Topic: Hydrology and Meteorology

Title: Groundwater Management utilizing a Safe Yield Range tool

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Abstract

Groundwater management in many countries has progressed over the latter half of the last century from virtually nil to a highly regulatory regime today. (Custodio, 2002) In this paper groundwater management refers to the planning, implementation and operation necessary to provide safe and reliable groundwater supplies as well as the sustainable development of this resource.

Utilizing the theory from both the safe yield and the sustainable yield approach, the safe yield range approach was developed. A safe yield range gives a guideline range where abstraction should be maintained to preserve the integrity of the aquifer system. It is the range between which water can be withdrawn from an aquifer system without hazardous depletion of the stored reserve and or deterioration of the water quality or causing unacceptable environmental, economic or social consequences. The lower boundary of the range is the point at which abstraction is preferred while the upper boundary of the range gives the point that abstraction should not exceed.

This approach was applied to three wellfields across Trinidad; Tucker Valley, Las Lomas and Penal. The Tucker Valley wellfield is positioned in an unconfined gravel sub aquifer system in the northwestern peninsula of the island. The Las Lomas wellfield taps into a confined sand system in the center of the island. The Penal wellfield is situated in a fully confined, fine-grained sand aquifer that is heavily faulted area. Engaging this safe yield range tool is beneficial in maintaining the quality and quantity of groundwater reserve while sanctioning groundwater abstraction to augment water supply.

Introduction

In recent decades it has become evident in many countries of the world that groundwater is one of the most important natural resources. As a source of water supply groundwater has a number of essential advantages when compared with surface water: as a rule it is of higher quality, better protected from anthropogenic pollution, less subject to seasonal and perennial fluctuations, and much more uniformly spread over large regions than surface water. (UNESCO, 2004)

Groundwater management is the effective planning, strategic implementation and operation necessary to provide safe and reliable groundwater supplies in a sustainable manner. In an effort to manage this natural resource several tools are usually employed including the development of quantified levels that abstraction should not surpass.

In Trinidad and Tobago, Groundwater Management has been studied previously in some detail going back to De Verteuil (1968), Dillon (1970), the Metcalf & Eddy (1970), the Water Resources Management Strategy for Trinidad and Tobago (1999), the Groundwater Master Plan (2000), the Earthwater Technology Incorporated Report (2002) (Water Resources Agency, 2007) and the revised Groundwater Master Plan (2013). Groundwater Management continues to be an area of study and development as groundwater is explored and abstracted in greater quantities.

When examining the groundwater resources it is recognized that some parameters are usually constant while others vary. Generally the size of an aquifer system and aquifer parameters including storage coefficient and transmissivity are relatively constant. Storage Coefficient is the ability of the aquifer to store water within the soil/rock pores. The storativity is defined as the volume of water released from storage per unit area of the aquifer per unit decline in hydraulic head. (Lohman, 1972) Transmissivity is the property of aquifer to transmit water.It is defined as the rate at which water is transmitted through unit width and full saturated thickness of the aquifer under a unit hydraulic gradient. (Lohman, 1972) Additional factors including rainfall and other hydrological parameters that affect recharge rates fluctuate year to year while land use is modified over time. Determining the recharge therefore allows for a guiding bases for groundwater management. Furthermore evaluating water level changes in the aquifer systems and its response to changes in the hydrological parameters and to abstraction is pivotal to progressive groundwater management.

Determining an efficiency rate of abstraction is necessary to augment water supply without endangering the aquifer system. There are many concepts adhered to while employing several methodologies and techniques. There are several definitions for these concepts including:

- Safe yield can also be defined as the amount of water that can be withdrawn annually from the aquifer without producing an undesired result (Dingman, 1994)
- "Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity" (American Society of Civil Engineers, 1998)
- “Development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences” (Alley, 1999)
- “The groundwater extraction regime, measured over a specified planning timeframe, that allows acceptable levels of stress and protects dependent economic, social, and environmental values” (Australian Department of Sustainability, 2004)
- “Withdrawals from the underground waters of the basin shall be boundaryed to the maximum draft of all withdrawals from a groundwater basin, aquifer, or aquifer system that can be sustained without rendering supplies unreliable, causing long-term progressive lowering of groundwater levels, water quality degradation, permanent loss of storage capacity, or substantial impact on low flows of perennial streams” (Delaware River Basin Commission, 1999)

Applying the theory from both the safe yield and the sustainable yield concept, a safe yield range concept was established. This concept gives a guideline range where abstraction should be maintained to preserve the integrity of the aquifer system. It is the range at which water can be withdrawn from an aquifer system without hazardous depletion of the stored reserve and or deterioration of the water quality or causing unacceptable environmental, economic or social consequences. The lower boundary of the range is the point at which the water levels and water quality in a wellfield should be more stringently monitored. The upper boundary of the range gives the point that abstraction should not exceed.

