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2 Executive summary

Work on groundwater management in the Philippines has focused on two pilot sites within neighbouring municipalities of Pasuquin and Burgos, Ilocos Norte in the north western tip of Luzon, Philippines. These sites were selected because in this relatively dry area, use of groundwater for irrigation to finish rice crops and support high-valued dry season crops was already enhancing agricultural production. Increased groundwater extraction could be expected to further increase production but the sustainable limit was undefined. Excessive groundwater extraction would most likely result in coastal saline intrusion into the groundwater resource which would be a serious problem for agriculture and for drinking water supplies from wells. A new wind-turbine power station near Burgos is likely to increase availability of electrical power supplies for pumping which could accelerate the rate of groundwater extraction. Furthermore, limestone aquifers and available runoff in the wet season at these sites suggested that managed aquifer recharge could provide a possible means of protecting these aquifers and supporting production if a groundwater overdraft were to occur. Limestone provides a much easier target for managed aquifer recharge than sand from which Philippine coastal aquifers are more commonly composed.

Initial activities (Year 1) included the conduct of training on “Groundwater investigation and management” (Feb 22-24, 2004), topographic survey and mapping of wells, soil and land use surveys, geologic investigation (i.e., including geo-resistivity survey) and installation and establishment of measuring devices. In the process, water table maps and salinity maps were prepared and water chemistry analysis was done. In the Pasuquin project site, 362 wells composed of 106 irrigation wells and 256 wells for household/domestic purposes were mapped. These wells tapped sandy to gravelly aquifers generally located 5 -12 meters below ground surface (mbgs). On the other hand, in Burgos project site, 184 wells were mapped with 85 irrigation wells and 99 individual household wells that tap limestone aquifers (i.e. within 2 to 30 mbgs). Elevated salinity, up to 12,500 µS/cm, was observed in the midstream section (or that portion being cultivated for crop production) particularly in the Burgos project site. Average water level fluctuation during the observation period was 2.52 m in Burgos and 3.57 m in Pasuquin. With the monthly observation of water level fluctuation for the period 2005-2006, the probable groundwater recharge was calculated (i.e. rise in water level in response to a significant rainfall event). As percentage of rainfall, it was estimated that about 10% of rainfall recharged the aquifers in Pasuquin while 13%-17% of rainfall recharged the aquifers in Burgos during the rainy months of Jul to Oct.

In Year 2, the characterization of the groundwater resource, and collection of data necessary to determine sustainable yield and to set up a groundwater model in both sites were continued. Piezometers were installed at both sites to collect information on lithology, groundwater levels and water quality. Pumping tests were conducted to determine aquifer hydraulic properties (i.e. transmissivity and storativity), and pressure loggers were installed in piezometers to frequently record fluctuations of water level. During the same period, sub-surface lithology from upstream to the coastal zone was described, depth and thickness of aquifers were observed and correlated with the results of the geo-resistivity survey. An economic assessment of agricultural productivity within the two field sites was also undertaken. In essence, the results of the study showed that shallow tube wells in both study sites have strong positive contributions to improving farmer’s income. Shallow groundwater is the most available water resource in the area and therefore needs proper protection and management.

For year 3, activities within the two sites focused on the construction and calibration of groundwater models. The models were used to determine future impacts of changes in groundwater extraction on the resource and demonstrate the level of uncertainty in the forecast impacts. At the onset, a training course in groundwater modelling was held at BSWM, Manila on June 2006. The course consisted of one-day introductory seminar with

26 participants from BSWM and other agencies and a hands-on training using the MODFLOW software that was attended by eight project staff. Afterwards, 2 BSWM engineers took part in a three-week advanced training program in Adelaide in November 2006, where they began developing a groundwater model for the Burgos site. The groundwater model for Pasuquin was set up in Manila with the assistance of Mr. Paul Howe who visited the Philippines in June 2007. They explored the possibility of increasing the areas for garlic production during dry season cropping considering the current level of recharge in both basins. The possible effect of reduced rainfall due to drought and or dry spell (i.e., usually associated with El Niño phenomenon) was also studied. The number of wells that could still be installed and the possible expansion areas were determined to ensure that groundwater extraction is not greater than recharge and that sufficient groundwater discharge occurs at the coast to prevent saline water intrusion. Preliminary water use and management strategies were also formulated based on the results of modelling under different scenarios and conditioned on field observations. Demand side water management (i.e., to reduce water consumption) was trialed when aerobic rice seeds were distributed to selected farmers of both Burgos and Pasuquin. Aerobic rice was introduced to reduce water consumption in rice production. During the Nov-Feb. 2006 cropping, a techno-demo farm on water management for garlic production was established in both sites in which farmer-cooperators were taught how to monitor the soil moisture in the root zone during the cropping period. On a daily basis, they recorded soil tensiometer readings and static and pumped water levels every irrigation application.

In the groundwater modelling exercise, there were 3 separate models evaluated to forecast different levels of sustainable groundwater pumping at each site. Each model fits equally well the field data on groundwater levels during the short period of model calibration, but results in a different estimate of sustainable yield of the groundwater system. Four future scenarios, as specific combinations of increased groundwater extraction, reduced recharge due to climate change and recharge augmentation were developed for each of the three models for each site. Further monitoring and evaluation will be needed to refine the groundwater models and the estimate of sustainable yield and this can be done during a period of gradual expansion of groundwater use.

From among the three candidate models of each site, only one model was selected as the basis for economic modelling for each site. The economic results therefore serve only as an example of the economic opportunities of increased or more efficient groundwater extraction, and are not regarded as reliable forecasts. This economic modelling can be repeated when the groundwater models are refined. It does serve as an indicator of what is likely and the process, now established, is easily repeatable.

The result of the simulation in Pasuquin site indicated that sustainable extraction of groundwater is conservatively estimated to be of the order of 280,000 m3 which is equivalent to about 90 ha for garlic production intensification in highly suitable areas during the dry season. This area is similar to the current level of irrigation utilization and, by relocating some production to soils that are highly suitable, this can be translated into improved production of 810 metric tons per year amounting to a production value (i.e. through shallow groundwater utilization) of PhP28.4 M. As yet there is no evidence of saline intrusion or of brackish groundwater at the base of any of the wells in Pasuquin so it is possible that the volume of extraction could be increased. However the area of soil suitable for growing high valued irrigated crops during the dry season is likely to constrain further irrigation development.

In Burgos, the selected groundwater model gave a mid-range prediction of sustainable yield of 190,000 m3. This is equivalent to 60 ha for garlic production intensification in highly and moderately suitable areas during the dry season. The current level of groundwater extraction is estimated at about 43 ha. Crop diversification with garlic and onion as major crops is also possible for an optimum service area of about 58 ha (i.e. since onion has higher water requirements than garlic). Garlic production intensification using shallow groundwater could be translated into equivalent production of 186 metric tons per year for a total production value of PhP11.1 M in highly and moderately suitable areas. In the case of crop diversification, with estimated production 160 MT of garlic and 197 MT of onion, the total annual production value will be about PhP8.6 M. In parts of Burgos there is evidence of brackish groundwater at the base of a number of wells and increasing salinity during pumping. Hence it is possible that the volume of extraction could only be increased in selected areas and that model predictions are optimistic. As in Pasuquin, the area of soil suitable for growing high valued irrigated crops during the dry season is likely to constrain further irrigation development to about the levels forecast in this model.

In essence, the levels of utilization of shallow groundwater resources in Pasuquin, and possibly also at Burgos, are considered to still be within their sustainable yields, subject to verification by ongoing monitoring. There are indications of competition in groundwater extraction during the dry season (i.e. as revealed by farmers during consultation meetings) but this could be corrected through a coordinated pumping schedule. Saline water could be pumped at deeper zones (i.e. particularly in Burgos) and this could be prevented by limiting the depth of new wells. With farmers observations and some spread of uncertainties in the result of the modelling further monitoring is required to validate each model and differentiate which model best fits in each site. In the future, when the groundwater models are validated, the economic evaluation may be updated also.

In July 2007, a two-phase consultation was held. The first phase consisted of a technical forum and workshop with the farmers in both pilot sites. The second phase consisted of workshop output presentations to local policy/decision makers. The farmers emphasized their observations on the threat of deteriorating water quality (e.g. high salinity) and the declining groundwater storage and yield during the dry season. At the end, a Covenant of Support to protect and manage our shallow groundwater resource was passed by the farmers. This covenant was presented to local policy makers who showed their willingness to provide a parallel effort to protect and manage our shallow groundwater resource by espousing related local policies. Furthermore, everybody agreed that this should be referred to the National Water Resources Board (NWRB), the national agency that regulates the utilization, protection and management of our water resources.

Meanwhile, parallel works were also undertaken in Australia, to design artificial recharge systems for use in sandy aquifers that predominate in lowland areas of the Philippines. An evaluation of the performance of roughing filters in removal of colloidal kaolin as a pre-treatment for biofiltration (slow sand filtration) was completed. A review of biofiltration was completed and a testing facility was established at the Urrbrae Agricultural High School to enable evaluation of stormwater biofiltration design variables. A review of well completion techniques enabled design of wells for construction at the Urrbrae site for an ASR pilot study. Unfortunately the thin alluvial aquifer was not encountered in either well and it is proposed that a deeper well be installed once water quality testing has established an effective pre-treatment for an ASR trial. This would give confidence before application in Ilocos Norte. Studies have identified indicators of labile nutrients in stormwater to predict biofilm growth and clogging in injection wells. Testing with combinations of roughing filters and biofiltration in either sand or granular activated carbon found that a suitable quality of water for injection into fine grained sand aquifers could not be obtained using natural materials alone. This contrasts with limestone aquifers where there is evidence that natural treatment of stormwater in wetlands is adequate to prevent clogging in aquifers.

Hence it is concluded that limestone, as found in parts of Pasuquin and much of Burgos could be a suitable target for recharge enhancement using roughing filters as a pre-treatment for settled stormwater but fine-grained alluvial aquifers are not viable as a target due to excessive pre-treatment costs. Alternatives such as pond infiltration using stilling basins and recharge basins may also be considered where aquifers are unconfined and soils are free-draining. No recharge should be considered within reasonable proximity (3-6 months travel time) of wells used as drinking water supplies to avoid potential contamination. Field measurements and modelling suggest that aquifers refill during the wet season and discharge to streams, at least in Burgos. Hence enhancing recharge during the wet season is not considered to be useful unless the aquifer is not fully replenished by natural recharge. If the dominant cause for salinisation of wells is up-coning from deeper saline groundwater during pumping, it is doubtful that additional recharge in the wet season will be effective against salinisation. However restricting rates of pumping, spatial intensity of pumping and well depths will be beneficial.

The project has assessed the potential of shallow groundwater resources in both pilot sites. Through modelling exercises (i.e. groundwater and economic modelling) the limit of future groundwater extraction was projected. Public consultations increased the level of awareness of farmers and decision makers on the current situation through which management strategies were formulated. However, the bottom line is that farmers as groundwater users should also learn how to monitor the impacts of unregulated groundwater extraction to the resource (i.e. in terms of potential groundwater level decline and increasing salinity) so that they could undertake immediate remediation measures themselves. They should be encouraged to contribute in the overall management of groundwater as “resource managers” to ensure a more sustainable use of this very precious resource.

In June 2008, the establishment of a Farmer-managed Groundwater System (FMGWS) in the project sites was implemented as a management strategy. It intends to increase the level of awareness and understanding of farmers about groundwater and its occurrence, cropping pattern development, and other technological concepts leading to a more sustainable management of our groundwater resource. This is a contingency option in the event that climate change reduces recharge or if initial estimates exceed actual sustainable yield. As a strategy of implementation, the concept of FMGWS was introduced through the establishment of a Farmer Water School (FWS) in the pilot sites. A training of trainers (TOT) was held in November 2008 to develop agricultural technicians of Ilocos Norte as potential trainers who will empower farmers and groundwater users with the required knowledge and skills to protect and manage the resource. Training modules that suit Philippine setting and culture were prepared. In broader terms, these modules consist of 1) human dimension of GW management; 2) basic concepts on GW, its occurrence and sustainable use and; 3) crop planning and formulating appropriate GW management (e.g. effective MAR and protection of coastal aquifers from pollution). With these modules, several other sub-modules were developed that include the facilitation and presentation skills to enable them to conduct the FWS in a more effective and interesting way for farmers. Sub-modules were expressed in local dialect so that farmers could easily understand each topic. From January-June 2009, FWS classes were conducted in both project sites with 2 sessions per month. The learning process considered 9 training modules that start from the discussion of the topic “knowing weather and climate” to “groundwater balance (recharge and discharge)” then to integration of “groundwater balance to crop planning”. An action planning session followed after the 9 modules/sessions were completed.

The sessions were supplemented by a Farmers Field Tour in Tarlac Shallow Well areas, Maasin Small Water Impounding Project in Talugtog, Nueva Ecija, Central Luzon State University, PhilRice and Pantabangan Dam to familiarize the farmers with various water saving technologies which could be adopted in their respective area. In essence, the FMGWS sequel of the project enhanced the capacity and skills of farming communities in understanding the groundwater systems and collecting basic field data and in utilizing this data in their own crop planning. It also strengthened the relationship among farmers through the various group activities that they undertook in every FWS session. As such an Association of FWS was organized in both sites to sustain the efforts started by the project. In simple terms, they were able to understand groundwater availability and crop planning concepts which increased their level of confidence to explain them during the FWS exhibit held in July 9, 2009. A graduation ceremony, attended by more than 200 farmers and guests culminated the FWS activities on the same date. However, follow up activities beyond the project duration will be undertaken to sustain the knowledge gained by the farmers and to develop them as an important sector that will contribute in managing our shallow groundwater resource to make it more sustainable.

3 Background

The Philippines has abundant shallow groundwater resources estimated to occur over about 5 million hectares. In general current groundwater utilization for irrigation is in its early stage due to relatively abundant rainfall with surface water as the priority resource for development due to the higher cost of pumping of groundwater with diesel engine driven pumps. In some areas, even where there are surface water irrigation systems farmers have found significant benefits in supplemental irrigation with shallow groundwater during extended dry seasons for the production of vegetables and other upland crops. This clearly shows that integrated use of groundwater and other water sources could improve agricultural benefits. Judicious use of groundwater enables planting of crops at times to command high prices, reduces gross groundwater extraction, enables second or third crops to be grown, and provides greater flexibility in the choice of dry season crops. In other areas where surface water sources are scarce particularly during the dry season, the utilization of shallow groundwater through shallow tubewells (STW) is more popular (e.g. Central Plain of Luzon and the lowland areas of Ilocos Region). However, if used excessively this would result in “over-exploitation” of the resource subsequently causing negative environmental impacts such as declining water levels, drying of wells, loss of base flow from streams, saline water intrusion and even land subsidence.

Essentially, as we pursue the utilization of shallow groundwater for agricultural production there is a need to ensure that increased groundwater use is sustainable to avoid problems of over-exploitation. The challenge is to increase production by the use of groundwater without encountering these constraints. Predictable future changes such as increased capacity for electricity generation and distribution may change the price of groundwater extraction, and pose new threats to resource sustainability, especially as awareness grows of the benefits of supplemental irrigation with groundwater. Similarly, the capacity to drill deeper wells and equip them with submersible pumps is likely to become increasingly available. Reducing over-consumption of groundwater is a very difficult resource management problem that in other countries has ultimately restricted consumption to those that are wealthy enough to deepen their wells, and whole aquifers have been depleted or salinised and remain unusable for generations. There is a need to formulate policies and develop management options before the resource becomes over-committed. Hence, this project was pursued.

4 Objectives

The overall aim of the project is to improve farmers' income by exploring the sustainable use of shallow groundwater to increase crop production in lowland, rainfed agricultural areas of the Philippines.

The specific objectives of the project are to:

1. Assess current and potential role and benefits of shallow groundwater use for agricultural production in rainfed lowlands
2. Identify strategies to ensure sustainable use of shallow groundwater
3. Pilot test and modify in Australia ASR systems that suit sandy aquifers in the Philippines and Australia
4. Implement appropriate management strategies at two pilot sites, in cooperation with local government units, to enhance sustainable production
5. Communicate and promote results at local and national levels to facilitate broader adoption and strengthen/advocate for related policy formulation.

Through a project variation additional specific objectives are to:

- Enhance the capacity and skills of farming communities in understanding the groundwater systems and collecting data
- Develop crop plans and related management strategies through the involvement and engagement of farmers
- Implement farmer-developed crop plan and management strategies
- Communicate and promote results to facilitate broader adoption and strengthen advocacy on the concept of farmer-managed groundwater systems in the Philippines.

5 Methodology

The project was undertaken in Ilocos Norte located in the North western part of Luzon. Specifically, two pilot study areas consisting of two basins or catchments that cover several villages (or barangays) were selected in the neighbouring municipalities of Pasuquin and Burgos in Ilocos Norte.

To achieve Objective 1 “Assess current and potential role and benefits of shallow groundwater use for agricultural production in the rainfed lowlands”, the following activities were undertaken by the project staff in coordination with the concerned local government units:

1. Confirmed the groundwater irrigated farms in the study areas and the number of shallow tubewells and dug wells that provide farmers access to the shallow groundwater resource. Mapping of existing wells was undertaken and current extraction rate and volume were obtained through pumping and interview of well owners/users (i.e. to determine frequency and time of irrigation application and crops planted during the cropping season.
2. Quantified the socio-economic values of current extraction and irrigation activities. A socio-economic survey was conducted with shallow tube well owners/users as respondents. The result of the survey was used to determine the potential socio-economic impact of increased groundwater use. In the process, factors affecting uptake of groundwater for irrigation were identified.
3. A range of scenarios to optimize benefits from shallow groundwater utilization (i.e., increased cropping intensity, changes in cropping pattern and calendar) was identified and evaluated in consultation with technical staff of the LGU, academe, and other national government staff, and local farmers. Farmers’ consultations and dialogue with LGU staff were therefore undertaken.

