Design of Sustainable Use and Management of Groundwater in Morobe Province

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Abstract: In the near future, Morobe Province of Papua New Guinea may experience a scarcity of water which is needed to meet the population and industrial needs in Lae City, the country's industrial hub and the gateway to the Highlands Provinces. This paper offers a wide review concerning studies related to groundwater resources in Morobe Province through the identification of the aquifer, wells, pumping stations and the chemical composition of the underground water. The aim of the study is to prevent the continuous depletion of groundwater resources and to sustain the aquifer usefulness in the development process in a manner that is adaptable to the prevailing economic, social, climatic, as well as hydrological conditions. This is necessary as rainfall patterns in Papua New Guinea are changing due to climatic changes and this affects the groundwater reservoir. The result shows that there is a need to keep the underground water sustainable because of the low water table that is already present in some areas of the province. The only surcharge is the rainfall that occurs in the province. Since this may be altered due to climatic changes, design and planning for sustainable use and management of groundwater such as artificial surcharge is important to prevent the depletion.

Keywords: Sustainability, Depletion, Groundwater, Aquifer, Groundwater Resources, Water Wells.

Introduction

Water is essential to human life support. It is needed in all aspects of man's life, for food, health, and economic development. It is a renewable resource, however the abundance has clouded the reality that renewable fresh water is an increasingly scarce commodity because it is depleted faster when the increase of users that draws water progresses heavily. Kumar (2003) stressed that there is essentially no more fresh water on the planet today as compared to the past 2000 years where it was less inhabited and exploited. Moreover, Brabeck-Lethmathe (2013) predicted that there will be scarcity of water for the world beyond twenty years by 50% and by 2030 water withdrawals will exceed natural renewals by 60%. Water overuse and scarcity are becoming critical issues in the new millennium at both global and regional levels. Increasing population and economic growth affect water needs for all kinds of activities and could result in a global shortfall of up to 30% in cereal production by 2025, giving us a great challenge as to how we will be able to feed the world's population in the near future. Although the groundwater is a resource that can be replaced, it is not uniform throughout the globe, making it abundant to others and scarce to some.

Groundwater is the portion of the Earth's water cycle that flows underground in soil pore spaces and in the fractures of rock formations with an unconsolidated deposit or a unit of rock that can yield a usable quantity of water, called an aquifer. Groundwater is often withdrawn to support man's activities that will support life such as use in agricultural activities, the industries in preparing their goods and households in the municipalities and cities by operating extraction wells which in the long run exhaust the resource. The long-term effect of water withdrawal may cause a gradual settling of land in the Earth's surface and also changes take place underground creating a sinking called subsidence. In some types of groundwater basins, water that is pumped to the surface is drawn from spaces between sand and gravel. In addition, layers of clay can contain large amounts of water, and water pressure in the surrounding aquifer keeps the clay particles slightly apart from each other. When the water pressure in such a basin drops due to extensive pumping, the clay particles are pushed together by the weight of the overlying sediments, which is no longer in equilibrium with the (now lower) water pressure. The lower water pressure affects the cohesion of clay particles making water getting away from the clay and the clay layers become compressed (thinner). The effect of thinner clay layers is seen as a lowering of the land surface – sometimes as much as 20 feet (6.09 m) or 30 feet (9.14 m) over several periods. The decline of land mass consequently lowers the potential of water storage naturally. Effective groundwater management utilizes the storage capabilities of groundwater basins while preventing significant subsidence from occurring. It is then, necessary to look into the condition of the area in relation to the abundance of this resource, groundwater, because water is among the most precious of natural resources that a country has, like Papua New Guinea (PNG).

For underground water to be sustainable the withdrawal of underground water from aquifers should be minimized if it is used faster than it is replenished through the natural geologic cycle. Sustainability according to Dresner (2002) as quoted from the Brundtland report “is a development that meets the needs of the present without compromising the ability of the future generation to meet man’s needs”. According to Ponce (2013) sustainability is “managing the resource at the local level in a way that satisfies the needs of both environment and the economy while ensuring the continued basin’s health”.

In the study of Bhunia *et al.* (2012) on deciphering prospective groundwater zones of Morobe Province of Papua New Guinea using GIS, they found that only 4.29 % of the Morobe Province is categorized as “very high groundwater potential zones” along the North-eastern part. There is a 15.71% “high groundwater potential zones” along the south-eastern part. 37.16% is occupied by moderate groundwater potential zone. And, 42.84% is “poor and very poor groundwater potential zone” as shown in figure 1.