Background

Trinidad and Tobago is an expanding industrial, oil and gas Caribbean country with an agricultural sector, a flourishing manufacturing sector, a tourism industry and an increasing population. Currently in Trinidad and Tobago, 60% of the national water supply is derived from surface water, 27% is abstracted from groundwater sources and 13% is drawn from the sea. Furthermore, an additional 10 imgd from the proposed water recycling plant is expected to be added to the system to supply the Point Lisas industrial estate. The thrust to meet the future needs of the population on a 24/7 basis by 2014 will place a substantial demand on the water resources of the country, and by extension the groundwater resources. Consequently, the challenges of increased abstraction from our aquifers will have to be managed by employing a proficient and effective strategy. (Santana and Noel, 2014)

Description of Study area

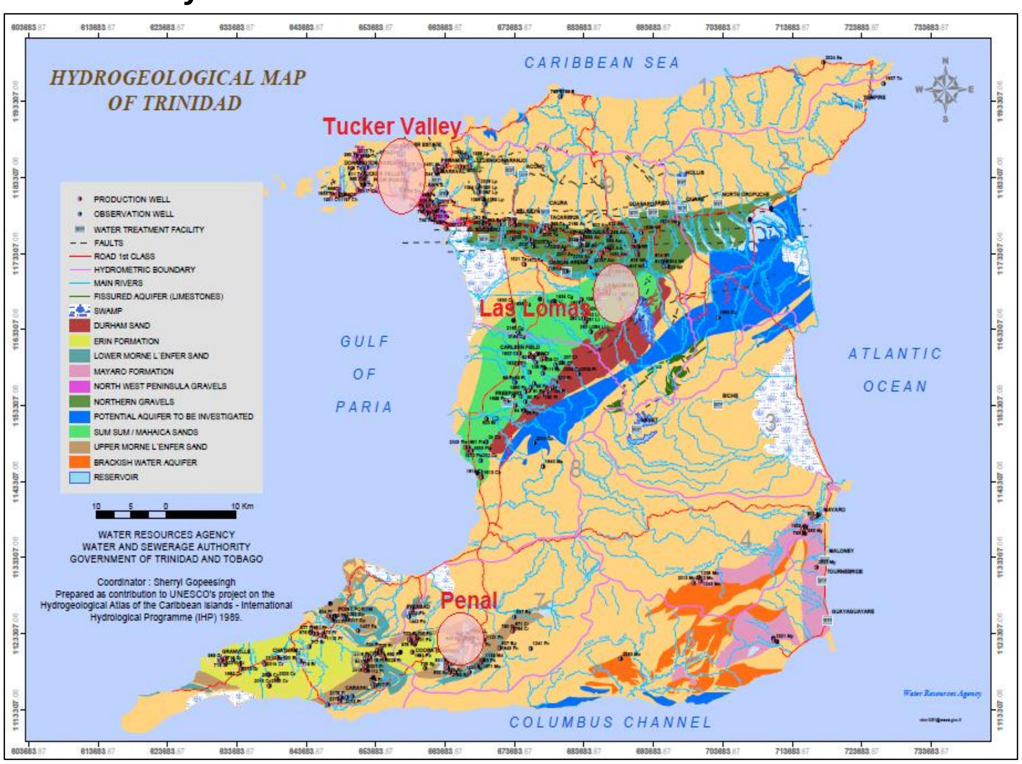


Figure #1 – Map of Trinidad illustrating the location of Tucker Valley, Las Lomas and Penal

In Trinidad, the majority of the groundwater abstracted is from sand and gravel aquifers, a minor amount from limestone aquifers and in more recent times from bedrock wells. The following map illustrates the geographic location of three areas selected for this paper including Tucker Valley, Las Lomas and Penal.

