Peak Water meets Peak Oil: Moving Towards Unitization of Transboundary Aquifers

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ABSTRACT

Economists and legal scholars in property rights suggest integrating the concept of "unitization", as employed in the development in oil and gas reservoirs, to the problem of excessive access and related drawdown to aquifers. Intensive exploitation of petroleum "reservoirs" has led to premature depletion and, in some cases, irreversible damage to the storage characteristics of oil and gas reservoirs. Unitization, as employed in the oil and gas industry, is defined by government-mandated single ownership and management of a reservoir or "field".

Unitization of groundwater is a pro-market approach that could be used to implementing the Law of Transboundary Aquifers. Unitizing some situations associated with transboundary aquifers could be used as one means to mitigate the inefficiency of a possession or use-based system of groundwater along with the inefficiencies associated with joint access to groundwater. Under a groundwater scenario, a single "unit operator" could extract from and develop the aquifer system with other parties tapping the aquifer system sharing in the net returns as shareholders.

Beyond the traditional focus of groundwater allocations from aquifers storing water, unitization can address many other situations and benefits associated with aquifers. The core principles, or "4P" framework, behind unitization of transboundary aquifers includes (1) Promote groundwater exploration and development in underutilized areas, for example, in "megawatersheds" that are being promoted as a new exploration paradigm, (2) Preserve the storativity of aquifers by promoting local control of groundwater development, (3) Private investment in the "post-modern hydrologic balance" including Aquifer Storage and Recovery (ASR), managed recharge (similar to secondary and tertiary recovery operations used in the oil and gas industry), nonrenewable groundwater which does not fit well within the paradigm of Integrated Water Resources Management, as well as other opportunities such as remediating contaminated groundwater, ecosystem services, and the spirituality of water, and (4) Prevent disputes instead of conflict resolution by "blurring the boundaries" thus creating a new community of users with a superordinate identity who agree to how to "share" of groundwater and the associated benefits.

Unitization may serve as one approach to eliminating the "race to the pump" ultimately directing extraction toward maximization of the economic value of the aquifer system, rather than trying to meet the unreachable star of maintaining the "sustainable" or "sovereign" water rights held by individual parties and jurisdictions within a megawatershed, transboundary aquifer, or in nonrenewable groundwater situations. A few case studies where unitization concepts are being applied to groundwater will be presented.

Key words: Institutional advances, unitization, dispute prevention, economics

1. INTRODUCTION

"Water is the oil of the 21st century".
Dow Chemical Chairman Andrew Liveris, World Economic Forum, February, 2008

The 2008 World Economic Forum in Davos, Switzerland brought to the fore the issue of water scarcity and its relationship to future economic wealth and political security. Contrary to the adage that oil and water don't mix, oil and water truly do mix when it comes to the global economy considering the "energy–groundwater nexus" or providing power to the groundwater–intensive agriculture industry (World Bank, 2010).

Building upon the doomsday proclamations about "peak oil" in the popular press and environmental texts, the concept of "peak water" is gaining momentum. The concept of peak oil was first introduced by geologist M. King Hubbert who predicted in 1956 and again in 1968 that oil production from the United States would peak in 1970. Although his predictions were dismissed at the time, US oil production in fact peaked in 1970. (Hubbert, 1969; Hall and Day, 2009). Heinberg (2007) examined other arrays of "peaks" by looking at the bigger picture of the production of global liquid hydrocarbons peaking in 2010, as well as the peaking use of freshwater resources, in his book "*Peak Everything*".