To achieve Objective 2 “Identify strategies to ensure sustainable use of shallow groundwater”, an assessment of the shallow groundwater resource in terms of water quality, spatial extent and maximum yield were undertaken for two years. Observation wells were established in strategic areas of both basins to facilitate the field measurements of groundwater elevations, aquifer hydraulic properties (i.e., through pumping tests). These observation wells also served as sampling sites for groundwater quality analysis. Groundwater elevation measurement was done every 15th and 30th day of the month while water sampling was done at least once a month. Pressure transducers were also installed in the 13 piezometers established in the study areas to monitor groundwater level fluctuation more frequently and acquire data automatically. During the installation of piezometers, the stratigraphic description (i.e. including the depth and thickness of aquifers) were noted. The stratigraphy was further described through the geo-resistivity surveys conducted at the upstream, midstream and downstream sections of both basins. Groundwater modelling was also undertaken in both sites using the data from field measurements and pumping tests to determine the potential of the resource, its probable response under different scenarios (e.g. increasing the area planted to garlic and planting other crops during the dry season), and the limit of groundwater extraction to make the resource more sustainable.

The result of the assessment provided inputs in the formulation of possible management strategies (i.e. including recharge enhancement technologies) to ensure equitable distribution of benefits from groundwater utilization. A soil survey and investigation was also conducted to characterize soil resources as another input in the formulation of the management strategies. The formulated strategies were firmed-up by presenting them to local farmers through consultation and dialogue.

To achieve Objective 3 “Pilot test and modify in Australia Aquifer Storage and Recovery (ASR) systems, the CSIRO undertook studies of the effectiveness of roughing filters for kaolin removal and established a testing facility at the Urrbrae Agricultural High School in Adelaide to evaluate the effectiveness of biofiltration for removal of colloids and nutrients prior to recharge. A review of ASR well designs was undertaken and wells were constructed adjacent the testing facility at Urrbrae wetland with the intention of pilot testing the pre-treated water by injecting into a sandy aquifer. This research work in Australia aimed to predict the potential for success of aquifer enhancement in comparable sandy aquifers in the Philippines. In this respect, samples from sandy aquifers (i.e. Pasuquin study area) were collected and characterized for the purpose. Parameters analysed include particle size distribution, clay content, mineralogy, carbonate, iron and organic carbon content.

To achieve Objective 4 “Implement appropriate management strategies at two pilot sites with local government units to enhance sustainable production”, appropriate management strategies were initially identified (as earlier discussed) after determining the potential shallow groundwater extraction and the capacity of the resource to meet the projected irrigation demand. For the local government units to recognize the need to implement appropriate management strategies, the current state of the resource was presented to them through consultation and dialogue. Appropriate management strategies as identified by the project staff and the farmers themselves were also presented. This is to facilitate the mainstreaming of the recommended management strategies in their annual agricultural development program specifically in the study areas. Likewise, during the consultation and dialogue, the formulation of policies relating to the protection and management of the resource was also sought so that appropriate management strategies could be fully implemented on a long term basis beyond the period of project implementation. In this case, the monitoring of impacts on agricultural production and groundwater resources was set to go beyond the project term.

To achieve Objective 5 “Communicate and promote results at local and national levels to facilitate broader adoption”, various IEC materials were prepared for technical personnel and farmers. These include brochures and flyers, posters and technical reports. A covenant of support from farmers and policy decision makers to protect and manage the shallow groundwater resource was worked out as a positive step to generate policy papers and recommendations for consideration by policy and decision makers. Project technical staff attended both local and international seminars to present the project outputs. Sessions for training of farmers were also conducted with a focus on water saving technologies.

In the project variation, the following activities were undertaken:

To achieve Objective 1, “Enhance the capacity and skills of farming communities in understanding groundwater systems and collecting basic field data”, a “Farmer Water School (FWS)” was organized in each of the pilot sites. FWS allowed farmers to understand and analyse groundwater concepts and availability; discuss impacts on crop growth and their role on groundwater sustainability, and to reach decisions by themselves on crop plans and management of groundwater. A training module was prepared with assistance and support from the Agricultural Training Institute, Mariano Memorial State University and the Provincial Government of Ilocos Norte A multi-cycle approach was adopted in the conduct of FWS. The approach involved the following stages:

- First cycle – Training of Pasuquin and Burgos agricultural technicians to serve as field facilitators: 10 – 15 trainees. The trainers consisted of BSWM project staff with support from the academe (i.e. Don Mariano Marcos State University) and ATI.

- Second cycle – Training of selected farmers in each barangay at pilot sites, who constituted the farmer-trainers core group: 25 – 30 farmers in each pilot site and/or groundwater basin. At this point the training modules were translated into local dialect and trainers were the trained technicians of the first cycle. This included season-long monitoring of groundwater levels in selected observation wells during the rainy season (when most recharge occurs) and during the dry season (when most extraction occurs).
- Third cycle – Training of farmers in different barangays at pilot sites with the trained farmers of the second cycle as the trainers. This cycle will not be covered by the project extension but will be organized in coordination with the LGU for continuity of the cycle.

FWS was conducted for one season or 6 months (with farmers meeting twice every month).

To achieve Objective 2, “Development of crop plans and management strategies through the involvement and engagement of farmers”, the farmers were allowed to analyse their collected data in their respective site to formulate a crop plan based on the local data generated. In the process, farmers were taught about the need for collective action in managing groundwater and develop their ability to prepare for critical and informed decisions on crop plans. Observation wells were selected at the downstream, midstream and upstream portions of the basin. Standard rain gauges were installed and local and simple water level measuring devices were procured and assembled for use by the farmers.

To achieve Objective 3, “Implement farmer-developed crop plans and management strategies”, the farmers were encouraged to adopt the crop plans they developed during the FWS. Due to limited time for the full implementation of crop plans, the activities for this objective will go beyond the project extension period which will be monitored and documented by BSWM as bases in replicating the project in other groundwater basins.

To achieve Objective 4, “Communicate and promote results to facilitate broader adoption and strengthen advocacy on the concept of farmer-managed groundwater system in the Philippines”, information, education and communication (IEC) materials were prepared through the project. These included video materials, flyers, and posters. Presentation of project accomplishments was also conducted through a technical seminar. An exhibit highlighting the different topics of FWS was organized with farmers and agriculture staff of other LGUs of Ilocos Norte as the audience. The activities to achieve this objective will also go beyond the project period.

6 Achievements against activities and outputs/milestones

Objective 1: To assess current and potential role and benefits of shallow groundwater use for agriculture production in rainfed lowlands

no.	activity	outputs/ milestones	completion date	comments
1.1	Confirm current use of shallow groundwater (sgw) in consultation the DA and irrigators group (PC and A)	Presentation of report updating shallow sgw exploitation maps	Sep 2005	Report completed covering 362 wells in Pasuquin & 184 wells in Burgos. GIS Database was also developed (i.e. Map of wells with attributes in each well)
1.2	Assessment of socio-economic benefit of current sgw resource usage (PC and A)	Report detailing current net value of sgw irrigated crops	Oct 2005	Report completed. Socio-economic survey involving 121 respondents was undertaken
1.3	Model socio-economic benefits of increased sgw exploitation under range of scenarios (PC and A)	Report detailing optimal return from increased sgw extraction	Sep 2006	Report completed. Range of scenarios established. Analysis was done through computer spreadsheet with reference to the results of GW modelling

PC = partner country, A = Australia

Objective 2: To develop demand management and recharge enhancement strategies and actions

no.	activity	outputs/ milestones	completion date	comments
2.1	Assess sgw resource (WQ, extent, and yield) (PC and A)	Report on sgw resource of the region	Jun 2006	Report (Aquifer Characterization Report) completed. Geo-resistivity surveys were conducted; 13 piezometers were installed for water level and water quality monitoring; conducted wet and dry seasons pumping tests; monitoring of water levels and water quality in 55 observation wells (32 in Burgos and 23 in Pasuquin)
2.2	Evaluate sgw potential to enhance agricultural production w/o adverse (PC and A)	Report on groundwater and economic modelling results	Jun 2006	Report on Groundwater modelling for Burgos and Pasuquin completed. Facilitated through the Advanced Training on GW Modelling held in Adelaide, Australia. The results served as a basis in the subsequent economic modelling.
2.3	Develop sustainable use strategies – consultation with farmers	Sustainable strategies aimed at policy decision makers	Nov 2006	Report on sustainable water use strategies completed. There were two reports. The first one contains strategies based on technical findings while the second one contains farmers' recommendations, in terms of local technologies and policies. A covenant of support from farmers and policy makers was passed during the final consultations with them.

PC = partner country, A = Australia

Objective 3: To determine the suitability of Aquifer Storage and Recovery (ASR) development in the Philippines

no.	activity	outputs/ milestones	completion date	comments
3.1	Undertake study on recharge enhancement in sandy aquifers (i.e., South Australia) (A)	Report and refereed journal paper on experiments on roughing filtration. Report on effectiveness of biofiltration for stormwater ASR. Report on ASR well design. Report on characterising organic material in water wrt ASR. Report on ASR well construction at Urrbrae Ag. High School.	Oct 2007	Activities occurred in three fronts, namely: Laboratory testing of pre-treatment methods prior to ASR (roughing filtration and biofiltration with sand and granular activated carbon) Methods for determining the biological clogging potential of the recharge water; Assessment of drilling and completion methods for unconsolidated aquifers Roughing filtration was highly successful and well characterised. Biofiltration found to be less effective for removal of labile organic carbon than needed for ASR in fine sand aquifers. The ASR wells failed to intersect a sand aquifer at Urrbrae to allow pilot testing.
3.2	Characterize sandy aquifers in the Philippines in areas for gw development (PC and A)	Report on potential to apply techniques to Philippines	Jun 2006	Completed the analysis of sandy aquifers in the Pasuquin site.

PC = partner country, A = Australia

Objective 4: To implement management strategies at two sites to enhance sustainable production

no.	activity	outputs/ milestones	completion date	comments
4.1	Implement harmonized groundwater development and management strategy (PC)	Implementation of groundwater management strategies	Nov 2006	Techno demo farms on shallow groundwater management for garlic were established; Farmers training on water management was conducted. Full implementation of identified and agreed groundwater management strategies were worked out in 2008 using available funds. The strategy involves the implementation of Farmer-managed Groundwater System (i.e., empowerment of farmers), mainstreaming of the identified strategies and issuance of local ordinance for the protection and management of the resource based on the output of the consultation. The concept of establishing the Farmer-managed Groundwater System through Farmers Field Schools (FWS) was presented to the LGUs and farmers leaders in the project sites
4.2	Monitor impacts on agricultural production and groundwater resource (PC)	Active agricultural productivity and resource monitoring program	Nov 2006	Monitoring of impacts will go beyond project duration in the same way that Implementation of management strategies will extend until 2008

4.3	Report results to farming communities and scientific community (PC)	Full technical report and Executive Summary	Nov 2007	Results were first presented to stakeholders (i.e., representatives of national agencies, LGUs, academe, and other partner agencies during the project mid-term review on Apr 11-13, 2007. During the consultation with farmers and policy/decision makers, the results were also discussed and presented on Jul 23-25, 2007. Part of the results was also presented in the International Learning Workshop on the Demand Side Management of Groundwater held in Hyderabad, India on Jul 29th – Aug 11th , 2007. This became a part of the published output of the workshop entitled "Cross Cultural Perspectives on Groundwater Based Institutions"

PC = partner country, A = Australia

Objective 5: To communicate and promote results at the local and national level to facilitate broader adoption

no.	activity	outputs/ milestones	completion date	comments
5.1	Utilize resources in partner organizations to publish materials. Conduct field days with irrigators. Generate policy papers detailing related policy recommendations (PC and A)	Delivery of training materials and program for extension work.	Nov 2007	Training and information materials include: Lecture notes on Groundwater Resource Assessment , February 2005; Groundwater modelling notes from Modelling Workshop held in Manila on Jun 8-10, 2008; Groundwater Resource Management Presentation on May 22, 2006 at WATERTECH 2006 by S. M. Contreras; Project Accomplishment Presentation by Provincial Agriculturist Norma Lagmay on May 24, 2006, International Celebration on Biodiversity Interim Aquifer Characterization Report and Economic Assessment of Agricultural Productivity, Jun 7, 2006; Project Video Presentation was provided to the LGUs Brochures and handouts for - Conduct of Pumping Test - Geo-resistivity Survey - Installation of Piezometers Concept of Farmer-managed Groundwater System as one of the implementation strategies presented to the LGUs, Dec 13, 2007

PC = partner country, A = Australia

For the Project Variation:

Objective 1: To enhance the capacity and skills farming communities in understanding the GW systems and collecting basic field data

no.	activity	outputs/ milestones	completion date	comments
1.1	Organize farmers/ shallow groundwater users (PC)	Organized farmers group	Target : Jul 2008	Completed: 20 farmers in Burgos and 30 farmers in Pasuquin representing upstream, midstream and downstream were organized for Farmer Water School (FWS)
			Actual: Nov 2008*	First payment was only received on Sep 2008

1.2	Prepare training module for farmer-managed groundwater system (PC)	Training modules prepared	Oct 2008 (TOT) Dec 2009 (FWS module)	Completed: Training module for Training of Trainers (TOT) with 16 sub-modules and 9 FWS Modules
1.3	Conduct farmers training through FWS (PC)	FWS training completed	June 2009	Completed. 1 TOT session for 25 trainers and 18 sessions for 50 farmers: 20 in Burgos and 30 in Pasuquin

PC = partner country, A = Australia

Objective 2: To develop crop plans and management strategies through the involvement and engagement of farmers

no.	activity	outputs/ milestones	completion date	comments
2.1	Selection and mapping of observation wells (PC)	Maps and reports w/ characteristics of observation wells	Dec 2008	Report Completed: 12 observation wells were selected and characterized. The well characteristics were presented and discussed during the FWS.
2.2	Installation of field measuring devices (PC)	Installed measuring devices	Dec 2008	Two water level recorders; 2 EC meters, 2 sets of simple discharge measuring instruments, and 2 rain gauges were procured and installed in the project sites.
2.3	Field data collection and hydro-ecosystem analysis (PC)	Report on farmers analysis of gathered data with technical assistance from project staff	Jun 2009	Report Completed. Monthly data on water level and rainfall was analysed by project staff and presented to farmers.
2.4	Preparation of crop plans and management strategies (PC)	Seasonal crop plans and management strategies	Jun 2009	Crop plans were prepared by the farmers during the FWS session

PC = partner country, A = Australia

Objective 3: To implement farmer-developed crop plans and management strategies

no.	activity	outputs/ milestones	completion date	comments
3.1	On ground implementation activities (PC)	Implemented seasonal plans	Jun 2009	FWS completion was achieved Jun 2009. Ground implementation will go beyond project duration; tree planting in the watershed of Burgos completed during the onset of the rainy season.
3.2	Monitor impacts on agricultural production and groundwater resource (PC)	Monitoring programs that will go beyond the project period	Beyond Jun 2009	To be prepared in consultation with Farmers and the LGUs

PC = partner country, A = Australia

Objective 4: To communicate and promote results to facilitate broader adoption and strengthen advocacy on the concept of farmer-managed groundwater systems;

no.	activity	outputs/ milestones	completion date	comments
4.1	Publish information materials and conduct field day and final evaluation (PC)	Delivery of information materials for extension works	Jun 2009	Conducted Exhibit/Field Day 8 min- Video Presentation shown during the Exhibit/Field day > 200 flyers of different FWS topics in local dialects distributed during the Exhibit 9 Posters of FWS modules presented 1 Table model of the GW Basin displayed during the Exhibit 1 Technical presentation completed in a Seminar Graduation Ceremony conducted which gain support and advocacy from LGU executives Project info in BSWM web site uploaded

7 Key results and discussion

Work on groundwater management within the Philippines has focused on two pilot sites within neighbouring municipalities of the province of Ilocos Norte, namely Pasuquin and Burgos, located on the northwestern tip of Luzon, Philippines (Figure 1). Initially, activities within these two sites focused on the evaluation of the project sites' hydrometeorology and physical characteristics (i.e. topography, soils and geology and land use), mapping of shallow tubewells and dug wells, and assessment of the groundwater supply and demand including water chemistry. In the process, observation wells were selected, and piezometers and monitoring systems were installed to assess groundwater recharge and sustainable levels of groundwater use, determine the current level of groundwater extraction and its potential, and the level of production of various crops within the region. During the project implementation several trainings of project staff were conducted in the Philippines and Australia. These trainings included: a) Groundwater resources assessment and management on February 5-8, 2005; b) Groundwater modelling on June 8-10, 2006; and c) Advance training on Groundwater modelling (i.e., application of Modflow) were undertaken in Adelaide, Australia for two project staff for 3 weeks in November 2006. The project key results are discussed in the following sub-sections.

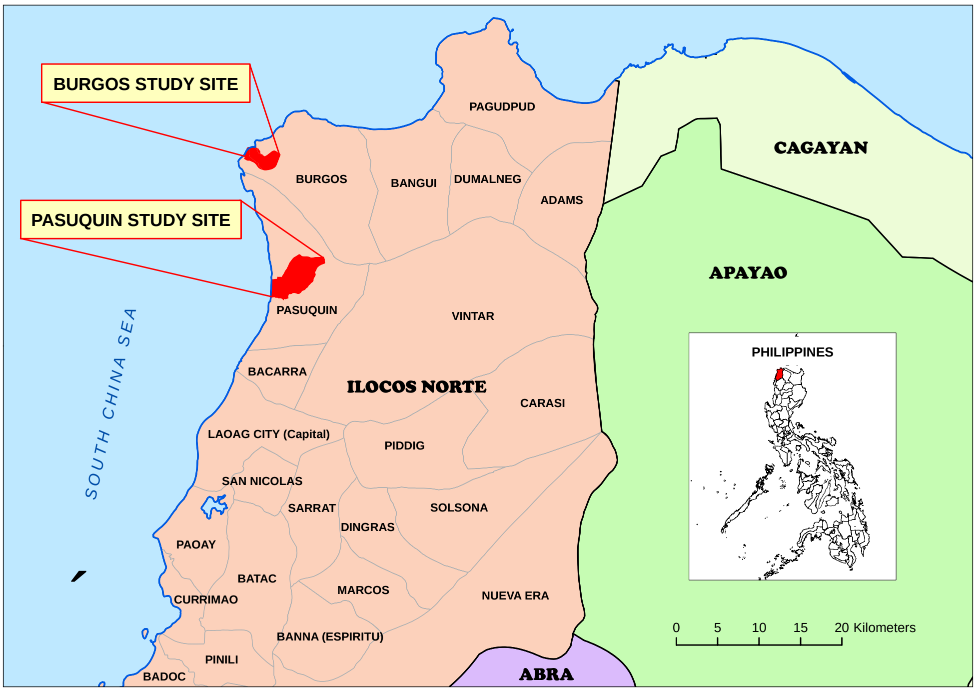


Figure 1. Location of pilot study sites.

