Management of aquifer recharge

Groundwater storage in the sand dunes of Viet Nam

**Nguyen Thi Kim Thoa, Giuseppe Arduino, Paolo Bono,
Nguyen Van Giang, Phan Thi Kim Van and Bui Tran Vuong**

The management of aquifer recharge (MAR) can be a valuable approach to increasing the volume of water supplies and to maintaining groundwater-dependent ecosystems. MAR can also be used to improve the security and quality of water supplies as well as to protect water resources from saline intrusion. MAR was carried out in sand dunes coastal areas of Viet Nam to fight desertification, for best practices on ecosystems rehabilitation as well as remediation techniques to restore aquifer systems and groundwater storage capacity.

Nguyen Thi Kim Thoa
Nguyen Van Giang
Phan Thi Kim Van
Vietnamese Academy of Science and Technology, 18 Hoang Quoc Viet Cau Giay, Hanoi, Viet Nam
E-mail: nkthoa@fpt.vn
Giuseppe Arduino
Hydrological/Geological Unit UNESCO Office, Jakarta, Indonesia
Paolo Bono
University "La Sapienza", Rome, Italy
Bui Tran Vuong
Division of Hydrogeology and Engineering Geology for the South of Viet Nam

Introduction

ater shortage has been identified, together with global warming, as a major problem of the new millenium. So, while the control and use of water has been a matter of importance from time immemorial, the management of water resources has become a new challenge in modern times.

In particular, the provision of safe drinking water becomes a greater challenge as socio-economic development and population growth place increasing demands on limited water resources. Often in developing countries, there is uncertain access to reliable supplies of potable water. Both rural and urban populations lack reticulated systems and depend mainly on access to groundwater. In many localities, particularly in coastal areas, unregulated use of groundwater has resulted in a dropping water table and related seawater intrusion. Water sewage systems and processing of human waste are often absent or unreliable and waste disposal may also affect groundwater quality on which people rely.

Among the factors contributing to a water crisis in developing countries are; a limited understanding of the requirements for sustainable water stewardship; gaps in local capacities - scientific, educational, institutional, managerial and political; and a failure to put in place a full suite of enabling systems needed to achieve sustainability. For sustainable development of water resources, the rate of extraction - both from surface and ground sources - should not exceed the rate

Figure 1: Location for MAR research in Binh Thuan, Viet Nam

of replenishment of the resource; and the extraction must not jeopardize the biodiversity of the ecosystem.

What is MAR?

Management Aquifer Recharge (MAR) refers to the intentional banking and treatment of water in aquifers. The term 'artificial recharge' has also been used to describe this, but the adverse connotations of 'artificial', in a society where community participation in water resources management is becoming more prevalent, suggested that it was time for a new name. The old name incorrectly implied that the water was in some way unnatural. And to be consistent we do not call wells "artificial discharge". Managed recharge is intentional, as opposed to the effects of land clearing, irrigation, and installing water mains, where recharge increases are incidental.

MAR has also been called enhanced recharge, water banking and sustainable underground storage.[1, 2] MAR often provides the cheapest form of new safe water supply for towns and small communities. With the help of training and demonstration projects, MAR has the potential to become a major contributor to the UN Millennium Goal for Water Supply, especially for village supplies in semi-arid and arid areas. The extent to which MAR can achieve its potential for water supplies will depend on an understanding of the capabilities and limitations of various techniques to use within the water catchment and aquifer system in relation to the needs, the existing water infrastructure, space for water harvesting, the social and regulatory environment, and the skills of personnel. Aquifers provide a store of groundwater, which, if utilized and managed effectively, can play a vital role in poverty reduction; risk reduction (in both the economy and health); increased yields from reliable irrigation; increased economic returns; and reduced vulnerability.

International Association of Hydrologists (IAH), through its Commission on MAR, has an important role in facilitating the creation and dissemination of new knowledge in partnership with other organizations so that MAR may achieve its significant potential.

Why Binh Thuan was chosen for a pilot project

Viet nam has an area of 330,000 sq. km, of which 75 per cent is hilly to mountainous terrain and 25 per cent is flat coastal and alluvial plains. Sand dunes are widely distributed along the coastal area of the central part of Viet Nam. During the last ten years considerable water shortage and even severe droughts occurred repeatedly in the dry seasons. Binh Thuan province covers the coastal plain of Southeast Viet Nam and has an area of approximately 8,000 sq. km, with a population of about 1 million (Figure 1).