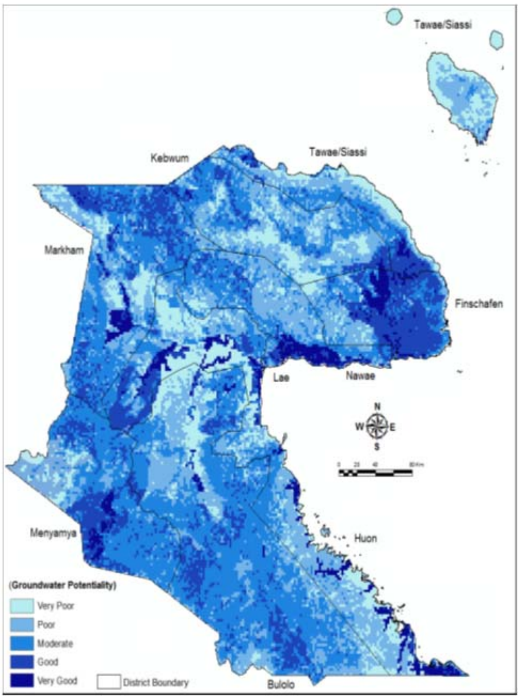

Figure 1. Groundwater Potential Zones. Adapted from Bhunia *et al.*(2012).

Morobe Province is divided into nine Districts: Bulolo, Finschafen, Huon Gulf, Kabwum, Lae, Markham, Menyamya, Nawae, and Tewai/Siassi. It stretches from the Sarawaget Range in the North along the Huon Peninsula to the east and through the Markham Valley in the center of the province. The Bulolo and Watut Valleys run north-south, with the Ekuti and Owen Stanley Ranges in the south as shown in figure 2. The Highlands Highway and a road between Lae and Wau provide reasonable road access in the province. Roads along the Huon Peninsula do not connect to Lae, making water transport more common, which becomes dangerous in the wet season. The very north of the province in Kabwum District and south of the province, around Garaina are very remote. Of all the districts of Morobe, Lae District covers the largest urban center of Papua New Guinea outside of Port Moresby and is a major commercial and industrial hub. Incomes are high from the sale of a range of goods in markets as well as many non-agricultural opportunities in Lae. Lae is a cargo port of Papua New Guinea with a population of 119,178. It is also the main land transport gateway from the coast to the Highlands region. At this urban and industrial zone, underground water in Lae is in large demand. Electricity in the province is powered by water which adds to more demand of water resources. Areas explored on locations of wells are Markham, Nawae, Huon, Bulolo and Lae because of the availability of road network. Other areas like Menyamya, Kebum, Finschafen and Tawae/Siassi were impassable so we use literature survey.

Figure 2. Morobe Province, PNG. Adapted from Morobe Province (2013)

Morobe Groundwater Characterization

From the Bhunua *et al.* (2012) GIS map on potential groundwater zones of Morobe Province of Papua New Guinea, only 4.29 % of the Morobe Province is categorized as “very high potential zones” of groundwater. Among those locations covered by this criteria are: Lae, Markham, Nawae, Huon, Finschafen (part) and Menyamya. Among those within the

15.71% as “high groundwater potential zone”, along the north-eastern are Finschafen and Bulolo at the south-eastern part. To determine further development and design, a study of the groundwater capability on the ground of the identified high groundwater potentials is what this study is all about, characterizing the Morobe ground water, and discussed in this part are the geography, aquifer, wells, and pumping stations.

Geography and Location

Papua New Guinea has a climate that is tropical, dominated by three factors: 1) the equatorial low pressure and sub-tropical high pressure, 2) the influence of ocean and 3) the influence of altitude. The climate is warm with temperatures generally ranging from 20 to 30 degrees Celsius across the majority of the country, with only minor diurnal variations. Morobe Province has a land area of about 34,500 km^2 and a population of 539,404 (Morobe 2014). Situated on the northeastern coast of the PNG mainland, Morobe's coast is bordered by Madang Province to the north, and Oro Province to the southeast. Morobe Province shares its western boundaries with Eastern Highlands, Gulf and Central provinces.