Falkenmark (2009) describes "peak water" as a "…new and apt name for the present and looming threat of amplified water scarcity of both blue and green water sources occurring around the world". Gleick and Palaniappan (2010) indicate that water has characteristics of both renewable and nonrenewable resources and provide a detailed assessment and definition of three concepts of "peak water": peak renewable water, peak nonrenewable water, and peak ecological water. Peak nonrenewable water is groundwater stored in aquifers. Consideration that groundwater is the world's most extracted raw material with withdrawal rates approaching 800 to 1,000 km^3 per year through millions of water wells gives some credence to the concerns over peak water (Shah, 2009). Reference to "nonrenewable groundwater" is controversial, but it usually refers to situations where present-day replenishment is limited but aquifer storage is large, many times "decoupled" from the hydrologic cycle (Foster and Loucks, 2006). The concept is not new; the seminal work of C.V. Theis (1940) determined that "All water discharged by wells is balanced by a loss of water somewhere…This loss is always to some extent and in many cases largely from storage in the aquifer…Some ground water is always mined".

But peak water is not limited to just mining nonrenewable groundwater. Narasimhan (2009) indicates that the definition includes aquifers where the storage characteristics have been permanently changed due to pumping. This phenomena is limited to confined aquifers "…when the geological material is subjected to unprecedented declines in water pressure (tens of meters of water level decline), it will behave in a 'non-elastic' fashion. Under such non-elastic deformation, a certain amount of porosity (groundwater storage) will be permanently lost (lost storage) when groundwater is extracted at rates causing large declines in water pressure". A national summary of neotectonic subsidence by Holzer (1991) found that neglecting reservoir compressibility in calculating hydrocarbon reserves in rock reservoirs lead to estimates that were potentially too large by a factor of two. Jarvis *et al.* (2002) observed a 50 percent reduction in productivity from a water well targeting a fractured-rock aquifer within just a few years after it was completed; this rock aquifer served as a nearby oil reservoir in Utah. Narasimhan (2007) reports permanent loss of about 80 percent of storage space due to non-elastic deformation in three of the large groundwater artesian basins in the US.

2. OBJECTIVES

When one considers any "peak" resource situation, economics comes into play (Hall and Day, 2009). For example, Vaux (2007) indicates "Where extractive behavior entails independent action on the part of competitors who seek to maximize their individual net benefits, the aquifer will be managed in a suboptimal and often nonsustainable fashion. In instances where groundwater is not recharged, any extraction is inherently nonsustainable. In these circumstances, the economic theory of the mine applies and the level of extraction should be that which maximizes net benefits over time. The economics of nonrenewable groundwater are identical to the economics of extraction of any nonrenewable resources such as coal, oil and diamonds".

These hydrologic, storage, and economic relationships between aquifers and oil reservoirs have direct bearing on the implementation of the Law of Transboundary Aquifers. Careful consideration of Article 2 detailing the use of terms indicates "utilization of transboundary aquifers or aquifer system includes extraction of water, heat and minerals, and storage and disposal of any substance". Clearly, the emphasis extends beyond the equitable and reasonable sharing of water to acknowledging that the available storage is also a shared resource as described by Puri and Struckmeir (2010). This is the foundation of the concept of "unitization" of oil fields that was developed to protect the "corresponding rights" or "sovereignty" of all pore space owners in the unit and to not waste valuable pore space. While some readers may consider the concept of unitization another name for common pool resource management, this paper will compare and contrast the two concepts as they relate to groundwater and aquifer resources. This discussion is followed by a framework arguing for the consideration of unitization in the portfolio of options for implementing the Law of Transboundary Aquifers.

3. THE COMMONS VERSUS UNITIZATION

3.1 Groundwater and the Commons

Groundwater is a resource that is found everywhere. The commons refers to resources, facilities, or property institutions with some aspect of joint ownership and access. Common pool resources are valued resources that are available to use by more than one person and subject to degradation due to overuse. Groundwater systems are an example of a "pure" common pool resource because of the costly exclusion and subtractability attributes.