7.1 Climate

The project area is under Type 1 Climate (Coronas Classification) characterized by two pronounced seasons, dry from November to April and wet during the rest of the year. Average annual rainfall is about 2,000 mm. Mean monthly temperature ranges from a low of 19.0o C to a high of 33.6o C while relative humidity is between 78% and 86%. During the rainy season (May-Oct), the area has excess water that could potentially be collected and stored so that it can be utilized during the dry season (Nov-Apr) for crop production. Depending on the physical characteristics and hydro-geologic properties of the study area, the excess rainwater could be stored in surface reservoirs and/or in aquifers.

7.2 General groundwater assessment

The country's groundwater resources are classified into; a) Shallow well areas, b) Deep well areas, and c) Difficult areas (NWRC, 1980). Shallow well areas are classified as those areas having potential for wells with a depth of 20 meters below ground surface (mbgs) or less, and static water level within 6 mbgs. They are usually located in recent formations with slopes from 0-3% and below an elevation of 50 meters above mean sea level. They are more exposed to contamination due to fertilizer and pesticides particularly in agricultural areas. Deep well areas are characterized by aquifers generally located at a depth of 20 mbgs or more and generally with good quality waters. They are within sedimentary formation with slopes of up to 10% and at an elevation of more than 50 meters above sea level. In the case of the limestone formation, however, water flows through solution channels/caves. It has limited filtration and purifying properties and is susceptible to pollution due to human and animal induced activities. Difficult areas are those within formations in which the probability of encountering non-productive wells is very high. These are usually located in mountainous areas and have varying slopes, elevations and water depths. They are characterized by formations in which only a negligible amount of water can move due to low permeability. The province of Ilocos Norte in general, has more deep well areas (1,530 sq. km) than shallow well areas (1,360 sq. km). The study sites in Pasuquin and Burgos are located in shallow well areas.

7.3 Geology of the project sites

7.3.1 Regional geology

The two project sites have different regional geological settings. Pasuquin project site (Figure 2) is characterized by older formations such as Laoag Formation, Serpentinized Peridotite, and Pasuquin Limestone. These supply the sediment in the Quaternary Alluvium deposit, which is predominantly made up of sand, clay, and gravel. On the other hand, Bobon Burgos (Figure 3) is underlain by Uplifted Coral Reefs (Late Pleistocene) and Bojeador Formation (Early Miocene).

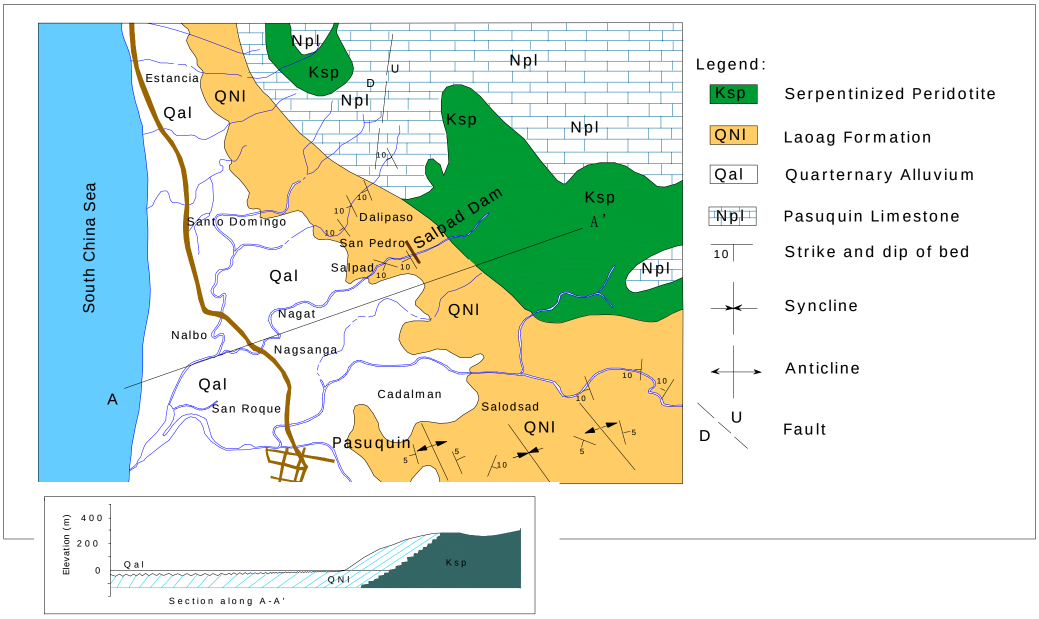


Figure 2. Geologic map of Pasuquin, Ilocos Norte project site (Source: Mines and Geo-sciences Bureau, 1985).

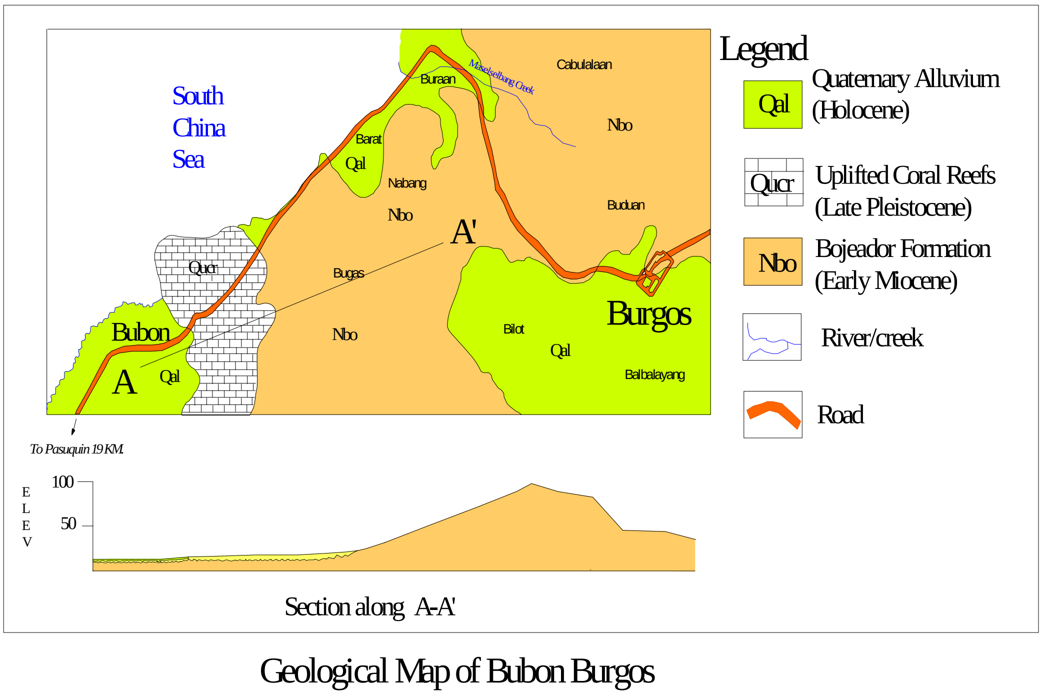


Figure 3. Geologic map of Burgos, Ilocos Norte project site.

7.3.2 Local geology

Stratigraphic description of alluvial deposit of Pasuquin and Burgos was based from the well logs obtained during the installation of piezometers. Figures 4 and 5 show the stratigraphic description from upstream to the downstream portion of the basin of Pasuquin and Burgos, respectively.

In Pasuquin, the downstream section (i.e. coastal area) is characterized by sedimentary deposits consisting predominantly of poorly graded sand and gravel. The underlying layer has traces of shell fragments possibly an extension of tidal flat deposit. The midstream section where the agricultural areas are located is overlain by silty and fine to medium grained sand in its upper layer. Below this layer consists of volcanic materials with occasional carbonate fragments of well-graded sand. At a depth 6.5 to 14 meters below ground surface (mbgs), bluish gray sandy silt is present with shell fragments. This is underlain by silty sand with few rounded gravel and shell fragments down to 25 mbgs. The upstream section of the basin has finer sediment of gray to black silty clay deposit on the surface layer. It is underlain by well graded angular to sub-angular lithic fragment silty sand. At 6 to 7.5 mbgs are fine to coarse-grained, sub-angular to sub-rounded basalt fragment gravels. Below this layer (i.e. down to 12 mbgs) is sub-angular to sub-rounded, fine to coarse-grain sand. This is underlain by bluish gray silty clay down to 30 m, the limit of drilling.

In Bobon, Burgos, the coastal zone has dark-brown clayey sand with angular limestone gravel topsoil. This is underlain by limestone deposit with coral fragments from 1 to 15 mbgs. The mid-section is characterized by alternating layers of clay, silty sand, and limestone. The deepest part (i.e. below 27 mbgs) is characterized by creamy-white limestone. It is overlain by brownish gray clayey silty sand with angular limestone gravel up to 10 mbgs. At 2.5 to 10 mbgs a hard limestone deposit is present with coral and shell fragments, possibly an extension of the coastal zone limestone deposit. The upstream section is characterized by medium to high plasticity silty clay with fine to coarse-grained sand and limestone gravel and shell fragments in its upper layer.

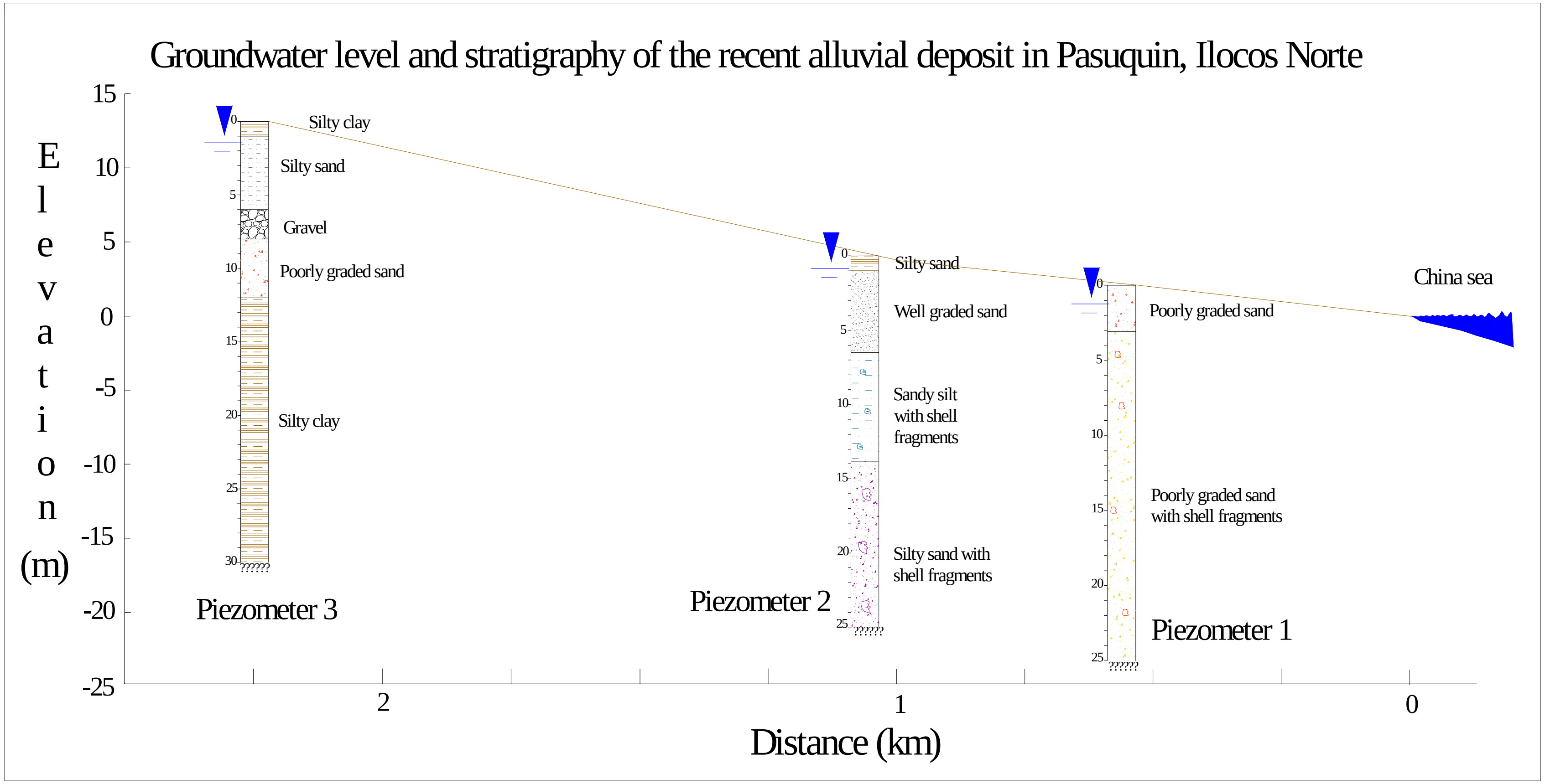


Figure 4. Stratigraphic description of recent alluvial deposits and observed groundwater level in Pasuquin pilot study site.

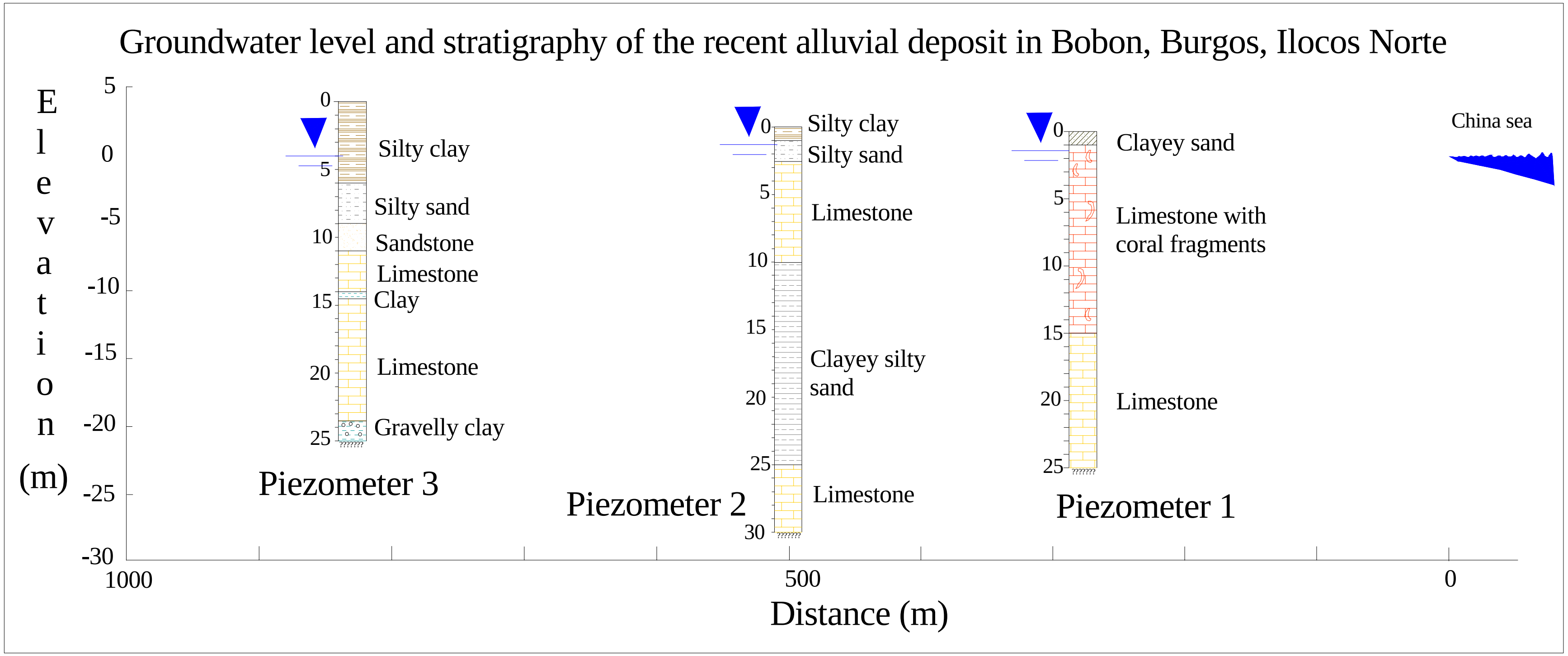


Figure 5. Stratigraphic description of recent alluvial deposits and observed groundwater level in Burgos pilot study site.

It is underlain by a creamy white silty sand with angular limestone gravel and shell fragments. At 9 to 11 mbgs is light gray to dirty white fine to medium grained sandstone. Hard limestone occupied the layer from 11 to 23.5 mbgs. A thin layer of clay deposit with sand and limestone gravel is found between 14 and 14.5 mbgs depth. Underlying this limestone is gravelly clay with high plasticity.

7.3.3 Geo-resistivity and well logs

Pasuquin Study Site

Resistivity values range between 0 and 450 ohm-m. Higher values can be attributed to predominantly clean sand or gravel deposits (Table 1) and/or fresher groundwater as reflected in Table 3. The resistivity profile at piezometer 1 located at the downstream section of the basin (Barangay Nalvo) has a small range of values (18-38 Ohm-m) that indicates an almost homogenous lithology with no sign of any deeper saline layer to a depth of 25m.