The Morobe geomorphology is 71.29% covered by mountains and hills with weak or no structural control (Bhunia *et al.* 2012). This shows that the geomorphological units for Morobe are in poor recharge zones because structural plateaus, hilly terrain, and volcanic landform are poor recharge zones. Geomorphological units such as flood plains and alluvial plains are good sources of groundwater but cover only 28.71% of Morobe Province, thus a recharge is necessary for sustainability.

Its topography includes the rugged Huon Peninsula, broad Markham Valley and Wau-Bulolo uplands. Much of the northwestern coastline is rugged and drops off steeply into the sea, whereas the southeast coastline to Salamaua slopes gently. Morobe Province's offshore islands include Umboi, Siasi and Tolokiwa in the Vitiaz Strait between Morobe and West New Britain. The topography on the GIS of Bhunia *et al*. (2012) is 35.39% lying >1500 m contour line with a total of 11882.25 km^2 area. The highest elevation zone found is in the northern and southern part of the province, while the lowest elevation is in the north-central and coastal area. The steep slope was found in the north-west part of the province, and some in the south east and central part. Flat topographies are found in north-central part and some part in the northern part of the province, while most is hilly terrain having moderate to steep slopes ranging from 0^o to $89.72^{o.}$ This shows that a high sloping region causes more runoff and less infiltration and thus has poor groundwater prospects compared to the low slope area.

The lithology was characterized as mixed or undifferentiated sedimentary rocks, limestone rocks, low grade metamorphic rocks and basic to intermediate volcanic rocks comprising about 59.47% of Morobe, with the soil class as humitropepts (moderately weathered soils having high organic carbon contents, >12 kg/m2, and low subsoil BS values) about 9172.73 km^2 and troporthents (define as mostly shallow soils that are seen in wet climates on moderate to steep slopes) about 7039.83 km^2 soils (Bhunia *et al.*, 2012). The quality of drainage network depends on lithology, an important index of the percolation rate. The drainage density of Morobe per Bhunia’s *et al.* (2012) map ranges from 0.02 km to 1.18 km, having 70% drainage density of 0.49 – 0.75 km^2. The specified range is capable to recharge the groundwater water table. The variation of groundwater recharge according to Todd (1980) is controlled mainly by discharge and rainfall. To make the groundwater availability sustainable the capability for recharge must be considering the facts that the annual rainfall of Morobe is between 2000-6000 mm (Morobe 2014; Bhunia *et al.* 2012) in which 69.97% (23493.11 km^2) are within 2000- 3000 mm rainfall zone. As of last year’s record of the World Weather Online (2013) the average rainfall is 9.575 per day, 287.25 per month, and 3447 per year, in which the highest of precipitation is in August, followed by April June, July, September and October helping the recharge potential in Morobe province through rainfall. Rainfall is the most vital input in the hydrological cycle as part of the water that falls on the ground is infiltrated into the soil, filling the soil moisture deficiency and part is percolated down reaching the water table known as recharge from rainfall to the aquifer.

Aquifer

There are two types of aquifers: confined and unconfined aquifer. A confined aquifer is a layer of water beneath the surface of the earth that is trapped below an impermeable upper layer. The confining layer is usually composed of clay as shown in figure 3. The figure shows and as per observation that the water level has already declined over the years and was narrated by residents nearby during one of our informal interviews. On the other hand, an unconfined aquifer (water table aquifer) is the saturated formation in which the upper surface fluctuates with addition or subtraction of water as shown in figure 4.

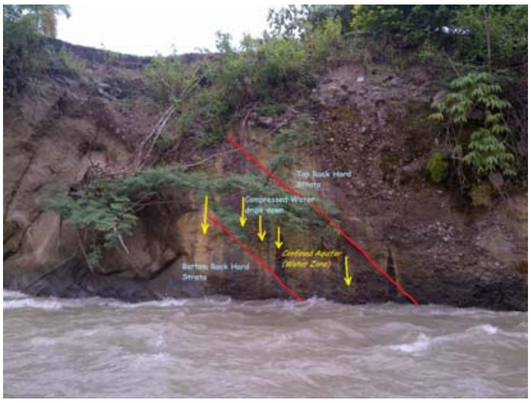

Figure 3. Cross Section of a Confined Aquifer in Erap Nawae

Figure 4. Cross Section of an Unconfined Aquifer in Erap Nawae

In the figures above it can be seen that the current water table is already far below than from years ago. Therefore, a groundwater recharge on the aquifer is necessary. To estimate the water stored in a confined aquifer, a piezometric head in the aquifer can be determined by examining wells. Flow in a porous medium is described by an equation that relates the rate of flow to the gradient of the water table and the characteristics of the aquifer known as Darcy's Law. The equation for Darcy's Law is based on the observations that the flow rate through a porous medium (such as an aquifer) is proportional to the cross-sectional area perpendicular to flow and is also proportional to the head loss per unit length in the direction of flow. Shown below:

$$Q = KA(h_L/L), \quad (1)$$

where
Q = flow rate of liquid through the porous medium, typically in m^3/sec,
A = cross-sectional area perpendicular to flow, typically in m^2,
h = head loss over a horizontal length, in m
L = in the direction of flow (in m)
K = hydraulic conductivity, m/sec ($m^3/sec/m^2$)

$$K = k\gamma/\mu,$$

where
k = specific permeability, m^2 (a property of the porous medium only),
γ = specific weight of flowing liquid, N/m^3,
m = viscosity of flowing liquid, N-sec/m^2,

Values of specific permeability are sometimes given with the Darcy as the unit, where 1 Darcy = 1.062 x 10^{-11} ft^2 or 9.869233 x 10^{-13} m^2.

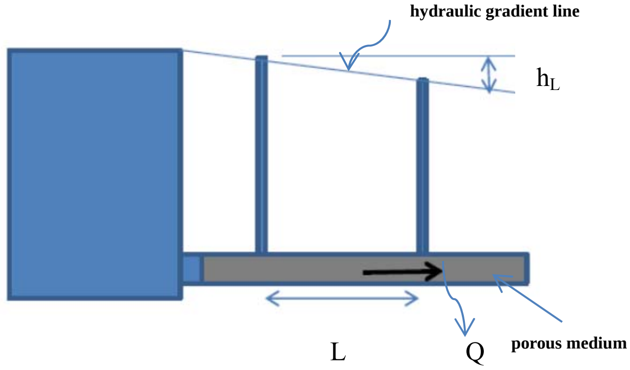

Figure 5. Darcy's Law Principle

Darcy's law demands that the head in the rock must increase with distance from the well and the piezometric surface then forms a cone of depression around the well. The extent of the cone of depression increases laterally with time with continuous pumping. At any time, there is a distance from the well beyond which there is no flow in the direction of the well. A confined aquifer has limited recharge, therefore requires analysis of water utilization and consumption. From the above figure concept, any opening near the immediate vicinity of the well the water drops very rapidly. In this case, we will discuss water well below.

Water Well

A water well is a structure either by natural state or man made created in the ground by digging, driving, boring, or drilling to access groundwater in underground aquifers (Water well 2013). Most of the wells used by villages here in Papua New Guinea are drawn by the use of buckets. In the cities, water in wells are drawn mostly using pumps. Wells can vary greatly in depth, water volume, and water quality. This study considers wells that are both drawn by hand and mechanized. Below are few of the images of the water wells inspected in the study area.

Figure 5. Open Well at Erap, Nawae

The continous flow of groundwater in the above figure is because it is located near the Busu river.

Figure 6 a. Open Well 1 at Boys town, Lae

Figure 6 b. Open Well 2 at Boys town, Lae

Figure 6 shows that well 1 in Boys town, Lae has low groundwater supply and while well 2 has high groundwater supply. This is because the population that uses the resource is less as compared to the other wells shown on figure 7. At this time, the water can still be abstracted from the well, as it is drawn only by hand which mean the drawing is less and the water level can be replenished before the next draw by human for consumption.

Figure 7. Open Well 1, 2, 3 & 4 at 40 mile, Markham

However, when water is pumped from the rock, the water pressure is lowered (i.e. water is released from elastic storage, the aquifer remains saturated). As pumping continues, the rate of local drawdown decreases and eventually stabilizes as the withdrawal is compensated for by inflow of groundwater from the surrounding area and if the pumping still continues the spreads of the water table depression goes outward which may cause the non-sustainability if it will not mitigated earlier. Below is a discussion of the current situation in the major city of Papua New Guinea.