Tucker Valley

The Tucker Valley aquifer system forms part of the Chaguaramas watershed and taps into the greater Northwest Peninsula Gravels. These gravels are comprised of piedmont and alluvial deposits. The aquifer system is semi-confined. The gravels of this region are medium sized, sub-rounded, loose and unconsolidated with sands and sub-ordinate clays. These clay beds divide the gravels but are rarely more than 6.6 to 9.8ft thick. The Tucker Valley aquifer system receives direct recharge. The valley is bounded on either side by hills, which extend from 505ft to the highest point of 1700ft in the northeastern end. The valley is bisected by the northeast southwest trending, El Pilar Fault. Approximately half of the area falls within slope categories of 20-30% with low levels of erosion. (Water Resources Agency, 2006)

Las Lomas

The Las Lomas wellfield is located in the Mahaica Sands, south of the Northern Gravels and forms part of the Central Sands. It is positioned southeast of Cunupia, north of Caparo, south of Carapo and southwest of Wallerfield. The Las Lomas wellfield is sited in a confined aquifer system and recharge occurs via direct infiltration from rainfall into the soil in the outcrop area and streambed infiltration. The Las Lomas wellfield experiences relatively high rainfall as it lies to the southern part of the northeastern region of Trinidad (Water Resources Agency, 2015).

Penal

The Penal wellfield taps the Upper Morne L'Enfer Sands, North of Los Bajos Fault, Basin D, and east of minor fault. The Upper Morne L'Enfer member consists of massive sands which are ferruginous. They also include grey silty to very silty clays with sand and silt laminae. Lignitic clays, lignites and porcellanites occur but are less common, the member ranges in thickness from approximately 500 to 750 ft. Recharge is mainly by direct infiltration of rainfall into the pervious soils at outcrop areas. (Water Resources Agency, 2006)

Methodology

There are several methods for estimating recharge and they can be placed into five main categories

1. Water Table Fluctuation (Groundwater Method)
2. Water Table Fluctuation and Abstractions (Groundwater Method)
3. Rainfall Infiltration (Water Budget Method)
4. Recession Curve Displacement (Streamflow Method)
5. Infiltration factors (Groundwater Method)
6. Empirical relationship (Groundwater Method)

The safe yield range allows for the development of two boundaries to form a range. Using several methods depending on the aquifer type, aquifer parameters and historic data availability is permissible. The highest value derived forms the upper boundary while the lowest value derived forms the lower boundary. Every three years the boundaries must be reassessed making the boundaries flexible with changes in rainfall, land use, abstraction rates and the introduction of technological advancement.

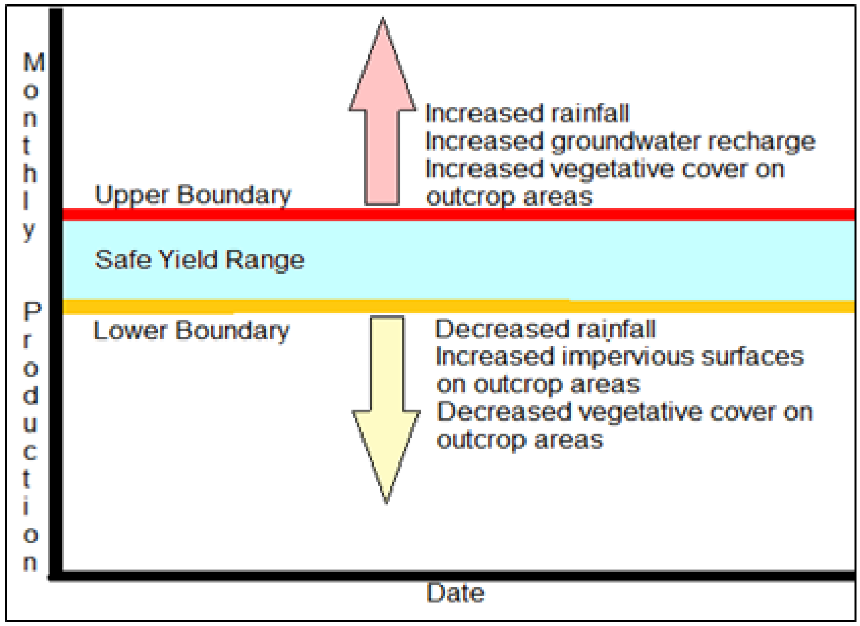


Figure #2 – Illustration of the Safe yield Range approach

In this paper a Rainfall Infiltration and Water Table Fluctuation and Abstractions methodology was applied to Tucker Valley, Las Lomas and Penal.