In the mid section of the basin (Piezometer 2, Brgy. Nagsanga) resistivity anomaly is almost horizontal and the value decreases with depth. Based on an EC profile (Table 3) groundwater in this area is fresh to at least 25m the maximum depth of piezometer. The silty sand profile revealed in the well log description is reflected by the resistivity profile. Piezometer 3 drilled at the uppermost portion of recent alluvium in Salpad has finer texture deposits with corresponding low resistivity values.

7.3.4 Burgos Study Site

In Bobon, electrical resistivity values range between 0 and 80 ohm-m. A decreasing resistivity anomaly with depth was observed at Piezometer 1, located downstream, where the lowest values were recoded (0-1.25 ohm-m). At this site Salinity at the base of the 9m deep piezometer was 1000 µS/cm whereas in the base of the 25m deep piezometer it was 12,500 µS/cm (Table 3) suggesting that saline groundwater underlies this area. Higher values represents limestone above the watertable and a localised higher value (57.5-80 ohm-m) may represent a limestone cavity.

Resistivity profile of piezometer 2 at the mid-section of the basin has the same trend of decreasing value with depth as at piezometer 1. Overlying limestone and sandy deposits represent high resistivity. Low resistivity (< 6.87 Ohm-m) of the deeper profile can be attributed to groundwater salinity. In the base of the 21.5m deep piezometer here was recorded the highest salinity groundwater (21,500 µS/cm, Table 3). This suggests that at this depth there is blend of approximately 40% seawater with fresh groundwater. It is expected that deeper in the profile the groundwater salinity may reach that of seawater, as would also occur at Piezometer 1.

Piezometer 3 in the upstream part of the basin illustrates an increasing resistivity value with depth. The overlying low value represents silty clay deposit while the underlying gravelly clay lithology has higher value (20.5-23.3 Ohm-m). The profile appears to suggest a limestone cavity at a depth below the piezometer. It is noted that the salinity of the deeper groundwater here (2,180 µS/cm, Table 3) in the 25m deep piezometer suggests that there may already be evidence of incipient saline ingress and that karst features may allow this to spread inland very quickly.

In essence, the overall results of 2-dimensional resistivity survey have good correlation with the well log description in the drilled piezometers and the electrical conductivity profile of groundwater at both project sites. The electrical resistivity profiles for the different sections of the two basins are presented in the BSWM Aquifer Characterization Report (2007).

7.4 Aquifer and well characteristics

Depth of aquifers

Table 1 shows the depth of aquifers in both sites based on the well logs and the equivalent apparent resistivity from the results of geo-resistivity survey.

Table 1. Depth of aquifers, aquifer characteristics and equivalent resistivity.

Project Site/Location in the basin	Depth , mbgs	Aquifer Materials Description	Apparent Resistivity, Ohm-meter
Pasuquin			
Upstream	7 - 14	Poorly graded sand with gravel	27 – 34
Midstream	1 – 6.5	Well graded sand with silt	112 -169
	14 - 25	Silty sand, fine to coarse grained and made up or rounded gravel and shell fragments	56 - 112
Downstream	6 -25	Poorly graded sand with shell fragment	23 - 25
Burgos			
Upstream	6 - 9	Silty sand with angular limestone gravels and shell fragments	6.5 – 9.5
	11 –23.5	Limestone, composed of coral and shell fragments	12 - 23
Midstream	2.5 -10	Limestone, composed of coral and shell fragments	20 -27
	25 -30	Limestone	7 - 14
Downstream	1 – 15 15 –25	Thickly bedded soft limestone with coral fragments Limestone with coral fragments	24 –35 12 - 24

In the Pasuquin site, aquifer materials primarily consist of silty sand to poorly graded sand. Upstream, aquifer layer consists of poorly graded sand materials located at shallow depth, is underlain by a very thick silty clay materials.

In the Burgos site, water bearing formation was noted in a thick layer of limestone. It was noted that a “losing water condition” was encountered during the drilling of piezometers in the midstream and downstream part of Burgos indicating that the limestone layers are very permeable. The discharge exceeds the maximum discharge limit (7 L/min) of the permeability apparatus.

Well Hydraulics

The water-bearing properties of aquifers were determined by conducting pumping tests (aquifer tests). Each test is conducted by using a discharging well and one or more observation wells. The discharging well is pumped at a steady state while the water level in the observation well is measured at scheduled time intervals. Well discharge is determined using a bucket of known volume and a timer to determine the time to fill the bucket. The difference in water level between the original water level or static water level and the level after a period of pumping is called drawdown. With the drawdown and recovery data obtained during the pumping test, the transmissivity, storativity (i.e., specific yield in case of unconfined aquifer) of the aquifers and the specific capacity of the well are determined. Pumping tests were conducted in selected dug wells and piezometers in the two project sites. Using the Time-Drawdown Method and Theis Recovery Test Method, transmissivity and storativity values were obtained. Also, specific capacity was calculated based on the observed drawdown during the tests.

The pumping tests conducted in November 2005 in the piezometers at Brgys. Nalvo and Salpad in Pasuquin, showed a significant drawdown in the observation wells during the tests so that the hydraulic aquifer characteristics were conveniently determined. The pumping tests were conducted for 8 – 16 hours. These tests utilized production wells and observation wells. The depth of production well in Nalvo, Pasuquin is 7.75 meters and the observation well is 24.54 meters. Both tap the same aquifer and a significant head decline occurred in the observation well during the test. In Salpad, Pasuquin the depth of the production well is 10.35 meters and the observation well is 13.77 meters. The tests revealed a transmissivity value of about 500 m2/day in the downstream (Brgy. Nalvo) and upstream (Brgy. Salpad) piezometers. The aquifer then can be classified as good aquifer. Storativity (specific yield) values were in the range of 0.002 to 0.019 (see Table 2). It was also observed that during the period Sept-Nov. 2005, the observed decline in water level ranged from 0.73 m (midstream) to 1.24 m (upstream) when the area received less rainfall. The results indicate that recharge to groundwater within the basin is accomplished by direct infiltration of rainwater through the overlying permeable soils.

In the case of the Burgos project site, insignificant decline in water level in the observation wells was noted during the pumping test such that aquifer characteristics could not be determined through the observation wells. Even the water level in the nearest observation well barely declined in response to pumping in the production well. Perhaps, the solution channels within the limestone aquifer are not continuously connected. The production/ pumping well was used in the calculation of aquifer hydraulic properties. At some point during the test, water level was observed rising despite continuous pumping, which was perhaps due to tidal influence. Based on the calculation and analysis, transmissivity value exceeds 80 m2/day (i.e., can be classified as a good aquifer) with specific yield of 0.11. During the period Sept-Nov., 2005, water levels declined from 0.76 m (i.e. at the downstream portion) to 1.39 m (i.e. at the midstream portion) in the piezometers. There was excessive drawdown observed in the piezometer in Brgy. Paayas reaching 6.54 mbgs at an average pumping capacity of 0.41 L/sec indicating low specific capacity.

Table 2. Pumping Test Result for November 2005

Well Location	Well Depth, mbgs.	Depth to Water Level, m		Ave. Capacity (lps) *	Draw down (m)	Spec. Capacity (lps/m) *	Trans-missivity, m2/day	Storage Coeff.
		Sep.	Nov					
Pasuquin (Piezometers)								
Nalvo (DS)	8	1.86	2.68	1.71	4.02	0.43	570	0.002
Nagsanga (MS)	8	0.87	1.60	2.97	5.65	0.53	180	--
Salpad (US)	10	3.75	4.99	2.23	1.67	1.33	535	0.019
Burgos (Dug well)								
Bobon (DS)	6			3.79	2.30	1.65	80	0.11
Burgos (Piezometers)								
Bobon (DS)	25	1.85	2.61	4.30	3.62	1.19		
Bobon (MS)	27	1.31	2.70	5.22	3.02	1.73	90	0.32
Paayas (US)	11	1.37	2.16	0.41	6.54	0.063	--	--

*Note: DS = Downstream; MS = Midstream; US = Upstream; * = Calculated for November*

Distribution of Wells

Most farmers preferred the utilization of surface water for irrigation in the light of increasing cost of fossil fuel required for diesel driven pumps to extract groundwater. However, the two pilot sites have limited surface water resource for irrigation in the dry season prompting them to utilize the shallow groundwater resource, which is abundant in both sites. This can be mirrored from the number of shallow tube wells and open dug wells constructed and installed in the pilot sites.

In the Pasuquin project site, a total of about 362 wells composed of 106 irrigation wells and 256 wells for household/domestic purposes were mapped. There were 6 piezometers installed in the basin through the project. Most of the irrigation wells are used to irrigate rice, garlic and vegetables using either small 1 ½ x 1 ½ inches or 2 x 2 inches centrifugal pump powered by 3 HP to 7 HP diesel engine. Wells for domestic purposes are utilized through manually operated pump or electric driven pump. Due to suspected poor water quality, water from the wells is not generally utilized for drinking purposes. The extent of shallow groundwater utilization and the abundance of shallow wells can also be mirrored in the Map of existing wells (BSWM Aquifer Characterization Report, 2007).

On the other hand, in the Burgos project site, a large number of irrigation wells serving an average of 0.30 ha and household wells were identified. A total of about 184 wells were mapped with 85 irrigation wells and 99 individual household tube wells. A majority of the farmers are using 7 HP diesel engine which is generally large for a 1 ½ x 1 ½ inches or 2 x 2 inches centrifugal pump. Some shallow dug wells ran dry during pumping because the rate of pumping exceeded the rate of groundwater replenishment of those wells.

Groundwater Flow Direction

The groundwater fluctuation was observed for the months of February, August and November in Pasuquin. In terms of groundwater flow, the direction of the flow line in the Pasuquin catchment is toward the sea. Groundwater elevation ranges between -0.6 to 14 masl. Flow direction is W to SW toward South China Sea. Low groundwater elevations were observed in wells near the coastline and at the midstream of the basin. Groundwater elevations were highest in the month of August when rainfall was at its peak. Due to suspected poor water quality, water from the wells is not generally utilized for drinking purposes.

In Burgos, groundwater depth ranges between -0.2 to more than 2 masl. The mid-section toward the North-east drainage creek has the lowest groundwater elevation. There was no major change with the pattern of groundwater flow, which is in a N to NE direction. The highest groundwater elevation was observed during the month of August when good recharge from rainfall occurred. It was observed that the flow line tends to go toward a creek/river on the northern part of the basin, which may indicate that the groundwater reservoir is discharging (losing) water to the adjoining river during the period (i.e., rainy season).

Water Level Fluctuation

Monitoring of water level fluctuations in the observation wells was started in December 2004 and April 2005 at Burgos and Pasuquin, respectively. Figure 6 presents the result of water level monitoring and rainfall observation in Pasuquin project site for 2006. As shown, the shallowest water level was also observed in July and August in synchrony with high rainfall during the period thus even reaching the ground level in some of the wells. The deepest water level was observed during March-April period, which is the peak of the dry season when groundwater extraction is high. Based on the groundwater level monitoring, the difference in water level (i.e., max and min) in a well ranged from a low of 1.74 m (max – 1.75 mbgs; min - 0.01 mbgs) to a high of 5.64 m (i.e., max – 6.27 mbgs; min – 0.63 mbgs). Average change in water level or water level fluctuation was about 3.57 m.

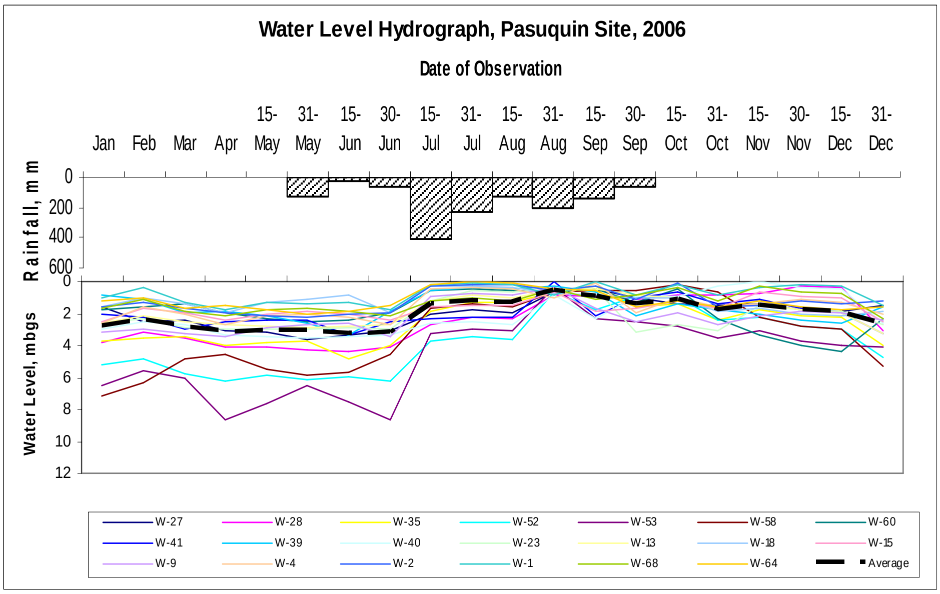


Figure 6. Observed groundwater level fluctuation in the observation wells at the Pasuquin project site (Jan –Dec 2006) (mbgs).

Figure 7 presents the result of water level monitoring and rainfall observation in Burgos project site for 2006. As shown, water levels follow the same pattern as in Figure 6 such that water level is also at its shallowest in July to September, coinciding with the peak of the rainy season. The deepest water level was observed from February to May during which the groundwater extraction also peaked due to the absence of rainfall. Based on bi-monthly measurements, water level fluctuations ranged from a low of 1.23 m (i.e. max – 1.81 mbgs; min – 0.58) to a high of 7.53 m (i.e., max – 7.60 mbgs; min – 0.07 mbgs) in any given well. Average water level fluctuation was about 2.52 m during the entire measuring period.

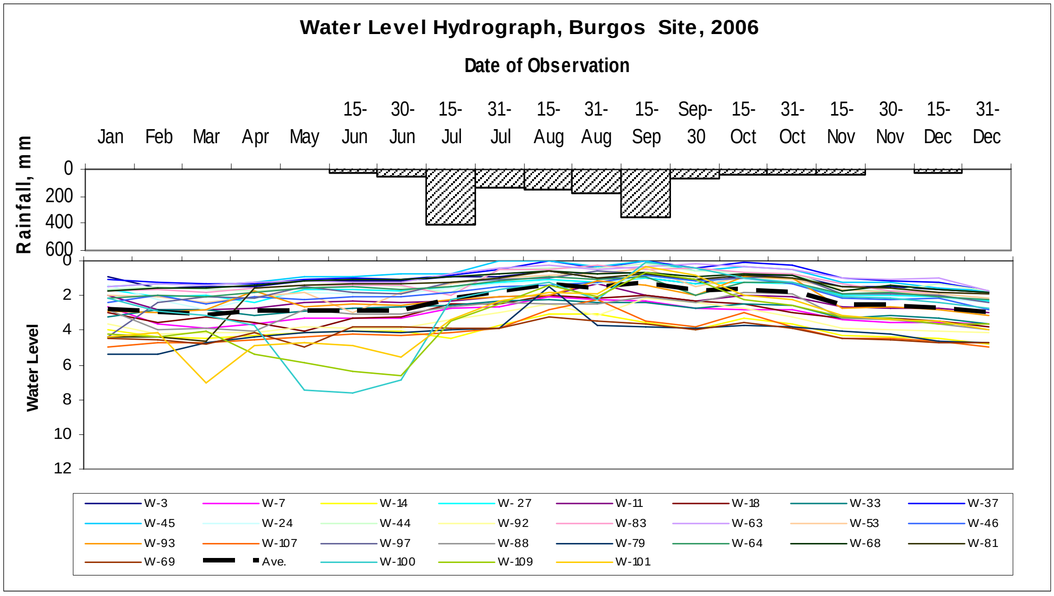


Figure 7. Observed groundwater level fluctuation in the observation wells at Burgos project site (Jan – Dec 2006) (mbgs).

Water level fluctuation every 15 minutes was also measured through a set of pressure transducers installed in piezometers downstream and upstream of both project sites. As presented in the BSWM Aquifer Characterization Report (2007), they were plotted with tidal fluctuations measured along the shore of Ilocos Norte. The groundwater level in the piezometer fluctuated following a define pattern (i.e., wavy pattern) with a declining trend. The trend, in the absence of recharge from rainfall, seems to follow the behaviour of the tidal fluctuation. The groundwater level was noted to be above mean sea level. During the rainy season, the behavior was different due the presence of recharge from rainfall resulting in abrupt rises in groundwater level in July.

The frequent monitoring of groundwater level in the upstream part of the Burgos Basin showed a more abrupt decline in water level during the month of March. This may indicate the high extraction of shallow groundwater in that area and leakage to the adjacent aquifer (i.e., the aquifer consists of silty sand underlain by thin sandstone and limestone aquifer). This will be confirmed through the analysis of more hydrographs.

Probable Groundwater Recharge

Groundwater recharge was estimated by considering the groundwater level rise in a given period (e.g. every half of the month) in response to rainfall events. For this purpose, the groundwater hydrograph in Figures 6 and 7 were analysed through the following procedure:

- Rainfall events that resulted in a rise in groundwater level were selected
- The rise in groundwater level associated with rainfall events was obtained from the groundwater hydrograph
- The equivalent recharge was estimated by multiplying the rise in groundwater level for the selected rainfall events by the specific yield of the aquifer, as determined from aquifer pumping tests at these piezometers
- Finally, the relationship between rainfall and recharge was established to determine the recharge rate with respect to a given rainfall amount (assuming that the regression passes through the origin).