Water Pumping

Man's needs for more water opt them to use mechanized tools such as pumps resulting to active withdrawal by pumping of groundwater changing the natural flow of water level. Our study found seven pumping stations of the Water PNG supplying Lae City's needs on water. Those seven pumping stations were just outside the fence of the Papua New Guinea University of Technology. Continuous drawdown without proper recharge will be detrimental to the health of the groundwater.

Figure 8. Pumping Station 1,2,3,4,5,6, & 7 Taraka, Lae

The above pumping stations will affect the future supply of groundwater if not mitigated earlier. The increasing population of Lae that need the vast supply of water will somehow put the supply of availability of groundwater in the future at risk if it will not be taken into consideration for recharge. Not only the availability of supply but also the condition of the ground may be affected in the near future. It is also of the same reason that the Papua New Guinea University of Technology (Unitech) ceased to pump water and supply its constituents (students and staff) to prevent this to happen and get supply of water from the services of the Water PNG.

Another attributing factor for massive drawdown of water level is attributed by figure 9 to 11 wherein each Colleges or schools are making their own pumping stations to supply water needs for their constituents. If these will continue and without the recharge plans to support continues withdrawal of groundwater, time will come for depletion of the resource, thus such study was undertaken to understand the conditions of the utilization.

Figure 9. Pumping Station Balob Teachers College a) Bore Hole b) Reservoir (2- 10,000 Liters, Supply 3000 Heads)

Figure 10. Pumping Station at Ampo Suction Pump, b)10000 Liters Reservoir

Figure 11. Pumping Station at Marthin Luther Seminary a) Suction Pump, b) 8000 Liters Reservoir

To summarize the field observations of wells, a table is presented listing the most common wells and pumping stations available on those areas, but this is not the final list as there is a difficulty for us to go the other villages of the province due to the bad road conditions. The journey will take us 2 or 3 days walking in the mountains and placing the safety of our team at risk. This constraints us to keep record of other wells. The ones we have accessed to are presented in table 1.

Chemistry of Water From Wells

Water pollution is inevitable; therefore we include determining the quality of water from the wells found in the area thru water test. Pollution of groundwater according to Nwankwoala *et al.* (2013) is an impairment of water quality by chemicals, heat or bacteria to degree that does not necessarily create hazards to the general public but will affect adversely for domestic, farm, municipal or industrial use. The water within the area studied was tested at the laboratory for chemical characteristics and the result is shown in table 2.

Table 1. Summary of Wells Observed in Morobe

Location	**Type of well**
Nadzab, Markham	3 wells
Erap, Nawae	2 open wells
40 mile, Markham	5 wells
41 mile, Markham	1 artesian well
Balob Teachers College, Lae	2 bore wells
Independence Drive Taraka, Lae	Bore well (7 pumping stations)
Bumbu (Kamkumu), Lae	2 open wells
Lae proper	2 wells
Ampo, Lae	1 bore well
Martin Luther Seminary, Lae	1 bore well

Table 2. Chemical Characteristics of Water From Observed Wells

Samples	**BOD (5 day)**	**Calcium(mg/) WHO, <7.5)**	**Hardness(mg) as CaCO3 (WHO, < 500)**	**Magnesium (mg/L) (WHO, < 0.1)**	**Turbidity (N.T.U)**
40 mile sample 1	4.2	20	190	57	3.6
40 mile sample 2	4.4	106	286	37	0.40
Erap sample 1	4.1	26	418	4.6	6.6
Erap sample 2	6.6	24	83	4.5	0.47
Boys town sample 1	3.8	72	79	19	26
Boys town sample 1	4.1	78	282	21	0.25

Based on the result above, the data are above that required of World Health Organization (WHO). Human health is dependent on the wholesome and reliable supply of water. It is noted that half of the people living in developing countries are suffering from water-related diseases caused directly disease-carrying organisms such as mosquitoes that breed in water and other parasites that may infect human beings living in the area. Most widespread disease occurring in Papua New Guinea is malaria. The results also show high concentration of calcium. Water with a high concentration of calcium according to Offodile (2002) is a hard water. This is the result of contamination of water from laundry and other domestic and industrial purposes. Generally, high calcium and magnesium make the groundwater “hard” or “very hard”. Hardness is very undesirable due to the potential incrustation build-up in pipelines and household appliances. This needs to be taken into consideration practically when considering the construction of a water supply system. A higher magnesium concentration according to Todd (1980) has a laxative effect.

