations of organic matter, nearly impervious, has in turn played
a major part in the karstification by adding acidity to the environment and increasing the partial pressure of the CO$_2$. At present, this accumulation confines the carbonate aquifer. The hydrogeochemical processes brought about by this situation, in addition to certain human activities (intensive pumping throughout the influx area), are the object of detailed study. The most outstanding aspect is the extremely horizontal contact between fresh and saline water, apparently due to the high average permeability of the materials. As a consequence of human activities, notable thicknesses have been detected in the mixing zone. Despite the relatively homogeneous karstification of the aquifer, the presence of certain sectors of preferential flow can be deduced, evident in certain hydrochemical anomalies.

Finally, a strategy for the exploitation and management of this peculiar system is proposed, analyzing the positive and negative consequences such exploitation could have for the aquifer and associated singular ecosystems.

The thermomineral springs blended to carbonate formations of Oran meseta (Algeria)

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The geomorphological and lithostructural factors with govern the infiltration and groundwater flow in carbonate rocks of Oran Meseta are examined.

The interpretation of both measured physico-chemical values, analytical results of chemical elements (majors and minors) and also isotopic analysis and geothermometry allow to state precisely the functioning mechanism of thermomineral water linked to this carbonate massif.

The modern dynamics of the upper Ribeira karst, Southeastern Sao Paulo state, Brazil

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The hydrology and hydrochemistry of the Perolas - Santana karst drainage system has been monitored for one hydrological year in order to estimate the chemical denudation rate of a subtropical humid karst system.

The Perolas - Santana system belongs to a karst area in dolomitic and calcitic metalimestones of the Middle Proterozoic Acungui Group in the Upper Ribeira river valley, between Apiaí and Iporanga, southeastern São Paulo State, Brazil.

The following hydrochemical facies have been defined: allogenic surface runoff, fluviokarstic runoff, vadose autogenic fissure seepage, vadose autogenic conduit flow, deep phreatic conduit flow, and karst resurgence flow. The hydrochemistry indicates that the karstification is basically controlled by meteoric water enriched in carbonic acid. Minor dissolution of carbonate by sulfuric
acid produced by oxidation of pyrite disseminated in impure limestone is thought to occur in deep flow routes.
The modern erosive dynamics of the studied karst has been quantified according to the following parameters: saturation rate in calcite and dolomite of allogenic rivers entering the limestone surface, the seasonality of the saturation index of the main hydrochemical facies and the rate of limestone surface lowering through dissolution. The calculated mean chemical denudation rate for the Perolas - Santana basin is 31.1±6 mm/ky, based on a one year water budget of the basin and water hardness variation with respect to the spring discharge.

**Geochemistry of the groundwaters from the Moneasa karst (Romania)**

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The karstic Moneasa region situated in the Apuseni mountains (Western part of the Carpathians, Romania) is known for its thermal waters where temperatures reach 24 to 32.8°C. The geological structure of the area is characterized by the overthrust of two nappes in relation with the alpine orogenesis. The karst is located in carbonates and black dolomites of the Middle Triassic in the upper nappe nearby the contact with the impermeable deposits of the lower nappe.

Water is largely used for thermalism since about one hundred years. Fourteen waters were sampled from natural emergences, pumped wells, and runoff. The water temperatures range between 7.7 to 32.8 °C while the electrical conductivities vary between 20 to 520 μS.cm⁻¹. A large range of alkalinity is found (0.05 to 6.30 meq.l⁻¹) for a pH variation of 6.02 to 8.21. The high contents of dissolved oxygen indicate a groundwater circulation under oxidized conditions.

The good correlation between temperature and mineralization of the karst waters shows a binary mixing between (1) cold, highly mineralized waters recharged in altitude through the carbonated formations and (2) slightly mineralized waters with higher temperature indicating a deep circulation. For the latter, the low mineralization is due to a contact with the silicated formations of the upper nappe basement.

The oxygen-18 and deuterium contents do not show large variations as values range within -9.6 to -11.0 ‰ vs. SMOW and -69.9 to 76.7 ‰ vs. SMOW respectively. All the waters of the karst, the runoff and the natural sources originated from oceanic air masses condensation as indicated in the deuterium vs. oxygen-18 diagram. However, the deep waters sampled from the wells show (1) characteristics of both Mediterranean and oceanic origin.
and (2) lower condensation temperatures than the other ones.

The Carbon-13 contents of the Total Dissolved Inorganic Carbon (TDIC) vary between -13 to -10‰ vs. PDB and are well correlated with the bicarbonates. Although the high altitude waters show the more depleted δ13C values, all the waters are mineralized under an open system with respect to the biogenic soil CO2. The radiocarbon activities present a wide range, from 16 to 100 % of modern carbon. The relationship 14C activities vs. temperature suggests a mixing between cold recent and warm old waters. The contribution of sub-surface with respect to the deep water in the mixing increases with the distance from the Moneasa fault which constitutes a drain of an upwards circulation.

**Determination of CaO, MgO ratio from core drilling on karst water resources of Maharlu karst basin (SW Iran)**

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One of the best methods for facies and lithological investigation of karstic resources is determination of porosity ratio, permeability assessment, karstification ratio, assessment of tectonic role in karstification ratio, and correlation between core drilling piezometers by using the results from CaO, MgO ratio, and micropaleontology of core drilling samples.

Maharlu Karst Basin is located in Fars Province between 52,12 and 53,28 Eastern geographical longitudes and between 29,1 and 30,6 Northern geographical latitude.

The area of this basin is 4027 km² and carbonate rocks composes about 1600 km² which include 40% from the total of the whole area basin.

These carbonate formations are belongs to Upper Campanian to Maestrichtian age (Tarbur Formation) and Eocene to Oligo-Miocene age (Jahrom-Asmari Formation).

Jahrom-Asmari Formation includes 97.5% of the carbonate rocks, that is why we have drilled 8 core drilling piezometers in Jahrom-Asmari Formation, it's worthy of mention that, this formation provides 68% of drinking water supply from Shiraz city. For determination of CaO, MgO ratio in this basin, about 328 samples from core drilling and from geological profiles of this formation were collected and analyzed (289 samples have sent for determination of CaO, MgO ratio and 39 samples for micropaleontology studies). According to the results CaO, MgO contents were between 26 to 55 and 0 to 20 percent, respectively. We have calculated effective porosity (8.1% to 21.46%), permeability from pumping tests (4.1x10² m/day), permeability from micropaleontology (8.3x10⁶ to 6.5x10⁷) and minimum of karstification ratio (zero to 68.8%).
Correspondence analysis for hydrochemical characteristics of karst water in Northern China

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With the development of industry and agriculture, groundwater in karst area has become an important supply source in Northern China. Then, the approach on the hydrochemical characteristic of karst water and the impacts of environment to karst water is an urgent need in the development of karst water.

This paper uses the correspondence analysis technique to carry out the research on the formulation and distribution characteristics of karst water in Qinhuangdao area, Northern China. From the analysis of hydrodynamic and hydrochemical field of karst water, the dominating factors and hydrochemical components of karst groundwater are determined, which can provide a scientific basis for groundwater quality evaluation and management. Through combination of Q and R factor analysis, the research result can be expressed in the same factor axes, and the interrelation between variables and the samples of karst water will be obtained. The approach can also combined explain the special distribution law and different type of sample characteristics on hydro-chemical components of karst water.

Study the migratory law and water bearing media characteristics of karst water by using mineral saturation index

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This paper takes the karst water system of Jixian, Tianjin City as an example, make use of mineral saturation index to study corrosional capacity of varying water and flowed direction of groundwater, solved some disputed boundary properties and important hydrogeological problems; make use of interrelated analysis of dolomite saturation index and CO₂ partial pressure to distinguish conduit flow and crevice diffuse flow, expounded the characteristics of water-bearing media of dolomite.

Formation of sulfate-calcic waters in cave massif

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The caves present the objects suitable for investigating hydrochemical processes which take place in the Earth’s crust. Perm University together with Kungur Station of the Ural Branch of RAS carry on complex investigation of Kungur ice cave. The cave of 5.6 km length was formed in gypsum and anhydrite interbedded by thin limestone and dolomite of Lower Permian Kungur stage. It is one of the most visited tourist caves in Russia.
The chemical composition of water in cave massif represents mainly a result of gypsum and anhydrite dissolution. The degree of water metamorphization is indicated by its "sulfateness", that is by the ratio of sulfate ion content to hydrocarbonate ion content (mg/l). Weakly mineralized water recharging the cave massif features low sulfateness: 0.5 - 1.6 snow, 0.5 river water. The sulfateness of atmospheric ice crystals in the cave equals to 0.6 - 0.7. In spite of similar sulfate-calcic composition and high mineralization (1-2 g/l) water and ice in the cave differ on sulfateness index: 10-21 drops, 11-16 karst water, 3-9 underground lakes and stream, 26-38 old ice, 9-10 young ice. Drops and karst water formed in rock fractures (i.e. in a closed system) show higher sulfateness compared to open reservoir, in the latter case water interacts with bottomset beds. Old ice is notable for the highest sulfateness. 

Sulfateness is a genetic feature that points out the sources and the centres of karst water recharge, conditions of their formation. The influence of anthropogeneous factor causes the increase of mineralization of atmospheric precipitation of above cave area, the appearance of nitrates and nitrates in karst water.

Forming of karst water composition by the technogenic factors

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Karst regions are the terrains of the specific geostructural and hydrogeological conditions. Geological environment of these regions is very unstable. Assimilation of the karst regions is connected with dangerous situations and irreversible changes of the natural conditions. Karst process determines the equilibrium of geological environment in the areas which cover more than 180000 square kilometers of the Urals.

Chemical composition of the coal mine water depends on contents of the sulfur, carbonated and diffused elements in the coal formation. If the contents of sulfur in coal is more than 4% karst water acquired acid reaction (pH=2-3) and sulfate composition. Sulfate - Iron - Aluminum - Natrium - Calcium water acquired mineralization 2.5-19 g/l.

The sulfur contained minerals and the organic compounds yield sulfuric acid by process biochemical oxidation. During exploitation of the coal deposits, in connection with increase of the water influxes, air exchange and volumes of the rocks in geochemical process the mineralization can increase to 35 g/l. In the mine water as compared with natural karst water content of lead, copper, zinc, silver, nickel, cobalt increased in several tens time.
The rivers of the West Ural coal mine districts have hydrocarbonate-calcium-natrium hydrochemical facies with mineralization 90-150 mg/l before of the mine water tributaries fall in water of this rivers is fresh and ultrafresh, slightly acid (pH=5.8). After of the mine water fall in water of the karst rivers acquired Sulfate-Iron-Aluminum composition and mineralization from 640 to 5000-6000 mg/l. Content sulfate is from 1000 to 3700 mg/l, iron from 160 to 900 mg/l, aluminum from 11 to 160 mg/l when pH=2.5-2.9.

Throw of the mine water has greatly changed the natural regime of the karst rivers. The iron contained deposits (with hematite about 46%) partly or fully had filled karst cavities in excepted underground flow and increased part of surface drainage.

The sediments of bottom have very intensive pollution too. The water extracts by pollution were changing from hydrocarbonate-calcium to sulfate-calcium. Contain of the chemical salt increased from 300-350 mg/l to 9500-9700 mg/l. The reaction was changed from slightly acid (pH=5.5) to very acid (pH=2.5-4). The sediments are sources of the secondary pollution.

The underground karst water are partly isolated from the surface stream and active pollution by naturally-technogenic reasons. Nevertheless, the pollution from the surface flows by filtration is existing and not only during the flood periods. Atmospheric water going through the coal slag-heaps are concentrated sulfate and polluted subsurface water on depth 30-50 m. Hydrochemical hydrocarbonate-calcium facies is changed under source of pollution to sulfate-hydrocarbonate-calcium (contain sulfate achieved 300-350 mg/l when mineralization is 700-760 mg/l).

Algae: An important agent in deposition of karstic travertines: Observations on natural-bridge Yerköprü travertines, Aladağlar, Eastern Taurids-Turkey
C.S. Bayarı and T. Kurttaş

Algae contributes physically to the deposition of travertine by means of trapping of inorganically formed calcite micro-crystals by algal filaments and mucilagenous secretions and by providing proper...
nucleation sites for calcite precipitation. Biochemical activity of algae also forces the aquatic system to deposit travertine due to the photosynthetic removal of free carbon dioxide from the solution. Field observations indicate that the rate of physical and chemical contribution to the deposition depends strongly on the hydraulic conditions. Physical and biochemical roles becomes important in high and low velocity/energy streams, respectively. The effect of algal association over the travertine deposition can be observed apparently especially in streams where the ratio of algal mass to the rate of stream flow is substantially high.

Since the climatic conditions (air temperature and insolation) have strong influence upon the abundance of algae, the rate of travertine deposited by algal contribution decreases during the winter months when algal population decreases. Similarly, the biochemical contribution shows a diurnal pattern with a maximum during mid day because of the higher uptake of carbon dioxide via photosynthesis.

**Hydrochemical characteristics of the karst groundwaters in Serbian Carpatho - Balkanides**

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The chemical composition of these waters reflects entirely the conditions of their formation, the intensive water exchange and the rapid filtration. They are weakly mineralized waters with a prevailing content of HCO₃ in the anion and of Ca in the cation composition. The average content of ion HCO₃ is 87 % mval and of ion Ca it is 75 % mval, therefore ions Mg, Na, K, SO₄, Cl, NO₃, etc. usually occur inferiorly. Ions of NH₄, Fe, Mn, as well as microelements, are usually absent, and if they do occur, it is always within the limits of the valid quality standards.

The pH values imply a generally alkaline, rarely a neutral character (mean value 7.6). With regard of the hardness value, these waters cover all transitions from soft to very hard waters.

The gas composition is dominated by N₂ and O₂. Very low values are characteristic of U, Ra, and Rd contents. All analyzed waters show a low mineralization rate of 0.2 - 0.4 g/l (only 10 % samples below, and 6 % above these estimates), the total average value being 0.28 g/l. Chemical composition of these waters usually does not substantially changes throughout the year. The amplitude of changes concerning the mineralization values throughout the year is only rarely higher than 0.1 g/l.

Chemical composition of these waters is usually pure in the sanitary aspect, mostly for the catchment areas on mountain massifs being unpopulated. Cavern and channel dimensions, high filtration rapidity, or the like, cause frequent bacteriological pollutants, therefore
the entire catchment area of each source should be proclaimed a wider zone of sanitary protection.

The results of tracing experiments with groundwaters indicate that under convenient conditions, the pollution may migrate as far as 10 km of rectilinear distance as early as 24 hours. Active hydraulic connections between the ground and surface waters, where by the harmful components may be carried from great distances including nonkarst terrains and infiltrated into the narrowest spring zone, have a particular significance in this regard.

ENVIRONMENTAL ISOTOPES IN KARST

Hydrodynamics of Almyros karst aquifer, Crete island, Greece

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The brackish karst spring of Almyros is located about 8 km west of Iraklion one km inland from the coast. With its discharge between 3 and approximately 50 m³/s, it is the largest spring on Crete Island. Because of its complicated underground drainage system a number of hydrogeologists have carried out local and regional studies. The spring itself emerges along a large pre-Neogene N-S fault separating the Neogene and alluvial plain of the Iraklion trench from the karst massif of dolomitic limestones.

Recent investigations were dealing with the mechanism of salinity, calculations of the seasonal fresh water components and its recharge dynamics. Almyros spring reacts quickly, though sometimes with a certain delay, to precipitation events. Looking at the mean flow duration curves for some investigated years one can see a very steep falling curve representing the fact that a discharge of 14 m³/s was only reached or exceeded for 30 days (<10%) in the year. This is caused by high runoff periods during the winter time mostly shown as direct runoff.

Chloride content of spring water usually decreases with increasing discharge. The highest sea water portion is calculated between 22 and 23%. As the maximum permissible chloride content for drinking water is given at 200 mg/l the spring ought to have drinking water quality with respect to chloride at a discharge of at least 11.8 m³/s.

During the season 1985 and 1986 the dynamic of the karst water body was investigated by the correlation of spring discharge, chloride content and concentration of oxygen-18. It is evident that the peaks of spring discharge are accompanied by an increasing of fresh water portion. At the same time the oxygen-18 content decreases since the fresh water is less enriched with stable isotopes because of the temperature effect. By calculating the ¹⁸O-curve of fresh water it is shown that the recharge
from high altitudes is reaching the spring about two months after the increase of spring discharge.

Finally the comparison of different methods leads to the conclusion of different storage capacities in the individual geological-tectonical units.

Isotopic and hydrochemical significance of a karst aquifer within the semi-arid Datong coal mine area, China

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Water resources become an urgent problem for the semi-arid Datong region, a main coal mine area of China. After decades of development of pore water from Quaternary aquifers, great attention has turned to the potential of the South-Kouquangully karst aquifer of Ordovician period extended about 710 km² with depths 170 to 400 m. This aquifer is geologically formed on a large syncline. However, two kinds of karst water within this large aquifer have been identified isotopically and hydrochemically. It is formed due to the distribution of local faults and igneous rocks. It reveals that two different hydrochemical environments accompanied with different recharge and discharge conditions are existed.

Stable isotopic data shows that the δD vs δ¹⁸O of local precipitation marches the world meteorological line WML, but this relationship of karst groundwater shows another picture. Two groups of karst water from this aquifer could be distinguished. Data of the first group is situated near to the WML, it implies that this kind of karst water is mixed by recent precipitation which could be demonstrated by comparing the annual variations of groundwater level within boreholes with that of precipitation. Data of the second group has a δD vs δ¹⁸O paralleled to WML with a deuterium excess very near to zero, it implies that this kind of karst groundwater is originated during ancient climate environment.

Two kinds of karst water show its hydrochemical differences. The first group has a hydrochemical water type of HCO₃⁻/HCO₃⁻:SO₄²⁻ but second group is rich in Na⁺ but poor in SO₄²⁻ which seems to be formed within a relatively isolated environment. Typical data of ions and other indexes e.g., carbonate-saturation etc. of these two kinds of karst water are compared and listed, and a piper diagram related to is shown.
Environmental isotope study and 2-D modeling of cold and thermal karst within the Gemlik (Bursa) area of Northwestern Turkey

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The main topic of the interdisciplinary MARMARA-Project of the Swiss Federal Institute of Technology Zurich is the relationship between active crustal movements, seismicity, heat flow, and characteristics of deep groundwater circulation in northwestern Turkey. The Armutlu Peninsula, between Istanbul and Bursa, is one of seven areas, where detailed hydrogeological investigations were performed. The peninsula is situated between two branches of the North Anatolian Fault zone (NAF). In the southeastern part of the peninsula a metamorphic sequence, consisting of greenschists, a marble unit and flysh-sediments, builds up a mountain region. Related to outcrops of the marbles seven big karstic springs with discharges between 30 and 160 l/s, and temperatures between 13 °C and 25 °C flow out at the slope of mountains. In the plain of Gemlik artesian thermal water (37 °C, 410 μS/cm) appears. Chemical analysis showed that thermal water as well as spring waters have the same origin and are controlled by solution of calcite. The isotopic compositions indicate a mixture between cold karstic water (12-15 °C, 250-450 μS/cm) and hot, stagnant karstic water (40-50 °C, 300-400 μS/cm).

Applying the FE-element code FRACture (Kohl et al., 1993) two-dimensional modeling of the coupled hydrothermal circulation pattern as well as of the tritium transport pattern were performed. Introducing 1-D linear elements the necessary high groundwater velocities in karstic aquifers were achieved. The differentiation between hot, subthermal, and cold springs were possible regarding the outflow temperatures as well as the tritium concentration of the different springs. It turned out that the high water velocities in the karstic systems in relation to the normal groundwater velocities of the country rock (not karstic underground) and also the appearance of fracture zones are very responsible for this special situation of groundwater circulation. The results of the hydrogeologic investigations were nicely confirmed by these quantitative calculations.