Binh Thuan is one of the driest parts of Viet Nam - according to rainfall data from Phan Thiet station for 1925-2007, the average annual rainfall is 1,112 mm/yr, with a minimum of 650 mm (1977) and a maximum of 2,017 mm (1932). Due to uneven rainfall distribution within a period of four months (December to March) characterized by very little precipitation (average 23 mm in 4 months), the area suffers considerable water shortage during the dry season. During the short rainy season 70-80 per cent of runoff occurs, together with high evaporation rates. Only a small portion of the runoff is retained by surface storages, while most of it infiltrates into the sand dunes. Only the larger rivers have water throughout the long dry season, but the water is very turbid and increases in salinity.[2, 3, 4]

The marine sand dunes formation (Figure 2) is characterized by the occurrence of an unconfined porous aquifer, of variable thickness (40 to 60 m), emerging at ground level in depressed morphological areas (20-30 m above sea level) and forming wetlands or natural reservoirs. The sand dune aquifer is exploited both by direct pumping in places where it emerges (in depressed morphology) or through shallow hand dug wells (5-8 m deep). During the dry season the need of the population for water becomes urgent (Figure 3).

Binh Thuan was chosen for the pilot experimental project of MAR in order to fight desertification, to establish best practices on ecosystem rehabilitation and to introduce remediation techniques to restore aquifer systems and groundwater storage capacity.

Assessing a pilot site

The pilot project in Binh Thuan was carried out according to the recommendation of IAH through its Commission on MAR.[5, 6, 7, 8]

Hydrogeological and hydrological study

The investigation included the acquisition and interpretation of existing data; and the acquisition of topographic, geological and hydrogeological maps, aerial and satellite photos, precipitation data, field geophysical survey, field hydrogeological survey, groundwater physio-chemical parameter measurements and groundwater sampling for water quality and isotopes analyses.

Six hydrogeological campaigns during 2004-2006 carried out in a selected network of wells, springs, lakes and ponds gave the basic information on the major parameters of Binh Thuan water resources.

The surface and groundwater physio-chemical characteristic, as estalished with the help of portable electrochemical equipment, is as follows:

- pH 4.79-8.42;
- Temperature 26-34°C;
- Electrical conductivity of 50-1,500 µS/cm; and
- Corresponding total dissolved solids (TDS by EC) of 30-800 mg/l.

Water sources

One of the factors that plays an important role in the success of a MAR project is the potential water source for recharge. Here the rain water source was estimated on the basis of an analysis of meteorological data from two new stations in Bau Noi and Hong Phong village installed since 2005.

According to the two-year average rainfall data of Bau Noi and Hong Phong stations, the amount of rainfall averages 140 mm/year, the period of water redundancy being from September to October at Bau Noi and in July, September and October at Hong Phong. The amount of rainfall which can be used as a water source for groundwater recharge is estimated at 140,000 m³/km²/year.

Infiltration in the area studied was calculated using chloride concentration in precipitation (5.32 mg/l) and in anthropogenic uninfluenced groundwater (59.65 mg/l). Since no chloride evaporation occurs in the sand dune, the infiltration (R) is calculated on the basis of the mass conservation equation, which results in:

$$P.\,Cl_{precipitation} = R.\,Cl_{groundwater}$$

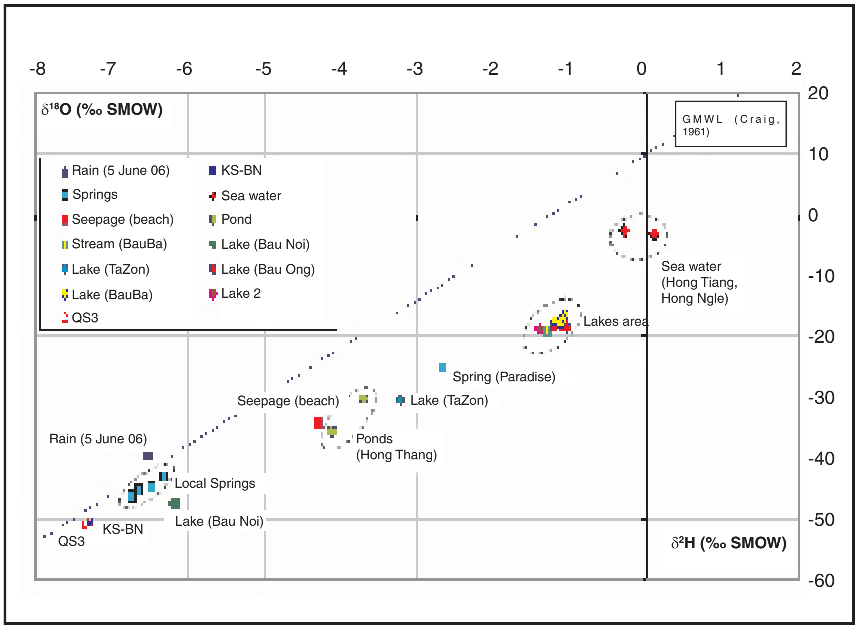
[P=precipitation in the study area]