Results

The following table illustrates the results after applying the two methods.

Table #1- Results of the Rainfall Infiltration (Water Budget Method) and the Water Table Fluctuation and Abstraction Method

Wellfield	Rainfall Infiltration (Water Budget Method) (imgd)	Water Table Fluctuation and Abstraction Method (imgd)
Tucker Valley	4.55	4.40
Las Lomas	1.76	1.59
Penal	0.64	0.71

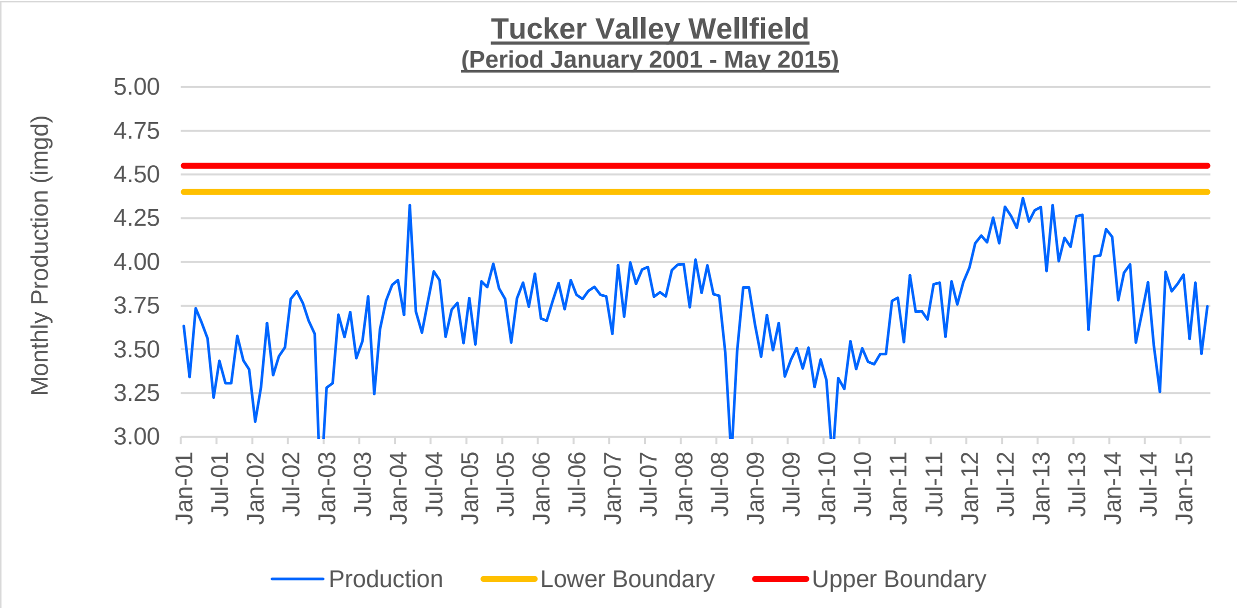
The following table illustrates the upper and lower boundaries derived from using the Rainfall Infiltration and Water Table Fluctuation and Abstractions methodology

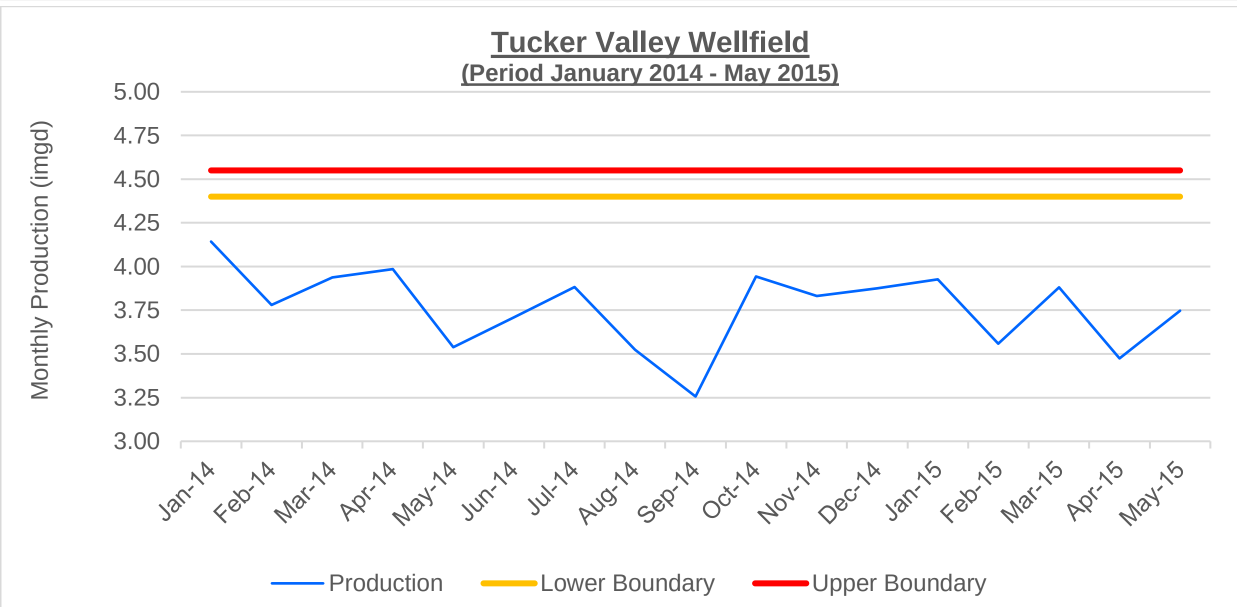
Table #2- Safe Yield Range for Tucker Valley, Las Lomas and Penal