Measurement of karst effluents into the streamflow by means of natural oxygen-18 content: Case study of the Ermenek basin: Central Taurids-Turkey

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The precise measurement of karst groundwater contribution into the streamflow bears special importance in reservoir tightness investigations that are carried out for the feasibility
of planned water structures in karstic areas. The interaction between the karst groundwater and the stream flow through the planned reservoir area should be carefully determined to ensure reservoir tightness. Although, precise streamflow measurements are usually accomplished by using classical velocity-area methods, in some cases, this approach can not be applied due to the difficulties (e.g., turbulent flow conditions) arising at the measurement site. In such cases, the use of tracer dilution techniques can help to overcome the specific problem existing at the desired measurement section. Artificial tracers, including fluorescent dyes, isotopes, salt solutions etc., have been widely used for determination of stream flow rate. However the present study demonstrates that the natural stable isotope ($^{18}$O) contents of the stream flow and the karst groundwater could also be used for this purpose. The stable isotope contents of the karstic groundwater and the streamflow at the points located at the upstream and downstream of the contribution site and the rate of the streamflow at the downstream part are the prerequisites of the proposed methods.

As verified by the dye dilution test, the present approach has been successfully applied for the determination of the karstic groundwater contribution into the Ermenek River located in the Central Taurids. The rate of karst groundwater contributions into the streamflow as determined by this method ($5.1$ m$^3$/s) and by the sudden dump dye dilution technique ($5.3$ m$^3$/s) was found to be quite consistent.

**Regional discharge of a Triassic artesian karst aquifer: mixing and age of spring waters in the Thuringian basin, Germany, estimated by isotope methods**

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The investigated karstic aquifer is a middle Triassic limestone (Muschelkalk), covered by impermeable upper Triassic (Keuper) clayey marls and shales and situated in a comparatively small basin (about $110 \times 70$ km) without important differences in the altitude of infiltration areas. Stable isotopes like $^2$H and $^{18}$O give therefore only a little possibility of genetic interpretation for the discharge of karst waters, concentrated in some places with bigger karst springs.

Good results give the contents of tritium ($^3$H) and radiocarbon ($^{14}$C): in the diagram of $^3$H versus $^{14}$C are visible areas of old, young, and mixed karstic groundwaters. It has been calculated mixing ratios and residence times of the mixing components for some of the karst springs.

Geochemical indicators like the bulk content of soluble matter, the geochemical type of water, the contents of $O_2$, Si, and F support the isotope results.
Determination of the recharge area of springs in an Alpine region by applying a model using the altitude effects of specific discharge and oxygen-18-content
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The area of investigation is situated in the Northern Limestone Alps near the lake Wolfgangsee (Salzburg, Austria). It consists primarily of Triassic dolomites with fine-fractured joint networks and high storage capacity and intensively karstified Jurassic limestones. The area reaches altitudes up to more than 2000 m asl and the mean annual precipitation being in the range of 1800-2200 mm.

The intensive and progressive use of the karstified region by tourism and pasture represent important pollution sources for the springs, most of them draining the karstified limestone are characterized by primarily bacteriological problems. Therefore the main purpose of the hydrogeological investigations was the determination of the main underground connections between pollution sources and the springs, and of their recharge areas and of the residence time of karst water as an important parameter for bacteriological pollution risks. The investigations were especially aimed at the main spring, the so called Kaltwasserquelle ("Coldwater spring") with a mean annual discharge of 174 l/s (fluctuations between 91 and 333 l/s), which is used for the drinking water supply of the small town Strobl.

The main directions of karst water flow were determined by means of combined tracing experiments which proved the existence of shallow drainage channels with high flow velocities in the Jurassic limestone, but the tracer could not be detected in the springs draining the dolomitic aquifer as the Kaltwasserquelle.

The investigation area was divided into various orographic drainage basins with continuous recording and partly periodic measurements of discharge. The hydrological catchment model is based on the following parameters, which were determined for the orographical drainage basins:

- surface A
- mean altitude H_r
- mean annual precipitation P depending on the altitude
- mean annual evapotranspiration E_r depending on the altitude
- theoretical mean annual specific discharge (l/s km^2) from the water balance equation
- mean annual discharge MQ (l/s) and specific discharge Mq (l/s km^2) (for catchments with only single measurements computed by correlation with the data of the next gauging station)

The data from small local catchment areas in less permeable rocks with different mean altitudes were used for the calibration of the model showing similar theoretical and measured specific discharges. A significant linear relationship
between mean altitude and mean specific discharge could be developed thus indicating their corresponding surfaces of the orographical catchments and the underground drainage systems. Deviations from this calibration equation can be quantified as deficits (recharge areas) and surplus (discharge area) and therefore give informations about the main underground drainage systems.

The altitude effect of the stable isotope $^{18}$O was used for the determination of the mean altitudes of the catchment areas of the springs. The isotope contents of the catchments and springs used for the calibration of the hydrological model show a strong linear relationship with the mean altitudes giving a slope of the regression equation of 0.22 $\delta^{18}$O/100 m the isotope data of a neighboring precipitation station being on the same calibration line. Based on this isotope model, it was possible to estimate the mean altitude of the recharge areas of karstic springs.

Introducing this parameter into the calibration equation of the hydrological model, one can deduce the theoretical mean annual specific discharge $M_q$ and from the ratio $M_Q/M_q$ the surface of the underground drainage basin. The effective porosity of the dolomites in the catchment of the Kaltwasserquelle could be estimated on the basis of these parameters as $p^o = 1.8\%$, a value which agrees well with the results from other investigations in alpine karstic regions.

The presented method gives the possibility to estimate the mean altitude and the surface of the recharge area of springs. Therefore, it represents an important base for the detection of pollution risks and for the delimitation of protection areas.

**Isotope hydrology study of the major areas of Paramithia and Koroni**


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The areas under investigation belong to the water district of Epirus, in the northwestern part of Greece. Limestones formations are the major constituents of the highlands, while recent deposits cover the lowlands. The flow rates of the big karstic springs suggest interrelations between the aquifers formed in the carbonic rocks of different ages, as well as between surface and groundwaters.

Sampling of springs at different elevations with well defined recharge areas established that the altitude effect on the $\delta^{18}$O value of groundwaters is uniform in the entire water district of Epirus, and namely – 0.18‰ per 100 m.
Based on the isotopic composition of surface and groundwaters, the origin and the dynamics of groundwaters and the interrelation of the major aquifers between each others or between them and the surface waters were determined.

Generally, the interrelation between aquifers formed in the carbonic rocks of different ages in the areas under investigation is confirmed.

The karstic system of the mountains of Paramithia and Souli is subdivided in three parts, each one forming its own aquifer. The northern one (mean annual yield $6.6 \times 10^6$ m$^3$) is feeding the spring of Kristalopigi. The highlands of the central and main one (mean annual yield more than $186.6 \times 10^6$ m$^3$) are recharging the river Acheron, mainly through the spring of Gliki. The regions of less than 700 m of altitude at the borders of this part are mainly contributing to the recharge of the aquifers of the surrounding younger formations by lateral intrusion. The southern part of the mountains Paramithia and Souli is mainly contributing to the recharge of the plain in the site of the community of Narkissos.

In the mountainous complex of Margariti two karstic systems are distinguished. The northern one is feeding the spring Neraida to the north, while the southern one, where at least two aquifers are developed, is recharging mainly the springs Ampoula to the east and Koroni to the south. The waters inflowing to the sinkholes of the Margariti mountainous complex contribute to the recharge of the aquifers formed in the nearby plains or to the feeding of very closely or at distances up to 30 km located springs, directly or by replenishment of the respective aquifers.

Concerning the system of Parga Mountains, which present a front to the sea, the entire dolomitic formation of its isolated southern part is recharging the saline spring of Ammoudia. The water of the swamp Kalodiki inflowing to the sinkhole at the borders of this part of Parga Mountains seems to be feeding submarine springs.

**Environmental isotope study on karst water of a typical coal mine in North China**

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Groundwater gush in coal mine is frequent especially in north China it is very large in amount, so that economic loss, even life loss are serious problem. We apply isotope techniques for identifying the origin and the mechanism of the water gush, the research work focused to the Zhao coal mine which is one of the most important coal mine in China and the research work has important meaning in both application and science.

33 water samples collected for oxygen-18, deuterium, tritium, and chemical analysis. The research has resulted in some important achievement, isotope and chemical data were used to divide groundwater system to trace the movement of
groundwater to determine the mixing ratios of various groundwater and its recharge source.

According to the isotope chemical data and related six figures, it seems that there are three kinds of water; the first one is precipitation, $\delta D = -71 \%e$, $\delta^{18}O = -10.0 \%o$, the second is surface water, $\delta D = -40.9\%e$, $\delta^{18}O = -3.64 \%o$, and the third is karst water $\delta^{18}O = -8.50 \%o$, $\delta D = -62.0 \%e$. The stable isotope compositions of the three kinds of water have no change, so it can be concluded that its recharge is stable. It is recharged by local precipitation. $\delta^{18}O$, $\delta D$ values of the karst water are very close to that of pore water of river Dashahe basin. The closeness indicates that they have same origin. It is the pore water of river Dashahe basin that recharge the karst water. The deep karst water belong to the zone of stagnation, replacement of groundwater is rather slowly.

Karst water is the key point of groundwater gush in research coal mine, pore water in river Dashahe basin is the main recharge sources of karst water. Karst water in relic karst develop zone is filled with Quaternary pore water from bottom to top. Karst water can be divided into deep and shallow parts. The shallow karst water has a relatively large removal range and strongly replaces with pore water. In contrast, the deep karst water has a small removal range and replacement with pore water is slow. There is no hydraulic contact between karst water and surface water. Therefore, in coal mine area we should do our best to prevent karst water from being recharged by pore water in river Dashahe basin so as to decrease the karst water recharge intensity.

**Stable isotopes of hydrogen and oxygen in study of North Caucasus gypsum karst**

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The present study comprises hydrogen and oxygen isotopic composition of precipitation, surface and underground water and water of gas-fluid inclusions in gypsum and halite.

It was established that all types of natural waters take part in the processes of gypsum cast formation, while precipitation and surface waters are predominant. The bulk points of isotopic composition of karst streams and reservoirs waters is along the GMWL. Some points of karst lakes are displaced to the right and down and those of water of cave walls - upper and to the left of this line.

These could be explained by fractionation of isotopes as a result of condensation-distillation processes. Another group of points locates to the right and lower of the this line, along the line of mixture of talassogenic and meteoric waters, what is also confirmed by the data on chemical composition.

In the Mineral Waters area meteoric water reaches a depth over 1000 m. Interaction of meteoric fluids with talassogenic waters, carbon dioxide and ionic-salt complexes of rocks
results in formation of unique mineral waters. The results of isotopic and geochemical studies, data of drilling and logging testify the development of karst processes at much greater depths, than those achieved by speleologists. This is also confirmed by the results of study of isotopic composition of gas-fluid inclusions in halite and gypsum and anhydrite, serving as an indicator of meteoric fluids presence in geological section.

**Determination of karst groundwater flow systems of different origin by means of environmental isotope and hydrochemical data: The Lower Dalaman basin (Western Taurids-Turkey)**

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The Dalaman basin of SW Turkey comprises autogenic and allogetic karstic carbonate aquifers of Miocene and Mesozoic age, respectively. The basin extending along the Mediterranean Sea to wards highlands has numerous karstic springs with different hydrochemical characteristics. Fresh-water springs and brackish thermal springs emerging from the same aquifer are encountered in different parts of the basin. Distinction among the different karst groundwater flow systems existing in the basin has been accomplished by the examination of hydrochemical and environmental isotope data from 10 karstic springs.

The results of both environmental isotope and hydrochemical data revealed that the regional karst groundwater system is rather complex and comprises of three subsystems which can be described as (1) an upper karst groundwater system, (2) a middle flow system exhibiting slight mixing with thermal groundwater, and (3) a lower karst groundwater system discharging waters composed of sea water and thermal groundwater.

In this paper, the author proposes an overall picture of the origin and the groundwater flow system of the large karst springs.

**Karst groundwater studies in Lamas river region (Limonlu-Erdemli-Içel), Turkey**

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The geology and hydrogeology of the karstic drainage basin in the Lamas region covering a surface area of 1500 square kilometers was investigated for the groundwater potential. The main objective of Lamas Project is to define the relation between the recharge to highlands and the discharge realized by the karstic coastal or submarine springs along the Mediterranean coast and assist to development of karst water resource.

Formations of Paleozoic, Mesozoic and Cenozoic crops out in the region. The base rocks of quartzite, schists and crystalline limestones of...
Paleozoic are unconformably covered by the dolomitic limestones of Mesozoic. The ophiolitic melange is overthrust to the north. Cenozoic, starting with marly limestones of Kaplankaya formation continues with Karaisah limestones. All important karstic activities are observed in this formation which reaches up to 1000 m in thickness.

The investigation area was extended almost 4400 square kilometers where the elevation varies between 0 to 2700 m. Mediterranean climate influences the region and the mean annual precipitation is 605 mm on the coastal line and 756.5 mm in Güzeloğlu (1400 m), and 673 mm in Kırobası (1400 m).

Lamas river is the main river crossing the area. The maximum discharge reaches up to 13.48 m³/s and minimum 2.77 m³/s. The discharge to and from the spring is observed by step measurements along the river bed. The average loss reaches up to 0.58 m³/s. The runoff coefficient is estimated as 0.28.

The springs in the region can be classified as karstic, coastal, and marine springs. The yields are between 2500 to 0.2 l/s depending on the hydrogeological conditions. The mean discharge of three important springs are K-3 34.0 hm³/a, K-14 18.0 hm³/a, and K-19 18.9 hm³/a.

The karstification has reached at least 250 m in depth almost to the base of Karaisah limestone. The karstic features are often observed and small poljes are found in various elevations. The sea water encroachment is observed on the coast line with the due to the karstification and the seasonal variations are identified.

The samples collected from the area represents precipitation, springs, streams, and drilled wells. The linear regression line representing Güzeloğlu precipitation is

\[ D = 7.07 \delta^{18}O + 7.91 \text{ where } r^2 = 0.91 \]

The regression line representing the samples is determined as:

\[ D = 7.7 \delta^{18}O + 13.67 \text{ where } r^2 = 0.91 \]

Depending on the \( \delta^{18}O \), \( \deltaD \), and \( T \) results the samples are collected in six groups. Evaluation is made by the analysis of variance to investigate the relation between and within groups in 95% confidence level. The estimated turnover time with \( \delta^{18}O \) values gave the result of approximately 30 years.

By taking into consideration the unmeasured discharge along the coast line, the infiltration from the precipitation is approximately 50-60 %. The groundwater flow is from north to the south and sometimes may not be affected from the low altitude precipitation. The effect of the sea water encroachment is detected by isotopic and hydrochemical analyses. Measures should be taken to protect the overpumping from the water along the coast line.

Depending on the hydrogeological and isotope hydrology investigations, it has been concluded that the development of the karst water resources can only be realized on the
coastal line. The deep water table conditions prohibit deep water well drilling due to the hydrogeological and karstic reasons.

The development of karst springs can locally be realized by drilling of water wells and establishing a reservoir volume and pumping relation.

**TRANSPORT PROCESSES**

Case studies of the subsurface pseudo-karst on preferential contaminant transport at the Savannah river site, South Carolina, USA*

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The Savannah River Site (SRS), located in the inner Atlantic Coastal Plain physiographic province, covers approximately 800 km² in southwestern South Carolina. The SRS is operated by the U.S. Department of Energy and was set aside in 1950 as a controlled area for the production of nuclear material for national defense. Past industrial activities at the SRS have resulted in soil and groundwater contamination at localized sites.

The sedimentary sequence at the SRS ranges from Cretaceous to Holocene in age and consists of unconsolidated sand, silt, clay, and minor mixed terrigenous-carbonate sediment with isolated zones of indurated sandy and muddy limestone. The calcareous lithologies, which range from 0.3 to greater than 15.0 m thick, occur sporadically throughout the SRS.

Hydrogeological studies of the Burial Ground Complex (BGC) and the Chemical, Metals and Pesticides Pits (CMPP) suggest that pseudo-karstic solution features within the Upper Middle Eocene Santee Limestone control the flow direction and transport rate of groundwater contaminants. Below the BGC and CMPP the Santee occurs as isolated lenses of unconsolidated calcareous sediment and indurated sandy and muddy limestone.

Core data coupled with loss of circulation and rod drops during drilling indicate that the limestones contain erratic zones of vuggy porosity. The hydraulic conductivities of the vuggy limestones are often significantly higher than the surrounding terrigenous and calcareous unconsolidated sediments. Groundwater monitoring well data and modeling studies indicate the presence of isolated flow paths within the limestones that are different in flow direction and gradient when compared to the surrounding sediments. In addition, contaminant data supports the hypothesis that the vuggy limestones serve as conduits for transport of contaminants.

* Information in this investigation was developed under contract DE-AC09-89SR18035 with US Department of Energy.
Investigations of groundwater flow and solute transport in fractured rock at the Grimsel test site (Switzerland)
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The Grimsel Test Site (1730 m asl) consists of a laboratory tunnel in a depth of 450 m in the fractured rock of the Central Aar Massive of the Bernese Alps. As part of the research program migration experiments were carried out in order to obtain chemical and physical information for both qualitative and quantitative characterization of nuclide transport in fractured rock, including matrix diffusion and sorption. As site of the migration experiment a steeply-dipping shear zone was selected, which forms a relatively strong water bearing fracture and is partially filled with porous, unconsolidated fault gouge material.

As part of an extensive hydrogeological and geochemical investigation program over a period of more than two years water samples were collected from all tunnel inflows as well as from springs, runoff, snowmelt and glaciers in the environment in order to study the recharge conditions for groundwater within the rock massive. The results of the stable isotope analysis of tunnel water yield to a well fit of the meteoric water line established for modern precipitation in Switzerland. In using the altitude relation for the stable isotopes a mean altitude of 2200 m was found for the catchment area of the tunnel waters. The tritium contents of the tunnel water show actual recharge at the slopes but prove with <1 TU a residence time of more than 40 a in the central part of the tunnel with a maximum of overgrowth. The residence time was confirmed by the results of TAMS dating of $^{14}$C in low volume dissolved organic carbon.

More than 50 migration experiments were carried out within a steady asymmetric dipole field in the shear zone with pulse or continuous injection. The numerical analysis of conservative tracer breakthrough curves produces data on fracture aperture ($\approx 1$ cm), dispersivity ($\approx 10$ cm) and porosity of secondary fill (0.3) and matrix ($\approx 10^{-2}$). These characteristic formation parameters were applied in the numerical analysis of the reactive nuclide ($^{137}$Cs and $^{85}$Sr) breakthrough curves in order to determine the field values of the coefficients of sorption and retardation as well as of matrix-diffusion which are essential terms for the modeling of transport processes.

Bacterial and chemical contaminant transport tests in a confined karst aquifer (Danuba valley, Swabian Jura, Germany)
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The transport behavior of bacterial and chemical tracers in a confined karst aquifer was examined by one-dimensional field investigations. A dipole of two wells (126 and 203 m
depth) gave access to a 200 m experimental distance in a massive, cavernous Malm limestone aquifer. By controlling the artesian outflow, potential gradient, flow direction and flow velocity of the karst groundwater could be varied.

The test substances were injected together with fluorescent dye tracers directly into the karst groundwater. As fecal indicator bacterium, *Escherichia coli* K 12 (wild type) was used. Terbuthylazine, Isoproturon and nitrate (as NaNO₃) were used as chemical tracers. As abiotic particular material, in comparison to bacteria, fluorescent polystyrene microbeads (φ1μm) were used. Radiohyrometrical single-well measurements (determination of local flow vectors) and isotope hydrological measurements (groundwater dating) were carried out as well.