Groundwater Sustainability Design

Below is the discussion on the groundwater sustainability design based on the data collected and presented in the previous pages. The presentation of the design is based on the concept of sustainable use and management of groundwater in Morobe. Currently we are continuing in the collection of data on storm water volume in a separate research project conducted both by our colleague and students. The use of underground model software’s for calculations and images of its flow are used in a separate research project that is still on going. So our discussion in the design concept is based on the five elements of sustainable water resources of which some are already implemented. These are:

1. Alternatives to Surface storage (e.g. water harvesting)
2. Wastewater reclamation and reuse
3. Water Conservation
4. Demand management
5. Protection of water resources.

1. Alternative to Surface Storage

For recharging depleted groundwater aquifers, a water collection initiative is run in the university as well as other parts of the city through programs on roof-top water harvesting structures that will help to restore the depleting quantity and quality of ground water as shown in figure 12. This is implemented in most of the residential areas of staff’s accommodation of the Papua New Guinea University of Technology or Unitech.

Figure 12. Water Harvesting in Unitech

2. Wastewater Reclamation and Reuse

The main purpose of artificial aquifer recharge technology is to store excess water for later use, while improving water quality (decreasing the salinity level) by recharging the aquifer with quality water. There are several artificial recharge techniques among those are infiltration basins and canals, septic-tank-effluent disposal wells, water traps, diversion of excess flows from flood into the surcharge tanks, cutwaters, and surface runoff drainage wells.

Infiltration Basins and Canals. This technology is planned to be used in the Markham River basin of Lae. This is the longest river of about 180 km and with the Busu River, which is categorized as the fastest flow river and is also the 7^{th} fastest flowing river in the world (Morobe, 2014), where artificial recharge experiments is proposed.

Septic Tanks and Effluent Disposal Wells. Another source of artificial groundwater recharge is effluents from septic tanks, using soakaways. Currently, the University is constructing a sewage system in which the effluent is planned to return to the groundwater. The soakaways used for this purpose are very similar to suckwells in design and construction methodology, with the exception that they are always covered. This is also conducted in a separate project and is undertaken in conjunction with the Project Office of the University.

Water Traps. Water traps are used to increase infiltration in streambeds. The traps are dams made of earth at different height, usually 1m to 3m, which are constructed using local materials. Water traps are arranged perpendicular to river banks 1 kilometer stretch at an interval of 70m to 100m designed to operate during rainfalls. Their storage capacities fluctuate between 250 and 400 m^3. They have an estimated life span of 20 to 25 years, given proper maintenance. This design is taken into consideration.

Diversion of excess flow from flood into surcharge tanks. This is also another source of artificial groundwater recharge. Lae is experiencing flooding that causes its road sealed with sand and gravel to deteriorate faster making more potholes prevalent and making the city as a pothole city, as shown on the photo below, figure 13 and 14.

Figure 13. Flooding in the City (Source: MKonzang)

Figure 14. Potholes in the City (Cource MKonzang)

3. Water Conservation

Recharge

Groundwater is naturally recharged upstream and discharged downstream. Recharge areas are close to mountain peaks, where precipitation is likely to be higher than in the adjacent lowlands. Shallow groundwater discharges directly into the valleys and other low lying zones while deep groundwater discharges directly into the ocean, rainfall infiltration (main component), return flow (e.g. irrigation), leakage from fresh water distributing systems, river and wadi flows (Runoff), artificial recharge (e.g. Injection wells), leakage from wastewater collection systems (e.g. discharge points) (Ponce 2013; Muath 2013).

Aquifer

Aquifers according to Muath (2013) can be sustained by the following:

1. Perennial Safe (Sustainable) Yield: The amount of abstractions that can be safely abstracted without long or short term adverse conditions occurring.
2. Maximum Perennial Yield: The maximum yield available annually subject to all available recharge resources being utilized at optimum level by allowing specific drop in storage on the calculation that this will be recovered during specific year circle of recharge.
3. Stressed Sustainable Yield: The amount of water that can be extracted > Perennial safe yield over a long planning period (e.g. 25 years) on the condition that the over pumped water can be recovered over a future period in which the basin can be managed wisely.