Figures 8a and 8b present the relationship between recharge and rainfall in Pasuquin and Burgos project sites. Based on the 2005-2006 well data, about 10 % of the total rainfall (i.e., of sufficient amount to recharge the aquifer) in a given period recharges the aquifer in Pasuquin while a higher recharge rate (i.e., 13% - 17%) was noted in the Burgos project site, which usually occurs during the rainy season (i.e., June to October). This is perhaps due to thicker soils overlying the aquifer at Pasuquin than at the Burgos project site.

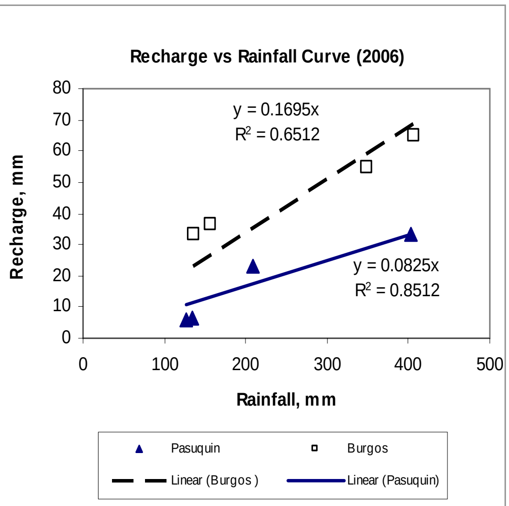
7.5 Groundwater chemistry

Water Quality in Wells

The following discussion is limited only to the chemical quality of groundwater in the project sites. Groundwater chemistry data has been collected for a number of open dug wells and piezometers from the both sites.

All samples for determining water chemistry were analysed in the laboratory. Water samples were collected every month using a submersible pump (i.e., BLA Self-Venting). These were placed in plastic bottles, which were thoroughly cleaned before using. All bottles with water samples were properly labelled before placing them in a cooler box and stored later in a refrigerator in the field station. While in transit going to the laboratory in

a. Estimated based on 2005 Data



b. Estimated based on 2006 Data

Figure 8. Curves showing the relationship between groundwater recharge and total rainfall in both Pasuquin and Burgos project sites (2005-2006).

Manila, samples were stored in the cooler box to preserve their inherent quality. The same procedures were applied in the collection of water samples from the rivers and creeks.

In case of EC, on site measurement was done bi-monthly using the down hole multi-probe that also measures the water level and temperature. EC was obtained from the surface and the bottom of the well. During the first in situ measurement, piezometers were thoroughly purged prior to the setting of the down hole probe to measure EC. Water was noted to be very clear before the purging was stopped. In the water sampling, however, the small submersible pump for sampling was also used in purging whose rate may not be enough to clean the well. Hence, succeeding water sampling used a bigger irrigation pump for purging.

Rainfall sampling was also undertaken as outlined in the following protocol:

- Rainfall was measured on each day that rainfall occurred. After recording the rainfall depth, the entire collected rainfall was poured into a 20-liter plastic container, which was then sealed to prevent evaporation. The container was initially rinsed with distilled water. At times of heavy rain, overflowing of the rain gauge was recorded and noted
- Rainfall volumes that were collected on the following days were added to that already in the 20 litre container
- When the 20 litre container was almost full, or at approximately two-weekly intervals (whichever occurs first), it was sub-sampled by filling up a 200 ml plastic bottle which was rinsed by using the collected rainfall from the 20 litre container. The date of sub-sampling was then recorded
- The 20-liter container was emptied and was re-filled on the following rainfall events.

In Burgos project site, the background groundwater salinity measured in February 2005 in the open dug wells is between 500 and 1000 μS/cm. This is dominated by calcium bicarbonate salts derived from weathering of the limestone. A few bores contain elevated salinities between 4000 and 5000 μS/cm despite their locations are almost 1 km from the coastline. The elevated salinity values which were noted in some of the dug wells (2 – 3 m depth) may indicate the area of highest groundwater extraction. It is possible that saline groundwater occurs at depth over much of the lower parts of the catchment, and that this has been drawn upwards into the bores by groundwater pumping.

Table 3 presents the in situ measurement of salinity (November 2005) in the newly installed piezometers at Burgos using the downhole multi-probe. The deepest piezometer (25.14 m) located about 300 m from the coastline yielded a high EC of about 3,700 μS/cm on the surface and 12,500μS/cm on the bottom. On the other hand, the deepest piezometer (21.5 m) midstream (i.e. about 700 m from the shoreline) gave a very high EC of about 7,400 μS/cm at the surface and 21,500 μS/cm in the bottom. This is located at the center of the paddy field in which groundwater extraction is expectedly high. It is noteworthy these elevated salinities are obtained near the dug wells in which high salinities were also observed in February 2005. These values may indicate the extent of saltwater intrusion along the coastal aquifers and the magnitude of groundwater extraction within the area. With the nature of the aquifer observed (i.e., thick limestone bed) saline water occurring at the deepest parts can be drawn upwards into the bores by groundwater pumping. The deepest piezometer in the upstream portion about 1.20 km from the coast has a much lower measured EC of about 2000 μS/cm.

In the case of Pasuquin sites, salinity measured in existing wells is relatively lower than that of the Burgos site (300 – 900 μS/cm). The elevated values were noted in wells near the shore and in those within the paddy field where groundwater extraction is intensive. Measured salinity in the piezometers was relatively lower than that of the piezometers in Burgos. It is just within the range of about 150 – 500 μS/cm as shown in Table 3. Even the deepest piezometers did not show elevated values of salinity unlike in Burgos, which may indicate a lesser salt water intrusion within the basin. This can be attributed to the differences in the nature and characteristics of aquifers (i.e., Burgos site with limestone aquifer as against sandy aquifer in Pasuquin) and extent of the basin (i.e., Pasuquin basin is broader than Burgos).

Table 3. Piezometer Readings in Burgos and Pasuquin project Site (November 18, 2005)

Piezometer No.	**Location**	**Depth of Well, mbgs**	**Water Level, mbgs**	**EC, μs/cm**		**Temperature, oC**	
				Surface	**Bottom**	**Surface**	**Bottom**
Burgos							
1 (DS)	Brgy. Bobon	9.00	2.18	642	1,003	37.50	37.20
2 (DS)		25.14	2.17	3,720	12,500	**	**
3 (MS)	Brgy. Bobon	8.65	1.98	278	288	**	**
4 (MS)		21.50	2.39	7,440	21,500	37.00	**
5 (US)	Brgy. Paayas	11.61	1.80	241	720	34.60	35.50
6 (US)		14.43	3.90	98	927	35.70	37.40
7 (US)		25.24	4.18	96	2,180	34.40	38.90
Pasuquin							
1 (DS)	Brgy Nalvo	7.75	2.68	276	282	30.60	37.50
2 (DS)		23.45	2.21	257	283	36.40	37.10
3 (MS)	Brgy. Nagsanga	7.75	1.27	159	398	30.70	36.10
4 (MS)		25.00	1.41	378	300	35.90	35.60
5 (US)	Brgy. Salpad	10.34	4.695	263	490	34.20	35.20
6 (US)		14.43	4.71	294	520	35.60	35.20

Note: EC of seawater = 42,000 μs/cm; DS – Downstream; MS- Midstream; US- Upstream

*** Measured temperature was too high; probable error in EC probe calibration may have been encountered*

Results of water chemistry of water samples from the two sites indicate carbonate source of origin. Water from Bobon wells is mostly of limestone origin while in Pasuquin, water composition is influenced by the mixture of limestone (Pasuquin Limestone and Laoag Formation) and volcanic deposits. Piper diagrams developed in 2005 (October and June) and 2006 (February, August and November) that described the shallow groundwater chemistry are presented in the BSWM Aquifer Characterization Report (2007). Based on these diagrams, there are two groups of wells identified at the Pasuquin site. The majority of wells have high total calcium and magnesium percentage (>80% of cations) and others have less (i.e. wells 7 and 10). All samples contained less than 50 percent of anions as chloride ion. On the other hand, wells in Burgos illustrate that mostly water samples are of carbonate origin. All samples except from well 79, have more than 80 percent total calcium and magnesium ion with less than 50 percent chloride. Well 79 water sample has less than 50 percent calcium with almost 60 percent chloride ion. Appendix 6a presents the piper diagram which also shows the composition of major cations and anions at the start of the rainy season (i.e., June) in the study area. Compared with the piper diagram for October, points are more disperse reflecting the variability of water quality in all the wells due to groundwater extraction in some of the wells during the fallow stage of land preparation at the onset of the wet cropping period.

In 2006, water quality in the observation wells was again analyzed. Groundwater ion concentration of Pasuquin is grouped into Ca (HCO3)2 and Na HCO3 particularly in Feb and Nov. In August, ion concentration fitted the Ca (HCO3)2 group. Because of high calcium and bicarbonate concentrations it can be inferred that groundwater is derived from a meteoric water source and influenced by adjacent limestone deposits. In the case of Burgos, during the months of Feb and Nov, groundwater ion concentrations are divided into two groups, Ca(HCO3)2 and, NaCl. Considering all SO4 was low in the second group, NaCl appears to dominate the group (as expected of sea water). Well 27 at the center of Bobon and piezometers are in the NaCl group. This shows relatively high concentration of salt in this area. However for August, ion concentrations fitted Ca (HCO3)2 and CaCl2 groups. Increases in Ca concentration are possibly caused by rainfall influx that passes through weathered limestone while Na ions decrease due to ion exchange (BSWM Aquifer Characterization Report, 2007).

Figure 9 shows the relationship between electrical EC and total dissolved solids from the water samples. The measured total dissolved solids (mg/L) are approximately equal to 0.6 multiplied by the electrical conductivity (μS/cm), which confirms that most salts in the groundwater have been accounted for. Figures 10 and 11 show the relationships between chloride concentration and electrical conductivity, and between bicarbonate concentration and electrical conductivity. They indicate that high salinity ground waters are associated with high chloride, presumably of marine origin.

EC values range from less than 0.65 to 1.66 mmhos/cm. EC values are much lower in Pasuquin than in Burgos. Higher EC value (more than 0.65) is delineated near the coastline at the mid section where tributary creek dissects the flat area. Like Burgos, EC values are reduced due to rainfall in the month of August. The spatial distribution of electrical conductivity (EC) in Burgos is presented in detail in the BSWM Aquifer Characterization Report (2007). Low conductivity (less than 0.65 mmhos/cm) is observed predominantly in elevated agricultural land. Higher EC (0.65 to 3.0 mmhos/cm) is observed in flat low land areas, where it becomes higher (3 to 5 mmhos/cm) at the mid-center of Bobon in the month of Nov. This condition is suitable only for highly salt tolerant crops. During the rainy month of August, EC values decrease considerably.

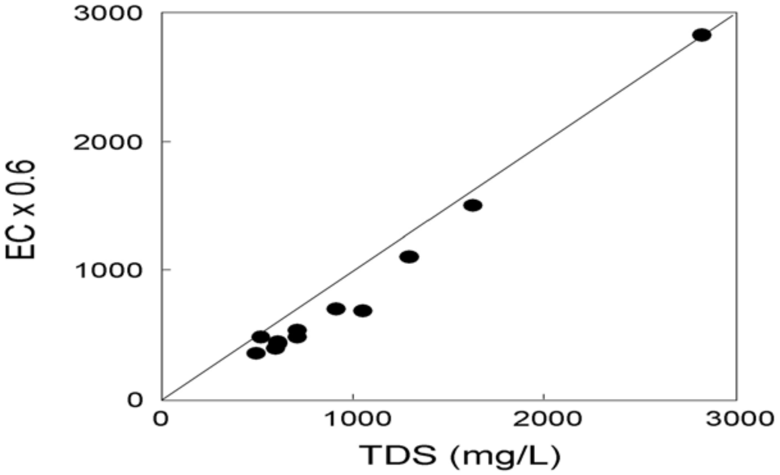


Figure 9. Relationship between total dissolved solids and electrical conductivity for groundwater from the Burgos field site.

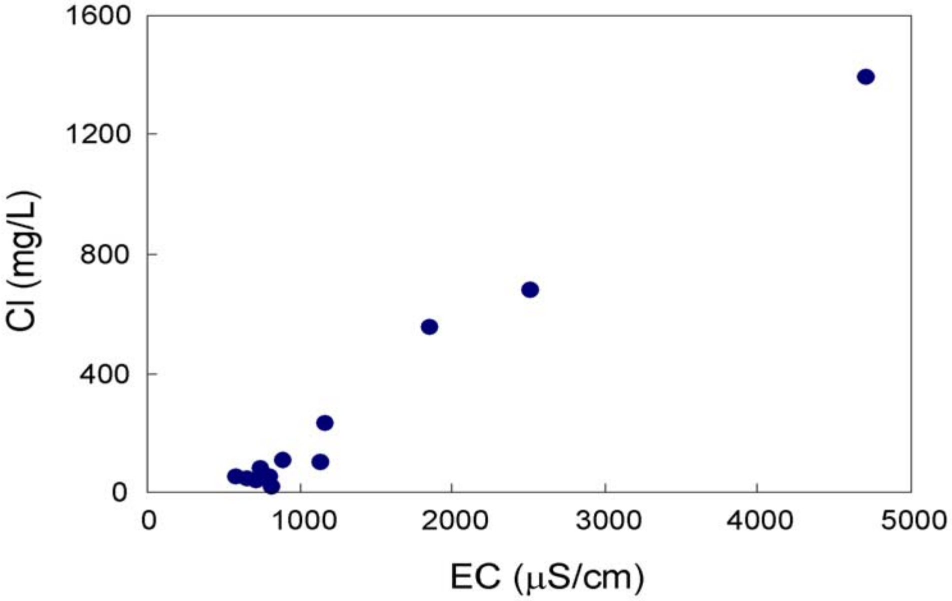


Figure 10. Relationship between chloride concentration and electrical conductivity for groundwater from the Burgos field site.

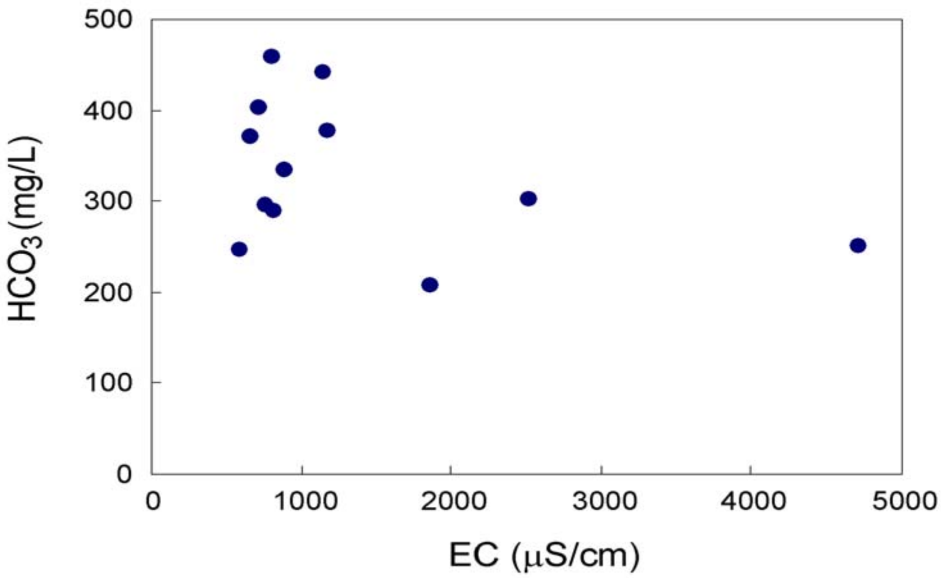


Figure 11. Relationship between bicarbonate concentration and electrical conductivity for groundwater from the Burgos field site.

Chemistry of water from river and rainfall

Determination of water quality from rivers and waterways is also essential to determine their suitability as potential sources of water (i.e. storm water) for aquifer storage and recovery (ASR), if feasible. Based on the results of the analysis, the water quality from these sources for both sites is not expected to pose any problem once ASR is implemented. Elevated salinity values and Sodium Absorption Ratio (SAR) were noted in Burgos but those may occur only in the downstream portion of the identified waterway, which is not expected to be the pumping point for ASR. Besides, those values can be classified as a representative of moderate class in terms of use for agriculture purposes.

Rainfall chemistry was also obtained considering that rain may contain traces of mineral matter, gases and other substances as it falls on the land surface. However, the chemical characteristics of rainwater may change considerably as it moves toward and within the zone of saturation. The change depends largely on the types of rocks through which water passes. The rainfall and water (from river) chemistry was obtained during the period June 2005 –February 2006. Turbidity analysis from drainage rivers within the project site during a specific rainfall event is shown in Table 4.

Table 4. Turbidity analysis from drainage rivers within the project sites during a specific rainfall event between June 2005 –February 2006 (Formazine Attenuation Units)

Pasuquin Site:	**Burgos Site:**
Downstream - 1 FAU Midstream - 0 FAU Upstream - 1 FAU	Downstream - 78 FAU Midstream - 11 FAU Upstream - 59 FAU

This suggests that at the time of sampling the surface water at Pasuquin had a low turbidity in comparison with that at Burgos. The dissolved organic carbon content of the Pasuquin water will determine whether it is suitable for aquifer storage and recovery via sand aquifers and the type of treatment required before injection. The water from this sample at Burgos would not be suitable for ASR except perhaps in the limestone aquifer. More samples are necessary to understand the temporal variability of water quality and draw sound conclusions on suitability of this water for enhanced recharge at either site.

7.6 Comparative assessment of agricultural productivity using shallow groundwater and surface water.

The economics of the use of shallow groundwater is necessary to determine economic sustainability. Farm survey and key informant interviews were undertaken to assess the economics of the use of shallow groundwater particularly open dug wells and shallow tube wells as supplemental irrigation in two groundwater basins or pilot study sites.

Considering average farm size of 0.6 hectare, only 30 to 50 percent is devoted to garlic. Farmers generally do not fully utilize the entire farm during the second crop because of water limitations, capital requirement for material inputs and also because of farm labor limitations. The predominant tenancy status explains the low capacity of farmers, whose farm sizes are small to access capital to increase their production. Based on 2005 prices, access to use of shallow ground water using shallow tubewell (STW) or open dug well (ODW) required investment of about P58,000 - PhP60,000 per unit when using a Japan-made engine and about P20,000 - P25,000 per unit when using a China-made engine and centrifugal pump.