The investigations revealed: The flow time of the tracers (first appearance) was between 1.5 and 6 d. The transport behavior of the contaminants pesticides and nitrate was nearly the same as that one of the fluorescent dissolved tracers. The recovery of *E. coli* (living cells) was similar to that one of the fluorescent microbeads and 0.1-1 % of the recovery of the fluorescent dissolved tracers. This indicates that the number of culturable cells significantly decreases during the passage and that abiotic particles sufficiently represent the transport characteristics of bacteria. In all cases the bacteria and microbeads arrived earlier than the dissolved tracers. The results indicate, that even in rock aquifers of high conductivity bacteria are quickly inactivated, whereas chemical contaminants are slowly eliminated.

**Contaminant transport from leaky landfills in karst areas**

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Leachates leaking from damaged landfills represents a potential threat of groundwater pollution and is increasingly matter of public and regulatory concern. Old landfills with no or insufficient leachate collection systems can constitute a frequent risk to groundwater quality because the leachates often contain specific organic pollutants as well as a substantial content of organic-matter.

The migration and fate of contaminants from leaky landfills in karst areas have been investigated, using soil gas surveys and geophysical methods. The investigation area was a municipal landfill above karstified limestones of Triassic age Northern Black Forest, Southern Germany. One karst spring north of the landfill is subject to severe pollution. Water samples from this spring and groundwater observation wells indicate that there must be an aquifer pollution by waste site leachate. Therefore, detailed hydrogeological and geophysical investigations have been carried out to detect contaminant flow paths from the leaky landfill. Historical
investigations showed that the former quarry walls have been sealed not correct. Geological investigations suppose a NNE striking extension fault zone underlying the landfill. The karstified limestones of the Middle and Upper Muschelkalk in the investigation area strikes west to westeast and dips with 5 to 10 degrees north to northeast. Soil gas sampling in the surroundings of the leaky landfill was carried out in 1.5 m deep, small diameter boreholes. The boreholes were closed against the atmosphere during the measurements with blowed up packers. The soil gas was analyzed for CO\textsubscript{2}, CH\textsubscript{4}, O\textsubscript{2}, H\textsubscript{2}S and 222Rn. Electromagnetical soundings on the 10 investigation profiles have been carried out with direct current process. Horizontal coplanar and vertical coplanar coil configurations with spacings of 10, 20 and 40 m between transmitter and receiver lead to 6 various depth penetrations (2.5 m to 40 m depth) along the cross-sections.

During the soil gas screenings neither CH\textsubscript{4} nor H\textsubscript{2}S have been detected in the soil gas. The CO\textsubscript{2} concentration along the cross-section varies significantly (Fig. 1).

At location 70 and 85 CO\textsubscript{2} maximas in soil gas were detected. These maximas correspond clearly with the detected minima in the soil gas O\textsubscript{2} concentrations. The positive CO\textsubscript{2} and negative O\textsubscript{2} anomalies at location 70 and 85 probably refers to the contaminant transport on the extension fault zone. The aerobic biodegradation of leachate compounds in the unsaturated zone and in the groundwater decreases the O\textsubscript{2} and increases the CO\textsubscript{2} in the soil air and in the groundwater. The degradation of leachate compounds on small, preferential flow paths, like the fault zone leads to elevated CO\textsubscript{2} and depressed O\textsubscript{2} concentrations compared to background levels within the karstified limestones. The results of the 222Rn investigations indicate also a main anomaly at location 70 and three minor anomalies at location 10, 85 and 130 (Fig. 1). The main 222Rn anomaly at location 70 refers to the extension fault zone. This positive 222Rn anomaly expresses probably the high Radon emanation in the fault zone. The results of the electromagnetic soundings show a broad zone below 35 meters and two areas with low apparent electrical resistivities at location 55 and 110 in 20-40 m depth (Fig. 1). The zone below 35 m depths refers to the groundwater of the karst aquifer. It seems that the two anomalies correspond to two separate inclined extension fault zones. The very low resistivities (< 100 Ohm. m) in those zones possibly refer saturated conditions (water, leachate) within the limestones. Especially at location 55, this low resistivity zone reaches up to 15 meters below surface.

In combination of soil gas screenings and geophysical investigations, two inclined fault zones have been detected. Leachate water leaks from the damaged landfill into those fault zones. Within the fault zones the
leachates are transported to the groundwater. The detailed investigations on other investigation profiles allow, in combination with hydrological and hydrochemical investigations, the detection of fault zones as well as the further run of preferential flow paths of leachate and contaminated groundwater.

Fig. 1: Results of the soil gas screenings and electromagnetic soundings on a cross-section north of the leaky landfill.

Transport mechanism in the subcutaneous zone
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Within the framework of the current research project of the International Association of Tracer Hydrology (ATH) in the classical karst area of Slovenia intensive investigations of subcutaneous zone of karst aquifers were started in summer 1993. The subcutaneous zone, also termed the epikarst or vadose zone, is of particular importance for a karst aquifer with respect to quantification of recharge, storage and discharge processes. It extends from the upper weathered part of the bedrock above the permanently saturated zone up to the soil. Arising from considerable chemical solution during downward percolation of water, a high secondary permeability characterizes the subcutaneous zone. Reliable estimation of the influence of the subcutaneous zone requires a detailed characterization of the hydrogeological and hydraulical properties and of the solute transport. Cave systems provide and excellent opportunity for intercepting water in the unsaturated zone and monitoring solute movement.

Our investigation have been carried out in the ca. 30 m thick subcutaneous zone above the cave Cerna jame, Slovenia. As observation network about 15 trickles and dripping points with varying discharge behavior was selected. Rainwater was collected with two parts. Event monitoring was carried out during autumn 1993, summer and autumn 1994. Daily measurements of discharge, temperature pH, electrical conductivity (EC) and carbon dioxide and bicarbonate have been carried out for the selected trickles and drippings. Additional water samples were taken daily for analysis of oxygen-18 content and weekly for a complete analysis of selected anions and cations. Point source experiments with artificial tracers were carried out in autumn 1994 to
supplement the information from the hydraulic observations and the environmental tracers (Oxygen-18, temperature and chloride).

Our results to date show that the observation points can be divided into at least two groups based on their response to precipitation events. This distinction reflects the existence of two flow components in the subcutaneous zone. A fast component is activated during the initial phase of a recharge event (within one or two days, partly within hours after the event), while a slow component acts with a significant delay (typically within one week, although sometimes without response depending on recharge intensity). Comparison of the baseflows of both components reveals that the fast recharge component only comprises about 10% of the total recharge volume, whereas the remaining 90% arrive in the drippings within a period of weeks.

**MODELING AND FLOW SYSTEMS**

Delineation of a carbonate-alluvial groundwater flow system using a mixing-cell model and the spatial distribution of deuterium

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We use the spatial distribution of the stable isotope deuterium to calibrate a mixing-cell model of the Railroad Valley groundwater flow system, a carbonate-alluvial system covering approximately 15000 km\(^2\) in central Nevada, USA. The model provides first approximations to the volume of groundwater in storage, recharge rates and groundwater ages. A two-layer model simulates the upper alluvial aquifer system and the underlying carbonate aquifer system. Since the system is poorly constrained we use two different cell configurations, each with three different flow scenarios. Our novel approach, applied herein to an arid-region, large-scale, carbonate-alluvial aquifer system, is independent of aquifer type or climate.

Total groundwater storage in the alluvium ranges from \(4.6 \times 10^{11}\) m\(^3\) to \(1.5 \times 10^{12}\) m\(^3\), groundwater storage in the carbonate aquifer ranges from \(2.0 \times 10^{11}\) m\(^3\) to \(1.0 \times 10^{12}\) m\(^3\). The total subsurface flow through the system is approximately \(1.4 \times 10^{8}\) m\(^3\)/year. Mean groundwater ages vary from 1200 to 46000 years; the oldest groundwater in the system approaches 150000 years old. Our modeling results indicate that the Railroad Valley flow system is not closed but receives inflow from an adjacent carbonate-alluvial flow system, the White River flow system.

**Study on the pollution of fracture-karst water in Boshan district, Shandong province, China**

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Boshan is an industrial city in the middle of Shandong Province.
Groundwater is the unique sources for the urban water supply. The main water resource is fracture-karst water in Middle Ordovician carbonate rocks. In this paper we studied the main pollution sources and the path of pollution, the main contaminants in groundwater and their characteristics of space-distribution, estimating groundwater quality by indistinct mathematics method. Geostatistical methods, such as trend analysis, and kriging method, were taken to simulate contaminants distribution in space. Grey system method and characteristic finite element solution of advective-dispersive equation were adopted to forecast pollution in the future. Finally, some proposals for protection of groundwater environment in Boshan area are suggested. They are:

1. Some factories which take the risk of serious polluting environment have to be moved out of the recharge area of fracture-karst water. In the other factories which were located in recharge area, drainage of sewage and heap of rubbishes have to be managed rigorously.

2. In leaky sections of the Xiaofu River and its branches impermeable clay laying on limestone has to be constructed.

3. Rubbish heaps and land fills on limestone in recharge area must be taken away.

4. The water quality in the new well field in Tianjinwan is good for drinking. We must protect the water resource from contamination and establish a water resource protection area.

Hydrology of Dreznicko polje in the karst (Croatia)

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Dreznicko polje is typical closed polje in the karst located in the central part of Croatia. Inflow in the polje comes from three main directions which have surface and groundwater components. From the hydrologic-hydrogeologic point of view the Dreznicko polje is a part of a wider system with catchment area of about 225 km\textsuperscript{2}. The annual rainfall varies from 1700 to 2200 mm with an average of about 2000 mm. Maximum volume of the Dreznicko polje retention is $50 \times 10^6$ m\textsuperscript{3}. The polje is regularly flooded in the cold and wet periods of the year, usually from October to April. The paper deals with the complex problems of the flow in karst terrain. The conceptual Streamflow Synthesis and Reservoir Regulation (SSARR) model was applied for definition all components of the Dreznicko polje inflow and outflow. The model was applied by using the daily hydrologic and meteorological data. In complete karst flow conditions very encourage results were achieved with a general non karstic model. Especially interesting results are connected with definition of the discharge curve of the Dreznicko polje swallow holes.
Groundwater flow in Karst terranes has been quantitatively described by numerous authors using analytical as well as numerical modeling approaches. Within these studies, one problem commonly encountered is the adequate representation of the extreme variabilities in the flow system which cannot be described employing classical single-continuum porous equivalent (SCPE) models.

An alternative approach using a double-continuum porous equivalent (DCPE) model concept was developed by the author in 1988. There, the first continuum represents the large conduits and the second continuum represents the numerous smaller fissures. This approach has been successfully applied for the modeling of various catchment areas on the Swabian Alb Jurassic Karst plateau in Southern Germany. However, a drawback of the DCPE approach is that the model parameters transmissivity, storage coefficient and the exchange coefficient between the two continua can only be obtained through calibration (inverse parameter fitting). Since there is no simple way of relating the resulting (calibrated) hydraulic parameters to experimental data from the field, extensive numerical studies were performed, where different karst aquifer systems (simplified prototypes) were simulated using different modeling approaches and the model results compared.

The paper presents the DCPE modeling approach including the results from different karst catchments and also the results of the numerical studies.

Hysteresis effect of karst vadose zone in Spring KR5, MT.
Krauterin, Austria

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The vadose zone of Spring KR5 is made of Dachsteinkalk limestone of Upper Triassic age. While surface sheet flows and rills appear in a few minutes during a rain event, echo in the spring is usually 2 hours later. A flooding process can be divided into pure lag stage in which no echo gives to rain event, pure energy inputting stage in which discharge increases due to tube air compression and then due flooding wave transmission, and material inputting stage in which fresh water arrives at the spring. A triangular matrix of the effect lag relations combined with hydrographic and chemographic analyses is applied to understand the master characters of the karstic vadose zone. Electric concentration is about 270 microS/cm (at 25 °C) for the input pulse, and can drop to 160 microS/cm in a tempest. The decline is usually lags to the discharge peak one hour. Before it a peak of water temperature may occur. Due to the water-absorption ability, rock walls
can hold some volume of infiltration and then the held water may evaporate in the following dry season. When the fall of a rain event is less than 5 mm, no echo occurs at spring system.

On the karst spring discharge forecasting by the means of stochastic modelling
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The present paper deals with the short range modeling and forecasting of the daily karst spring discharge, having relatively isolated drainage area. The idea is to apply "black box" type stochastic model when detailed information on the flow formation processes is not available. The model used includes autoregression on the dependent variable as well as on the residuals and multiple regression on the independent variables—precipitation and other inputs, using different time lags. Data from the typical karst spring at the town of Kotel have been used. The results obtained show real possibilities to establish forecasting procedure, but the model accuracy needs improvement during the winter period as far as the snowmelt process have not been included in the model.

The karst springs in the Rhodopes mountain, Bulgaria
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For the purposes of the water policy planning and increasing the capability of the water supply systems, statistical analyses of spring discharges in the Rhodopes mountain is applied.

In this study graphical methods are used for estimation of the spring discharges. The partial flood peak series are used for the extreme values as they are more representative than the annual peak series.

The application of the cluster analysis for an objective classification of karstic springs in the study area is discussed.

Developments and achievements in the mathematical simulation of cave systems
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In the last ten years the author has developed a mathematical model to forecast the three-dimensional spatial distribution and time evolution of cave passages in karstic carbonate regions. Several real systems have been simulated with an acceptable degree of accuracy.

Tested under different initial and boundary conditions, modeling has allowed to: 1) the derivation or extension of different sets of governing equations describing-in time and space- the development of limestone caves; 2) to forecast the position and some geometrical characteristics of known galleries and unknown cave passages, and 3) to test, in particular cases, the theories
performed to explain the origin of simulated cave systems.

When active hydrologic cave systems are simulated, model shows the local and sometimes regional distribution of flow patterns, allowing to forecast the position of the underground drainage network, the location of springs and the position of groundwater divides, among other important tasks of karst hydrology.

Conceptually, the model has been performed involving several principles from the theory of automatic control of non-linear self-regulated feed-back systems under random inputs, non-equilibrium thermodynamics and inertial, time dependence, scaling effects, entropy variations and mass, moment and energy transfer properties of the involved constitutive spaces within the considered media.

Examples of model output of real systems are shown, with a special discussion on the "unsuccessful" spatial outputs and their relation with the high level of performance required by several theoretical factors.

Computer simulation of the karst water table in the Transdanubian mountain ranges Hungary

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During the last four decades the water resources of the Transdanubian karst reservoir were endangered by the karst water withdrawal of mines. The water-discharges of the main karstic aquifer surpassed the average recharge, therefore, the water-table decreased 30-80 m or more, over whole reservoir area. The horizontal extension of the karst is more than 10000 km², the infiltration area is about 1500 km².

Efforts of the last years have been concentrated on creating a hydraulic model of the karst-reservoir. From hydrogeological point of view the whole region is explored in detail, due to the large-scale dewatering operation of mines. The karst water observation network, established from the end of '60'es covers the whole reservoir area. The network consists of more than 500 wells.

The applied methods for the infiltration-estimation enable the model to perform simulation of the natural karst-water level changes. The database used by the model contains all the essential natural, and artificial factors, (i.e., precipitation, climatic parameters, discharge of spring, wells, and shafts) affecting the karst water-table since 1950. Thus the hydraulic model can simulate the variation of the water-table in the karst reservoir for the last forty-four years.

The developed finite element model is able to forecast water table changes in the future. Several important decision were made in connection with management of bauxite and coal mines, as well as water-supply considering model results.
Modeling, exploration and development of deep water level confined karst water in Zhungeer coal district

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Zhungeer coal district is situated in the northeastern part of Zhungeer county, Yikezhaoer prefecture at the Inner Mongolia Autonomous Region. As a big coal field with high reserves abundance it has been included in list of the major projects of energy base construction during the period of China's Eighth Five-year Program.

Previous work in this area had got the conclusion that the Cambrian-Ordovician karst aquifers of the coal measure basement where poor of water and the water supply prospects would be bad.

In order to solve the problem of water supply in this coal district, based on ascertaining the karst hydrogeological condition, we applied the theory of karst water system, established a Tian Qiao Karst Water System, setup a model for the transformation between the rain water, the Yellow River water and the Karst groundwater and the multistage discharge of deep karst water in the Yellow River Walley area, found out strong runoff zones in the deep water level confined karst aquifer and two water supply sites have been completed, with a capacity of 74000 m³/d. This has been proved to be successful and have achieved remarkable economic and social benefits.

Determination of specific yield of a carbonate aquifer by analysis of discharge curves for wells and springs and laboratory tests

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Mathematical modeling, commonly used in hydrogeology, requires a detailed characterization of hydrogeological properties of rocks. The pumping tests are a preferred method of determination of those properties. However, it is costly and, therefore, it cannot extensively be used in regional studies. Moreover, the pumping tests are too short and the yield is often too low for satisfactory results in the case of karst-fractured aquifers. Therefore, it is necessary and advisable to use results of laboratory investigation and data obtained during exploitation of already existing water intakes and springs.

In this report, we present results of determination of specific yield of carbonate rocks of the Triassic karst-fractured aquifer. Calculations of the specific yield were made on the basis of interpretation of hydrograms of a water intake and two springs and by use of laboratory tests.

Because of the relatively steady consumption of water, changes in the depression are caused predominantly by changes in recharge of the aquifer by rainfalls. A hydrogram of specific
capacity was made for the period of 1978 to 1994 and discharge curves were plotted. The Maillet equation was used for the interpretation of hydrograms of water intakes and springs.

Specific yield was determined in 28 samples using centrifuging method. Pore-size distribution analysis by a Mercury Injection Scanning Porosimeter was applied. This enabled calculation of a theoretical specific yield from the distribution curves.

Values of the specific yield obtained by centrifuging ranged from 0.37% to 23.76%; on average 6.64%. The theoretical specific yield obtained from the pore-size distribution, was low and ranged from 0.06% to 0.15%. Hydrograms of springs gave specific yield of 0.3% up to 12% depending on the spring and on both rate and time of drainage (recession of discharge of spring). The hydrogram of the water intake gave values of the specific yield between 2.67% and 3.78%. Relatively high scatter of values of the specific yield coefficient in rock samples suggests a structural micro-scale inhomogeneity of the aquifer. Differences in values of the specific yield for springs resulted from the lithological variability in the catchment area of the springs. Small variation in values of the specific yield derived from the hydrogram of the water intake indicates both structural and hydraulic homogeneity of the aquifer within the catchment area of a 45 km².

Radial flow toward a karstic spring

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Physically based approaches to karstic discharge problems have been appeared in literature. These assumes unidirectional groundwater flow. However, radial flow seems to be more representative of natural phenomenon.

Using linearly connected multicell reservoir model, it is shown in this study that karstic discharge recession equations empirically proposed by Maillet and Schorrell are also valid for the watersheds which are approximately a circular sector with a circular sectorial angle $\phi$ and radius $R$.

Some important points in the evaluation of flow analyses in karst springs

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Relationships among discharge, time, and active reservoir volume are investigated by using spring discharge analyses but the sensitivity of the estimated reservoir volume can not be checked. In this study, the sensitivity of this type of analyses was investigated in the Gökpınar spring in karstic environment of western Taurus and the water volume of the Kovada Lake which is the reservoir of this springs. A correlation coefficient of 0.99 was found for the relationship between
the spring flow and the reservoir volume by doing base flow analyses properly. In order to do these types of analyses properly, contribution of surface water, interflow coming from major cracks and small streams to the measurement point must be eliminated.

In this type of analyses, the method that will be applied should be chosen according to type of flow (confined-unconfined or laminar-turbulent). It must be considered that the Maillet formula can be used for confined and laminar flow or when reservoir volume is larger than total volume of flow or changes in flow with time at unconfined aquifers are small.

In this type of studies, continuity of spring flow is important. Because of this reason at the Köprü spring, flowing or drying according to the water level of the Kovada Lake, water level-flow analyses could not be done accurately. Small channels drying and loosing their water during dry season keep the some of water coming from the lake from reaching the spring when the water level rises. At the end of wet season no water comes from the lake, however, stored water in the small channels may feed the spring. As a result of this, correlation between level and discharge can not be established accurately. This indicates that applying these flow analyses mentioned above to seasonal springs do not give accurate results.