The yield for unconfined aquifers is calculated by the formulas:

$$Q = \frac{\pi K\,(h_w)}{\ln\,(r_w)} \tag{4}$$

where: Q, is the discharge in m^3/day
K, is the permeability of the soil m/day
h_w , is the depth of water in observed well
r_w , is the distance to the observed well

$$Q = \frac{\pi KB\,(h_w)}{\ln\,(r_w)} \qquad (5)$$

where: Q, is the discharge in m^3/day
K, is the permeability of the soil m/day
h_w , is the depth of water in observed well
r_w , is the distance to the observed well
B, is the thickness of aquifer

The volume of recharge over the aquifer is calculated as:

$$Rv = \sum_{i=1}^{n} (R_d)_i \times A_i \qquad (6)$$

where : Rv, is the recharge volume in m^3/yr
R_d, is the recharge depth in m/yr
A ,is the area in m^3
i, is the cell
N, is the number of cell

The equation above calculates the recharge volume to replace the volume abstracted or discharges from wells and pumping stations which can be made possible either by artificial surcharge.

Using this equation we are now observing the fluctuation of the volume of the aquifer and calculating the possible recharge volume using modeling software that the University is still in the process of acquiring. We are currently using free downloadable demo software and so the results cannot be presented at this time.

Rainfall

On rainfall recharge, below are the equations used in the design.

Rainfall-Recharge Equations

R = 0.6 (P -285)	P > 700 mm	
R = 0.46 (P – 159)	700 mm > P > 456 mm	(7)
R = 0.3 (P)	456 mm > P	

Where: R is the recharge from rainfall in mm/yr
P is the annual rainfall in mm /yr

Rainfall data for Lae as provided to us by Mr. Nimiago of the Forest Research Institute, using Nylex rain gauge 1000 type, calculated an annual rainfall that ranges from 4000 – 5800 annually since year 2007 – 2012. This also conforms to that conducted by Bhunia. He further stated that the months of October to March are the low rainfall months while April to September are the months with a lot of rainfall, and the wettest period is between June and September. Currently, the only natural surcharge affecting the groundwater is the rainfall. Other parameters affecting this are also presented in the geography part as discussed that may affect the slow process of recharge than that of its withdrawal or use. Therefore, a demand management is presented below.

4. Demand Management Pumpage

Focusing our attention on the effects of withdrawing ground water due to a huge demand, a management system should be established to properly make the water resources available for the next generation. Therefore, whenever pumpage of water is increased according to Alley (2013) it must be supplied by more water entering the ground-water system (increased recharge), opt for less water leaving the system (decreased discharge), and removal of stored water in the system, or some combination of these three. This statement can be written in terms of rates (or volumes over a specified period of time) as:

Pumpage = Increased recharge + Water removed (8)

The withdrawal can be prevented or minimized not by using the resource but by ensuring that there is a capability to replenish the water taken due to withdrawal. Therefore the process of incorporating this in the building code of Papua New Guinea is being proposed so that a zoning provision or be incorporated in the issuance of building permits to assure that no reduction of groundwater level on any construction site or industrial activities without a recharge mechanism to help raise up the level of groundwater to safe level. Also planned along this is to map out in detail the available supply of water level on ground.

5. Protection of Water Resources

In this regard to protect the water resources, educating the population is the best way. This can be accomplished by incorporating this concept in the education system of the country, providing awareness via media and other means to provide campaign awareness to protect the water resource.

Conclusions and Recommendations

The present groundwater is already showing depletion. This will continue if not mitigated based on observations of different wells and pumping stations around the study area, Morobe Province. In as much that direct precipitation is the main source of recharge where annual rainfall for the province is as high as 3000 – 4000 mm annually, which makes the Lae City, the urban city of Morobe Province, to be known as rainy Lae. However, because of the changes in climate, hence, it is recommended to conduct precise estimation of ground water resource and recharge potentials as it is a prerequisite for planning and development. Also recommended to determine the actual discharges of the wells identified in the study and provide a groundwater map level using groundwater software models or simulation software's. FEFLOW simulation software model is recommended as it provides a flexible environment to represent different kinds of groundwater flow systems in 2D horizontal or cross sectional projection as well as 3D representation, confined, partially confined or unconfined conditions, boundary conditions including multi-layer wells, physical constraint to boundary conditions and constraint, definition of selected parameters (e.g., groundwater recharge) by applying user-defined equation, and possibility to couple groundwater flow simulation.

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