The farms are traditionally grown to rice during the wet season and predominantly followed by garlic. Other preferred crops aside from garlic include corn, peanut, onion, tomato and mungbean. On crop productivity, the supplemental use of shallow groundwater for rice has improved rice yield level. The use of shallow groundwater during the dry season enabled second cultivation of farms to the above-mentioned crops. Otherwise farms would be fallowed because of the water limitation.

The economic analysis based on partial farm budgets revealed that growing a hectare of garlic generated a total return three to four times than that of rice. In terms of gross margin, garlic provided a return five to six times that of rice. The data supported the choice of majority farmers that growing garlic using shallow groundwater remained an attractive option relative to onion, tomato, corn, peanut and mungo bean. Indeed, the use of shallow groundwater contributed substantial margin to farmers at the two sites in both wet and dry seasons. The sensitivity analysis revealed that farmers also have to be knowledgeable of farm prices to realize higher margins from use of shallow groundwater.

The efficient use of shallow groundwater will enable expansion of farm utilization. Additionally, combination of preferred crops should match capacity of farmers to provide investments and farm labor.

Considering the results of this study, the positive contributions of shallow groundwater to improving farmers' income is confirmed as cited in the BSWM Report "Comparative Economic Assessment of Agricultural Productivity using Shallow Groundwater and Surface Water in Ilocos Norte" (2007).

7.7 GIS Data base development

In view of the voluminous data and information generated by the project, the processing, consolidation, and integration of these data were done within the GIS framework as one of the project major components. The specific objectives of this project component are the following: to provide a structured database that can both handle and integrate spatial and tabular datasets; provide data processing and analyses that would complement and substantiate the modeling and simulation components of the project; and provide digital mapping capability for the two study sites.

7.8 Framework and data organization

The overall framework of the project is geared towards a sustainable utilization of shallow groundwater to enhance agricultural production. Hence, each of the undertakings and initiatives of the different teams were collectively directed to produce better options and strategies in the management of groundwater, which is a limited resource. As shown in Figure 12, the framework is virtually composed of two parts: the database composition and the modeling and simulation aspects. The organization of the database was dependent on the collected/generated data from the multidisciplinary teams, while the modeling and simulation part basically utilized and manipulated the database to derive vital information that would influence sustainable groundwater management. A groundwater model called MODFLOW (modular three-dimensional finite-difference groundwater flow model) was employed to assess and evaluate the sustainability of groundwater supply, including groundwater dynamics (McDonald and Harbaugh, 1988). Whereas, spreadsheet calculation/simulation was carried out for agro-economic modeling to determine cropping systems viability in relation to the use of groundwater.

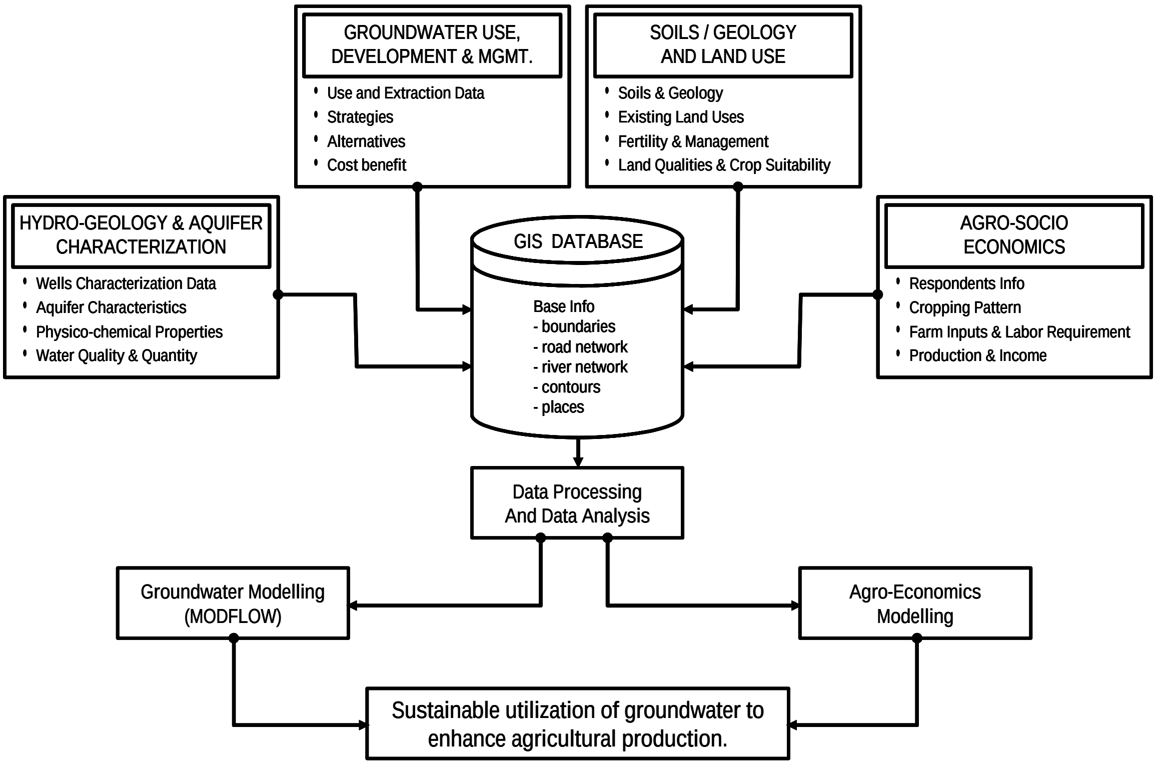


Figure 12. Framework for a GIS-based data integration.

7.8.1 GIS Database

The core of the framework is the GIS Database where the data are stored, organized, and managed. This is essentially the repository of all the data that were gathered from site or field evaluation and from other existing information, collected from a number of installed instruments within the study sites as well as from physico-chemical analyses, and those generated from experimentation. More importantly, the database contains the base map and other thematic layers, with corresponding attributes, where the rest of the data or records were linked geographically. Attribute datasets were organized in a relational tabular format, wherein a particular record corresponds to a specific feature on the map, and vice versa. The initial spatial data included base maps for Ilocos Norte province and the two study sites at the municipalities of Pasuquin and Burgos. Base map features consisted of boundaries, road network, river network, contour lines, and names of places.

The following are the major project outputs that were processed, analyzed and integrated in the database:

- ArcGIS graphical user interface (GUI) that shows the compiled data sets and assembled base information (i.e.,main view window) for both Pasuquin and Burgos study sites
- Soil maps and parent rock type maps as an attribute of the project soil map
- Crop suitability maps that indicates suitability ratings for specific crop (e.g., rice, garlic, corn, and onion) for a specific cropping pattern and calendar being practiced in the project site
- Digital elevation models with the generated maps utilized in the MODFLOW model
- Map of existing wells and pumping density map that indicates the volume of groundwater being extracted per area per year
- Maps of seasonal variations of salinity in both basins or study sites.

The details of project GIS database establishment and output description are presented in the BSWM Report on Geo-information for sustainable shallow groundwater management (2007).

7.9 Groundwater modelling

In June 2006, a training course on groundwater modelling was held in BSWM office in Manila. A one day introductory seminar was attended by 26 staff from BSWM and other agencies concerned with water management. Eight of these staff then received hands-on training using the MODFLOW software. Following this course, Engineers Jane Fantilanan and Oscar Carpio took part in a three week advanced training program in Adelaide in November 2006, where they began construction of a groundwater model for the Burgos site, under the guidance of Dr Peter Cook (CSIRO) and Mr Paul Howe (REM). Paul Howe then spent three days at BSWM in Manila in June 2007, to assist Engrs. Fantilanan and Carpio set up the model for the Pasuquin field site.

In the modelling exercise, the scenarios they look into include the possibility of increasing the areas for garlic production during dry season cropping that is considering the current level of recharge in both basins. The possible effect of reduced rainfall due to drought and or dry spell (i.e., usually associated with El Niño phenomenon) was also studied. In the process, possible expansion areas were determined such that future groundwater extraction will not exceed the rate of recharge.

Groundwater pumping regimes are reasonably well defined for the model domain. However, recharge, which is an important component of the model water balance (especially in relation to the proportion of water inputs compared to pumping and coastal discharge; water outputs), remained an ill defined input for the model requiring evaluation. Consequently at each site three separate models were developed to express the uncertainties relating to net recharge rates and aquifer hydraulic parameters. For each site models with low, moderate and high recharge rates were calibrated to fit the observed groundwater level data, and gave low, moderate and high permeability respectively. This sensitivity testing of recharge rates and aquifer parameters, as documented for both sites, has the benefit of revealing the risks posed to useful aquifers by groundwater development.

The results of the groundwater modelling are summarized below.

Burgos Groundwater Modelling

The important conclusions arising from the numerical groundwater flow modelling assessment of the Bobon site are the following:

Bobon3 model

The Bobon3 model predicts that under conditions of low recharge on the coastal plain (60 mm/yr) and low coastal aquifer hydraulic conductivity (1 to 6 m/day), higher rates of pumping and prolonged drought are likely to critically reduce groundwater levels and groundwater discharge at the coast to such an extent that sea water intrusion may compromise irrigation and domestic water supplies.

Bobon5 model

The Bobon5 model predicts that under conditions of moderate recharge on the coastal plain (100 to 120 mm/yr) and moderate coastal aquifer hydraulic conductivity (2 to 10 m/day), higher rates of pumping and prolonged drought are likely to reduce groundwater levels and groundwater discharge at the coast such that sea water intrusion may compromise irrigation and domestic water supplies. However, the risk appears less than that which may become apparent in the case of the Bobon3 model.

Bobon6 model

The Bobon6 model predicts that, under conditions of high recharge on the coastal plain (150 to 175 mm/yr) and moderate coastal aquifer hydraulic conductivity (2.5 to 15 m/day), simulated higher rates of pumping and prolonged drought are unlikely to reduce groundwater levels and groundwater discharge at the coast to such an extent that sea water intrusion becomes a major problem for the Bobon catchment. However, this is not to say that high rates of pumping at the coast will not give rise to some instances of seawater intrusion.

Artificial recharge

Artificial recharge during the dry season (October to November), possibly using surface water collected during the wet season as a water source, has been shown to have the potential to partially off-set the effects of increased rates of pumping and drought during the garlic growing season, particularly in the case where low recharge and aquifer hydraulic conductivity occurs (i.e. the Bobon3 model simulations).

Only one artificial recharge strategy has been tested during the model development work documented in this report. It is possible that other strategies, involving artificial recharge at different rates and over different time periods, or alternative locations, may provide better results. Further testing will be required to fully assess the potential of this management option.

Burgos Conclusions

With the existing information available, it is not yet possible to differentiate between the three candidate models at Burgos as each can be fitted with similar precision to the observed groundwater levels and water level changes. Continued data acquisition will ultimately show which of these models best fits the relevant site data, taking account of any changes in groundwater extraction.

Models with higher recharge rates (and corresponding higher aquifer transmissivities) will result in higher values for sustainable groundwater extraction than the other models. For the purposes of economic evaluation, an estimate within the likely range of sustainable shallow groundwater extraction was made. Thus, the Ground Water Flow Model 5 (Bobon5) was selected to initially represent the groundwater system of Bobon, Burgos, Ilocos Norte. Simulation runs were conducted for different areas for garlic production to determine the optimum area that could be irrigated by the shallow groundwater system without any adverse environmental impacts (e.g. salt water intrusion). Basic assumptions include: the cropped area for rice does not vary with year and additional water demand for domestic water supply will be extracted from deeper aquifers. The annual water requirement for garlic use in the simulation is 3,128 cum/ha per season (i.e. at an average potential evapo-transpiration (PET) of 3.4mm/day for 92 days growing period). The model groundwater recharge values are 100, 15, 120 mm/year assigned to zone 1, zone 2 and zone 3 respectively. Simulation results indicated that the potential available water for extraction is about 190,000 m3 which could irrigate about 60 ha for garlic intensification during the dry season.

Note however that the vertical gradient in salinity at piezometers 1 and 2 suggest that increasing production at Burgos may possibly result in up-coning of deeper saline groundwater (Table 3) into wells that would increase the salinity of irrigation water where this occurs. Groundwater discharge to sea will be needed to maintain the head of freshwater in the aquifer to inhibit up-coning and keep groundwater supplies fresh. Further monitoring of groundwater use, groundwater levels and salinity at Burgos is recommended to allow adaptive management, in response to wet and dry years and as crop areas and patterns change. If salinity increases in any wells, it will be necessary to reduce the maximum drawdown of those wells and possibly all wells, which may involve reducing total extraction as well as changing the patterns of pumping from each well to allow recovery of heads between successive pumping cycles. The proposed increase in extraction at Burgos should only take place if accompanied by groundwater monitoring and adaptive management practices.

The details of the result of groundwater modelling in Burgos are presented in the BSWM Groundwater Modelling Report (2007).

Pasuquin Groundwater Modelling

The important conclusions arising from the numerical groundwater flow modelling assessment of the Pasuquin catchment are the following:

Pas4 (GW model 4)

The Pas4 model predicts that, under coastal aquifer (zone3) conditions of low recharge (110 mm/yr) and low hydraulic conductivity (5 m/day), higher rates of pumping and prolonged drought are likely to critically reduce groundwater levels and groundwater discharge at the coast to such an extent that sea water intrusion may compromise irrigation and domestic water supplies.

Pas5 (GW model5)

The Pas5 model predicts that, under coastal aquifer (zone3) conditions of moderate recharge (135 mm/yr) and moderate hydraulic conductivity (10 m/day). The higher hydraulic conductivity cause about 70% of the annual recharge to drain to the sea. Higher rates of pumping and prolonged drought are likely to reduce groundwater levels and groundwater discharge at the coast such that sea water intrusion may compromise irrigation and domestic water supplies. However, the risk appears less than that which may become apparent in the case of the Pas4 model.

Pas6 (GW model6)

The Pas6 model predicts that, under coastal aquifer (zone3) conditions of high recharge (180 mm/yr) and moderate coastal aquifer hydraulic conductivity (14 m/day). The high hydraulic conductivity is the mean parameter that causes about 90 per cent of the annual recharge from rainfall to drain directly to the sea. The simulated higher rates of pumping and prolonged drought are unlikely to reduce groundwater levels and groundwater discharge at the coast to such an extent that sea water intrusion becomes a major problem for the Pasuquin catchment. However, this is not to say that high rates of pumping at the coast will not give rise to some instances of sea water intrusion.

Pasuquin Conclusions

For the purposes of economic evaluation, an estimate within the likely range of sustainable shallow groundwater extraction was also made. The Ground Water Flow Model 4 (Pas4) was selected to initially represent the groundwater system of Pasuquin, Ilocos Norte study site. Simulation runs was conducted for different areas to be cultivated to garlic (i.e. during the dry season) to determine the optimum area that could be sustainably irrigated by the Shallow Groundwater System. Basic assumptions include: the cropped area for rice does not vary with year and additional water demand for domestic water supply will be extracted from deeper aquifers. The annual water requirement for garlic as use in the simulation is 3,128 cum/ha-yr (i.e. @ potential evapo-transpiration (PET) of 3.4mm/day for 92 days growing period). The model recharge values used in the model were 15, 90, 330 and 180 mm/year that were assigned to the respective model zones. Based on this groundwater model, about 280,000 m3 are available per year for optimum groundwater extraction that could be translated into an equivalent of 90 ha for garlic production intensification.

Although the existing information does not permit differentiation between the three alternative models at Pasuquin, continued data acquisition will ultimately reveal the potential of the groundwater resource at this study site. Currently, there is no evidence of groundwater salinisation to a depth of 25m in the Pasuquin study area, suggesting that groundwater use could be increased. However constraints on the availability of land with soils that are suited to dry season irrigation of garlic or onion may restrict the potential for increased agricultural production through sustainable use of groundwater in the Pasuquin study site. This is discussed further under the section on economic modelling.

The details of the groundwater modelling prepared for Pasuquin are presented in BSWM Groundwater Modelling Report (2007).

In the future, when the groundwater models are validated, the economic evaluation may be updated also. Once this outcome is achieved, our resolve to advocate a groundwater management regime that will ensure sustainable use of the groundwater resource can be strengthened.

7.10 Economic Modelling

Using the Microsoft Excel, the different scenarios, management options and alternatives were laid out in the spreadsheet. The detailed results of the economic modelling are presented in BSWM Economic Modelling Report (2007).

Economic model for Burgos

Sustainable groundwater utilization

Groundwater utilization at different scenarios, management options and alternatives was compared to the optimum groundwater extraction. The study showed that at optimum extraction of 190,000 m3 as suggested by the mid-range Burgos groundwater model (Bobon5), the use of shallow groundwater for intensified garlic production can be expanded from existing areas of about 43 hectares to 60 hectares of highly and moderately suitable areas. This means full utilization of 60 hectares to garlic out of 85 hectares currently devoted to rice-garlic. Intensified garlic production at this level translates to an increase in effective area utilization of about 17 hectares from the existing use of about 43 hectares. Garlic production intensification would mean expanding garlic production to include portions of moderately suitable areas.

Full utilization of 60 hectares from the existing areas without regard to soil suitability may inevitably result in lower farm productivity and income. Crop output per unit of shallow groundwater from these areas becomes less compared to crop output from highly and moderately suitable areas.

On the other hand, diversifying production to garlic and onion at optimal level of groundwater extraction means lesser farm utilization equivalent to 58 hectares (30 hectares for garlic and 28 hectares for onion since onion has higher water usage than garlic). This translates to an increase in effective area utilization of about 15 hectares from the existing use of 43 hectares.

Enhanced farm productivity

At optimum groundwater extraction of 190,000 m3, the 60 hectares when cultivated to garlic regardless of soil suitability classes, will translate to a production of 186 mt based on existing average yield level of 3.1 mt/ha. However, directing garlic production in 60 hectares of highly and moderately suitable areas would enhance productivity to 318 mt/yr; indicating an increase of 132 mt of garlic (BSWM Economic Modeling Report, 2007).