**EBB and flow behavior of a karst spring, Kings canyon national park, California**

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Big Spring, the resurgence of the karst aquifer in the Lilburn Cave-Big Spring system (Kings Canyon National Park, California), displays the uncommon phenomenon of ebb and flow discharge during periods of high runoff. Hydrograph and spectral analyses of stage and discharge time-series data, sediment size analyses, and a bench scale model were combined to elucidate the internal hydrology of this karst aquifer system.

Digital stage data have been recorded almost continuously at two critical hydraulic junctures: the Z-Room (the upstream storage chamber with a 3 year database), and Big Spring (the resurgence of the karst system with a 6 year database). The Z-Room is located within Lilburn Cave approximately 700 m north and 10 m above Big Spring. Time-series observations of the Z-Room and Big Spring stage levels revealed two distinct flow patterns during the high runoff season (February through June). The first is an ebb and flow, 180 degree out-of-phase response in which a drop in Z-Room stage results in an instantaneous rise at Big Spring. The second type of flow recognized is a high, sustained flow.
suggesting an in-phase relationship between the Z-Room and Big Spring stages. The triggering mechanism between these modes of flow is poorly understood, but our initial results suggest that the transition may be chaotic.

Hydrograph analyses indicate that the section of Lilburn Cave between the Z-Room and Big Spring is primarily a conduit flow aquifer discharging approximately two-thirds of its flow through large diameter conduits, one-fourth in smaller conduits and open fissures, with the remainder through small fissures and fractures.

Power spectra performed on multiple data sets strongly indicate a nonlinear system, with evidence of small-scale quasilinear behavior. Both types of flow at the Z-Room (input) behave stochastically, possibly the result of flow path blockage from a variable sediment load present within the system. Transfer and kernel function analyses confirm the presence of nonlinear and quasilinear flow regimes, and further indicate that no additional significant inputs or outputs to the system exist.

A bench scale model built to simulate the ebb and flow cycles observed in the Lilburn Cave-Big Spring system was developed, and results were compared to the currently accepted theories of 1) a natural siphon within the rock matrix, 2) a reciprocating spring, and 3) blockage by a sediment plug. Our model, in conjunction with analytical results and observations of diverse Cave Research Foundation scientists, is a single large conduit with a sediment plug in its lowest sump behaving stochastically to cause the ebb and flow behavior during periods of high runoff.

**KARST MORPHOLOGY AND PALEOENVIRONMENT**

**Sannur Cave: A crescent shaped cave developed in Alabaster formation in Eastern Desert, Egypt**

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An expedition to Egypt set out to explore the Wadi Sannur where no speleological work had taken place. The most notable karst feature identified to date is the Sannur Cave, the largest subterranean chamber known in Egypt. It is situated about 70 km to the southeast of Beni-Suef city in the remote Wadi Sannur of the Eastern Desert where the main rock units belong to Eocene and Pliocene periods. The Eocene is represented by limestone including alabaster which is known to be quarried first by the ancient Egyptians. Sannur Cave is first explored during blasting in the alabaster quarry which caused an artificial entrance to the cave.

The cave is a single crescent shaped chamber approximately 275m long and can be arbitrarily divided into two sections having different characteristics; left side gallery and right side gallery. Few speleothems occur in the left side gallery while
the right side gallery is decorated intensively with many kinds of speleothem including stalagtites, stalagmites, flowstones, microgours, helictites, and soda-straws etc.

In addition to surveying the cave, based on the geologic, structural and morphologic observation inside and outside the cave some interpretations on the paleoenvironment and the origin of the cave. Surveying was performed with GRADE 5D according to BCRA Gradings.

**Speleogenesis in the Miocene gypsum strata in the Western Ukraine as a governor of underground water exchange between aquifers in a storey artesian system**

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The artesian aquifer system of the Miocene sequence is one of the major regional water-bearing unit in the Western Ukraine, in the southwest and south part of the Volyno-Podolsky artesian basin. The main aquifers are that in the Lower Badenian sandy-carbonate thickness and in the Upper Badenian carbonate and argilo-carbonate horizons; the 10 to 40 m thick gypsum stratum normally lies between these two aquifers.

Due to continuing differential Plio-Pleistocene uplifts the aquifer system became unconfined and drained in the part of the territory (the Podolsky sub-basin) while in the other part true artesian settings still prevail. In this later region the gypsum stratum was usually treated as an aquifuge dividing the aquifers beneath and above the gypsum.

Recent speleogenetic studies have shown that extensive maze cave systems form in gypsum due to dispersed upward recharge from the beneath-gypsum aquifer. Such recharge occurs where erosional entrenchment occurs in the capping clay thickness (in zones of piezominimum). The paper shows how speleogenesis in the gypsum controls and governs water exchange between major aquifers in the Miocene artesian system. Speleogenetic evolution caused alteration of hydrogeological function, performed by the gypsum stratum, from an aquifuge to a karst aquifer. During such evolution the flow pattern has altered deeply in the whole Miocene artesian system. Distribution of karst permeability in the gypsum and extent of interconnectivity of the aquifers in the system is controlled by local regularities in the formation and occurrence (distribution) of cave systems, which in turn are determined by peculiarities of paleo- and recent surface relief.

The understanding of the true rule which the gypsum stratum and cave systems in it play in a water exchange in the Miocene aquifers system, is of great importance for solving of many scientific and practical problems of regional geology, such as a genesis of native sulfur deposits, formation of H₂S mineral water deposits, prediction of water inflow during open-cut mining.
Paleoclimate and paleokarst in South Africa

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A good paleoclimatic record for the uppermost Quaternary, has been derived from a speleothem in the karstic Cango caves, located in the southern Cape Province (Talma and Vogel, 1992). The paleo-temperatures were calculated from the $^{18}$O content of the carbonate. There is a temperature decrease from about 30000 BP, reaching a minimum value between 19000 and 17000 BP. Afterwards, up to 13800 BP the temperature increased. At this date, precipitation of carbonates stopped and was renewed only at 5000 BP. It is suggested that the absence of deposition of calcium carbonate from ca. 13000 to 5000 BP is due to the fact that as temperatures started rising, the winter rains started to decrease while summer rain increased. The vegetation being dominantly arboreal absorbed and transpired all the water infiltrating the subsurface. Only after the ecosystem changed into a floral assemblage, which did not have deep roots, did recharge to groundwater and thus drip water restart.

Environmental isotope uranium (U) in karst aquifer of Southwest Datong, China

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The research area of about 710 km$^2$, southwest of Datong, extended from 112°41'-113°03' E and 39°38'-39°58' N is mountainous within the semi-arid region of north China with an annual mean precipitation about 400 mm. Water resources seems the serious problem of this coal mining area, it leads to a groundwater research focused on its main karst aquifers of Ordovician carbonate which exist in general more than 500 m below the ground surface, about 114 km$^2$ of carbonate limestone is exposed. Environmental isotope U is used for the fundamental research of this karst groundwater which is sampled from boreholes by a specially designed sampler to bail deep groundwater from 20 sites distributed within this area, the dewatering of karst water from 3 sites and the rainwater, phreatic water, surface water are also sampled.

Characteristics of U in waters: U content and $^{234}$U/$^{238}$U of Ordovician groundwater are compared with that of surface water, phreatic water and groundwater from the aquifer of Permian Period. A higher range of $^{234}$U/$^{238}$U about 2-6 are detected from
Ordovician aquifer. Two regions with different $^{234}\text{U}/^{238}\text{U}$ ranges are identified, it reveals the different relations between surface water and groundwater for these regions.

Karst water runoff: $^{234}\text{U}_{\text{ex}}$ and $^{234}\text{U}/^{238}\text{U}$ are used for karst water runoff research where $^{234}\text{U}_{\text{ex}} = ^{238}\text{U}(^{234}\text{U}/^{238}\text{U} - 1)$. Two regions with different runoff conditions are identified. Runoff directions of different regions are found from the relationships of $^{234}\text{U}_{\text{ex}}$ versus $\text{U}$ and from the isolines of $^{234}\text{U}/^{238}\text{U}$.

Source of karst groundwater: The recharge sources of karst groundwater of this area are identified from relationships between $^{234}\text{U}_{\text{ex}}$ and $\text{U}$ contents of various waters. Results from most boreholes show that in general it is composed by three water sources i.e., surface water ($s$), phreatic groundwater ($q$), and the old groundwater stored in Ordovician aquifers ($o$).

Recharge contribution of surface water to karst groundwater: It is an important item for the development of karst groundwater of this area, a spatial distribution of the portion contributed by surface water is demonstrated. For karst water from borehole $x$ with volume $V_x$, the portion of surface water $V_s$ is related to end members $s$, $q$ and $o$ as follows

$$ (U_x - U_o)(\frac{U_{\text{exq}} - U_{\text{exo}}}{U_q - U_o} - \frac{U_{\text{exs}} - U_{\text{exo}}}{U_q - U_o}) $$

Karst geomorphology and the exploitation of water resources in South China

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The very thick carbonates aged from Precambrian to Tertiary developed in the south China, it occupies about 50 km² in Guizhou, Guangxi, Yunnan, West Hunan, and South Sichuan provinces. Under the several intensively function of the geoforces, the carbonates were formatted as fractures, faults and folds which formed a complicated structural systems according to the geoforce property and the nature of the structures, such south-north structure, east-west structure, Neocathaysian system etc. The Himalaya uplift effected the regional geomorphological development and the characteristics, such three terraces of landform, Tibetan plateau, Yunnan plateau and Guizhou plateau and Guangxi basin. The uplifting also cause the erosion base and karstic base lower down, that made the rivers cutdown to form the canyons such as the Jinsha Jiang gorges, Yangtze three gorges, Wujiang gorges, Nanpan Jiang gorges, Beipan Jiang gorges and so on. The great regional geomorphology controls the karst water flow direction and distribution, because they constitute the drainage base of karst water.

Under the conditions of the tectonic movements and climate, the local karst geomorphology developed in different way. For example, Fenglin landscape developed in the Guangxi...
basin and the block of water divide of Guizhou plateau, Fengcong scape in the slope of geomorphological units and near the banks of rivers, so the karst water relatively homogeneously distributes and water level is near ground surface, some places appears karstic pools and surface rivers, in the Fenglin areas and conduit flows and underground lakes are very well developed in the Fengcong landscape and the transmitting zone from Fenglin to Fengcong landscapes. In Fengcong areas, the groundwater is buried very deep, some places more than 100 m, and surface streams are lack of.

The patterns of exploitation of karst water resources are quite different. The karst water in Fenglin areas is easy developed, such as by pump. In Fengcong areas, water is also mainly by pump, but to make dam to form the underground reservoirs is very popular in south China. In the Fengcong region, the people concentrate to develop the rain water resource as to make the water tank in different dimensions.

REGIONAL KARST SYSTEMS

The origin of a high transmissivity zone in the Floridan aquifer system and its relevance to karst

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South Florida's Boulder Zone (BZ) is one of the most enigmatic examples of a highly transmissive (2.8x10^5 m^2/day) groundwater zone. It is a deeply buried (500-1100 m, deep) cavernous zone in the Floridan Aquifer System, currently being used for the disposal of municipal liquid wastes. The BZ developed in the Paleocene and Lower and Middle Eocene marine carbonates and evaporites. Petrographic analyses of rock cores, water and rock geochemistry, geophysical logs and regional structures studies support the following hypothesis. Fracturing and faulting of Cretaceous and Tertiary rocks, during the tectonic evolution of the Caribbean and Gulf of Mexico, created conduits for the migration of diagenetic fluids. Non-marine and marine groundwaters have repeatedly flushed this sedimentary package during sea-level fluctuations and migrations of groundwater mixing zones over the past 15-20 m.y. Geothermal convection enhanced the effectiveness of fluid circulation and sea-water exchange from the Florida Straits.

Groundwater of varying compositions and oxidation states, perhaps in concert with bacterial chemosynthetic production and hydrocarbon fluid migration from Cretaceous sequences, brought about dissolution of carbonates and evaporites in fractured zones. Resulting H_2S-rich water, ascending through fractures, mixed with more oxygen-laden groundwater to produce sulfuric acid and caused more massive dissolution and later precipitation of CaSO_4 as veinlets
and pore fillings in the upper parts of the section.

The geochemical reactions invoked to explain creation of the BZ can also be applied to deep burial dolomitization events and the origin of submarine karstic features of the margins of the Florida Platform. The lack of a well-developed BZ in north Florida and the southern Atlantic Coastal Plain may be the result of thinner early Tertiary evaporite sequences and less tectonic fracturing in these areas. Stable isotopic analysis of the diagenetically derived mineral assemblages in the carbonate host rocks is being used to reveal the precise nature and origin of the diagenetic fluid from which they formed. Secondary minerals include gypsum, anhydrite, calcite, and dolomite.

Peculiarities of karst water resources of the Black Sea basin, their possible variability in future

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Karst water and aquifers in alluvial deposits recharged with it, are the main source of water supply in the northern and eastern parts of the Black Sea basin. Water supply of Sevastopol, Simferopol, Yalta Lvov, Novy Afon, and many other towns depends on the karst water. Therefore, the study of these resources and predictions of their possible variability in future is of great practical value. Characteristic property of karst water resources along with abundant water is their close dependence on atmospheric precipitation that determines highly dynamic discharge both annual and perennial. Thus, mean annual groundwater discharge for springs and recharged with them small rivers, changes in this region from 3-4 l/s.km$^2$ to 20-25 l/s.km$^2$, dynamic coefficient ($Q_{max}/Q_{min}$) are from 5-10 to 600. Rates of discharge variations after precipitation fall-out amount to 100 and even 1000 liters per second with a time lag in 1-3 days only and the level of aquifer depletion ($Q_{min}/Q_{average}$) changes from portions of a percent (that is periodically intermittent springs actually) to 20-30%. A portion of annual atmospheric precipitation recharging karst aquifer changes from 20 to 80% and depends on some geological, hydrogeological, orographical and climate conditions. The stated relationship between this portion variability on the level of a year water content serves a basis for predicting assessment of possible variability of karst water regime and resources under the impact of man-induces climate transformations. The assessments made have revealed that a reduction of karst water resources in this region will continue to the end of the current and beginning of the next century. This resulted in the necessity to work out measures for karst water rational use, management of its withdrawal, including the development of the system for joint use of surface and groundwater. The solution of the last problem bases on
the study and prediction of possible alternation of an excess and deficit in surface runoff and a choice of an average value for optimal discharge that can compensate possible water deficit in low water periods using speeded up exploitation of karst water geological reserves (lower the basis of its drainage).

**Hydrological balance in finding out the catchment area of major groundwater sources in the Donovaly area**

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Five springs of the Jergaly branch of the Pohronie water-supply system in Donovaly-Dolny Jelenec area make up a major groundwater source, its average total discharge being about 502 l/s. The springs have only one small obvious catchments area in their vicinity. Likewise, this unit is discharged only by the above-mentioned springs. The recharge potential of this Donovaly - Hanesy - Stubne hydrogeologic structure composed of Krizna nappe Triassic carbonates derived from its area and 1982 precipitation is 45.78 l/s (16.79 l/s.km²). This recharge potential calculated according to empirical equations based on ten-year-long monitoring (Kullman, 1990) for representative closed karst-fissure structures in the Veliky Choc outlier and Harmanec syncline situated close (40 and 15 km) to the investigated area. South of the Donovaly-Hanesy-Stubne structure lies another carbonate body-Bukovec syncline in the Donovaly envelope series. Geologic situation suggests that these two hydrogeologic structures are not hydraulically connected with one another (Rakus in E. Kullman, 1971) but hydrogeochemical, balance and isotopic evidence indicates the opposite. The Bukovec syncline covers an area of 10.248 km², its average altitude is 936.5 m and its recharge as well as discharge capacity based on the area of carbonates exposed on the surface is as much as 184.41 l/s (assumed i.e. potential specific discharge is 17.99 l/s.km²).

But if we also admit the underground hydraulic connection of these two hydrogeological structures, the total discharge thus exceeds recharge by 184.59 l/s whose recharge area must lie somewhere outside these structures. Nevertheless, gauging indicated that carbonate rocks of this until are recharged from the immediate vicinity-brooks on the southern slopes of Mt. Motyckova hol'a and Mt. Zvolen gradually disappear in their alluvia and seep into the carbonate substratum. Geologic evidence also indicates that the overlying nearly horizontal Tithonian-Neocomian beds of the Krizna nappe along with the permeable Triassic substratum stretch further north beyond the Vah / Hron water divide (leading through Mt. Zvolen 1402.3 m and Motyckova hol'a 1292.1 m high) on an area of 6.8 km² roughly as far as the lower edge of Krizna nappe Triassic carbonate inliers in Zarnovka and Vel'ka Bzdova valleys and
approximately the lower edge of the higher Krizna nappe Triassic carbonate inlier in the Hrickov valley. Therefore, we assume that groundwaters circulate below the geomorphologic water divide. Two of these units displayed deficits in comparison with their recharge potential -18.00 l/s (carbonate inlier in Vel'ka Bzdova valley) and -16.44 l/s (carbonate inlier in Zarnovka valley). This fact alone does not explain the surplus in the Donovaly-Hanesy-Stubne structure and Bukovec syncline below Donovaly, but provides clues for a possible solution. The lower margins of these units situated north of the water divide lie at an elevation of 860 m (carbonate inlier in Zarnovka valley) and 720 m (carbonate inlier in Vel'ka Bzdova valley), and the lower one of the two inliers in Hrickov valley ends at an altitude of 720 m. If the effective recharge amounts to only a half of the recharge potential inferred by equations for local total precipitation, i.e. 9 l/s.km² instead of 18 l/s.km², possible recharge in the latter two territories is about 175 l/s. This amount corresponds to the 184.59 l/s surplus above the recharge capacity of carbonates exposed in this area. The existence of such a recharge area in the north was later also suggested by oxygen isotopic compositions in the major springs in the Donovaly area. As this area is intensively used for winter sports and tourism and estimated recharge area is intersected by a frequently used motor road, the danger of damaging the water quality is quite already present and the delineation of protection zones in this area is being under discussion.

Groundwater velocities in low gradient, glaciated carbonate strata in Ontario, Canada

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Much of Southern Ontario is underlain by Proterozoic and Paleozoic carbonates. Surface evidence for karst is limited, since glaciation has eroded pavements and buried ancient karst features. However, there are both pre- and post-Wisconsin caves longer than 1 km in length. Recent sink-to-spring and well-to-spring tracer tests indicate that karstification of the carbonates is widespread.

Results from four low-gradient sites are presented. Ottawa River Cave, near Pembroke, has a network of 4 km of submerged passages ranging up to 20 m in width and 6 m in height. At Marble Cave, near Kaladar, the major flow route is a single submerged passage 150 m long. At Smithville there are two traced flow routes to a common spring; one is via the vadose Smithville Cave, and the other is an unexplored route from sinks in Twenty Mile Creek. At Dewdney's Cave, near Bobcaygcon, multiple allogenic inputs from a forested swamp recharge two vadose streamways. At all four sites, the
hydraulic gradients are extremely low, ranging between 0.00014 and 0.002 for submerged conduits, and ranging up to 0.007 for vadose conduits.

More than 40 quantitative tracer tests have been conducted at different discharges. The largest velocity range demonstrated is from the sinks of Twenty Mile Creek, where groundwater velocities between 0.0008 and 0.22 m/s have been measured. In all cases velocity-discharge relationships are described by power functions, with exponents ranging from 0.55 to 1.0.

It is significant that some of the most rapid groundwater tracer velocities ever measured occur in the very low-gradient, large-diameter conduits at Ottawa River Cave, with velocities up to 0.34 m/s. These high velocities in large low-gradient conduits are expected from the Manning and Hagen - Poiseuille equations. In both equations conduit diameter is more important than slope in determining velocity.

It appears to be counter-intuitive that the fastest velocities are found in the lowest-gradient situations, and these results contradict the commonly-held notion that the fastest velocities are associated with the highest groundwater gradients. However, it is worth noting that similar results have been demonstrated for surface rivers. Leopold (1953) showed that the highest velocities are found in large, low-gradient rivers; this finding came as a shock to most geologists of that time.