According to the data of Bau Noi station, with average precipitation of 760 mm/year, the amount of rainfall, which infiltrates into groundwater, is estimated at 67,900 m³/km²/year, while, according to the data of Hong Phong station, with average precipitation of 815 mm/year, the amount of rainfall which infiltrates to groundwater is estimated at 73,000 m³/km²/year.

Figure 2: Sand dune in Binh Thu-

Figure 3: Dry shallow well in March 2004

Figure 4: Isotope results of water samples taken during 2004-2007 in Binh Thuan



As many as 74 water samples were taken for isotope analyses and performed at the laboratory of the Institute of Atomic Energy in Viet Nam and Geokarst in Trieste, Italy. Tritium data at the wells and in Bau Noi suggest that the age of the groundwater is only 20-40 years, representing significant localized recharge,[9] even though groundwater is deep over most of the area. Figure 4 shows that groundwater has an origin from rainwater.

Aquifer thickness

The methods of Vertical Electric Sounding (VES) and seismic prospecting are considered favourable techniques for assessment of ground water resources in the study area. While VES is currently used in shallow bedrock (<40 m) areas, seismic prospecting is used for deep bedrock estimation. The rainy season is a suitable period for VES investigation, because good electrical contact can be established for electrical resistivity soundings.

An interpretation of VES logs shows that aquifer thickness varies from 45 to 105 m. The seismic refraction investigation was carried out by means of an 8,000 m long section to determine the depth of bedrock. Figure 5 shows the cross seismic section in Binh Thuan.[1] The interpretation of the seismic data indicates the occurrence of the ryo-dacitic bedrock at depths between 60 and 140 m below ground level, and the occurrence in the sand deposits of a

Figure 5: Section of seismic refraction in Binh Thuan (The values within the section present the velocity in m/s)

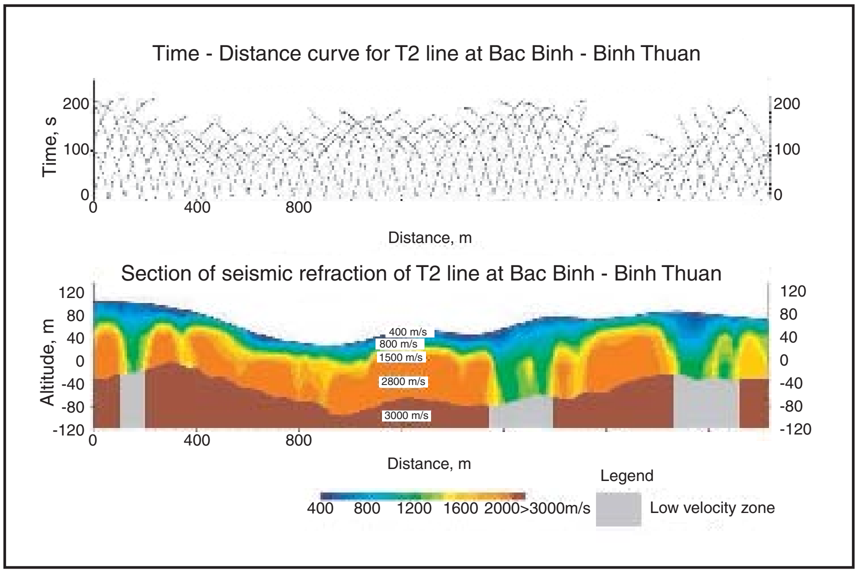
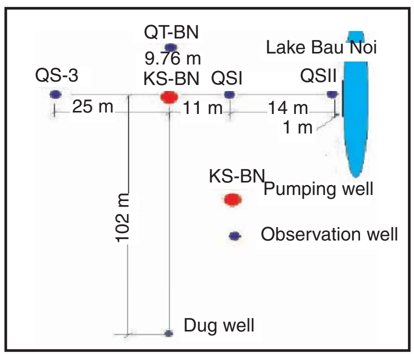