Wellfield	Safe Yield Range (imgd)	
	Lower Boundary	Upper Boundary
Tucker Valley	4.40	4.55
Las Lomas	1.59	1.76
Penal	0.64	0.71

Discussion and Recommendations

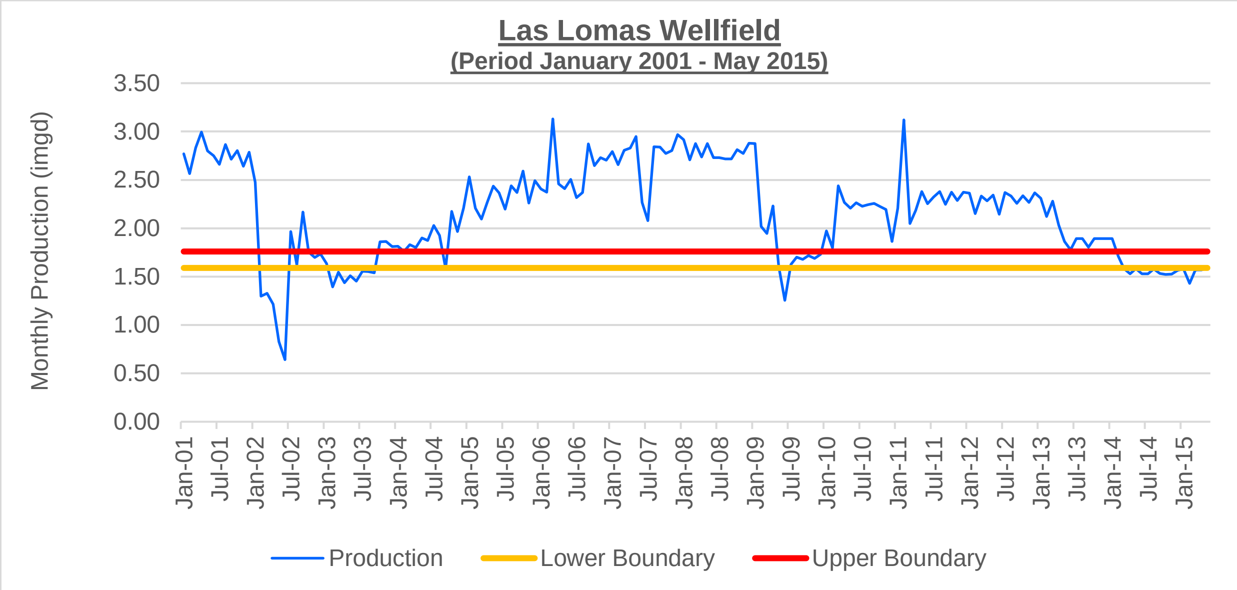
Figure #3- Safe Yield Range and Production for Tucker Valley