**Groundwater flow in a young karst terrane developed along a coastal setting, Northern Guam, Marina Islands**

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Recent site characterization activities at Andersen Air Force Base, Guam, Mariana Islands, has provided some interesting data challenging the expectations of rapid conduit flow in this karst terrane. Guam is located approximately 2400 km south of Japan and approximately 5300 km southwest of the Hawaiian Islands. The Mariana Islands are a complex island-seamount system, divisible geographically, tectonically, and chronologically into two island arcs; an older frontal arc includes the relatively large islands of Guam, Rota, Tinian, Saipan as well as two smaller uninhabited islands. A younger arc of active volcanic seamounts and islands lies to the west and north of the older arc.

The main water bearing limestones of northern Guam consist of coralline reef limestones of the Barrigada and the Mariana Limestone Formations. The Barrigada lies on top of the underlying Tertiary aged volcanics. The Mariana Limestone covers most of the surface of the northern plateau and onlaps the Barrigada Limestone as a vertical and transgressional facies change from a deep to a shallow water depositional sequence.

There are no surface streams on the northern plateau because of the porous nature of the limestone. Rain water rapidly infiltrates through the
limestone and supplies the freshwater aquifer. The aquifer is commonly referred to as the Northern Guam Lens. The water table is encountered several feet above sea level with a flat gradient toward the sea approximately 160 meters below land surface. Other factors influencing the lens are tidal fluctuations, storm surges, stratigraphic relationships and karstification of the limestone. This can alter groundwater flow paths, velocities, and salinities. Evidence from boreholes drilling inland and near the coast confirm other documented occurrences of cavern formation developing between the phreatic and vadose zone, and within the transition zone between the fresh and saltwater interface in coastal carbonate terranes. Caves investigated along the lower coastal terraces also provides evidence, by the steeply sloping entrances that formed within the transition zone, that the sea level was higher in the past and/or tectonic activity vertically displaced the transition zone responsible for the active dissolution of the limestone and the formation of caverns. Although one might expect rapid, conduit flow in this karst aquifer, non-flashy responses on water levels in wells after rainfall and current results from a dye tracing study, suggest groundwater movement is indicative of diffuse, advective flow. During a 15 month dye trace study monitoring over 70 monitoring wells, water supply wells, and cave pools, indicate groundwater flow velocity on the order of 30 ft/day within the aquifer. However, flow within the epikarst/vadose zone can be several times the velocity of the aquifer and very difficult to predict the direction of groundwater movement.

**Study the migration of pollutants in soil and groundwater**

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The protection of soils and groundwater resources has emerged in recent years as a first priority for many countries.

The prediction of transport of contaminants in soil and groundwater porous media through measurements and modeling is of great interest being the growing trend towards subsurface waste disposal practices.

The modeling of groundwater pollution is mainly at growing a descriptive and predictive management tool practical for field problems, whose type and resulting accuracy will depend on the considered management objectives and, naturally, the socio-economical constraints of the study.

Laboratory field and experiments are two important approaches but are differentiated in respect to their objectives. Investigations at laboratory scale are being directed towards a better understanding of the physical, chemical and biological processes with affect the solute concentration during contaminant transport through the porous media in the laboratory, these processes can be
isolated and studied under controlled conditions at a minimum cost.

The transport of pollutants which in part determines their residence times in the soil solution was described by physical laws translated into differential equations, which affected by the chemical reactivity of the transport pollutant. In experimental studies concerned with environmental behavior of hazardous contaminants, great efforts have been invested in the measurements of solid-liquid coefficient "KO".

**Underground waters of carbonaceous rocks of the Great Caucasus and their hydrochemical peculiarities**

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In Azerbaijani part of the Great Caucasus that characterized by multiple folding watery carbonaceous rocks (CR) and less watery tuff sandstone and tuffs of Quaternary, Cretaceous and Jurassic ages have widespread occurrence.

More than 288 springs with summary flow 525 l/s and in individual from 0.1 to 25 l/s are confined to the Quaternary alluvium-Talus deposits that mainly consist of CR. Their waters are cool (3-12 °C), fresh (0.15-0.25 g/l), hydrocarbonate calcic with hardness 3-8 mg/eqv.

Accumulated in the river valleys alluvial deposits are more watery, springs flows amount to 5-30 l/s and their quality is same as described above. In Bazarjozi (4466 m), Shakhdag (4243 m), and Babadag (3629 m) mountain ranges constantly acting cool (3-4 °C) springs with the flow 1-30 l/s are coming from glacial rocks.

Fresh and mineral (cool and thermal) hydrosulphuric waters are confined to CR, mainly consist of limestone and partially of marlstone. The flow of springs, those confined to the Upper Cretaceous limestone usually amount to 36 l/s, karst limestone 10-30 l/s. These deposits are spread on the drainage areas of Kozluchai, Pirsagatchai, and Geokchai rivers. Carbonaceous rocks of Turon-Dat ages are spread on the east of Shakhdag-Kizilkaya zone, where springs flow not more than 0.1-2 l/s. Waters are cool, fresh (0.3-0.9 g/l) and hydrocarbonate calcic.

Mineral waters are confined to tectonic fractures of carbonaceous rocks-limestone. Depends on circulation depth waters are cool with the flow 0.013-0.3 l/s and thermal (46.2-48.8 °C) with the flow 0.01-0.1 l/s, hydrosulphuric (4.7 mg/l) with hydrocarbonate-sulfate natrium-calcic composition. Thermal waters also are stripped by wells in Chulkhur-Urt region. The specific capacities of water in wells to 0.1-1.6 l/s.m, mineralization -0.3-1.3 g/l, water type-hydrocarbonate natrium and calcic.

In the Lower Cretaceous carbonaceous rocks the springs flows are not more than 3-10 l/s and in karst locations the spring flows are not resistant. Their waters are fresh (0.2-0.3 g/l), hydrocarbonate calcic with hardness 4.52 mg/eqv.l.
Jurassic carbonaceous rocks are less watery springs flows—not more than 2 l/g. Waters are fresh (0.21-0.9 g/l), hydrocarbonate calcic with hardness 4.3-1.1 mg/eqv. 1. C ol and thermal (23-40 °C) hydrosulphuric waters also are confined to the fractures of limestone of this age. Springs flows reach 0.5-3 l/s, mineralization 0.9-1.7 g/l, waters are hydrocarbonate natrium content of H₂S 0.4-12 mg/l.

Identity of chemical and gas composition of waters depends on geochemical conditions of water bearing rocks.

**The hydrogeology of Upper Cretaceous limestone aquifer at Areif el-Naq'a area, East Central Sinai-Egypt**

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The most significant occurrence of carbonate rocks in central Sinai is the limestone and dolomitic strata of Upper Cretaceous and Eocene periods. The chronostratigraphically equivalent Galala, Wata, Matulla, Thebes, and Minia Formations over an area of about 40000 km² attains a maximum thickness of 1500 m.

In this paper, attention will be focused only on Areif El-Naq'a area, East-Central Sinai, Egypt. The area is most beneficial for demonstrating general hydrogeological characteristics of karst features which is well defined in the Syrian folding belt. Research in these region stimulated the origin of karstology and speleology.

Recent detailed hydrogeological investigations carried out by RIWR including geophysical, geological and test drilling have contributed much to the hydrogeological information as an additional water resources in Sinai and its development.

**Underground karst water circulation in Peloponnesus, Greece**

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The hydrogeological characteristic of Peloponnesus are given by the lithological variance of the strata as well as by the distribution of fault patterns due to the tectonic development. The highly fractured and karstified carbonate rocks of Peloponnesus deformed during the Alpine Orogeny and later by block faulting, form prolific aquifers that exhibit a high permeability due to their secondary porosity. They also form rugged mountains extending to the eastern and southern coasts where the karst water is discharged to the (Mediterranean) sea by brackish onshore and offshore springs. This indicates a good circulation of underground water in fairly large structurally controlled conduits.

There is a scarcity of surface runoff in the limestone terrains. Most of the streams, in one way or another, discharge into swallow holes.

Peloponnesus lies in the Eastern Mediterranean between latitudes 21° 05'- 23° 30' East and longitudes 36° 25'- 38° 20' North. Most of it is rough
country. Mountains (elevation 700-2500 m) comprise almost 50% of its total area, hills (300-700 m) 30% whereas the plains (<300 m) the remaining 20%. High infiltration and low runoff are characteristic of the hydrology of karst terrains in Peloponnesus.

There are nine mountain chains (highest Ziria reaches 2400 m) that follow roughly the direction of the main thrust zones: The surface drainage takes place from central Peloponnesus. The greatest rivers flow south. However, there is a number of smaller streams with less significant surface flow in the north. Eastern Peloponnesus due to its lower precipitation and the presence of highly karstified limestones does not have any significant runoff. Discharge to the sea takes place only once every ten-twelve years.

The principal carbonate rocks, limestones, dolomitic limestones, dolomites and marbles of the Pelagonian, Tripolitsa, Pindus and Ionian zones, represent the main karstic aquifers here. Hydrogeologically they are separated by less permeable rocks of the ophiolitic complex, flysch and the phyllites. Moreover, vertical and lateral displacements during and after the overthrusting initiated the development of subsurface drainage systems.

Hydrogeological investigation of Alashtar basin (West of Iran)

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The Alashtar plain is located to the north east of Khorramabad in western Iran.

Geomorphologically, the plain forms a graben whose horsts are the high Garrin, Varkhash, and Mahab Mountains.

The plain is covered by alluvium which is composed of cobble, sand, and clay. The maximum thickness of the alluvium occurs at the center of the plain as much as 150 meters. The surrounding geological formation are mainly of Mesozoic and Cenozoic Era. The karstic limestones of Jurassic-Cretaceous age are the major recharging units. The alluvium aquifer supplies water to the wells about 15 MCM per year.

The Kahman River having a mean annual discharge of 120x10⁶ MCM, drains the surface water of the basin has two district characters; it is a losing stream at the upstream sections and is recharged by groundwater at the downstream area.

The regional groundwater flow is controlled strongly by structural aspects. Almost all karstic springs issue at the intersections of the lineaments.

Isotopic data revealed that the springs discharging at the area are recharged mainly by recent precipitation but from different altitudes. The flow analyses of Amir and Honam springs suggest that they are affected by only one groundwater circulation system, whereas the Zaz
and Chenare springs exhibit more complex hydrodynamic structure being affected by at least two distinct groundwater circulation systems. The quality of the waters from the springs is degraded generally due to lithological contamination, particularly from extensive dissolution of gypsum. Anthropogenic pollution is not observed.

The conceptual model developed for the regional groundwater system is based on the hydro-chemical evaluations. The model distinguished three categories of waters as alluvial, of shallow circulation, deep circulation, and mixed waters.

The safe yield of the aquifer is calculated as 40 MCM per year which can be available for agricultural, industrial, and domestic use.

**Comparing of hydraulic conductivity of carbonated rocks obtained by an empirical formula and field measurement**

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According to observation and field measurement of joints surveying in diversion gallery of Saveh dam, Iran, situated in Oligo-Miocene limestone, six joint systems were distinguished. First, hydraulic conductivity of this rock was calculated by an empirical formula with regard to the width of joints (Kc). Then, this parameter was measured in five exploratory drillings with 170 meter depth using Lugeon test in descending method (Km). Comparison of the obtained hydraulic conductivities indicates that measured hydraulic conductivity is smaller than calculated one in this experiment. This result along with the monitoring of other engineering geological properties of joints indicate that the joints are not interconnected. This means that no developed karstification could be occurred in Saveh dam’s foundation rock. This result was verified during grout-curtain execution. Thus, it may lead to an actual approach about karstification phenomena by a precise joints surveying of carbonated rocks.

**Karst hydrogeology in Fengcong landscape of Xichou country, Southeastern Yunnan plateau**

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The study area is located in the transmitting zone from Yunnan Karst plateau to the Vietnam low hilly and lowlands, geographically at 23°05’-23°37’ N and 104°22’-104°58’, the annual average temperature is 15.9 °C, annual mean precipitation is 1260 mm, the rainy season from May to October falls 1096 mm. As the effect of different humid current from the Bac bo Gulf and the Bay of Bengal and dry current from the plateau, regional precipitation greatly changes in the area.

The 5000-6000 m thickness of carbonates had been rotalled as to form the ear geological structure. The
carbonates distribute between the shale, sandstone, and metamorphic rocks in which the deep rivers developed for the Yunnan Plateau uplifting since Cenozoic era. In the water shade block, the characteristics of plateau geomorphology is still remained. The karst hydrogeology is characterized as: (1) The hydrogeology is strongly controlled by the geological structure; (2) The karst water appears as the underground streams; (3) The water level is controlled by the drainage base which is constituted by the different lithology of carbonate rocks; (4) The longitudinal gradient of the karst drainage system is lower in the upper stream and higher near the springs; (5) The drainage capacity of the ground conduits is lower than the income of collected water, the most depressions are flooded in the rainy seasons; and (6) The storage of the karst aquifer is getting less and less as the decrease of the coverage rate of forest.

**Thermal water in karst areas of China**

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Thermal water is widely distributed in karst areas of China. Many famous hot springs occur in karst area of North China with large flow rate. For instance, issuing from Ordovician limestone, Jinci hot spring with temperature of 17.5 °C and flow rate of 1.945 m³/s are situated at the Jinci Hall at the foot of Xuanweng Hill in the southern suburb of Taiyuan City, the capital of Shanxi Province. Niangziguan (Women-soldiers Pass of Great Wall in Shanxi Province) hot springs with temperature of 18 °C are the largest in flow rate (12.58 m³/s) in North China and famous for its water-supply for industry and agriculture as well as for its splendid scene of waterfall from a limestone cliff 32 m high. In addition to these famous hot springs, there exists a huge reservoir of thermal water with temperature up to 104 °C at a depth more than 2000 m in the so-called "buried hill" of Proterozoic-Cambrian-Ordovician carbonates with extensive paleo-karst. The estimated recoverable resources of this thermal water reservoir amount to $4.2 \times 10^{10}$ m³ which contains the heat of $9.4 \times 10^8$ J and equals to 0.36 billion ton standard coal. Nowadays, thermal water from this reservoir has been widely used for space heating, agriculture, aquaculture, and industrial use in Beijing, Tianjin cities and rural area of the vast country sides in North China. Sometimes, thermal water from this paleo-karst reservoir may invade into shifts and galleries of coal mines and cause serious environmental impacts. Case history is given in this regard.

**Karstic terrain and major karstic systems in Romania**

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The carbonate rocks in Romania are distributed on a territory of about 10,000 km². Hydrogeological
features of the Romanian Karst are specific for each of the main geostructural units of the country. Such differences, supported by field data resulted in identifying four hydrogeologic types of karst: Carpathian orogene karst type, North Dobrogea karst type, platform karst type, and post-tectonic Carpathian's cover karst type. Various investigation methods (tracing tests—more than 150, water budget analysis, etc.) have been used for the delineation of more than 15 major karst systems.

The hydrodynamic and hydrochemical features of systems in Banat, Pădurea Craiului, Vâlcăn, Bihor and Codru-Moma Mountains are synthetically outlined. The average discharge of these systems ranges from 500 to 1200 l/sec, many of them being tapped for water supply of major Romanian cities.

**Permeability and hydrodynamic behavior of a karstic environment**

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The karstic environment has often been summarized from a hydrogeological point of view by a network of highly permeable, organized and interconnected conduits which drain a volume of fractured, low-permeability rock (Kiraly, 1978). On-site measurements carried out on two test sites in Switzerland demonstrate the validity and the limitations of this summary. First and foremost, it is necessary to estimate the percentage of infiltration water which transits within the karstic network (rapid flow) and that which transits the low permeability sections (slow flow). The comparison of the annual flow volume of the base flow with that of the flow during floods demonstrates that 47% of the flow volume corresponds to the base flow and 53% to the rapid flow. The comparison of effective infiltration, estimated on the basis of climatological measurements and the volume of flood water, makes it possible to calculate that the proportion of effective infiltration which directly supplies the karstic network (rapid flow) varies from 50 to 70% and inversely, the proportion of effective infiltration which supplies the low-permeability sectors is approximately 30 to 50%. Finally, observations in the low permeability boreholes indicate that the fluctuations measured correspond to the variations in the base flow.

Measurements of the hydraulic head in the karstic network and between packers in the boreholes have revealed the existence of major and extremely rapid reactions in the karstic network and slower and less significant reactions in the low permeability sections. Moreover, they clearly demonstrate the limitations regarding the use of piezometric maps (of water levels) in a karstic environment.
Hydrogeological investigation of the karstic system within the tectonically complicated part of the Jura region of the canton of Solothurn, Switzerland

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In the WSW-ESE striking anticline and syncline complex of the Weissenstein and Farisberg of the folded Jura, three areas with local SW-NE fault sets in the limestone of the Malm and of the Hauptrogenstein were localized. They have a strong influence, showed by the tracer experiment on the function and speed of the karst systems and also on the connection to the springs.

In the Malm limestones they act as important lateral drains of the whole karst systems which results in decreased flow of the water diagonal the faults. In the karst systems of the Hauptrogenstein a continuous increase in velocity parallel to increasing distance could be found. The difference can be attributed to the fact that the Hauptrogenstein is underlain by and overlies by aquicludes.

The research shows that not only the karst systems of the Malm were drained but also a small portion of the largest karst system in the Hauptrogenstein. So the karst systems of the Malm and Hauptrogenstein limestones were partly mixed along this fault zones.

Determination of aquifer parameters by step pumping tests

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Aquifer parameters, transmissivity (T) and storage coefficient (S), and the well losses, presently have been estimated independently from each other. This independent estimation means that pumping well is assumed to be 100% efficient in determination of aquifer parameters. On the other hand, drawdowns, observed during the course of a pumping test, are strictly related to the well losses as well as the aquifer parameters. This interrelation, implies the necessity of simultaneous determination of both aquifer parameters and the well losses. Thus, in this study, a computer program is written for this purpose using nonlinear curve fitting techniques and, it has been shown that estimated aquifer parameters may be erroneous if the well losses is not taken into account.

Karst hydrogeological investigation of the gypsum at near east of Sivas, Turkey

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In this study, karstification developed in the Miocene aged gypsum which covers a large area around the Sivas, the relation between karstification and regional tectonics and
hydrogeological features have been investigated.

The karstic features in the gypsum have developed conformable to the fault zones and the general strikes of gypsum beds. In the study area numerous sinkholes and dolines of different sizes are observed. Most of these karstic features are located in the different sized longitudinal depression (troughs) which are developed conformable to the tectonic structures. In general, on the occurrence of these karstic features, NE-SW directed bedding planes and about NW-SW and N-S directed fracture zones have been effective. At the intersections of these longitudinal throughs, high yield karst springs are observed. The most important of these are Göydün and Seyfe Springs.

Göydün and Seyfe Springs, which located within the same surface drainage area, have the average discharges of 1.10 m$^3$/sec. and 0.25 m$^3$/sec. respectively. In addition, there are some low yield springs in the same drainage area. The groundwater recharge from the precipitation in the surface drainage area can not provide the total groundwater discharge from Göydün and Seyfe Springs. According to the water budget calculation results, more than 70% of the water discharged by these two springs are provided from the adjacent basins. Göydün and Seyfe Springs are rich from the point of dissolved species and average electrical conductivities (EC) are about 13000 µS/cm. The major cations in the waters are Na and Ca, major anions are SO$_4$ and Cl and the waters are in the brackish water class. Because of these properties, especially in summer and autumn, these springs cause extreme salinization in Kızılhrmak river whose runoff decreases to the 4-5 m$^3$/sec. In similar way, the extension of the gypsum in large areas, effects the other water resources, restricting the use of them as drinking and domestic waters.