Figure 6: Bau Noi- location of the pilot site (picture was taken in 2004)

Figure 7: Well lay-out for aquifer test at Bau Noi



potential aquifer of the same thickness. The seismic refraction also pointed out the occurrence of fractured zones in the bedrock itself (low velocity zones) that could therefore be interpreted as further potential bearing water-bearing zones due to secondary permeability.

A drilling exploration campaign was undertaken in order to:

- Confirm the lithostratigraphy and the hydrogeological asset;
- Carry out aquifer pumping tests for aquifer hydraulic characteristics determination;
- Collect water samples for chemical, bacteriological and isotope analyses;
- Monitor groundwater levels; and
- Determine groundwater flow direction and velocity through tracer tests (Rhodamine).

A total of 600 m of drilling was carried out in the research area, including exploratory, observation and exploitation wells.

The results of the above investigations confirm that the main aquifer is unconfined, having a thickness varying from 33 to 68 m. The groundwater level ranges from ground level to 26 m, with well yield varying from 1.3 to 2.5 l/s. The aquifer is represented by upper-middle pleistocene and holocen marine-eolian sediments, consisting of fine to medium loose quartz sands.

Aquifer test

Bau Noi was chosen as the site for the MAR project (Figure 6) due to its close proximity to Hong Phong village, affected by longstanding droughts during the last ten years.

Bau Noi lake was formed in November 1999 due to the rising of the piezometric head of the aquifer, as a consequence of direct infiltration into the sand aquifer during the previous 30 years (in turn, because of the removal of land cover). Since the water occurrence is perennial, only slight level changes during the wet and the dry seasons are observed. Water samples were collected from both the pond and the pumped well KS-BN; the results indicate that nitrates are 0.3-17 mg/l. Because the Bau Noi pond is extensively used as a drinking trough by cattle from the vicinities, the bacteriological analyses of both the pond and the water well indicated the occurrence of very high concentration of *coli* bacteria, therefore making the water unsuitable for human consumption.

Due to the elevated contents of contaminants (*coli* bacteria) in the Bau Noi groundwater, an aquifer recharge trough bank filtration technique was envisaged.

An aquifer test, according to the well lay-out in Figure 7, was conducted for 162 days of uninterrupted pumping (a constant rate of 2.4 l/s or 207 m^3/day), commencing on 27 May 2005, with the following aims:

- To determine the hydrogeological parameters of the aquifer (transmissivity, hydraulic conductivity, sustainable yield), in order to assess the potential of the aquifer for groundwater supply; and
- To apply managed aquifer recharge through bank filtration techniques while also improving water quality (in order to remove the high content of *E-coli* in ground water).

During the aquifer test, a quantity of 33,600 m^3 of groundwater was abstracted. The drawdown at the end of the test in the pumping well and the observation wells was as follows:

KS-BN (pumping well) = 2.8m
QT-BN = 0.38m
QSI = 0.24m
QSII = 0.15m
QS3 = 0.30m.

From the results of the pumping, the hydrogeological parameters were determined using Thiem-Dupuit, Cooper-Jacob (drawdown-time and drawdown-distance), and Recovery Theis - Jacob methods (Table 1).

The kD and k values for each

method in Table 1 are shown as average values of kD and k calculated at each well.

Two Rhodamine tests[12] were carried out in 2 observation wells located on the well axis and down gradient to the production well. The velocities of groundwater flow were 44.6 cm/day and 17.70 cm/day, respectively.

Water samples for chemical and microbiological analyses were taken weekly and showed that the nitrates as well as the *coli* bacteria in the water decreased as pumping time increased. Therefore, the bank filtration technique gave very satisfactory results in terms of water quality improvement.