An exhaustive analysis of common pool resource theory as applied to groundwater resources is beyond the scope of this paper. The topic has garnered international interest for decades. Groundwater was one of the common pool resources profiled by the seminal work of Ostrom (1990 among many others. On the basis of over two decades of research on the commons, Ostrom (1990) developed the following eight design principles for the management of common pool resources: (1) Clearly define boundaries for the user pool and the resource domain; (2) Appropriation rules should be developed for local conditions and provisional rules be developed for resource maintenance; (3) Collective choice arrangements should be developed by the resource users; (4) Monitoring programs should be developed for the resource; (5) Graduated sanctions should be developed for "violators" of the rules; (6) Conflict management schemes should be developed; (7) Rights of organized environmental regimes should be respected by external authorities; and (8) Nested enterprises are used to administer the management of the common pool resource. Blomquist (1992) provided a case study of implementing the design principles for the management of groundwater in southern California.

Shah (2009) promotes the importance of "aquifer communities" as a means to "taming the anarchy" of groundwater development by the over 20 million wells in India. India epitomizes a "peak water" situation as the largest groundwater user in the world. Groundwater resources are being depleted at an alarming rate with 29 percent of groundwater blocks are semi-critical, critical, or overexploited, and the situation is deteriorating rapidly. And by 2025 an estimated 60 percent of groundwater blocks will be in a critical condition (World Bank, 2010).

The World Bank (2010) completed The Andhra Pradesh Drought Adaptation Initiative (APDAI), a pilot project that implemented the design principles of common pool resource management in India. Before the APDAI project, only the richer farmers had access to groundwater because they could afford to dig deep wells. The poor farmers had to depend on the unreliable monsoon rains to irrigate their crops. But according to Narenda (2010), "…convincing the richer farmers to share the water from their wells was not easy. However they agreed to do so because many of them too had fields that were far from their wells. If a pipeline was laid, these fields would also gain access to water". The project's success can be summarized by some of the rules for community management of common pool resources.

3.2 Aquifers and Unitization

The subject of unitization is too broad to be covered in a single paper as multi-volume law treatises are dedicated to the subject. The reader is referred to Libecap and Wiggins (1985) and Libecap and Smith (2001) for excellent summaries of unitization theory as applied in the US oil industry. Unitization is defined the joint operation of an oil or gas reservoir by all the owners of rights in the separate tracts overlying the reservoir or reservoirs (Weaver and Asmus, 2005). "Pooling" is sometimes referred to as unitization. While oil exploration and production are usually regarded as private property, the production of oil and gas has always been treated as affecting the public interest because has beneficial use to both the private and public welfare and is an important revenue stream for the many states and countries (Knowlton, 1939).

Without unitized operation of the reservoir, the common law "race to the pumps" results in competitive drilling and production with consequent economic waste, physical damage to the pool and reservoir, with each owner drilling more and pumping faster than their neighbor. The concept was designed to permit reservoir engineers to plan operation of an oil "pool" in order to conserve petroleum resources. To dispel the myth that unitization is part of the theory on common pool resources, it is important to note the early history of unitization is centered almost entirely around a pioneer in the US oil industry, Henry L. Doherty, who apparently coined the term and promoted the concept in the early 1890s (Knowlton, 1939). While the institution of unitization started in the US, it is spreading to other parts of the world such as Australia, United Kingdom, and Brazil (Weaver and Asmus, 2005).

Units are generally are classified as to purpose and are acknowledged as the best method of producing oil and gas efficiently and fairly. On the basis of over 100 years of application, Knowlton (1939) and Weaver and Asmus (2005) conclude that the purposes and advantages of unitization include the following attributes: (1) Develops and operate as a unit; (2) Uses pressure maintenance on the reservoir; (3) Provides foundation to carry out a secondary-recovery program; (4) Avoids the economic waste of unnecessary well drilling and construction of related facilities that would otherwise occur under the competitive rule of capture; (5) Allows sharing of development infrastructure, thus lowering the costs of production through economies of scale and operating efficiencies; (6) Maximizes the ultimate recovery of petroleum from a field according to the best technical or engineering information, whether during primary production operations or enhanced recovery operations; (7) Gives all owners of rights in the common reservoir a fair share of the production; and (8) Minimizes surface use of the land and surface damages by avoiding unnecessary wells and infrastructure.