**Karstification around Bucak and surrounding area and problems arised**

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Karst is terrain with distinctive geology, hydrology and geomorphology arising from the combination of solution cavities, secondary porosity, and rock structure. Especially in Turkey, the Mediterranean basin have been the focus of karstic studies, because the western Taurus are mainly covered by carbonate rocks. These rocks supply the domestic water for most of the population in the area.

Most of the carbonate rocks of Mediterranean basin are intensively karstified. Orogenic movements raised carbonate rocks above the sea level, so the above mentioned soluble rocks highly jointed and fractured due to tectonism. These discontinuities helped circulation and passage of the underground water.
Bucak and surrounding area are covered by karstic features such as terra rossa, lapies, sinkholes, caves, travertine, and natural tunnels which are characteristic of the Mediterranean region. In an advanced stage of solutional decomposition and erosion of limestone which formed residual hills around Kestel plain especially upper parts of the area.

The town of Bucak has one of the towns with waste water treatment facilities. The waste water which went through water purification processes given to a karstic dolines to the east of Kestel plain where the drinking water of Bucak is obtained. But, after 3 years operation period the doline is plugged, so cause of contamination of drinking water of aquifer.

For the purpose of investigation, approximately 300 square kilometers area is mapped and studied by preparing geological and hydrological maps with the scale of 1/25000, consideration from geology, hydrology and geophysics point of view.

Consequently, without leading to pollution and damage, the exploitation of karstic resources forms a matter of great importance.

Indicator principal component kriging as a decision tool in assessing groundwater pollution

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In a polluted groundwater environment the choice of a water well location becomes highly critical. Decisions based on estimates of a pollutant considered to be important are subject to error. Decision makers can avoid risks if they know the probabilities of exceedence of a critical threshold. Indicator principal component kriging may be a valuable tool in the evaluation of these exceedence probabilities. This paper describes applications of the methodology to groundwater pollution problems. The paper presents the variograms of the indicator principal components for nitrate concentration in groundwater samples taken from the Eskişehir plain (Turkey). It maps the conditional probabilities that the true values are greater than the recommended maximum for nitrate.

Karst systems of Turkmenistan and karst hydrochemistry

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Karst water occurrences on the territory of Turkmenistan are associated with the southern part of the Cissar mountain range (Govurdak-Koitendag area) and with the Central Kopetdag (the Kow-Ata karst lake).

A typical peculiarity of the Govurdak-Koitendag area is availability of the karst form relief such as craters, grotts, caves which
are connected with different lithologic structure rocks (with limestones, gypsiums, sodium and potassium salts). The dimension of some karst systems reach dozens and hundreds of meters.

Karst waters of this area are connected mainly with the water-carrying complex of the upper part of the Jurassic deposits. This complex includes also sulfur carrying limestones, laying in the foot of Kimmerige - Titon directly on the Kelloway - Oxford limestones.

Sulfur carrying limestones are a very good penetrated and highly water-abundant collector for karst and crack-stratum waters. Average values of the filter factor are to 0.55 m/hour, those of specific output are to 0.013 m³/sec, open porosity is about 10%.

There is a clear natural regularity of alteration of mineralization of underground, karst and crack-stratum waters on the most researched part of the territory of the Govurdak sulfur deposit. These waters are sulfate, sulfate-calcium chloride, and sodium-calcium chloride types of natural waters with mineralization from 3 up to 50 kg/m³. Sodium chloride type brines with mineralization from 50 up to 200 kg/m³ appear in the direction of general immersion. These brines contain such rare elements as iodine, bromine, lithium, rubidium and others. Brines with high content of H₂S are discovered in the limestone layers of the southern section of the Govurdak sulfur deposit.

Karst and crack-stratum waters of Govurdak - Koitendag and Central Kopetdag areas are used for various illnesses treatment.

JAMES F. QUINLAN

POLLUTION CONTROL AND KARST WATER PROTECTION SESSION

Standard guide for the design of groundwater-monitoring systems in karst and fractured-rock aquifers: ASTM standard D 5717

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ASTM, the American Society for Testing and Materials, one of the largest organizations in the world for the development of voluntary standards for materials, products, systems, and services, has been generating an extensive series of standards and guidance documents for groundwater and vadose zone investigations. This has been in response to perceived needs and requests by regulatory agencies. The task group concerned with karst and fractured rock has written a guidance document for groundwater monitoring in these heterogeneous, anisotropic aquifers. In June 1995, after a series of ballots and revisions over several years, this document was approved. It will be published as Standard D 5717 in Volume 04.09 of the 1996 Annual Book of ASTM
Standards but will be available separately before then and after from ASTM (Prepaid cost: $15 within the U.S.; $17 to other countries; from ASTM, Publications Department, 1916 Race Street, Philadelphia, PA 19103-1187, USA).

The standard guide was written to promote the design and implementation of accurate and reliable groundwater-monitoring systems in settings where the hydrogeologic characteristics of an aquifer do not allow invocation of a porous-medium equivalent. Most commonly, this is any unconfined carbonate or fractured-rock aquifer. Some of the topics discussed are: 1) karst-related concepts, 2) use of tracing to determine the destination and velocity of groundwater flow from a site to be assessed, 3) probable need for monitoring off-site, and 4) groundwater monitoring at only springs, cave streams, and wells that have been shown by site-specific contaminants and by tracing to drain from the site. Groundwater monitoring at traditionally-used, randomly-located or fracture-trace-located wells that have not been tested by tracing is unlikely to be reliable - except by chance.

Many of the guidelines given in D 5717 had already been adopted by the U.S. Environmental Protection Agency and by numerous state environmental protection agencies. Now that they have been confined, these guidelines will be more widely adopted and applied, thus becoming a national standard and greatly increasing protection of groundwater quality in carbonate and fractured-rock aquifers. Other karst-related and fractured-rock-related standards and guidelines are being written.

Are deterministic numerical models helpful to delineate groundwater protection zones in karstic aquifers?

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In karstified media, the main difficulty consists in finding a good adequation between the highly heterogeneous reality of the aquifer and its representation using "equivalent" parameters in the framework of the Representative Elementary Volume (REV) concept. The parameters describing the aquifer (hydraulic conductivity, effective porosity, and dispersivities, etc.) chosen with "equivalent" or averaged values on the REV, do not describe with accuracy the reality of the aquifer but they represent globally behaviors of the different zones of the aquifer.

A practical case study is described where a finite element model using the REV concept has been realized. The study was asked by a Belgian water supply company exploiting two wells producing about 3000 m³/day from a limestone karstified aquifer. More than 10 piezometers have been drilled, pumping and multi-tracing tests have been completed and interpreted. The finite element model used to simulate transport and flow
processes has been realized using the code AQUA. The results of the study show the difficulty to represent adequately the particular behavior of the aquifer.

From this example, many lessons can be drawn about the advantages and the limitations of the application of a REV based model in karstic hydrogeological conditions. Emphasis is given to the consequences on the way of considering the delineation of protection and prevention zones around a production well in karstic aquifers.

**Factors controlling groundwater protection of the karst islands of Croatia**

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In the Adriatic Sea, there are more than 1200 islands, islets and just bare rocks. All of them are in Croatia, except less than ten islets in Italy and Montenegro. The islands extend along the mainland coast. The largest island has an area of 410 km$^2$ and 13 islands are larger than 50 km$^2$, but only 66 islands are permanently inhabited. The inhabitants have been engaged mainly in shipping, shipbuilding, fishing, fish processing, vinegrowing, olive-tree raising, and sheep rearing. A high-developed marine tourism, occupying countless caps, doves and beaches of those "necklaces of rocky pearls" has become a main field of insular economy augmenting several times the local population during summer.

The islands are mostly composed of Cretaceous carbonates and, to a less extent, of Jurassic carbonates and Paleogene carbonates and flysch. The geological structure is typically imbricate abounding in numerous folds and reverse and other faults. The islands are mostly elongated extending parallel to their structural forms and being often 6 to 7 times longer than wide. They were the peaks and ridges while the channels and bays were dry valleys of the Dinaric Mountains some 25000 years ago when the sea level was about 100 m lower than today.

Massive and thick-bedded limestones, which prevail, are karstified and very permeable. Laminated limestones and dolomites are considerably less permeable, practically impermeable. So are also flysch deposits. On sufficiently wide islands (over some 2-3 km) impermeable and low permeable formations usually form barriers to transversal groundwater flow. If such barriers are deep and appear at both longer sides of the islands, they may decrease substantially fast groundwater drainage and protect fresh groundwater from sea water penetration during its abstraction by pumping. If there is only one barrier, the effect is somewhat similar but incomparably poorer. Various tectonic deformations make the conditions considerably more complex.

The insular groundwater under "natural" conditions, i.e., without overexploitation that results in the rise of its chlorides content and
without pollution, has a very good quality and may be used for public water supply. The actual and potential sources of groundwater pollution are: the use of fertilizers and pesticides in the vineyards, rare ship farms, and rare settlements. The latter two sources are caused by an inadequate (or better to say nonexistent) sewerage system.

The main problem in the insular groundwater protection is the water management policy. That is to say, the decision makers' opinion is that the good-quality potable water should be conveyed by long pipelines from major karst springs situated in the mainland and to use the local insular groundwater only for technical purposes. Meanwhile, there is a relatively wide and well-argued opposition to such attitude and the authors of the paper share that view.

**EPIK a methodology for evaluating vulnerability of groundwater to contamination in karstic aquifer; its application on a test site in Swiss Jura**

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EPIK, for Epikarst, Protective cover, Infiltration conditions, and Karstic network development, is a general methodology for delineating and rating landscape in relation with groundwater sensitivity to all kinds of pollutants: It is based on a hydrogeological conceptual model of karstic aquifer.

The objective of this methodology developed with the contribution of the Swiss Federal Department of Environment, Forest and Landscape (OFEFP) is to produce vulnerability mapping specifically for a spring or well water catchment area as groundwater protection zones mapping, where the OFEFP's ways of delineating protection areas are not satisfactory. It can also be used realize vulnerability mapping at a regional scale in the framework of groundwater management. The vulnerability mapping is at the present moment obtained by a manual method; it will be possible to obtain it with a GIS software.

After delineation of the water catchment area of the spring s.l., the methodology employs a four-steps procedure: (1) characterizing the existed karstic network and attribute a global factor the area, (2) mapping the infiltration conditions using different methods, (3) mapping the protective cover of the karstic aquifer (pedological cover and overlayered rock formations), and (4) mapping the epikarstic layer. Also, four key parameters are treated, divided in classes that are weighting by some theoretical factors. The superposition of the four parameters maps and calculation of the rating for each resulted vulnerability zones (mathematics mean) give the final vulnerability map.

The EPIK methodology was developed and tested on three different test sites. Differences of those test sites are size, available or known informations related to
geological and hydrogeological characteristics, elevation and land's use. Results of the test site of La Raissette spring (St-Imier, Folded Swiss Jura) one of the three test sites, and comments are discussed in the present paper.

**Groundwater exploration in a confined karst aquifer of the Swabian Jura (Germany)**

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The definition of protection zones in karstic aquifers requires the modeling of groundwater flow and contaminant transport in the presence of high velocities and limited possibilities for contaminant attenuation and purification. Such a modeling is predominantly based on a hydraulic characterization of the host rock and retardation data. In-situ migration experiments provide a method for producing realistic information on transport and retention of contaminants and for testing the extrapolation of laboratory data to field conditions.

The study area (10 km\(^2\)) for in-situ investigations is located in the transition of the Swabian Jura into the Danube Valley. The confined karst aquifer displays a wide variability of porosity and permeability of the anisotropic fracture and fissure distribution in the carbonate rocks even within short distances. In order to measure the complex flow conditions with a reasonable degree of certainty as many tools as possible, among them isotope hydrology techniques were applied. The gradient of the potentiometric surface of the regional flow is perpendicular to the main fracture direction. Hydraulic testing produced hydraulic conductivities in the range of $3 \times 10^{-5}$ to $2 \times 10^{-4}$ m/s and effective porosities in the order of 2%. The $^{14}$C results indicate recent karst water recharge, and tritium analyses display the simultaneous presence of tritium free and tritium rich groundwater and mirror the heterogeneous permeability distribution. Also the local flow vectors measured by single well nuclear tracer techniques scatter from well to well and the velocity amounts vary considerably. Groundwater tracing with dyes over distances from 1.5 to 3.5 km were unsuccessful to prove any underground connection for migration tests.

In view of these findings a small scale dipole for solute injection and detection was established over a distance of 200 m, where groundwater in the acceptor well is under artesian pressure of about 5 m. Due to results of dye tracing and local flow vector measurements the donator well is located within the catchment of the acceptor even at different discharge conditions. The results of the migration tests are discussed by the abstract of ORTH et al. (*Bacterial and chemical contaminant transport tests in a confined karst aquifer (Danube*
Synthesis of polymers for membrane preparation, polymer bulk modification for novel separations: Extraction of organics from waste aqueous solutions by pervaporation

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This work concerns the extraction of volatile organic components in aqueous media by pervaporation through elastomeric membranes made of polydimethylsiloxane (P.D.M.S).

The extraction process (batch and continuous) for a model compound ethyl acetate was modeled. Moreover, the proposed model allowed us to completely characterize the considered membrane liquid mixtures from an unique pervaporation operation. The pervaporation of elastomers based on a bi-component silicone resin whose preparation temperature and relative proportion of the cross linker containing component and the systematic determination of their mechanical and physical properties showed that the hardness, the density, the glass transition temperature are close to the preparation conditions of the membrane material. Finally, in order to predict quantitatively the solvent contents in the membrane at the upstream face in pervaporation and consequently to predict the pervaporation flux. We used Flory-Huggins approach which appears to be valid, in its simplified form (applicable to binary mixtures) for ethyl acetate sorption. The values of the interaction parameter of the model were determined for different elastomeric materials in the whole range of composition.

Chemico-physical pollution in urban areas of groundwater flowing in a littoral carbonate aquifer

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In the run of the last decades the coming up of new technologies as well as new needs has increased the interest in ground-water likely to be found in aquifers below massively urbanized areas, even where said water could not be proper for ordinary urban proposes. Such an assumption has led to a study aiming at ascertaining the extent of the chemical-physical characteristics degradation of groundwater flowing in the aquifer underlying Bari town.

The aquifer is a part of Murgia hydrogeological unit in carbonatic Apulian region. The karstic hydrogeology of Murgia is characterized by the relative low and discontiners presence of fractured of karstificated rocks.

Surveys proved that significant groundwater alterations are mostly due to massive widespread water
taking and sewage releasing in the subsoil.

Air-conditioning systems or generally heat changer plant play an important role.

In order to ascertain the extend and how such heat exchanges, mostly unauthorized take place numerical simulations were resorted to during investigations.

**Groundwater pollution in İskenderun karst basin Southerstern Turkey**

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İskenderun city, situated in the East-Mediterranean region of Turkey, has a shortage of water as a consequence of rapid economic development and population increase. Scarcity of surface water resources in the region lead the authorities to search for possibilities of utilizing the groundwater resources.

The two main water bearing lithologic units in İskenderun province are the coastal alluvium and the extensively karstified carbonate rocks. The former has already been contaminated by sea water intrusion. The karstic carbonate rock aquifer is also being polluted by inhabitants who ignore the important role of the karstic features such as sinkholes, dolines and other depressions, in the hydrologic and pollutant cycle. Misuse of the karstic depressions and solution cavities as waste disposal sites threatens the karst aquifer seriously. This will most probably cause to abandon them in the very near future unless the authorities prevent these adverse activities.

Another source for contamination of water resources in İskenderun area is the lithology. High content of iron sulphur, magnesium, and manganese where deep faults exist degrade the quality of the groundwater.

The main sources of groundwater contamination in İskenderun area were determined from monitoring the springs and wells. The protection areas were then delineated by means of morphologic, hydrologic analyses, and tracing techniques. Apart from technical side, it is demonstrated that educating the local authorities and the public about the role of karstic features in karst groundwater pollution is an important task as the technical works in preventing pollution. Measures to be taken in this task are discussed in this paper.
A Mechanism of reducing sulfur contents of coal by centrifugal-pneumatic comminution
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Sulfur is one of the most harmful substances in coal and it is the major cause of the global environmental problem of acid rain. In this study, scanning electron microscope and x-ray microanalysis is used to investigate a formation mechanism of the pyrite in Iowa coal and then a possible mechanism of removing or reducing a pyritic component of sulfur content by centrifugal-pneumatic comminution.

Thermodynamic factors control the precipitation of the pyrite precursors. A common product formed in coal is pyrrhotite then it can be converted to pyrite or marcasite in the presence of excess sulfur. Once formed, the iron sulfide precipitate is highly stable and will not go back into solution expect under extreme conditions. Pyrite and marcasite are also stable, however, it may be oxidized and go into solution as ferric iron or sulfate sulfur.

To remove the pyrite component the coal must be powdered. The mechanism used in practically all comminution process is compaction namely crushing and grinding. The crushing and grinding industry uses about 16 % of the world’s electric power. Of this vast usage of energy only 3 % is used to comminute the product. The remaining is lost to heating, radiation to the environment, friction of the machinery, etc. It is obvious then a more efficient comminution mechanism will benefit the coal industry as well as other industries where a large percentage of the total energy expenditure is in crushing.

The Centrifugal-Pneumatic (CP) coal mill is a comminution device that produces micronized particles. It disintegrates particles by high speed particle-to-particle attrition rather than crushing particles against a surface. The attrition process continues until the coal particles are small enough to be drawn through the impeller and thrown into the outlet duct. The flow of air created by the impeller conveys the particles pneumatically from the mill to a centrifugal classifier that separates them at a desired size. Drag forces are applied by internal baffles to the coarse particles and allow the air to pass through them for separation of the fines. The heaviest particles drop to the bottom of the classifier and are discharged to the control hopper. Other particles above the cut point follow into the coarse particle discharge. The air system carrying the fine particles follows a spiral path to the outlet on each side of the unit. Therefore, CP coal mill produces smaller particle size distribution with a high specific surface area at a low energy expenditure and help to remove and/or reduce pyrite framboids from the coal.
Complex refining of high mineral water and its influence on the environment

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Turkmenistan are rich in various kinds of hydromineral raw materials, such as the brines of the largest salt lake the Karabogazgol Gulf, underground high mineralized iodine and bromine containing waters, accompanying waters of oil and gas deposits, and layer waters of sulfur deposits, etc.

Iodine and bromine containing brines of operated deposits of Turkmenistan are treated as natural waters of chloride-sodium-calcium type, which contain different salts up to 150-250 kg/m³, iodine-0.02 - 0.05 kg/m³, and bromine-0.2 - 0.4 kg/m³. At present, only iodine and bromine are extracted from the brines. Worked out brines, which contain, besides sodium, calcium and magnesium chlorides, such as valuable microelements as boron, lithium, strontium, rubidium, cesium, etc., are poured off to natural man-made sewage farms.

The great amount of mineral salt is loosed because of sewage and in addition to it, the ecological problems connected with submerging of large territories and the toxic elements pollution of the territories nearly the Caspian Sea.

In the Institute of Chemistry of Academy of Science of Turkmenistan, the technology of complex processing of water solutions of iodine-bromine plants for getting of magnesium oxide are carbonate, different salts of boron and lithium, chlorides of calcium and potassium, white salt is worked out.

Extraction of magnesium is carried out by its precipitation by lime milk in the form of hydroxide. By means of calcination different kinds of magnesium oxide, as well as by carbonization, magnesium carbonates are obtained. Preliminary extraction of magnesium ions prevents the pollution of sodium chloride by doubled magnesium salts during the further precipitation of NaCl by sun evaporation. White salt is obtained by washing NaCl by concentrated solution of sodium chloride.

From concentrated solution, which contain valuable microelements, the following elements are obtained: boron by ion changing sorption; lithium by hemosorption by doubled hydroxysulfate of aluminum and magnesium; strontium by precipitation with barium sulfate; potassium chloride by crystallization. The finite product-calcium chloride is obtained in melt form.