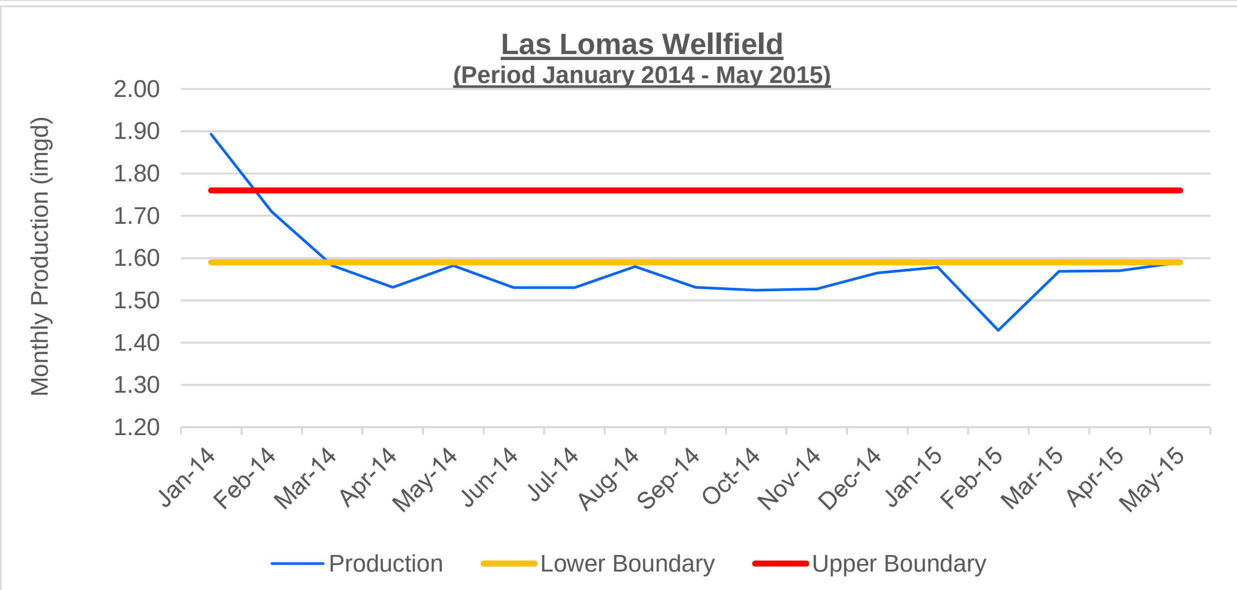




Abstraction from the Tucker Valley wellfield between January 2001 and May 2014 was averagely 3.73 imgd which beneath the lower boundary of 4.40 imgd. The upper boundary is set at 4.55 imgd. Tucker Valley's production over the period January 2014 to April 2015 averaged 3.77 imgd. Centered upon the safe yield range concept there is additional potential for further abstraction of about 0.63 imgd and with comprehensive monitoring as much as 0.78 imgd. It is forecasted that this additional abstraction will not endanger the aquifer system in any way.

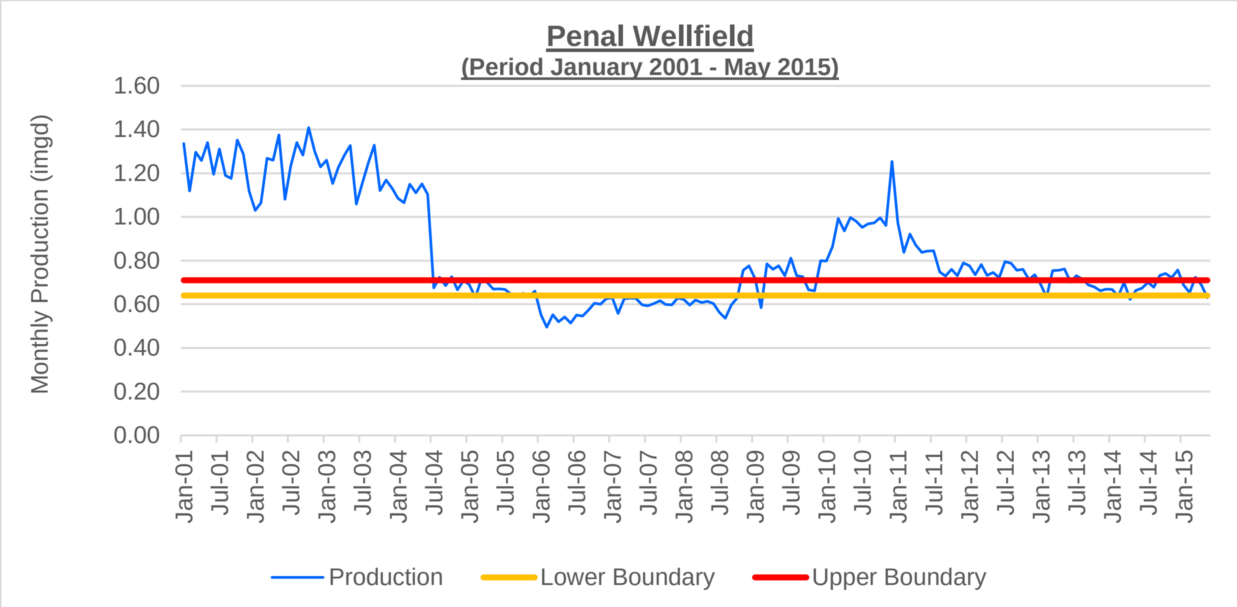
Figure #4- Safe Yield Range and Production for Las Lomas