There are a broad spectrum of oil units recognized by legal scholars and depending where the units are used, but they are of four general types as summarized by Kumar (2007): (1) *Voluntary Units* – Agreements among interested parties which can be undertaken for exploration or conservation; (2) *Compulsory or Conservation Units* – A high level of knowledge of physical characteristics of the "pool" is required for conservation; (3) *Geographic Units* – Typically applied where poor well control precludes defining boundaries of productivity, or in areas of complex geology; and (4) *Geologic Units* – Typically applied based on geology, productive area, lease position, precedent in a field, producing horizon or trend, or economics.

In the case of groundwater, Libecap (2005) suggests that "…government-mandated unitization of groundwater…is a solution to excessive access and drawdown…[where] a single "unit operator" extracts from and develops the reservoir. All other parties share in the net returns as share holders".

Knowlton (1939) recognized three principal fronts upon which the problem of unitization could be attacked in the early stages of oil unitization in the US. By comparison to groundwater, the least difficult units to form will be the ones addressing the problem of underutilization of groundwater as described by Giordano (2009) or deeper, undeveloped aquifer systems such as the "megawatersheds" described by Bisson and Lehr (2004). In these cases it should not be difficult to develop the means of establishing and dividing equities and benefits.

Conversely, the difficult task is met when an attempt is made to unitize an area undergoing intensive exploitation. At this stage there is only a limited amount of information available to all parties due to information asymmetry; however, Knowlton (1939) long ago recognized that agreements can be reached "…by the broadmindedness and generous approach to the problem by those who are conscious that the benefits received from unit operations will far offset any loss which might be suffered by their failure to receive their accurate equitable share".

No case studies exist regarding unitization of aquifer systems, but the principles of unitization are being applied in a few settings. In 2010, farmers and ranchers in the Escalante Valley of southern Utah located in the southwestern US were facing water level declines over 30 meters that occurred in the past 50 years. Lost aquifer storage was revealed through neotectonic subsidence – earth fissures tens of meters in length and up to two meters in depth. While the State of Utah introduced a plan to reduce groundwater use by 90 percent, the water users found the plan unacceptable and "pooled" their water rights to share in reductions in water use by voluntarily forming a unit – the Escalante Valley Water Users Association. The State of Utah passed legislation transferring the management of groundwater to the district that covers two counties (Hansen, 2010).

Shimada (*forthcoming*) provides an interesting case study balancing the spiritual value of water with private property rights using the concepts of unitization in Kumamoto, Japan. The city water is 100% supported by groundwater. Under Japanese law, groundwater resources belong to the landowners. Drilling data in the Kumamoto area permitted mapping with a high degree of certainty a region lacking a confining layer separating the unconfined and confined aquifers. The absence of a confining layer in this area permitted rainwater and irrigation water to recharge directly into the principal aquifer system. The groundwater recharged in this area flowed to springs filling Lake Ezu in Suizenji Park a spiritual shrine; the spring flows have diminished 20 percent in the past decade. The recharge area is overlain by rice paddy fields that lie outside the jurisdictional boundaries of Kumamoto. Kumamoto pays the local farmers who voluntarily fill their abandoned paddies within the identified "unit" to recharge of the aquifer.

4. DISCUSSION AND CONCLUSIONS

While the design principles for common pool resource management work well for the modern geohydrologic balance, unitization provides a more holistic approach to the post-modern geohydrologic balance because the post-modern view of groundwater resources acknowledges not only the pumped groundwater, but also storage of the aquifer system as outlined by Ragone (2007). Examples of "privatizing" groundwater include the unintentional poisoning of groundwater by agricultural and industrial wastes that are manifold in nearly every country; unitization of contaminated groundwater may provide new opportunities to remediate and market the previously unusable water and storage. Likewise, unitization may promote increased private investment in manufactured water (e.g., Aquifer Storage and Recovery) much like the enhanced recovery methods used in the oil industry. Indeed, the concept can be extended to the new strategies to combat climate change by storing carbon in aquifers. For example, the State of Wyoming passed HB 80, which became law on July 1, 2009, and provides for carbon sequestration units.