The worked out technology is wasteless, and does not require acid and alkali to change pH of solutions. Most reagents used in different stages of processing (lime milk, magnesium and sodium sulfates) are produced in Turkmenistan.
An initial assessment of sanitary bacterial dynamics in the Castleton karst, Derbyshire, England

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The fact that pollutants may move rapidly through karst aquifers has long been known to researchers although pollution incidents continue because of the ignorance of many planners and land managers. However, there have been very few studies of the sanitary bacterial dynamics at karst springs. This paper outlines initial results from the Castleton area of the Derbyshire Peak District which contains an extensive and complex karst drainage system. Recharge is provided by a series of stream sinks which drain a 5 km² allogenic catchment and by diffuse infiltration into a 8.5 km² soil covered autogenic catchment. The influence of land use practices within the allogenic catchment on sanitary bacterial dynamics in surface streams is currently the subject of a detailed investigation by the first author. This paper reports the results of weekly measurements of concentrations of the sanitary indicator bacteria faecal coliform (FC) at the P6 stream sink and at two contrasting springs (Russet Well and Peak Cavern Rising) over a 68-week period. The P6 stream drains grassland-dominant agricultural grazing land which includes unimproved, semi-improved and improved pasture. There is a very low population density and no large point sources of faecal bacterial contamination are known in this area or in the larger autogenic catchment which is also predominantly grazing land. However, several farmsteads discharge effluent to septic tanks. Of the two springs, Russet Well drains the allogenic catchment, but also receives some autogenic recharge whereas Peak Cavern Rising receives only autogenic recharge except at high stage when it functions as an overflow spring for the Russet Well system. Over the year as a whole and during each three-month season, median FC concentrations at P6 are significantly higher than at Russet Well. The difference is greatest during the spring and summer months and is lowest in winter and it appears that FC concentrations at the rising are a complex function of faecal inputs and flow-through time which varies from 1-10+ days. Underground flow velocities in the allogenic system are 24 to 175 m/hr and, on the basis of limited water tracing experiments, autogenic waters are thought to take significantly longer to reach the cave. Hence, it was hypothesized that FC concentrations at Russet Well would be consistently higher than at Peak Cavern Rising. However, the situation proved to be much more complex. Over the sampling period as a whole and during the spring months (March-May) there was no significant difference between median FC concentrations at the two risings; during the autumn and winter periods, when discharge was highest, median FC concentrations at Russet
Well were significantly higher than at Peak Cavern Rising; and during the summer months FC concentrations at Peak Cavern Rising were significantly higher than at Russet Well. Further work is in progress with the aim of determining whether the pollution results from point inputs, possibly of human origin, or diffuse inputs from a bacterial land store.

The case for upland recharge area protection in the rocky mountain karsts of the Western United States

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Thick sections of Paleozoic carbonate rocks crop out along the crests or flanks of a considerable percentage of the mountain ranges in the Rocky Mountain west of North America. Invariably these carbonates are karstified. The karsts commonly comprise the principal recharge areas for extensive artesian aquifers in the adjacent basins. All are the headwaters for spring fed streams that serve as important municipal, agricultural and fishery water supplies.

Alpine and subalpine karsts are among the most sensitive of upland recharge areas owing to the rapid flow-through hydraulics operating within the highly organized dissolution networks that drain them. There is virtually no interstitial filtration and the water typically travels down gradient at surface water velocities through the cavernous permeability. Introduced contaminants including pollutants, soils, and even wood debris arrive at springs many miles from the source within hours to days in typical settings.

Rocky Mountain alpine karsts are characterized by well developed epikarst zones that generally overlie highly organized networks of caves which rapidly conduct water down gradient to the flanks of the ranges. Most of the water in the cave networks is rejected through springs from the lower slopes of the ranges to surface streams owing to basinward decreases in hydraulic gradients and to greatly diminished permeabilities within the aquifers. Basinward decreases of permeabilities occur either because the carbonate aquifers are fault severed by range bounding faults or because dissolution permeabilities decreases toward the basins in cases where carbonate strata continue unbroken into the basins beneath confining layers.

The epikarst zones generally do not store appreciable quantities of water beyond the snowmelt period. The intricate networks of dissolution widened fractures and dissolution tubes are extremely permeable. Consequently, the epikarst is most efficient in conducting infiltrating snowmelt and storm waters to down gradient springs on the ranges or into deeper zones containing the cave networks that channel the water off the ranges. Thus, the alpine epikarsts have poor storage characteristics and tend to be ephemerally saturated.
The underlying cave networks rapidly conduct water to the lower flanks of the ranges. The caves are in hydraulic connection with the saturated fractures and interstitial porosity of the host rocks, and all of these elements combine to form alpine karst aquifers. Alpine karst aquifers possess varying, but generally limited, degrees of storage. The conduit networks within them serve as highly permeable drains and the tubes in them have a hierarchical order which increases in the downstream direction.

Alpine karsts supply large quantities of excellent quality water to low elevation springs. Because storage within the karsts tends to be small, stream flows decrease with the cessation of snowmelt and onset of dry seasons. Typical winter discharges from karst springs are two orders of magnitude less than early summer yields. One consequence of minimal aquifer storage and large conduit permeability is that spring discharges tend to be flashy in response to rain storms.

Forests on mountain karsts are extremely important in retaining water in the uplands. The water is held primarily in mosses, the organic mat that comprises the root zone, and bogs held in place by organic structures. Removal of the forest canopy through clear cutting results in increased temperatures, decreased humidity, increased solar albedo, and increased ground wind velocities. The result is destruction of mosses, oxidation of the organic mat, and, ultimately, desiccation of the thin forest soils. If forest regeneration is not rapid, upland soils erode and are lost to the subsurface karst networks. The hydraulic impact on springs is that early summer discharge rates are increased, recessions are abbreviated, and flows become more flashy.

Unsightly as they may be, the residual wood slash and stumps provide a degree of protection to karst soils, particularly by allowing certain species which preferentially root in wood debris to become reestablished. In areas where the wood is burned, regeneration is further retarded.

The role of forests as upland reservoirs in karsts cannot be overstated. From a quantity perspective, significant volumes of water are retained by forests to be released gradually as late season recharge to the karst. These delayed releases sustain stream flows in the lowlands. From a quality perspective, retention of mosses, the organic mat and bogs affords a first and only line of defense against the migration of contaminants released in the uplands.

The Chinese, who are now living with the consequences of massive deforestation, call their forests "the green reservoir". This is not a whimsical term, but an accurate description of an integral component in a healthy hydrologic system. They found that removal of too great a percentage of their forests from their karsts resulted in regional climatic modification characterized by drying and increased temperatures. The consequences were desertification.
and severe soil loss, both of which thwart regeneration of their forests.

**ENVIRONMENTAL IMPACTS AND LEGAL ASPECTS - HI**

The impacts of massive recent deforestation on the unconfined karst aquifers of South China

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The sublime south China karst belt, host to some of the most exotic karst landscapes found on earth, has been profoundly and detrimentally impacted by massive post-1958 deforestation. Although south China occupies a subtropical monsoon climatic zone, it endures an annual flood-drought cycle. This cycle has been sufficiently exacerbated by the loss of the "green reservoir" that desertification has occurred over significant areas.

A primary impact of deforestation has been lost retention of water in the uplands. Surface runoff has become more flashy, and stream discharge recessions brief. The consequence has been increased flood hazards during the rainy seasons followed by parched conditions during the dry season. Water that was formerly retained beyond the wet season in the forested uplands, later to be released to the shallow karst aquifers under the lowland plains, now passes quickly through the region during the wet seasons.

Wildlife populations were decimated. Risks of crop failures have risen. The situation has grown precarious for a regional population of over 100 million people who are two crop failures away from starvation.

Two trends thwart recovery: (1) heavy dependence of the local population on wood for fuel and (2) a population explosion. Reforestation efforts are underway but they are gradually losing to human encroachments.

Development of groundwater offers a degree of mitigation. However, the thin shallow karst aquifers present are characterized by (1) large lateral permeabilities which rapidly transmit large volumes of water to surface streams where it then flows out of the region and (2) minimal reservoir storage.

Remarkable groundwater developments, driven by desperation, are proceeding, but they are fraught with frustration as renewed emphasis on development of wood resources takes places and the population continues to swell.

**Discussion on geological-ecological environments and economic developmental ways - The karst regions in South China as the example**

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The most important and typical karst regions in southwest China and middle-south China are in Yunnan, Guizhou, Sichuan, Hubei, and Hunan provinces and Guangxi autonomous region, the area of bare and semi-bare karst that include about 540000 km².
In these regions, the four main resources, are energy, water, mineral and biogenic which are abundant but many natural disasters have affected these resources. This paper discusses the comprehensive evolution about the qualities of geological-ecological environments in these karst regions.

A series of maps of geological-ecological environments have been compiled as the attachment of the new work, which contents are related to: (1) general situation of karst types and water-land resources; (2) main energy resources and water resources; (3) main reserve zones and tourist resources; (4) geological disasters; and (5) prospects for economic development. The five maps together reflect the basic compound features of geological-ecological environments in these karst regions that should be used to insure a reasonable development in these regions and environment protection.

This paper is introduced some contents of a new research by the author of the past several years.

**Importance of public awareness in improvement of effectiveness of karst groundwater protection studies**

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Scarcity of water, particularly in cities situated along the Mediterranean coast where the main aquifers are made of karstic carbonate rocks, require more thoroughness in exploiting and protecting the groundwater resources. Geomorphologic and hydrogeological studies have exhibited large quantities of the input and throughput features like sinkholes, dolines, uvalas, and poljes in the recharge areas of many karst aquifers in Turkey. Naturally, recharge areas are generally located at higher elevations and remote regions from the urbanized areas. These factors are considered as favorite by the local authorities and local people to utilize the karst features for their own purposes. Dolines and ponors are commonly utilized as injection points for waste water while uvalas and poljes are used as solid waste disposal sites. In doing this, the people are unconscious of the connection with the wells or springs that provide water for their supply.

A number of experiences in Turkey, have demonstrated that no matter how perfect is the efficiency of the technical work, protection of the water resources is primarily related to the consciousness of the local authorities. These people will either take the proper measures to protect the resources or to educate the public in this issue. To achieve this purpose, it is very important to involve the public administrative sector as well as technical sector in preparing guidelines for integrated environmental evaluation of karst water resources. The main phase of a study should include locating...
appropriate sites for disposal of waste water and solid waste that will satisfy requirements by the administrators as well as providing a water supply of good quality for the public.

This paper discusses how to overcome the public awareness problem. Some examples demonstrate how the technical achievements failed to be effective and applicable due to the lack of contribution of the local authorities and the public. A series of suggestions is made for revision of the current regulations which fall short in this account.

An example of regulation of karst aquifer

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For valuation of the karst aquifer potential and more, effective and rational use of water to be possible, it is necessary:

1. To perform extensive exploration work so as to obtain relevant data concerning the regime of aquifer, the water resources and quality as well as other elements necessary to provide the basis for technical solutions to be applied to regulation and control of the aquifer.

2. To arrange artificial regulation of the regime of water discharge with induced tapping of water from deeper parts of karst aquifer, to arrange for overpumping of the source of karst groundwater in the periods required, and to provide additional reserves either by natural flow or through the induced infiltration. The analyses made so far show enormous possibilities in this respect on numerous localities in karst areas.

Based on the project by experts of the Faculty of Mining and Geology, Belgrade University, few systems for artificial regulation of karst aquifer was made in the region of Carpatho-Balkanides in eastern part of Serbia. One of the successful projects has been developed within the investigations for regional water supply for the towns in the region of Timok. The previous complex investigations included the test of long duration pumping from the siphon channel of Mrljis spring, during which almost twice as large yield was obtained compared to the natural regime of discharge (from 170 to 325 l/s), with a depression in the broader zone of exploitation field of only 1 m and without any influence on surface waters of the river flowing near the spring. The preliminary water regulation project includes, besides installations for water abstraction from large springs, the construction of vertical wells up to 100 m deep at three most favorable localities determined by preliminary investigations, about 500 m in diameter from the main spring. This will also provide the possibility for making a larger depression in the karst aquifer in the necessary periods of groundwater recovery.

As one of the bases for the forecasting of the conditions and possibilities for groundwater recovery in this area, the
A karst model ordinance
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Significant portions of the eastern United States are underlain by Cambro-Ordovician-aged carbonate deposits. These solution-prone rocks often lie in scenic folded and faulted valleys, once prime farmland, but now under relentless development pressures. The problems posed by development in these areas are both structural and environmental in nature.

In March 1988, one of the first "limestone" ordinances in the USA was passed in Clinton Township, New Jersey. The ordinance was not of a "no build" nature, but rather a "build with care and understanding" law. Slowly, interest grew in the surrounding region and the crusade for rational development guidelines was joined by the North New Jersey Resource Conservation and Development (RC&D) Council, a Federal and County sponsored organization. The RC&D identified "limestone geologic areas" as a regional issue for inclusion in their work program. One of the first tasks in this program was to draft a model ordinance for use by municipalities.

The first step in developing the model ordinance was to provide both a practical rationale for its existence and a legal basis for its implementation. The concept of a "Carbonate Area District" overlay to the existing land-use zoning maps was the means used to identify areas of concern. Definitions of specific terms were provided to give both credibility and understanding to the legal and intellectual process of interpreting the ordinance. An attempt was made to provide rational, but non-confining engineering performance standards.

The procedural and submission requirements for a geotechnical and environmental evaluation were defined. A technical checklist format was employed to guide the applicant through the phased site investigation and review process. Construction inspection and ongoing evaluation of project sites in the "Carbonate Area District" were deemed necessary and became a part of the model ordinance requirements. To aid the prospective users of the ordinance, explanations and comments were provided on a section-by-section basis. The technical aspects of the ordinance were developed by planners, geologists, and engineers. Pro bono legal review was provided by two local land-use attorneys.

The model ordinance has been used as the basis for some six Township ordinances passed under New Jersey Land-Use Law up to the time of the preparation of this paper.
Environmental impact on karstic aquifers in Istria in Western Croatia
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On the Istria Peninsula in western Croatia karstic aquifers are developed that are suitable for study of sustainable development on one side of this touristically developed area, and on the other side of inland that has important agricultural supply. The area has high demand for water-supply during the summer/dry season.

The geological framework, morphology of terrain, high precipitation in hinterland together with well developed karstification that creates deep circulation of underground waters and important migrations of watersheds of individual springs. The study of the quality of underground water and monitoring of it during the period of low-water level becomes especially important for monitoring of environmental impact on underground waters in real conditions. The most realistic data will probably be obtained from overpumping conditions. Favorable conditions for this procedure exist because of the extensive hydraulic connection of springs with caverns that reach the depth of approximately 50 m below the sea-level. This research could contribute to the definition of scales in the exploration of karstic aquifers.

Hydrogeological aspects of karstified aquifers and its environmental impacts in Eastern Desert-Egypt
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With the population growing and increasing demand of water, deteriorating water quality and increasing environmental degradation, more effort is required to investigate and evaluate additional sources of groundwater from unexplored carbonate aquifer systems. Carbonate rocks are widely distributed in Egypt and cover more than 50% of its surface area, and are penetrated in many of the deep bore holes.

Karstified aquifers underlie a good proportion of the Eastern Desert between the Red Sea Hills and the River Nile. It is over 1000 m thick, and is a part of the Neogene, in the Gulf of Suez area; the Eocene and the Upper Cretaceous in the central area of Eastern Desert, which forms the conspicuous elevated plateau of El Galala, Ataqa, El Mukattam, and El Maaza. Carbonate rocks are affected by intensive fault systems, which play a significant role in the development of fissures and consequently in formation of springs.

The paper discusses the geographical distribution, the hydrogeological characteristics, possible potential of karstified formations in the Eastern Desert and its environmental impacts for sustainable development and redistribution of population in Egypt.
Investigations on the causes of salinity in karstic springs of Rahmat mountain, Zagros, Iran

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Rahmat Anticline is located at 55 kilometers NE of Shiraz city, in south of Iran (29.45 - 30.00 N and, 52.45 - 53.15 E). The anticline is in the zone "three" (simply folded belt) of Zagros ranges. The exposed formations of the anticline are mainly carbonate rocks of Sarvak formation (Cenomanien) and marls of Kajhdumi formation (Albian). Karstification is developed in the carbonate rocks due to the effect of climate and existence of faults and joints. Several small and large springs around the anticline discharge karst water from the Sarvak formation.

The quality of water from springs along the southern flank of the anticline decreases from NW towards SE. Electrical conductivity ranges from 698 to 10710 micromhos/cm.

An attempt has been made to determine the reason for the increase in salinity of the springs in the SE of the Rahmat anticline. Water samples were collected for hydrochemical analysis from springs and several shallow and deep wells in the adjacent area in the SE of the Rahmat anticline. Isochemical maps, composition diagrams, and isopotential maps were drawn and groundwater flow direction was determined from a isopotential map.

In the study area the climate is semi-arid, the soil texture is heavy (clay and silty clay), and the depth to water table is close to land surface, thus evaporation from groundwater is high. Data indicate that the saline water in the upper alluvial aquifer, which flows from NW to SE, is mixed with karstic water in Rahmat anticline and discharge from saline springs at the lower portions of the anticline rim.

Karstic area erosion in Iran

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Many large areas of Iran are underlain by dolomite and limestone formations such as Zagros mountain west and south-west of Iran and Alborz mountain in north and other mountains in center of Iran. The main factor of erosion in karstic regions is dissolution of limestone by stream flow. If limestones are impermeable flow through cracks will cause gully erosion, caves, tunnels, and dry channel. Creation and improvement of soil in karstic region is affected by physical and chemical, characteristics of the karstic formation.

In this investigation, the drainage area of Alamarvedasht in south of Iran of 5000 km² contains gypsum, dolomite and Sarvak, Ilam, Asmari, Jahrom, Gachsaran, Mishan and Aghajari formations were studied. Mean annual precipitation in this...
drainage basin is 150 mm and the mean annual temperature is 23.9 °C. Climate of this basin is in the Domarten classification as dry.

In this investigation causes and mechanism of soil erosion phenomena and relationship between soil erosion and karstic formation were studied and results were submitted.

The effect of salt domes on karst water
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Outcrops of karst formations occur over about 23% of the surface area in the middle of southern Iran. In general, the electrical conductivity is less than 500 μmho/cm (Raeisi, 1992). The karstic formations form aquifers containing water of good quality, especially in the Fars Province (Southern Iran). There are about 200 saltplugs in the southern part of Iran and Persian Gulf. In some places of this area salt piercements are adjacent to carbonate rocks, therefore the karstic waters are of poor quality.

The water of the Kuh-e-Siah spring, which is located in the vicinity of Firoozabad, is flowing from the Sarvak Limestone Formation. This spring is adjacent to a salt dome. Thus its water is of poor quality.

A geologic map with a scale of 1:50,000 has been prepared. Moreover, concentration of the following ions: Ca^{2+}, Na^+, Mg^{2+}, K^+, SO_{4}^{2-}, HCO_{3}^{-}, and Cl^-, the water pH, EC and the temperature, and also the discharge of the Kuh-e-Siah spring have been determined triweekly for a duration of 9 months. Additionally the discharge of a few seasonal springs issuing from the salt dome have been measured as well. Based on these data it is concluded that the salt dome is the source of contamination.

Environmental impacts on the karst aquifer systems in Wadi Arab catchment area Jordan
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Wadi Arab is one of the northern rift side catchments of Jordan draining from the escarpment towards the Jordan valley. The area is 267 km².

Six high productive flowing wells were drilled in the area in 1982/1983. These wells have been used for water supply purposes to Irbid district since 1985.

In addition, Wadi Arab storage dam has been constructed at the outlet of the Wadi. It started receiving the effluent from the sewerage treatment plant of Irbid city during the first years of operation. Kufr Asad observation well is used for monitoring the groundwater quantitatively and qualitatively.

The natural flow and the withdrawal from Wadi Arab well field caused a decline in the equipotential head of 54 m recorded in the observation well. This caused drying of the total base flow in the Wadi.