At said optimum level of extraction, diversifying production to garlic and onion in 58 hectares of highly and moderately suitable areas would yield 160 mt of garlic and 197 mt of onion, considering existing yield levels of both crops.

Economic benefit

With crop intensification, economic benefit in terms of total production value is estimated at PhP6.5 million from production of 186 mt garlic in 60 hectares (i.e. regardless of soil suitability). Higher benefits would result from intensified garlic production in highly and moderately suitable areas to garlic considering optimum ground water extraction of 190,000 m3. This translates to an additional economic benefit of about PhP 4.6 million considering a total production value of PhP 11.1 million from about 60 hectares of highly and moderately suitable areas (BSWM Economic Modelling Report, 2007).

Under crop diversification scheme with 160 mt of garlic and 197 mt of onion harvested in 58 hectares at optimum ground water extraction, total production value is calculated at PhP8.6 million.

Considering the total production value from use of highly and moderately suitable areas, intensified production of garlic would provide greater benefit for the economy than diversified production of garlic and onion. Production support from the local government and the private sector is thus important for the farmers considering their limitation in capital to expand garlic production.

Economic model for Pasuquin

Sustainable farm utilization

Using the more conservative model (Pas4) for estimating groundwater resource potential, the study showed that utilization of 280,000 m3 in Pasuquin, about 90 hectares could be devoted to intensify garlic production. This is similar to the existing area of garlic production during the dry season (i.e. equivalent to just half of total cultivated area of 180 ha during the rainy season). However, instead of using only the existing garlic farms, directing cultivation to highly suitable areas would result in substantial increases in farm production.

With this more conservative model (Pas4), diversification is no longer a practical option as onion requires more water than garlic. Larger prediction of the resource as in Pas5 and Pas6 models may provide more options for diversification.

Enhanced farm productivity

The optimum groundwater extraction of 280,000 m3 in 90 hectares of highly suitable areas translates to an improved garlic production of 810 mt (BSWM Economic Modelling Report, 2007), primarily as a result of shifting irrigation to highly suitable areas.

Improved economic benefit

Economic benefit in terms of total production value is almost PhP28.4 million from production of 810 mt garlic in 90 hectares of highly suitable areas considering optimum ground water extraction of 280,000 m3 (BSWM Economic Modelling Report, 2007). Restricting production to highly suitable areas would positively contribute to the economy as the current area of 90 hectares generates only almost PhP 11 million. Thus, the benefit to the economy would be more than double. Farm investment and labor can be directed to other less water consuming crops.

7.11 Sustainable Water Management Strategies

One of the final outputs of the project will be sustainable water use strategies that could be adopted in the project sites. They consist of options for water supply and demand management that will ensure shallow groundwater resource sustainability while enhancing agricultural production particularly in areas in which the primary source of water for irrigation is the shallow groundwater resource. This will pave the way for developing a Philippine approach to the sustainable utilization of shallow groundwater to enhance agricultural production in rainfed lowlands.

As previously discussed, the assessment of shallow groundwater resource in terms of water quality, spatial extent and yield was first undertaken. The result was then utilized to evaluate the potential of shallow groundwater to enhance agricultural production under range of scenarios through groundwater modelling and economic modelling. Within each groundwater basin, sustainable groundwater use strategies were formulated based on the following:

The potential of shallow groundwater resources;

- Future scenarios of shallow groundwater utilization in terms of
    - Potential increase in shallow groundwater utilization (i.e., through crop intensification and/or crop diversification)
    - Probable annual decrease in rainfall and groundwater recharge
    - Combination of both (a) and (b)
- Farmers suggestions in consultation with them
- Current water management status
- Existing relevant policies (e.g., Water Code of the Philippines)

This section contains formulated specific sustainable water use strategies identified based on the results of technical studies and consultation with farmers and local government unit agricultural staff and other local stakeholders. These strategies are anchored on the basin approach of shallow groundwater management and guided by national policies on the protection, management, and conservation of our shallow groundwater resource.

7.11.1 Institutional empowerment and creation of an enabling environment

The allocation and appropriation of the country's water resources is vested to the NWRB (National Water Resources Board). It is the central regulatory and coordinating body for the proper utilization, exploitation, development, conservation and protection of the country's water resources. However, it lacks regional and local offices that could implement the management control at the local level, much more at the basin level. This is the persisting issue being raised by water users particularly on the implementation of the water permit system. With that limitation of NWRB as a regulatory body, the management control mechanism for groundwater use as embodied in the Water Code cannot be effectively implemented.

The Local Government Code of 1991 provides for the local government units (LGU) to prepare their own comprehensive land use plan. This plan has relevance to the potential increase in water demand. As such, the LGU should play a key role in undertaking regulation and control at the local level to ensure that groundwater extraction will not go beyond the acceptable limit (i.e., sustainable yield). To perform such role the following should be undertaken:

- Strengthen LGU capability on shallow groundwater resources management that include water level and groundwater extraction monitoring. In this aspect, LGU staff were involved in the mapping of wells and measurement of groundwater levels and water sampling
- Explore the possibility of LGU as a deputized agency of NWRB. A letter of inquiry was sent to NWRB regarding this matter. Initially, NWRB provided initial information but with more emphasis on the implementation of the Philippine Water Code
- Encourage the LGU to pass local ordinances that pertains to the protection of groundwater resources. This was suggested by the farmers during the consultation and is currently being tackled by the municipal councils of Pasuquin and Burgos
- Involve local farmers' participation through the establishment of Farmer-managed groundwater systems in the pilot study sites. The concept was introduced to LGU, farmers and stakeholders aimed at ensuring the sustainability of the groundwater resource. The concept recognized the role of the farmers in the protection and management of the resource. They should be trained to understand the full process of groundwater recharge and extraction within the basin to encourage them to prepare a cropping pattern plan that would reduce groundwater extraction. During the project extension, the Farmer-managed Groundwater System was pursued in 2008-2009 as a scheme to implement the sustainable water management strategies developed through the project. Farmers' trainings were done through the establishment of Farmer Water Schools (FWS) which where agricultural technicians were trained as trainers for farmers. In FWS, the following topics were discussed in layman's terms: groundwater concepts and availability; impact on crop growth; role of institutions in sustainability and gender equity. Initial consultation was undertaken December 12, 2007. The preparation of training module was also completed. The highlights of the meeting are presented in the BSWM Farmers Consultations and Project Meetings Report (2007).

7.11.2 Specific Strategies

Specific strategies are activity and land use based strategies that could address specific issues and concerns. Hence, some of the management approaches may vary according to individual situations. On this premise, specific strategies are classified as those that cover shallow groundwater resource management, field water management and on-farm management as outlined below:

Shallow Groundwater Resource Management

Provide alternative water supply sources to avoid over exploitation of shallow groundwater resources. This strategy considers the best available option for water resources development. Areas where surface water development is more appropriate and feasible should be assigned a lower priority for shallow groundwater development. This will reduce the pressure on groundwater and will lead to the conjunctive management of water resources. This strategy was also suggested by the farmers during the first farmers/public consultation held in both study sites.

Limit shallow groundwater extraction in coastal areas to avoid saltwater intrusion. Considering that both study sites are located within coastal aquifers, elevated EC values were observed particularly in Burgos. Both groundwater levels and water quality should be regularly monitored as coastal aquifers exist in a delicate balance with the sea and need extremely careful management. This strategy was also identified by the farmers during the public consultation in July 23-25, 2007. Limiting the depth of new wells may assist in inhibiting excessive drawdown and up-coning of deeper saline water.

Limit crop intensification and/or select less water consuming crops during dry season. In reference to the initial results of groundwater modelling, doubling the current area for garlic production during dry season may significantly enhance salt water intrusion. This could be further aggravated if there will be a 20% reduction in annual rainfall say due to El Niño and related events as aquifer recharge is consequently reduced.

Establishment of unprotected dug wells should not be allowed. To protect shallow groundwater resource from contamination, establishment of unprotected dug wells (i.e., without lining and cover) should not be allowed. Unprotected wells endanger the health of local populace through polluted groundwater that goes into their domestic water supply. Standard designs for dug wells and tubewells should be prepared so that existing unprotected wells should be reconstructed accordingly.

Proper waste (i.e. household liquid and solid wastes) management to avoid contamination of shallow groundwater resulting to unpleasant odor and poor water quality particularly in the built up areas of the basin. This problem was identified during the public consultation. After the project output presentation, they realized that this problem could be solved by them through proper waste disposal and management.

Maintain proper distance between wells. The problem of well interference during dry season was identified by the farmers. After thorough discussion, they agreed that appropriate distance between wells should be applied and so BSWM will provide such information to them.

Regulation of shallow groundwater use through proper irrigation scheduling and crop selection. The problem of insufficient groundwater supply due to excessive use was identified by the farmers during the consultation. Knowing this as a seasonal problem, they suggested this strategy to alleviate the problem and avoid conflict between and among users.

Field Water Management

Essentially, this involves proper water allocation and distribution at the farm level to ensure efficient water use while obtaining maximum benefits and protecting the environment. Some of the recommended management strategies are:

- Preparation of appropriate irrigation scheduling applicable to specific crop, soil types and cropping season. As a strategy, farmers will be provided with assistance in determining “when to irrigate and how much volume to irrigate”. Farmers will be trained on this aspect. Initially, a water management study was conducted for garlic production using the farmers’ traditional practice and alternative practice as recommended in past studies (i.e., in terms of timing of irrigation application with respect to measured soil tension).
- Maintain rotational pumping as method of water extraction from existing wells during dry season. Most farmers are practicing rotation pumping (e.g., 2 to 4 pump sets at a dug well extracting water from only one at a time) to reduce drawdown of the shallow aquifer, and hence reduce the upconing of deeper more saline groundwater, through more efficient water distribution. Such practice also slows down further establishment of additional wells for irrigation and helps maintain the right amount of water application. This practice, therefore, should be maintained and promoted among farmers.
- Establish appropriate design of wells based on water demand and well characteristics. Wells should be properly designed to economically extract the optimum quantity of water from a given geologic formation. The choice of open wells or tube wells depends upon the geologic conditions of the underlying strata, depth of water table, the quantity of water required, and the depth of the saline groundwater interface from which up-coning of saline water may occur in response to an excessive pumping rate.

On Farm Management

Introduce organic based farming system. The rising prices of inorganic fertilizer and the abundance of farm waste and residues that can be converted into organic fertilizers are opportunities for the establishment of organic based farming system. This approach is recommended to minimize the use of agricultural chemicals that could contaminate the shallow groundwater resource.

Provide guidance to farmers on the right amount and kind of fertilizers for a specific crop. Similarly, this strategy will help minimize the probable pollution of groundwater due to excessive application of chemical fertilizers.

Formulate appropriate cropping pattern and calendar. The cropping pattern and calendar should be developed such that utilization of rainfall is maximized and application of irrigation water to be extracted from shallow groundwater resource is minimized. This strategy could facilitate crop intensification and diversification with less pressure to the groundwater resource.

The implementation of the sustainable water use and management strategies was started through pilot schemes in the project. Training sessions on water conservation and management technologies (e.g. alternate wetting and drying for rice, aerobic rice technology, and soil moisture monitoring for garlic) were undertaken through the project. However, the participation of farmers, the main users of shallow groundwater is crucial for the successful implementation of these strategies. They are the heart and soul of sustainable groundwater resource management being the direct steward of the resource. As a major step, the establishment of the Farmer-managed groundwater systems (FMGS) was pursued in 2008 in cooperation with the LGUs which gave their full support and cooperation.

7.12 Application of aquifer storage and recovery (ASR) in the project sites (i.e. through the parallel Australian research

Work was also undertaken within Australia, to design artificial recharge systems for use in sandy aquifers that predominate in lowland areas of the Philippines. An evaluation of the performance of roughing filters in removal of colloidal kaolin as a pre-treatment for biofiltration (slow sand filtration) was completed. A review of biofiltration was undertaken at a testing facility established adjacent the Urrbrae Agricultural High School wetland to enable evaluation of biofiltration design variables. Studies were completed to characterise labile nutrients in stormwater as a predictor of biofilm growth and clogging in injection wells. These are available to design a water sampling and evaluation program in Ilocos Norte. A review of well completion techniques enabled design of wells for construction at the Urrbrae site for an ASR pilot study. Unfortunately the thin alluvial aquifer was not encountered in either well. It is proposed that a deeper well be installed once water quality testing has established which treatment method is likely to be effective for an ASR trial in fine-grained sand. This would give confidence before application in Ilocos Norte.

Results of water quality analysis for the potential source of recharge are presented in BSWM Aquifer Characterization Report (2007). Information on sandy aquifer characteristics are also discussed in the same report. Analyses of washed drill cuttings revealed particle size distributions within the range from coarse to fine sand, that contains quartz, calcite, siderite, pyroxene and amphibole. Siderite indicates the presence of some iron, but the mineral proportions are unknown. As the finer fraction was discarded by washing of samples, it is not possible to conclude whether geochemical problems are likely with ASR, however there is no evidence to suggest that aquifer mineralogy would inhibit ASR at the study sites.

7.13 Farmer-Managed Groundwater System Sequel

The concept of farmer-managed groundwater systems was introduced in late 2007 through farmer workshops. The local government units (LGU) officials, academic representatives, and famers in the two areas, Pasuquin and Burgos warmly received the concept. Capitalizing on the momentum gained by the project, taking the successful experience on establishing farmer-managed groundwater systems in India, and with the commitment of support by the LGUs and farmers, the establishment of Farmer-Managed Groundwater System (FMGWS) as a project sequel was pursued. It aims to ensure the sustainable use of shallow groundwater for increased agricultural production through the empowerment of farmers and creation of an enabling environment on groundwater management in the pilot sites.

As a strategy of implementation, the concept of FMGWS was introduced through the establishment of a Farmer Water School (FWS) in the pilot sites (i.e. also following the Indian model). A training of trainers (TOT) was held in November 2008 to develop agricultural technicians of Ilocos Norte as potential trainers who will constitute the FWS team (Figure 13). Training modules that suit Philippine setting and culture were prepared. In broader terms, these modules consist of 1) human dimension of GW management; 2) basic concepts on GW, its occurrence and sustainable use and; 3) crop planning and formulating of appropriate GW management (e.g. effective MAR and protection of coastal aquifers from pollution). With these modules, several other sub-modules were developed that include the facilitation and presentation skills to enable them to conduct the FWS in a more effective and interesting way for farmers. Sub-modules are expressed in local dialect so that farmers could easily understand each topic.

Figure 13. The FWS team consists of LGU agricultural technicians and technical staff of BSWM, ATI, and MMSU.

From January-June 2009, FWS classes were conducted in both project sites with 2 sessions per month. The learning process considered the following topics that were discussed during the entire FWS course:

- Module 1 - Knowing Weather and climate as important tool to develop cropping pattern and calendar
- Module 2 - Operation and Maintenance of Pump and Engine Set
- Module 3 - Soil Management
- Module 4 - Hydrologic Cycle and Understanding Groundwater Supply
- Module 5 - Groundwater Movement and Quantity
- Module 6 - Groundwater Quality and Contamination
- Module 7 - Groundwater Balance (Recharge and Discharge)

- Module 8 - Introduction to Crop Planning
- Module 9 - Integrating Groundwater Balance to Crop Planning

Action Planning Session

Figure 14 shows the members of the FWS classes organized in Pasuquin and Burgos. From the 50 members of the class, 46 were able the complete the 9 sessions. The sessions were supplemented by a Farmers Field Tour in Tarlac Shallow Well areas, Maasin Small Water Impounding Project in Talugtog, Nueva Ecija, Central Luzon State University, PhilRice and Pantabangan Dam to familiarize the farmers with various water saving and conservation technologies which could be adopted in their respective area.


The Pasuquin FWS Class, 30 members

The Burgos FWS Class, 20 members

Figure 14. The FWS Class with the participants and resource persons

Figure 15 shows the conduct of FWS in one of the sites with the classroom and the field as learning venues. For every field exercise, farmers were required to internalize and present the knowledge they gained to the class and its potential application to their respective farm. In simple terms, they were able to understand groundwater availability and crop planning concepts which increased their level of confidence to explain them during the FWS exhibit held in July 9, 2009 (Figure 16).

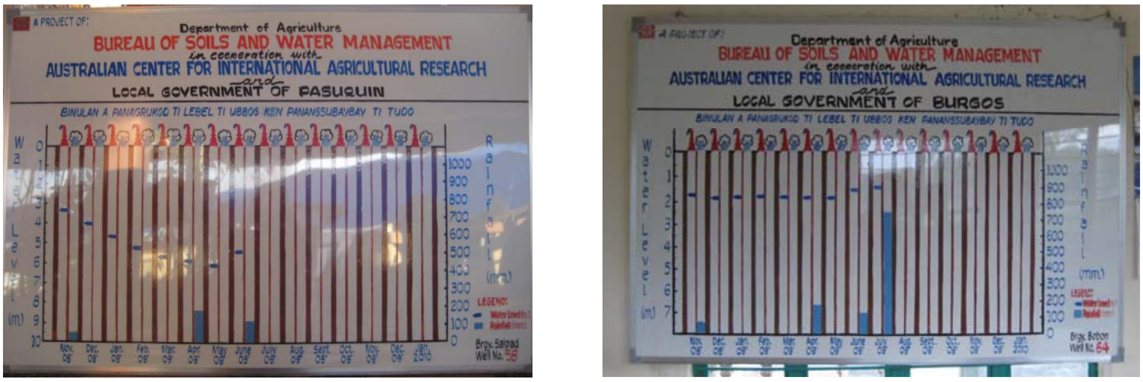

Field exercise on soil water movement

Presentation of Action Plan

Figure 15. FWS in action as field work and classroom sessions are conducted to allow participants to "learn by experience" and present their findings and action plan.