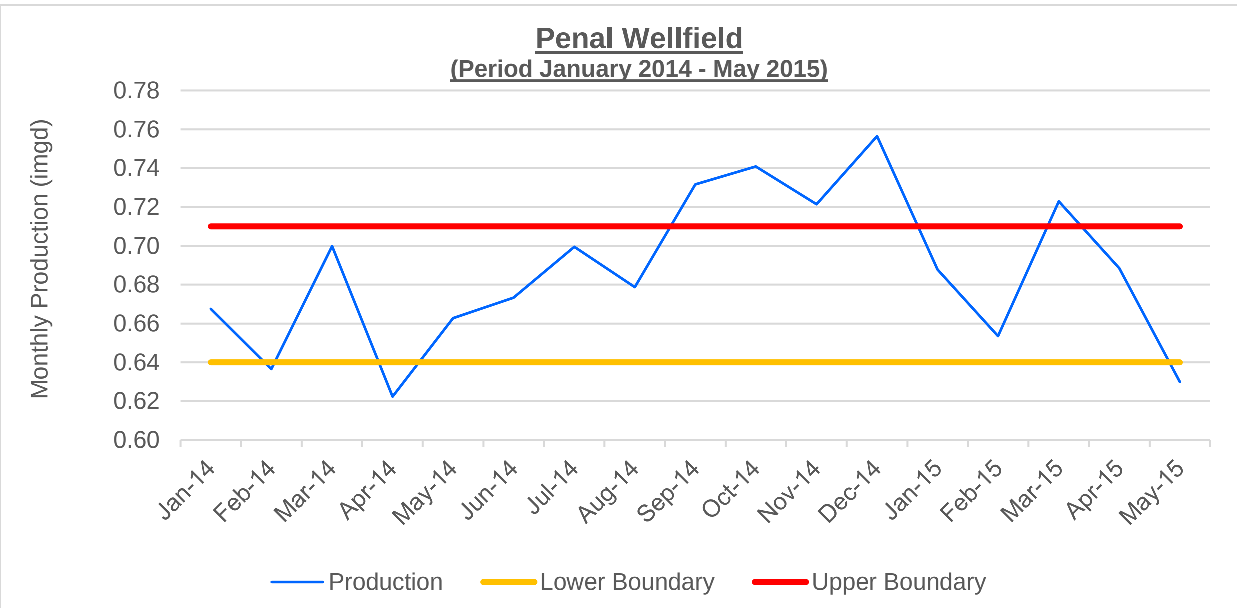




Abstraction from the Las Lomas wellfield between January 2001 and May 2014 was averagely 2.16 imgd. During this period the upper boundary of 1.76 imgd was generally exceeded more than 80% of the times. The lower boundary is set at 1.59 imgd. Las Lomas' production over the period January 2014 to April 2015 averaged 1.58 imgd. Based on the concept outlined in this paper, currently, the wellfield is almost within the range. This wellfield was identified as a critical wellfield in 2010 by the Water Resources Agency. Production rates should remain within this range at all times. It is recommended that no additional production wells be drilled in this system. However utilize the existing wells to obtain small quantities of water not passing 0.18 imgd collectively. It is forecasted that once abstraction stays within the range, it will not endanger the aquifer system in any way. Additionally once abstraction passes 1.59 imgd, water level trends should be monitored stringently.