In addition to the hydrological and hydrogeological data, monitoring of
water quality and complete chemical analyses of Wadi Arab well field are available since 1982. \( \text{NO}_3 \), BOD, COD have been analyzed in those wells as well as in the Kufr Asad observation well. Also included are the results of stable and radioactive isotope samples collected from the wells. A sampler has been used for sampling the monitoring well from different horizons and depths.

One of the results of the study indicates that the water in the monitoring well is influenced by several components of water sources. There is significant fluctuation of tritium content, \( \text{NO}_3 \), BOD and COD in the monitoring well, also enrichment of the stable isotope as a result of evaporation. This is due to the direct infiltration of some sewerage effluent and local recharge within the Wadi to the calcareous karst aquifer tapping the water table. The seasonal variation has an effect on the variation.

Protection of water from these wells as well as the water in Wadi Arab dam from possible contaminants becomes necessary. WAJ constructed diversion dam within the drainage of Wadi Arab and a pipe line to convey the effluent to the Jordan valley. More precautions could be taken for possible environmental activities within the catchment area.

Evolution of geoeocological environments in some karst regions in China

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The surroundings of the Earth as the spaces for living all the organisms will be referred to as geoeocological environments, which usually consists of dual features. In China, these are nine types of geoeocological environments, which are related to karst regions, loess regions, littoral lands and islands, plains, grasslands, deserts, high mountains, inner basins and high plateau. This paper is concerned with the evolution of geoeocological environments in some main karst regions in China.

The basic environmental problems are discussed first, which include earthquakes, floods and drought, rocky desertification, and sea water intrusion. The statistics of larger earthquakes in the past 500 years are summarized, and the energy released related to the earthquakes for larger magnitudes have been calculated. The statistics of the frequency related to drought, flood and waterlogging during the past 500 years are also summarized and analyzed.

The discussion in this paper is paid more attention to the regions, where the industry and agriculture are quickly developing in the near future. The prospect of the evolution of the geoeocological environments in these regions and related qualities have been put out as a primary results in this paper. The geoeocological environments of the Earth as the living spaces for mankind are the compound surroundings to hold the geosphere, hydrosphere, atmosphere and biosphere. But it is most
important that the mankind's actions have obviously influenced the evolution of geoecological environments in karst regions in China.

**Pollution transport in the vadose zone: An example from Postojnska jama - Slovenia**

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The paper gives the observation results of pollution coming from the karst surface through 100 m thick limestones into the underground of Postojnska jama at the time of active pollution (communal waste water) in the years 1988-91 and later when the origin of pollution was removed and the cave ceiling underwent transport controlled washing and cleaning.

The pollution advanced together with rainwater into the karst interior. Thus in Postojnska jama on the area of about 20 m of diameter at four permanent trickles we assessed various stages of pollution. We mostly concentrated on detection of essentially increased specific electrical conductivity, increased nitrates, phosphates, sulfates and hardness contents and minor increase of chlorides and organic pollution (chemical oxygen demand). As a comparison we used a near unpolluted trickle. The communication of the surface with the cave was better explained by the tracing experiment, the tracer was injected on the point of pollution. The test indicated variously permeable conduits leading to particular trickles in the cave but only these where the pollution was detected. The permeability and the dynamics of drainage in respect to particular trickles is controlled by the pollution transport from the surface and by eventual autopurification processes, the latter being assessed in the case of polluted water percolation into Pivka jama.

After the removal of the pollution origin the percolating water progressively improved. After good three years of washing (annual amount of precipitations is 1700 mm) we may assess minor pollution only at the trickles with very slow and weak exchange of water.

**Environmental impacts on calcareous water-bearing formations in Tunisia**

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Calcareous water bearing formations constitute potential aquifers in Tunisia. Their outcrops cover about 32% of the surface of the country. In most areas, they stretch out deeply under a sedimentary cover. They are particularly developed in NW, Center-West, and SE regions of Tunisia. It is a matter of fractured and fissured carbonated layers with different ages: Jurassic, Cretaceous and Eocene.

Exploitable renewable resources are estimated as 430 Mm$^3$/year, they represent 36.7% of the total resources of Tunisian deep aquifers. The replenishment of these calcareous aquifers is provided by precipitation, and the groundwater
discharges from springs are significant. The quality of calcareous groundwater is usually good and is in demand for the industry, as mineral water and for the water supply of the population. The exploitation of calcareous aquifers is made by the means of tapping of springs or galleries and of digging wells for buried structures. Water use at present is about $355 \text{ Mm}^3/\text{year}$ from the $861.3 \text{ Mm}^3/\text{year}$ produced by the whole deep aquifers in 1992.

These karstic aquifers are very vulnerable considering that their recharge area is on the surface or situated under a covering of variable thickness and permeability. Already, in some aquifer structures, signs of contamination have emerged and chemical quality of exploited groundwater has begun to deteriorate of areas with problems. Examples cited in newspapers are as follows:

Sraa Ouertane: where groundwater contains a high concentration of nitrates increase as a result of the use of nitrate fertilizer.

Bulla Regia: where groundwater contains a high concentration of salts because of the proximity to salty outcrops.

"Complexe Terminal" aquifer of Nefzaoua: where the groundwater salinity raises progressively according to the exploitation increase.

This problem of evolution of groundwater quality of calcareous aquifers suggests to set up a strategy to preserve this quality.

### Ecology and pedogenesis of karstic lands in Turkey

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Karstic areas of southwestern and western Turkey have special importance in terms of ecology and pedogenesis. As a result of carbonate dissolution soils are developed from the clay residues (impurities) and they are in clayey texture.

As the soils can not be preserved on the steep slopes of the karstic lands, they are found along the cracks and between the bedding surfaces in the karstic regions both in Mediterranean and Aegean regions. When water penetrates into cracks and diffuses into sedimentary layers, locally weathering processes take place. These soils are common on the western part of the Taurus mountains. As a result, the formation of soils proceeds in situ along the cracks and within the layers and not necessarily related to the transportation of soil materials from higher elevations.

Sedimentology and mineralogy of the limestone in the karstic region are also important factor that control the nature of the soils. Soils are generally thin and stony on the massive and less cracked limestone. While soils are thick and common within the densely cracked/fissured limestone and especially those that have alternating layers of marl and sandy-silty layers.

Soil particles move towards the deeper parts of the limestone as a
result of the widening of the lapies which are mostly formed along the crack. In these areas transportation of the soil particles takes place in the vertical direction.

The oxidation process and/or the reddening of soil brings about easily in the limestone in comparison with the other parent materials, since the cracked structure of limestone leads to water and air circulation in good conditions. Presence of pyrite in limestone can very much accelerate this process. Most of the red soils in the karstic land may have developed during the Tertiary and hot and humid periods of the Quaternary time. The thick soils which are found within the limestone clearly testify the paleoclimatic conditions.

The existence of the dense forest communities reflect the favorable ecological conditions of karstic lands with respect soil formation and easily developing of root systems of trees in the Taurus mountains.

**Determination of hard metals traces in groundwaters and influence of environment**

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The determination of microelements in highly mineralized natural waters is of great importance for understanding the formation of precipitation, chemical elements balance in the Earth cheath, and also for estimation of ecological situation. The straight determination (analyzing) of microelements in these case even by modern method like atomic absorption is rather labor-consuming (difficult) because of low concentrations of metals and highly salt background.

Development of highly sensitive and at the same time the express-method of determination of metals in natural waters is the aim of present work. The investigation included the following steps:

1. Development of effective (efficient) and rapid method of metals preconcentration
2. Optimization of concentrating condition and determination (analyzing) of metals by the method of AAS.

Last time more and more application is found for the polymeric helatic absorbents, containing the same functionally-analytic groups and possessing the similar helatoforming properties like corresponding monomolecular organic reagents.

For carrying out of efficient and quantitative concentrating of hard metals, characterized by great volume capacity of passing sohdion and adequate quantitative desorption of metals into the minimal element's volume and by the possibility of carrying out multiple sorption - desorption cycles, by high dynamic of sorbents volume the following sorbent was carried out: polystyrol - methylene - imino - 4 - nitro- 6 - sulphophenyl.

For the quantitative extraction of the microelements, being found in the natural waters in different forms,
before concentration they are transferred into the labile forms.

The method of the group concentration of the hard metals (Mn, Fe, Zn, Cr, Pb, Co, Cd, Ni, and Cu) in the static conditions in the natural waters with the application of the polymeric helatic sorbent has been studied. The optimum conditions of sorption are when pH=5-6 for Mn, Fe; 9, 5-10 for another elements. Relative standard deviation of the atomic absorbing derivation of the toxic microelements, being analyzed, does not change within the limits from 0.01 to 0.07.

Environmental impacts of an allogenic surface water-groundwater system on the Floridan aquifer

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This paper attempts to discuss environmental problems caused by urbanization and industrialization on a karst terrain in North Central Florida with special emphasis on the potential of groundwater contamination due to surface water-groundwater interactions in a karst system.

The Floridan aquifer, consisting of highly karstified Tertiary carbonate rocks, and known as one of the most productive karst aquifers in the world, is subject to severe environmental hazards due to high population growth. It underlies the whole Florida peninsula and is the main source of drinking water in most of the State. The part of the Floridan aquifer discussed in this paper occurs within the "Marginal Zone" formed by the retreat of an escarpment due to surface water erosion. This transition zone is situated between the Northern Highlands plateau (~150 m asl) in which the Floridan aquifer is under confined conditions due to the overlying clay and sand deposits, and the Western Valley (15-30 m asl) where it is overlain by a thin blanket of sand. Allogenic surface waters originating from the non-carbonate rocks of the Northern Highlands have resulted in discrete recharge points and extensive karstification in the Marginal Zone. The area is represented by numerous sinking streams, dolines of various sizes, closed karst prairies, and karst resurgences. Point recharge to the Floridan aquifer occurs via discrete conduits connected to well-developed phreatic cave systems of anastomotic pattern. The overall structure of the karst system is further complicated by paleokarst horizons developed during low sea-level stands. Nevertheless, the close interaction between surface waters and many spring systems has been established by speleological research and groundwater tracing experiments. Based on the accumulated data and information provided by previous studies, this paper presents typical cases of environmental degradation in karst areas and addresses the roles of geology, hydrochemistry, geomorphology, and anthropogenic impacts in these processes.
HYDROLOGY

Evapotranspiration from karstic mountain grassland

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The karstic formation which build high ridges due to tectonic activity are one of the important water resources in the south of Iran. The objective of this study is to estimate the evapotranspiration and crop coefficient of karstic mountain grassland which is a very valuable factor in a karst aquifer water budget. A climatological station was set up at an elevation of 2810 m in 1991. Temperature, relative humidity, precipitation, pan evaporation, wind speed, and sunshine duration were measured daily for a period of one year. The actual evapotranspiration was estimated by the difference of soil water content during a no-rainfall interval.

The equations by Penman (1963), Jensen-Haise (1963), Priestley-Taylor (1972), Hargreaves-Samani (1985), Thornthwaite (1948), Cristiansen-Khosravi (1972), VanBawel (1965), Turc (1961), and Blaney-Criddle modified by FAO (1977) are selected to estimate potential evapotranspiration. Class A pan using doorenbos and pruitts coefficients was chosen as a criterion for comparing accuracy of the selected methods. Auto correlation, Kolmogrov-Smironov, and Chi-square test were used respectively to determine the independency and normality of the data. The regression coefficient, standard error, different percent, and slope of regression line are the statistical parameters being used to determine the accuracy of the mentioned equations.

The results reveal that the Blaney-Criddle and Turc equations are the most suitable methods. Penman, VanBawel, Priestley-Taylor, Hargreaves-Samani, and Thornthwaite methods were calibrated for the study area. The crop coefficient curve of regional pasture was proposed by using actual and potential evapotranspiration.

Stochastic response of karst aquifers to rainfall and evaporation, Maharlu basin, Iran

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Maharlu karst basin with an approximate surface area of 400 km\textsuperscript{2} is located in central part of Fars Province, Iran (29°, 30'- 29°, 50' N, 52°, 10'-52°, 30' E). The basin falls in zone three (simple folded belt) of the Zagros orogeny. The exposed geological formations in decreasing order of age consist of Pabdeh-Gurpi shales and marls, Sachun gypsiferous, Asmari-Jahrum limestone and dolomite and Razak evaporates. The well karstified Asmari-Jahrum formation covers about 40 percent of the area with huge reservoirs of karst water, including Sabzposhan aquifer. This aquifer is discharged by a number of production wells and few major springs. Due to lack of vegetation,
discharge through transpiration is practically zero.

For geological reasons, salt water intrusion takes place in the aquifer and as a result Pol-e-Brengi spring reaches an EC value of 1554 μmhos/cm. Other springs and also production wells have lower value of EC ranging between 400 to 60 mhos/cm. The main recharge source of karst aquifer is rainfall. In order to establish a relation between rainfall and evaporation with groundwater levels and springs discharge, time-series techniques both in time and frequency domains are employed. The results of study are presented as correlograms, spectrums, phase diagrams, coherency-diagrams and cross-correlograms. A time lag of 1-3 months distinguished between rainfall occurrence and groundwater response and springs discharge.

Very low cross-correlation coefficient and low coherency indicate that water table in Sabzposhan aquifer bears no relationship to evaporation. The time lag gives some indication of flow path length and the extent of karstification in the aquifer. The time lag together with geological evidence may be used to propose preventive measures for salt-water intrusion of springs in the area.

**Base flow retention time determination of some karst springs in Slovenia**

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The objective of our research was to determine the base flow recharge dynamics of some karst aquifers in SW Slovenia. Three major karst aquifers, situated in close proximity to one another, were included into the research: the aquifers of the Vipava, Hubelj and Podroteja. Their recharge areas lie in the Trnovski Gozd plateau with prevailing altitudes between 700 and 1000m a.s.l.

In water dynamics modeling, the exponential model was used. Data on oxygen isotope composition of precipitation on aquifer recharge areas were modeled and the results were compared with measurements of isotope composition of spring base flow waters. Due to different time spans between individual sampling periods, an appropriate time correction of input data was used.

Modeled results are in good accordance with measured data, which leads to the conclusion that the exponential model can adequately describe the accumulation and discharge of base flow reservoirs of karst aquifers. Data on the average groundwater retention time and base flow rate were also used to estimate the volumes of base flow reservoirs of individual springs.
Assessment of the karst spring contributions of Lamas basin modelled by exponential functions
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Based on recession hydrograph during dry periods, in the exponential form, reciprocal exponential functions, a decreasing one for the dry period of 6 to 7 months, an increasing one for the wet period of 5 to 6 months, was proposed to model the karst related part of the deterministic component of river runoff with significant karst spring effluents whereas the surface runoff part of the deterministic component will be represented by periodical Fourier functions, covering only the wet period (Keloğlu 1984, 1985, and 1988).

This approach is applied to daily flow series of Lamas basin at the Kızılgeçit station, in order to analyze and assess the karst spring effluents of this interesting basin.

Flood peak reducing effects of karst
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In order to evaluate the flood reduction effect of karst on the floods, a comparison of the frequency distribution of dimensionless annual peak floods (flood indices) between karst and non-karst river basins has been carried out.

Data from six hydrometric stations located in different karst basins and from two stations located in two different non-karst basins in Turkey were selected.

Under the assumption that dimensionless peak floods follow a Type-I external (Gumbel) distribution, it has been shown that the presence of effluents originating from karst springs reduces significantly the intensity of floods.

This reduction effect reflects that, in the frequency distribution, a small rise of the flood discharge corresponds to a considerably large increase of the return period.

Snowmelt effects on flow in Upper Zamante river basin of Türkiye
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The contribution of snowmelt as direct runoff can be estimated by the analysis of hydrologic budget components or statistical approaches using data such as snow layer thickness, snow density, snow water equivalent, percentage of the drainage area covered by snow, and air temperature, etc.

In case of the contribution to the subsurface flow through conduits, the separation of hydrograph is more difficult in karstic areas. Besides the methods of the snowmelt hydrograph...
separation for non-karstic areas are not directly applicable in karstic recharge areas.

In spring thaws, the water produced by melting at the bottom of the snow layer as well as that comes from the surface of the snow cover enters the enlarged cracks or other features to reach the main conduits and then contributes to the main spring discharges. Statistical analysis of discharge data of the springs do not completely reveal the contribution of the snow pack because snowmelt contribution to base flow may continue over the dry season according to prevailing meteorological conditions.

A case study is presented for Upper Zamanti subbasin of Seyhan river located between central and southern Anatolia. The perennial snow cover is found on average at an elevation of about 1400 m (a.m.s.l.) and according to snow data collected from 14 snow courses, extending from 1978 to 1992, the snow cover reaches an average depth of 925 mm, with a mean density of 290 kg/m$^3$.

**Average base flow rates of karst spring effluents in Turkey**

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Dokuz Eylül University, Civil Eng. Dept, Bornova, Izmir, Turkey

Karst springs contribute significantly to streamflow along a belt extending from Dalaman to Tigris basins in southern Turkey. Since a large part of the country's water resources are in karst regions, studies to identify the effects of karst formations are of great importance for their appropriate development and operation. Karst spring effluents are emerging at several locations near the river bed and are not readily measured by direct hydrometric methods. Hence, indirect evaluations, based on modular runoff rates, and/or linear regression equations, and/or exponential mathematical models are used to estimate the characteristics, especially the average base flow rates of karst spring effluents. The results are summarized for all involved hydrometric gaging stations in the Mediterranean, Göksu, Seyhan, Ceyhan, Euphrates, and Tigris basins in Turkey.

**How much precipitation on Manavgat karst?**

A.S. Wain
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Annual water balances of Manavgat surface subcatchments (rainfall 1500 to 1700 mm, runoff up to 8240 mm) infer that total contributing areas are many times larger than surface catchment areas. This is not disputed but in such remarkable circumstances it is argued that improved assessment of areal rainfall in the mountainous catchment is essential, and should not be delayed, for the purposes of karst research and development planning and environmental impact assessment of development proposals. A preliminary proposal for a rainfall research program-increasing the rain gauge network from seven to 37 gauges, with some additional ground level gauges for estimating errors in catches of standard gauges is made for the purpose of stimulating debate.
Determination of the surface flow component by separation of groundwater and interflow components using mathematical simulation models based on exponential discharge functions in river flows with significant karstic spring effluents

I. Atış

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In the presented study underground storage outputs, which constitute karstic baseflows and interflows, have been represented by a conceptual model using the exponential discharge function of a single linear reservoir in a river fed by karstic spring flows. The approach considered reflects the physical structure of the basin since the discharge coefficient is included as an important parameter of the karst environment.

The flow processes is considered in two periods of wet and dry months of the year. It has been assumed that the parameters of dry period, which are determined by means of the recession hydrograph, are also valid in the wet period. The total of the karst spring flow and interflow in the wet period has been determined by a model which has successive recession hydrographs in a stepped structure and by using the parameters of the dry period. With an increase in the total flows, the model outputs that represent the sum of the karst spring flow and interflow reflect increased values as a result of precipitation contributing to the underground storage. This period is followed by a recession hydrograph which continuous until the following rising hydrographs.

Exponential discharge function have been used for modeling the karst spring baseflows separately. These functions have been defined by the parameters estimated directly from flows in the recession hydrographs of the dry period. In the period the parameters are determined by considering the beginning and the end of two successive recession hydrographs.

Manavgat river basin is situated in a karst environment where the effluents of the karst spring considerably contribute to the river flows. The method has been applied to the daily flows of Homa stream gaging station to separate the total flows into their components during the period between 1964-1982.

Within this period, the average total flow of Homa is 139.4 m$^3$/s and it has been found that it involves 62% of total flow (86.6 m$^3$/s) as karst spring baseflow, as 22% interflow (31.2 m$^3$/s) and 16% as surface flow (21.7 m$^3$/s).

In a river fed by karstic springs, the analysis of surface flows obtained by subtracting the spring baseflow and interflow components from the total flows, is significant in research studies on frequency analysis and precipitation - surface flow transformation in karstic basins. This is due to the fact that such surface flows are clear of any effects of karstic spring flows and interflows.
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