Social psychologist Mark van Vugt (2009) identified four conditions for the successful management of shared resources: information, identity, institutions, and incentives. Clearly, transboundary aquifer situations can create competition and conflict between communities and institutions that do not promote the welfare of groundwater resources. Van Vugt (2009) suggests that it is important to think of ways to "blur" the boundaries by promoting that "we are all in this together" to prevent disputes and promote efficient management of shared resources. Knowlton (1939) promoted this philosophy when recommending that unitization agreements be entered into "…with an open mind. Although we may feel, when the deal is consummated, that we have not received the share in the unit which the value of our properties warranted, we also know that because we have been willing to cooperate we are now the owner of an interest in a unit which will pay far more ultimate profit than our individual holdings would have netted".

The core principles, or "4P" framework, behind unitization of transboundary aquifers includes (1) Promote groundwater exploration and development in underutilized areas, (2) Preserve the storativity of aquifers, (3) Private investment in the "post-modern hydrologic balance", and (4) Prevent disputes by "blurring the boundaries" thus creating a new community of shareholders. Unitization can serve as one tool in implementing of the Law of Transboundary Aquifers by not only acknowledging equitable and reasonable use of groundwater, but also recognizing the sovereignty of the each aquifer State by valuing the pore space.

"We have conquered Mother Nature; now we have only to conquer human nature".
D.R. Knowlton, Phillips Petroleum Co., Address to the American Petroleum Institute, 1939

REFERENCES

Bisson, R.A. and Lehr, J.H. (2004): *Modern Groundwater Exploration: Discovering New Water Resources in Consolidated Rocks Using Innovative Hydrogeologic Concepts, Exploration, Aquifer Testing, and Management Methods*: Wiley Interscience, Hoboken, NJ

Blomquist, W.A. (1992): *Dividing the Waters: Governing Groundwater in Southern California*. ICS Press. San Francisco, CA.

Buck, S.J. (1998): *The Global Commons: An Introduction*. Island Press, Washington, DC.

Falkenmark, M. (2009): Peak Water – Entering an Era of Sharpening Water Shortages. *Stockholm Water Front*. December: 10-11. http://www.siwi.org/documents/Resources/Water_Front_Articles/2008/Peak_Water.pdf

Foster, S. and Loucks, D.P. (Eds.) (2006): *Non-Renewable Groundwater Resources: A Guidebook on Socially-sustainable Management for Water-policy Makers*: IHP-VI, Series on Groundwater No. 10. United Nations Educational, Scientific and Cultural Organization, Paris.

Giordano, M. (2009): Global Groundwater? Issues and Solutions. *Anns. Rev. Environ. Resourc.*, 34: 7.1-7.26.

Gleick, P.H. and Palaniappan, M. (2010): Peak water: Conceptual and practical limits to freshwater withdrawal and use. *Proceedings of the National Academy of Sciences (PNAS)*. http://www.pacinst.org/press_center/press_releases/peak_water_pnas.pdf

Hall, C.A.S. and Day, J.W., Jr. (2009): Revisiting the Limits to Growth After Peak Oil. *American Scientist*, (97)3 http://www.pelicanweb.org/solisustv05n06page2halldayamsci.html

Hansen, J. (2010): It takes a district: Utah landowners control groundwater use Escalante Valley citizens plan to save their declining aquifer. *High Country News*. http://www.hcn.org/issues/42.8/it-takes-a-district

Heinberg, R. (2007): *Peak Everything*. New Society Publishers, Gabriola Island, BC.

Holzer, T.L. (1991): Neotectonic Subsidence. In: Kiersch, G.A (Ed.), *The Heritage of Engineering Geology: The First Hundred Years, Centennial Special Volume 3*. Geological Society of America, Boulder, CO.

