KARST WATER RESOURCES

extract from pages 481-483 of:
Gunn, J., (editor) *Encyclopedia of Caves and Karst Science*, Fitzroy Dearborn, NY.

Large numbers of people live in areas underlain by carbonate rocks and it has been estimated that up to a quarter of the global population is supplied largely or entirely by karst waters, including over 100 million people in China and a significant proportion of the population in many European countries. However, water supply in karst regions is often a limiting factor in human occupation and development, because it is so variable in both quality and accessibility in time and space. Paradoxically, karst water is often abundant deep underground, but successful exploitation requires equipment and capital. Utilizing karst water resources therefore requires an understanding of the location of the water and consideration of the technology available; location determines accessibility and hydrogeological factors determine the quality and quantity of water; technology determines whether the water is practically available and potable.

The primary control on water resources is climate, and as karst occurs in all climatic zones, this dictates the overall water resource conditions. The high permeability of karst rocks often results in little surface water, but enhanced groundwater recharge. Surface runoff is occasionally retained in "dew ponds" in locally impermeable depressions, but these have limited capacity and duration, and are prone to contamination by surface activities. In the shallow subsurface the epikarst aquifer may retain water for many months, sometimes sustaining small, temporary springs in the side of depressions. High permeability also results in a low-gradient water table, which translates into a thick unsaturated zone. Recharge water descends through the unsaturated zone to the water table, beneath which it is stored in the matrix and fractures, travelling along a limited number of conduits to emerge briefly at karst windows, or permanently at springs. Karst aquifers also receive recharge from allogenic sinking streams. In contrast to autogenic recharge, allogenic water tends to be variable in quality and quantity, in part because disappearing streams seem to lend themselves so naturally to waste disposal! A disconcerting paradox of karst water resources is that spring water is not necessarily pure, but may become contaminated with sediment, pathogens, and pollutants, especially during high flows. Some karst regions are traversed by surface rivers, often occupying deep gorges, making the water inaccessible.

Readily accessible water resources are therefore restricted in their distribution and reliability (see Table), but may be somewhat enhanced by development. Dew ponds can be artificially constructed, deepened or sealed, or runoff can be retained in cisterns. Excavations in the epikarst can tap the shallow aquifer. In all cases the objective is provision of sufficient storage to sustain supply through dry periods. In contrast, many settlements have developed around karst springs that can provide much more abundant and reliable water supply, sustained by the karst aquifer. However, springs vary a great deal in quantity and quality of water supply, reflecting the mode of recharge and the storage capacity of the associated aquifer. Allogenic recharge routed through a discrete conduit to an overflow spring can result in intermittent flooding by contaminated water, whereas a large, confined, autogenic aquifer may provide sustained excellent quality water supply. Sometimes, karst water reserves can be enhanced by damming springs and rivers. In successful cases, the resulting elevation of the water table significantly amplifies the storage capacity beyond that of the apparent surface reservoir. However, the permeability of karst rock means that any form of surface barrage tends to be bypassed quite quickly by leakage and only at great expense can effective grout barriers be installed in the subsurface (see Dams and Reservoirs on Karst).

Karst Water Resources: Karst water resource classification.				
Location	**Resource**	**Origin**	**Quality**	**Quantity**
Surface	dew ponds, cisterns	surface runoff	soft, vulnerable	limited transient
	epikarst springs	epikarstic aquifer	moderate, vulnerable	small, short-lived
	springs/karst windows	autogenic aquifer	hard, reliable	abundant, steady
		allogenic aquifer	variable, vulnerable	variable
	rivers	surface runoff	variable, vulnerable	variable
		aquifers		
Underground	adits	aquifer	good-poor	good
	dug wells	aquifer		variable
	drilled wells	aquifer		variable

Access to subsurface karst water has sometimes been possible through caves, and in some cases horizontal tunnels have been driven to tap the aquifer. The great thickness of the karst unsaturated zone makes for demanding construction of vertical dug wells, and the rubbly, eroded character of weathered carbonates can make modern rotary and air track drilling somewhat difficult due to loss of circulation pressure and collapse of the bore wall. Drilled wells revolutionize exploitation of karst water because they permit more arbitrary access to water, freeing settlements from limited surface occurrences. However, karst aquifers are heterogeneous, and this results in very diverse production from wells; those encountering exclusively matrix storage have very low yields, whereas those encountering conduits can have massive yields, sometimes sufficient for cities or industries with demands beyond the normal viability of groundwater exploitation. Most wells have intermediate performance in terms of yield, or can have their yield enhanced by "development" using intensive pumping or pressurized injection of hydrochloric acid or dry ice. A simple strategy, occasionally used in regions with explored caves, is to drill directly into a cave stream, although this demands quite precise mapping. Some success has been gained by drilling along surface fracture traces, or fracture intersections, because these zones are taken to indicate the likely presence of enhanced solutional development in the subsurface. There has been relatively little success with the use of subsurface geophysics to locate reliable karst water supply.