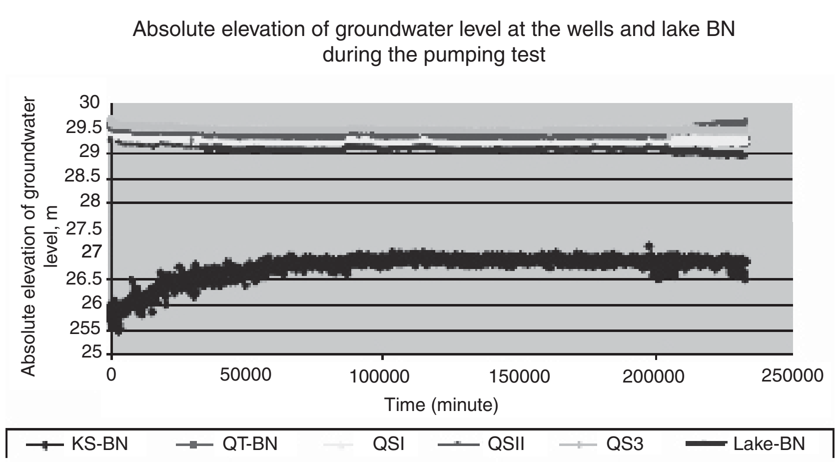
The pumped water was conveyed through a 3-inch pipe to a cattle pond (Figure 8), constructed within the project and located some 600 m away to the north of the pumped well, at an elevation of 52 m higher than the well elevation. The resulting head loss due to the elevation difference affected the pump yield, which stabilized to approximately 2.5 l/s. The entire area of Bau Noi has also been fenced to prevent cattle from continuing to pollute the groundwater.

Table 1: Transmissivity, hydraulic conductivity and specific yield of the unconfined aquifer

Method	Transmitsivity kD (m^2/day)	Hydraulic conductivity k, m/day	Specific storage
Thiem-Dupuit	230	-	
Cooper-Jacob (drawdown-time)	538	13,7	0,170
Cooper-Jacob (drawdown-distance)	235	7,8	0,157
Recovery Theis- Jacob	594	16,5	0,175
Average	**399**	**12,67**	**0,167**

Figure 8: Water from pumping test (left) and the cattle pond (right)

Figure 9: Groundwater level during a pumping test in wells and lake Bau Noi



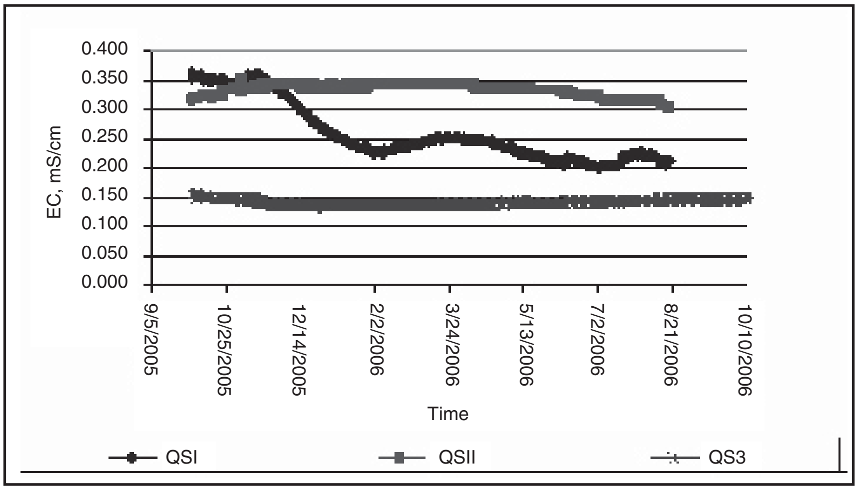
Groundwater monitoring and flow model

Groundwater monitoring is indispensable during the development of a MAR project. Information from the monitoring is essential to plan the quantity and quality of recharge water as well as recovered water. Information from monitoring is also used to evaluate the effectiveness of MAR, and to estimate the volume of water to be recharged and recovered or to ensure adequate residence time of recharged water in the aquifer for necessary water quality improvements, such as inactivation of pathogenic viruses and bacteria, before the water can be used for drinking.

Groundwater monitoring was conducted by automatic transducers and dataloggers for electrical conductivity, temperature and water level (CTD divers) in wells and surface water in Bau Noi. The plots of the groundwater level and electrical conductivity of the groundwater *versus* time of these wells and Bau Noi are shown in Figure 9 and Figure 10.