Hubbert, M.K. (1969): *Energy resources*. In the National Academy of Sciences–National Research Council, Committee on Resources and Man: A Study and Recommendations. W. H. Freeman, San Francisco, CA.

Jarvis, W.T., Yonkee, A. and Matyjasik, M. (2002): Sustainability of Fractured Bedrock Aquifers, Implications for Growth Management Policy, Summit County, Utah: Proceedings of 2002 Annual Meeting, American Institute of Hydrology.

Knowlton, D.R. (1939): *Unitization-Its Progress and Future, Drilling and Production Practice*, American Petroleum Institute Report 39: 630-635.

Libecap, G.D. and Wiggins, S.N. (1985): The Influence of Private Contractual Failure on Regulation: The Case of Oil Field Unitization. *Journal of Political Economy*, 93: 690-714.

Libecap, G.D. and Smith, J.L. (2001): Regulatory Remedies to the Common Pool: The Limits to Oil Field Unitization. *The Energy Journal,* 22: 1-26.

Libecap, G.D. (2005): *The Problem of Water*. Essay prepared for National Bureau of Economic Research. http://www.aeaweb.org/annual_mtg_papers/2006/0108_1300_0702.pdf

Narasimhan, T.N. (2009): Groundwater: from mystery to management. *Environ. Res. Lett.* 4 (July-September 2009) 035002 doi:10.1088/1748-9326/4/3/035002.

Narenda, C. (2010): India: An Innovative Way of Sharing Diminishing Groundwater. http://www.mynews.in/News/india_an_innovative_way_of_sharing_diminishing_groundwater_N41355.html

Ostrom, E., 1990. *Governing the Commons: The evolution of institutions for collective action*. Cambridge University Press. Cambridge.

Puri, S. and Struckmeier, W. (2010): Aquifer Resources in a Transboundary Context: A Hidden Resource? – Enabling the Practitioner to 'See It and Bank It' for Good Use. In: Earle, A., Jägerskog, A. and Öjendal, J. (Eds.), *Transboundary Water Management: Principles and Practice*, Earthscan, London, 73-90.

Ragone, S.E. (2007): The Post-Modern Water Balance and its Role in Groundwater Management. In: Ragone, S., de la Here, A., Hernandez-Mora, N., Bergkamp, G. and McKay, J. (Eds.) *The Global Importance of Groundwater in the 21st Century.* NGWA Press, Westerville, 119-127.

Shah, T. (2009): *Taming the Anarchy: Groundwater Governance in South Asia*. Resources for the Future Press. Washington, DC.

Shimada, J. (*forthcoming*): The Trans-boundary management of groundwater resources in the Kumamoto area, Japan – Sustainable management of groundwater resources for over 700,000 residents. In: Research Institute for Humanity and Nature (RIHN) (Ed.), *Dilemma of Boundaries - Toward a New Concept of Catchment Area*, Springer, Springer Japan KK, Tokyo.

Theis, C.V. (1940): The source of water derived from wells-essential factors controlling the response of an aquifer to development. *Civil Engineering*, 10(5):277-280.

van Vugt, M. (2009): Triumph of the commons: Helping the world to share. *New Scientist*, 2722: 40-43.

Vaux, H., Jr. (2007): The economics of groundwater resources and the American experience. In: Ragone, S., de la Here, A., Hernandez-Mora, N., Bergkamp, G. and McKay, J. (Eds.) *The Global Importance of Groundwater in the 21st Century*. NGWA Press, Westerville, OH., 167-176.

Weaver, J.L. and Asmus, D.F. (2005): Unitizing oil and gas fields around the world: a comparative analysis of national, laws and private contracts. *Houston Journal of International Law*. http://findarticles.com/p/articles/mi_hb3094/is_1_28/ai_n29238427/

World Bank (2010): *Deep Wells and Prudence: Towards Pragmatic Action for Addressing Groundwater Overexploitation in India*. The International Bank for Reconstruction and Development/The World Bank, Washington, DC.