The theory of groundwater exploitation through wells is based on easily defined porous or equivalent porous media in which the hydraulic head in a well is reduced by pumping, inducing a radially symmetrical inward flow, and "drawdown" (lowering) of the water table in a characteristic cone of depression centred on the well. The depth and extent of the cone of depression depends on the size of the well, the pumping rate, and the hydraulic properties of the rock. The theory has been extended in recent years to define "capture zones" for wells: the area from which water is drawn to provide the flow from the well. Such definition is important, not just in defining the practical limits of well spacing, but in determining the possible risk or source of groundwater contamination.

Drawdown and capture zones in karst aquifers are much more difficult to determine because of heterogeneity. Most wells intersect only small conduits, a few centimetres or less in aperture, and have capture zones that may be elongated in the direction of the conduit. Occasionally a large conduit is intersected by a well; such a conduit acts essentially as an extension of the well. The drawdown is focussed not just on the well, but also on the conduit, drawing water from the adjacent fractures and matrix. The resulting cone of depression will be highly eccentric, being dependent as much on the conduit(s) as on the forcing well. Some karst aquifers show metres or even tens of metres of water table rise in response to a rain storm, and the resulting flow field in the aquifer and well is rather complex. Capture zones for karst wells are therefore not only highly eccentric, but will vary with time, frustrating application of standard management practices.

Karst Water Resources: Sulphur Spring, a major rising exploited for its water resources in the lowland karst of central Florida. (Photo by Tony Waltham)

Many aquifers are currently compromised or threatened by over-exploitation or contamination. Excessive withdrawal of water from karst aquifers was not possible with self-regulating springs, but pumped wells can more completely drain an aquifer and its springs. It is therefore common to monitor groundwater levels using passive observation or monitoring wells. The high-permeability connection of major conduits to springs results in lower heads in the conduits than in the surrounding fractured bedrock. The water table is thus not a simple planar surface, and requires a large number of well-water levels for adequate definition. Contamination of karst aquifers is often rapid in entry and transmission, and poorly attenuated compared to porous media. Contaminants may be difficult to detect and track in monitoring wells, so that *a priori* planning may be required in anticipation of possible problems.

A number of specialized techniques for monitoring karst groundwater have been developed. Foremost has been the use of tracers for defining groundwater trajectories, and defining catchment areas, prior to occurrence of contamination (see Water Tracing). Second has been use of springs to provide a monitoring point which integrates flow from a large area. These methods work well in karst where sinking streams and springs are accessible. However, many karst aquifers lack such convenient access points, or information may be required for areas removed from primary conduits. Monitoring wells provide the key here, and appropriate techniques have been slowly developed. Collecting data from both springs and wells gives a more complete understanding of a carbonate aquifer than either can alone; springs provide information on the conduit network, and wells (in a rather idiosyncratic manner) provide information on matrix and fracture hydrogeology. The behaviour of karst aquifers often varies dramatically with flow. It is therefore essential to implement continuous or high-frequency monitoring and sampling if such conditions are to be identified and characterized. Idiosyncratic short-term responses of wells to recharge events arise from the connectivity of the particular well to the various levels in the aquifer, and may misrepresent broader aquifer conditions.

Karst groundwaters are a major resource around the world, but in many cases the water is poorly managed due to the absence of regulation, or the application of inappropriate methods of waste management and water use. In general, it is best to take a precautionary approach and presume that carbonate aquifers are karstic, and assume that there may be rapid recharge and rapid flow through the aquifer via a conduit network. In the worst case such groundwater has similar properties to surface river water with its attendant problems of turbidity, pathogens, and chemical contaminants, and requires appropriate filtration and sterilization treatment.

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See also **Groundwater in Karst**

Further Reading

Domenico, P.A. & Schwartz, F.W. 1998. *Physical and Chemical Hydrogeology*, New York: Wiley

Drew, D.P & Hotzl, H. 1999. *Karst Hydrology and Human Activities: Impacts, Consequences and Implications*, Rotterdam: Balkema

Ford, B.C. & Williams, P.W. 1989. *Karst Geomorphology and Hydrology*, London and Boston: Unwin Hyman

Price, M. 1996. *Introducing Groundwater*, 2nd edition, London and New York: Chapman and Hall

Quinlan, J.F. & Ewers, R.O. 1989. Subsurface drainage in the Mammoth Cave area. In *Karst Hydrology: Concepts from the Mammoth Cave Area*, edited by W.B. White & E.L. White, New York: Van Nostrand Reinhold

White, W.B. 1988. *Geomorphology and Hydrology of Karst Terrains*, Oxford and New York: Oxford University Press

Worthington, S.R.H., Davies, G.J. & Ford, D.C. 2000. Matrix, fracture and channel components of storage and flow in a Paleozoic limestone aquifer. In *Groundwater Flow and Contaminant Transport in Carbonate Aquifers*, edited by C.M. Wicks & I.D. Sasowsky, Rotterdam: Balkema