Figure #5- Safe Yield Range and Production for Penal





Abstraction from the Penal wellfield between January 2001 and May 2014 was averagely 0.83 imgd just above the upper boundary of 0.71 imgd. The lower boundary is set at 0.64 imgd. Penal's production over the period January 2014 to April 2015 averaged 0.69 imgd. Constructed on the safe yield range concept the wellfield is within the range. It indicates that the ability to maneuver the abstraction rate is constricted. Production rates should remain within this range at all times. It is recommended that no additional production wells be drilled in this system. However utilize the existing wells to obtain no more than 0.02 imgd collectively. It is forecasted that this once abstraction stays within the range, it will not endanger the aquifer system in any way. Additionally water level trends should be monitored stringently.

It is recognized that during periods of emergency, increase abstraction may be permitted on the optimal yield basis, provided that an impact assessment identifies that an acceptable level of risk is involved and that system recovery is reasonably guaranteed through the adoption of appropriate mitigation measures. (Water Resources Managemnt Unit, 2005). Utilizing the upper boundary of the safe yield range is a good indicator of the optimal yield that has an acceptable level of risk and it gives a favourable level of assurance and feasibility.

This concept leaves room for year to year changes in rainfall, surface runoff and other hydrological parameters which causes recharge to differ annually. It also accommodates for some level of land use changes and environmental alterations. However it is recommended that ranges be reviewed every three years. Consequently water level trends should be monitored monthly in every wellfield, while areas producing within their respective ranges should be monitored every two weeks.

The safe yield range also takes into account the Precautionary Principle from the National Integrated Water Resources Management Policy of Trinidad and Tobago which states “If there are threats of serious irreversible damage to human health, ecosystems, aquifers surface and coastal waters, watersheds or water supply systems, lack of full scientific certainty will not be used as a reason for postponing preventative or mitigating measures” (Water Resources Managemnt Unit, 2005). This is imperative because as technological advancement occur and more research go into groundwater development, aquifer dynamic and further geological and hydrogeological assessments, the greater the level of guarantee while the level of risk to the aquifer decreases.

Conclusion

Striking a balance between groundwater development in aquifers with additional potential and reducing abstraction rates in over-pumped aquifers is feasible in Trinidad and Tobago even if there are associated risks and capital investments that are required to supplement the groundwater abstraction to satisfy the water demand. Engaging the safe yield range will optimize production in aquifers with additional potential while protecting those that are over-pumped.

A safe yield range which gives regulatory boundaries where abstraction should be maintained to preserve the reliability of the aquifer system is innovative yet has a built-in cautionary mechanism. Employing more than one technique to obtain recharge also reassure the protection of the aquifer system. The safe yield range fits into groundwater management meticulously as it ensures adequate planning, it corroborate implementation and operation while maintaining safe and reliable groundwater supplies.

References

American Society of Civil Engineers. (1998). *Sustainability criteria for water resource systems.* Unesco/IHP-IV.

Alley, W. T. (1999). *Sustainability of ground-water resources.* USGS.

Australian Department of Sustainability, E. W. (2004). *Definition and approach to sustainable groundwater yield, Annex A.* Sydney: The Government of Australia.

Custodio, E. (2002). Aquifer overexploitation: what does it mean? *Hydrogeology Journal, Vol. 10, No. 2* .

Delaware River Basin Commission. (1999). *Delaware River Basin Commission ground water protected area regulations southeastern Pennsylvania.* DRBC.

Dingman, S. L. (1994). *Physical Hydrology.* Waveland Pr Inc; 2 edition (January 31, 2008).

Hiscock, K. R. (2002). Sustainable groundwater development. *London Geological Society, Special Publication No. 193*.

Lohman, S. W. (1972). *Ground-Water Hydraulics.* U.S. Geological Survey, Groundwater Research. U.S. Geological Survey.

Santana and Noel, C. S. (2014). Groundwater Resources Planning in Trinidad and Tobago utilizing the Groundwater Master Plan 2013. Caribbean Water and Wastewater Association.

UNESCO. (2004). *Groundwater Resources of the world and their uses.* United Nations.

Water Resources Agency. (2006). Grounwater Assessment and Recommendations on Additional Production within the Diego Martin and Tucker Valley area. Water Resources Agency.

Water Resources Agency. (2006). Penal Wellfield Assessment.

Water Resources Agency. (2007). *State of the Water Resources (Unpublished Report).*

Water Resources Agency. (2015). A review of the Las Lomas Wellfield.

Water Resources Managemnt Unit. (2005). *National Integrated Water Resources Management Poicy.* Port of Spain: Ministry of Public Utilities and the Environment.