The Groundwater Modelling System - GMS version 3.1 - was used to forecast the impacts of proposed groundwater abstraction plans as well as the effectiveness of managed aquifer recharge. The study area has an area of 927 sq km, and the groundwater system was simulated as a two layer system. The first layer represents the unconfined interganular aquifer, with horizontal hydraulic conductivity, k, of 12,67 m/day; porosity, n, of 0.36; specific yield, S_y, of 0,167, and vertical hydraulic conductivity of 1/10 of the horizontal hydraulic conductivity. The second layer represents the weathered zone and bedrock, which is considered as an aquitard, having hydraulic conductivity of 10^{-4} m/day. The results of

Figure10: Changes in groundwater electrical conductivity *versus* time



the steady state model show that the groundwater potential reserves of the area are 230,000 m^3/day and the safe amount of groundwater abstraction is 138,000 m^3/day; amounts that can be considered as average for many years. During the dry season (December to March), the unsteady state model shows that the groundwater potential reserve is 110,000 m^3/d, and the safe reserve is 43,000 m^3/d. These numbers are considered as minimum amounts of groundwater potential and safe reserves. The unsteady state model shows that in the rainy season the groundwater potential reserves and the safety reserves are 470,000 m^3/d and 201,000 m^3/d, respectively.[10] These numbers are considered as maximum amounts of groundwater potential and safety reserves.

Capacity building and knowledge transfer

The MAR technology had never been used in Viet Nam before. Therefore, a further component of the project was focussed on capacity building, with the participation of Vietnamese scientists in different international workshops; as well as the transfer of knowledge and experience about MAR to scientists in Viet Nam, especially young scientists and Masters students at National Universities, through three training workshops. The results of the MAR pilot project in Binh Thuan, including the existence and occurrence of potential groundwater resources and MAR options for water's supply, were introduced to the leaders of the Binh Thuan Province, as well as to the Government of Viet Nam, donors and NGOs, in order to allow them to develop future policies and decisions. Information about MAR was also disseminated to the public through television, broadcasting, newspapers and VCDs.

Conclusions

The pilot project area is located in the Binh Thuan province along the coastal plain in the lower part of Central Eastern Viet Nam. Due to an uneven rainfall distribution and a four-month period (December to March) characterized by very little precipitation, the area suffers considerable water shortage during the dry season.

Extensive geophysical, hydrological and isotopic investigations, including drilling campaigns, long-term pumping tests and continuous monitoring of ground water levels in four monitoring wells, show that the sand dune formation is characterized by the occurrence of an unconfined porous aquifer, of variable thickness (40 to 60 m), with a water table emerging at ground level in depressed morphological areas (20 to 30 m above sea level).

A 162-day pumping test carried out at this site proved that the use of the bank filtration technique considerably improved the quality of water, originally highly contaminated by *E-coli* bacteria. The well field developed within the present project is now capable of supplying 220 m^3/day of good water quality to the Hong Phong community, recurrently affected by severe droughts.

The pumping tests and observations of an experimental bank infiltration in the sand dune area of Binh Thuan can be used as a model for others parts of the country.

The study also showed that growing water demands, due to agricultural, domestic and tourist requirements, could in the long term affect the quality of the existing groundwater resources, if massive exploitation occurs. That would start an irriversible process of saline intrusion into the coastal areas.

Acknowledgements

This research study is supported by the Ministry of Science and Technology of Viet Nam (DTDL 2004/07, NCCB 711706), UNESCO IHP, the Italian Ministry of Environment Land and Sea and ICSU during 2004-2007. The authors sincerely thank Dr. Peter Dillon, Dr. Salvatore D'Angelo, Prof. Dr. Gianmaria Zuppi, Dr. Fabrizio Gherardi, Mr. Pham Van Hoa for their great help as well as active participation in field trips and research during the implementation of this project.

References

1. Nguyen Van Giang, Nguyen Ba Duan, Lai Cao Khiem, Le Ngoc Thanh, Nguyen Quoc Dung, 2006. "The interpretation of geophysical data for studying hydrogeological characteristics of Bac Binh, Binh Thuan area," *Viet J. Earth Sci.*, Vol 28 No. 4, pp 410-422.
2. Vu Ngoc Tran, Vo Cong Nghiep, 2005. "Necessity and possibility of applying artificial recharge of groundwater in sand dune coastal area of Binh Thuan province", Proc. UNESCO-Viet Nam Workshop on Augmenting groundwater resources by Artificial Recharge in South East Asia, Hochiminh city", December 15-17, 2004, pp 57-75.
3. Nguyen Thi Kim Thoa, G. Arduino, Nguyen Van Giang, Phan Thi Kim Van, Bui Tran Vnong, 2005 "Project for Management of aquifer recharge in Binh Thuan," Vietnam Proc, UNESCO-VIETNAM Workshop on Augmenting groundwater resources by Artificial Recharge in South East

Asia, Hochiminh city, December 1-17, 2004, 25-5.
4. Nguyen Thi Kim Thoa, G. Arduino, Nguyen Van Giang, Phan Thi Kim Van, Bui Tran Vuong, 2006. “The model for Management of Aquifer Recharge in sand dune area of Bac Binh, Binh Thuan. *Viet J. Earth Sci.*, Vol. 28, No. 4, pp 389-410.
5. Dillon P.J. (Editor), 2002. “Management of Aquifer Recharge for Sustainability”, A.A. Balkema Publishers, Australia, p 567.
6. Dllon P.J. (Editor), 2002. “Management of Aquifer Recharge”, Brochure of UNESCO-IHP, IAH-MAR.
7. Dillon. P.J., Miller. M., Fallowfield H. and Hutson J., 2002. “The potential of riverbank filtration for drinking water supplies in relation to microsystem removal in brackish aquifers”, *J. Hydrol*, Vol. 266, Issue 3-4, pp 209-221.
8. Dillon P., 2005, “Future Management of Aquifer Recharge” Proc. UNESCO-Viet Nam Workshop on Augmenting groundwater resources by Artificial Recharge in South East Asia, Hochiminh city, December 15-17, 2004, pp 9-25.
9. Bono P., R. Gonfiantini, M. Alessio, C. Fiori, L. D’Amelio, 2004. “Stable isotope ($d^{18}O$, d^2H) and Tritium in precipitation: Results and comparison with groundwater perched aquifers in Central Italy”, TEC-DOC (IAEA) 2004.
10. Bui Tran Vuong, 2006. “Groundwater regime monitoring at Le Hong Phong area, *Viet. J. Earth Sci.*, Vol. 28, No. 4, pp 446-458.
11. Jin Young Lee, Jung Woo Kim et al, 2003. “Combined performance of Pumping and Tracer tests: A case study”, *Geosci. J.*, Vol. 7, No.3, pp 237-241.
12. Gale I., Neumann I., Calow R., Moench M., 2002. “The effectiveness of Artificial Recharge of Groundwater: a review”, Phase 1 Final report R/02/108N. *British Geological Survey*, p 45.
13. Gale I., Macdonald D.M.J., Neumann I., Calow R., 2003. “Augmenting Groundwater Resources by Artificial Recharge”, AGRAR, Phase 2 Inception report, *British Geological Survey*, p 42.
14. Huisman L. and Olsthoorn T.N., 1983. “Artificial groundwater recharge”. Pitman Advances Pub. Program, Boston, p 309. ❒

Water for the People Network

Water for the People Network (WPN) is a campaign network that supports the various water-related struggles at the grassroots in order for them to achieve national and international projection. It also serves as an information and resource centre as well as a coordinating body for joint actions and campaigns on the national and international levels. WPN seeks to put forward a “People’s Water Code”, an alternative paradigm to private, foreign corporate-led development, management and operation of water resources and services. It upholds the human right to water and the people’s collective rights to manage their water.

The Water for the People Network seeks to:

- Strengthen networking among various civil society organizations, grassroots organizations, peasants and workers’ advocates and consumer groups working on water issues and develop a structure for networking and sharing;
- Clarify issues, share experiences, explore alternatives and draw up plans for a sustained campaign;
- Develop coordinated campaigning and solidarity in advocacy work in national and international issues and arenas;
- Develop resource-sharing and capacity-building to engage in research, education and advocacy; and
- Promote people’s sovereignty on water as the long-term solution to issues surrounding water.

WPN regularly holds conferences and capacity building workshops on water issues in the region. WPN conducts and supports researches. The network supports various water-related struggles and serves as a coordinating body for joint actions and campaigns. It explores venues to facilitate the exchange of information, share experiences and strengthen the unity among water and human rights stakeholders.

For more information, contact:

Water for the People Network - Asia
IBON Center, 114 Timog Avenue
Quezon City, The Philippines 1103
E-mail: webmaster@w4pn.org
Web: http://www.4pn.org