Figure 16. FWS Field Day and Exhibit with each station manned by selected FWS farmer-participants.

Measurement of rainfall and groundwater levels was continued in both study sites by selecting 12 observation wells. Results of the measurement were displayed in the village hall for viewing of farmers as shown in Figure 17. The display gave farmers the idea on how groundwater levels are affected by rainfall and extraction. Groundwater recharge is also affected by the condition and activities within the watershed. Realizing this factor, the farmers themselves recommended the planting of trees within their watershed as their support to the efforts of protecting the groundwater resource. Hence, a tree planting activity was held on July 9, 2009 as part of the project field day (Figure 18).



Brgy Susugaen, Pasuquin

Brgy. Bobon, Burgos

Figure 17. Monthly rainfall and groundwater level information display

Figure 18. Tree planting activity attended by farmers and representative from partner agencies and institutions (e.g. MMSU, PAGASA, ATI, and LGUs)

A graduation ceremony, attended by more than 200 farmers and guests culminated the FWS activities on the same date. However, follow up activities beyond the project duration will be undertaken to sustain the knowledge gained by the farmers and to develop them as an important sector that will contribute in managing our shallow groundwater resource to make it more sustainable. The members of the graduating class of the first Farmer Water School in the Philippines is presented in Figure 19.

Figure 19. The First Graduates of Farmer Water School (FWS).

8 Impacts

8.1 Scientific impacts – now and in 5 years

The scientific impacts of the project can be gauged from the full project report that indicates how each project output was obtained. Through the project a more systematic and scientific approach of groundwater investigation was realized (i.e. basin mapping, geo-resistivity survey, pumping test, GIS database framework establishment and groundwater modelling). It became a scientific blueprint which BSWM will be adopting in its future groundwater investigation. With the equipment provided by the project, the BSWM became more confident and ready to respond and undertake future related projects. The development of GIS database and the application of groundwater modelling are also major project outputs that have scientific impacts to BSWM and other agencies. It allows the development of a more structured system for processing and integrating voluminous data and/or information and to study different groundwater scenarios and cropping patterns that will enhance decision-support capability.

An understanding of water treatment effectiveness for ASR in alluvial aquifers has increased. The effect of roughing filters has been systematically documented and published as a journal paper, and the performance of biofiltration of stormwater has also been quantified in relation to water quality characteristics identified to be indicators of the potential for clogging of alluvial aquifers. A report reviewing the design, construction and maintenance of ASR wells has also been published. These series of outcomes provide foundations to determine the viability of managed aquifer recharge in the Philippines, Australia and elsewhere.

8.2 Capacity impacts – now and in 5 years

Capacity impacts by the projects occurred in two fronts. Representatives of collaborating agencies and project staff were trained on the aspects of groundwater resource assessment and management and groundwater modeling. On the other hand, farmers and selected farmer-cooperators were taught water conservation and management technologies. This new knowledge was applied by the project staff and became part of the BSWM guidelines on groundwater development and management. These trainings include:

- A three-day workshop on Groundwater Investigation and Management was conducted in Ilocos Norte from Feb 22-24, 2004 and attended by 25 staff from BSWM and other agencies involved in water management in the Philippines. The workshop concentrated on basic hydraulics and calculation of groundwater balances which the project staff applied and utilized during the entire project implementation.
- A three-day workshop on Groundwater Modelling was conducted in Manila from June 8-10, 2006. The first day was attended by 26 staff from BSWM and other agencies involved with water management in the Philippines. The second day involved hands-on demonstration of computer modeling, and involved eight staff working on four computers. The workshop discussed the principles of groundwater modeling, and the demonstrated the practical aspects of modeling with the MODFLOW software. The workshop contributed to capacity-building efforts of BSWM particularly in the area of groundwater management in the Philippines.

- A three-week advanced training on groundwater modeling was attended by Engrs. Jane Fantilanan and Oscar Carpio in Adelaide, Australia on November 2006 in which the Groundwater Model for Burgos was completed. Paul Howe then spent three days at BSWM in Manila in June 2007, to assist in setting up the model for the Pasuquin field site. Following completion of this project, BSWM will have two staff that are trained in groundwater modelling, and this will be beneficial to BSWM and will be useful to pursue groundwater management in the Philippines.
- Trainings attended by other project staff in various fields (i.e., Engrs. Patrick Espanto and Henry Cacayan on “Advances on Ecological and Hydrological Modeling: Concepts, Parameter Estimation and Application” and Ms Rose Reforma on Financial and Economic Research Methods for Natural Resource Managers) will also be useful in the implementation of the project and other future BSWM activities related to Groundwater Management and Project Financial and Economic Analysis.
- A two-day farmers training on water savings technologies was also conducted in Pasuquin on May 4-5, 2006 preparatory to the formulation and implementation of water use strategies in the project sites. The training, attended by 45 farmers and agricultural technicians, consisted of lectures and field practicum on alternate wetting and drying (AWD) on rice production, use of aerobic rice, and organic-based nutrient management. The knowledge from the training once adopted by the farmers can contribute to a more efficient and economical use of shallow groundwater in the project sites.
- Farmer-co-operators were taught how to record soil moisture readings (i.e., through tensiometers) and static and pump water levels in production wells. It provided them the opportunity to appreciate the decline in soil moisture over time that serve as a basis for deciding when to irrigate. Looking towards future actions, this exercise provided the basic idea that farmers can also work as “scientists” and therefore a farmer-managed shallow groundwater system could be considered as the next step.

The conduct of the first Farmer Water School (FWS) in Pasuquin and Burgos has also provided capacity impacts to 25 agricultural technicians who participated in the training of trainers (TOT) in November 2008 and 50 farmers who attended the 9 FWS sessions from January to June 2009. The TOT equipped the participants in understanding the human dimensions of groundwater management; weather and climate elements; groundwater hydrology; crop planning and knowledge on the need to balance groundwater recharge and groundwater extraction. The activity increased their level of confidence to present and discuss the topic of ‘groundwater management and crop water budgeting’ and developed their skills as trainers. On the other hand, the 9 sessions of the FWS have nurtured the farmers understanding on the need to protect the shallow groundwater resource to make it more sustainable. The field activity and group work introduced in every FWS meeting were learning experiences for them to fully understand their role as water users and at the same time as stewards of the resource. More importantly, the class presentation which they handled every meeting developed their skills to explain and articulate important and critical topics on groundwater management. Full impacts will be achieved when the action plan that the farmers prepared is implemented within the year with the support from the LGUs.

8.3 Community impacts – now and in 5 years

The project has significant impacts to the community. The members of the community became aware of the needs to protect, conserve, and manage our shallow groundwater resource. It made them realize that such efforts should come not only from national agencies but also from the local government units and more importantly from members of the community. This was further strengthened by the project initiative to establish the farmer-managed groundwater system in the two project sites in which different stakeholders (i.e. ATI, MMSU, and LGUs) accepted and supported.

8.3.1 Economic impacts

The economic impact of the project can be felt in the future after full implementation of sustainable water management strategies. These impacts would be in terms of expansion of irrigated areas sourced by shallow groundwater resource due to more available water, increase in crop production and reduction in production cost for different crops (e.g. rice, corn and garlic) including reduction in pumping cost. With proper guidance (i.e. also in reference to the results of the groundwater modelling) on crops to plant with respect to land suitability and water availability and the application of their learning from Farmer Water School, the farmers are expected to benefit from the increased production and reduced costs in 5 years time.

8.3.2 Social impacts

The project provided the community an opportunity and venue to raise issues and concerns on the utilization of shallow groundwater resource and for them to identify possible solutions in terms of local policies and appropriate technologies to address those issues. However, this requires empowerment of the farmers and collective action to address those issues and concerns which they identified. The direct impact of the project would be felt more in the future when we see them working collectively to protect and manage our shallow groundwater resource. The Farmer-managed Groundwater System that was introduced in the project sites in 2008 facilitated advocacy and awareness among farmers on the need for sustainable use of the resource which paved the way for the full participation of the farming community on this effort. With the implementation of the farmers-formulated Action Plan, more tangible community impacts of the project are expected in the next five years.

8.3.3 Environmental impacts

The findings of the project revealed that there are many threats to the sustainability of the shallow groundwater resource due to current practices on its development and extraction. Farmers and LGU officials fully recognized the need to change these practices and efforts have commenced to prepare local ordinances that would prevent the construction of unprotected dug wells, regulate the distance between wells and manage extraction rate from existing wells. The implementation of these local policies and adoption of technologies emphasized by the project are expected in the next 2 years. While there are already some individual initiatives, the environmental impacts could be felt in the next 5 years. This would be in terms of improvement in water quality particularly at the downstream section or coastal zone and prevention of saltwater intrusion and groundwater pollution. Also, lessening the pressure on our shallow groundwater resource will mean lesser impact on the environment. The recognition of the difficulties with clogging during ASR and the poor prospects for enhanced recharge in the wet season to prevent up-coning of saline groundwater in wells pumped at too high a rate in the dry season has underlined the importance of effective demand management.

8.4 Communication and dissemination activities

Throughout the entire project implementation, communication and dissemination activities were undertaken. The following IEC materials were prepared and became parts of the project output:

Video

Orientation Material on ACIAR Ilocos Project (2005) 8-minute Video

Omnibus Video Material - Updates on the ACIAR Ilocos Project (2007)

11-minutes

Farmer-Managed Groundwater System 8-minutes Info Video (2009)

Posters

Project Briefer---Project Activities and Outputs

Project Briefer ---Rationale and Objectives

Soils of Burgos, Ilocos Norte (Upon the request of the LGU, the poster was given to them and displayed at the Office of the Municipal Agriculturist)

Soils of Pasuquin, Ilocos Norte (Upon the request of the LGU, the poster was given to them and displayed at the Office of the Municipal Agriculturist)

Comparative Economic Assessment of Agricultural Productivity Using Shallow Groundwater and Surface Water in Ilocos Norte

Aquifer Characterization

Study on the Utilization of Shallow Groundwater for Irrigation on Garlic Production in Pasuquin and Burgos, Ilocos Norte

FWS Modules 1-9 displayed during the Project Exhibition and Field Day

Brochures

Project Briefer

Vertical Electrical Sounding using PASI 16GL Electric Resistivity Meter

Well Construction and Development

FWS Modules 1-9 in Ilocano Dialect with 200 copies each.

Hand-outs

Conduct of Pumping Test

Installation of Piezometer

Reports

Segalen, A-S., Pavelic, P. and Dillon, P. (2005). Review of drilling, completion and remediation methods for ASR wells in unconsolidated aquifers. CSIRO Land and Water Tech Report 04/05, March 2005.

http://www.clw.csiro.au/publications/technical2005/tr4-05.pdf

Lin, E., Page, D., Pavelic, P., Dillon, P., McClure, S. and Hutson, J. (2006) Evaluation of roughing filtration for pre-treatment of stormwater prior to aquifer storage and recovery (ASR). CSIRO Land and Water Science Report 03/06, February 2006, 224p. http://www.clw.csiro.au/publications/science/2006/sr3-06.pdf

Pavelic, P., Dillon, P.J. and Barry, K.E. (2005) Results from the drilling of two wells in the Upper Quaternary aquifer at the Urrbrae Wetland site. CSIRO Land and Water Client Report, December 2005.

Page, D. and Dillon, P. (2007) Measurement of the biodegradable fraction of dissolved organic matter relevant to water reclamation via aquifers, Water for a Healthy Country report series, ISSN: 1835-095X.

Page, D., Wakelin, S., van Leeuwen, J. and Dillon, P. (2006) Review of biofiltration processes relevant to water reclamation via aquifers, CSIRO Land and Water Science Report 47/06, October 2006,

http://www.clw.csiro.au/publications/science/2006/sr47-06.pdf.

Journal Papers

Lin, E., Page, D. and Pavelic, P. (2008). A new method to evaluate polydisperse kaolinite clay particle removal in roughing filtration using colloid filtration theory. Water Research 42 (3) 669-676.

Wakelin S.A., Page D., Pavelic, P., Gregg, A.L., and Dillon P.J. (in press). Structural composition of microbial communities in water treatment biofilters: effects of filter matrix and depth on Bacteria, Archaea and Eukarya. Water Science and Technology.

Conference Papers and Posters

Segalen, A.S., Pavelic, P., Dillon, P. and McCann, D. (2005). Review of effects of drilling and completion methods on performance of ASR wells in unconsolidated aquifers. Proc. ISMAR5, Berlin, June 2005.

Lin, E., Hutson, J., Le Gal La Salle, C., Dillon, P., Page, D. and Pavelic, P. (2006) Assessment of roughing filtration for pre-treatment of urban wetland waters, in Recent Progress in Slow sand and Alternative Biofiltration Processes, Gimbel, R., Graham, N.J.D. and Collins, M.R. (Eds), IWA Publishing, London UK, ISBN: 9781843391203

Page D., Chassagne, A, Barry, K., Wakelin, S., Pavelic, P., Dillon, P. (2007) Biofiltration as a pretreatment prior to managed aquifer recharge: reduction of dissolved organic carbon to reduce biologically mediated injection well clogging potential. Procs ISMAR6, Phoenix 28 Oct-2 Nov 2007.

Wakelin, S., Page, D., Chassagne, A., Gree, A., Barry, K. and Dillon, P. (2007). Unravelling the complexity of microbial communities in biofilter using community level DNA fingerprinting. Procs ISMAR6, Phoenix 28 Oct-2 Nov 2007.

Contreras, S.M. (2007). The people of Pasuquin were awakened. “Cross Cultural Perspectives on Groundwater Based Institutions”, A proceeding of “International Learning Workshop on the Demand Side Management of Groundwater held in Hyderabad, India on Jul 29th – Aug 11th , 2007”. FAO.

Pascual C, Contreras S., and Sandoval T. (2009). Capacity Development in Adaptive Water Management: Experiences and Lessons Learned at Farmer Water School in Northern Philippines (May 2009 presented during the MMSU Research Review)

Dillon, P., Gale, I., Contreras, S., Pavelic, P., Evans, R. and Ward, J. (2009) Managing aquifer recharge and discharge to sustain irrigation livelihoods under water scarcity and climate change. (IAHS/IAH Congress, Hyderabad, India, 6-10 September 2009);(IAHS Publ. 330, 2009).

Others

Groundwater modelling notes from Workshop held in Manila on June 8-10, 2006

Groundwater Resource Management Presentation on May 22, 2006 at WATERTECH 2006 by Samuel Contreras

Project Accomplishment presentation by Ms. Norma Lagmay, Ilocos Sur Provincial Agriculturist, during the International Celebration on Biodiversity on May 24, 2006

Presentation of the Interim Aquifer Characterization Report and Economic Assessment of Agricultural Productivity undertaken on June 7, 2006.

Part of the results was also presented in the International Learning Workshop on the Demand Side Management of Groundwater held in Hyderabad, India on Jul 29 – Aug 11, 2007. This became one of the published stories in the workshop proceedings “Cross Cultural Perspectives on Groundwater Based Institutions

The concept of Farmer-managed Groundwater System as one of the implementation strategies was presented to the farmers, academe, and LGU representatives on Dec 13, 2007

Contreras S. Establishment of Farmer-Managed Groundwater System: A Local Approach to empower Farmers in Managing our Shallow Groundwater (Powerpoint presentation material presented at the weekly seminar of SEARCA, UPLB on March 2009).

9 Conclusions and recommendations

9.1 Conclusions

Based on the foregoing results, the following are therefore concluded:

The assessment of the current potentials of shallow groundwater resource in both pilot study sites revealed that the resource use is still less than its maximum sustainable yield although there are threats of deteriorating water quality (e.g. elevated salinity at lower depths) and potential decline in water quantity particularly during dry seasons. The technical evaluation suggests that crop intensification and diversification can still be pursued in Burgos site using the shallow groundwater resource using measures to avoid compromising its quality. Shallow groundwater-based irrigation in Burgos is likely to be sustainable at 190,000 m3 (i.e. from the results of groundwater modelling) such that irrigated areas during dry season could be increased to 60 ha from its current level of 43 ha (i.e. equivalent to one half of the total cultivated area as farmers cultivate only half of their landholding during dry season for garlic production). However, new wells should not be dug or installed deeper to avoid up-coning of saline water during pumping. Rates of pumping from any well may need to be restricted to prevent excessive drawdown and upcoming of saline groundwater that is already present at a depth of 21-25m in at least two locations at Bobon.

In Pasuquin, the groundwater model indicated a sustainable groundwater extraction during the dry season of at least 280,000 m3 that could support 90 ha of garlic. This is similar to the current level of farm utilization during the season (i.e. also equivalent to one half of the total cultivated area). Future expansion of irrigated agriculture through crop intensification and diversification and the current competition in groundwater use during the dry season may lead to unsustainable shallow groundwater use. As the groundwater models predicted, under conditions of low recharge in the coastal plain (e.g. during El Nino events), higher rates of pumping and prolonged drought are likely to critically reduce groundwater levels and groundwater discharge at the coast to such an extent that sea water intrusion may compromise irrigation and domestic water supplies. However, with some spread of uncertainties in the result of the modelling, further monitoring is required to validate each model and differentiate which model best fits each site.

Shallow groundwater resource development through shallow tube wells and dug wells remains the prime mover of development in the study sites and therefore must be protected and managed. With current estimated agricultural production value of PhP 9.4 M and PhP 19.6 M in Burgos and Pasuquin study sites, respectively, about 70-73% was derived from shallow groundwater irrigation. This is considering that during the first cropping (i.e. with rice) farmers relied on rainfall while on the second cropping (i.e. with corn and high value diversified crops such as garlic and onion) there is the full utilization of the resource when crop intensification and diversification can be pursued.

In Burgos, the selected scenario suggests that future crop intensification of garlic regardless of soil suitability could result in a total production of 186 MT (i.e. harvested from 60 ha area) which is equivalent to a total production value of PhP6.5 million annually. Higher production value PhP11.1 million could be expected if the area for garlic was expanded in highly and moderately suitable areas. Under a crop diversification scheme, economic benefits in terms of total production value is estimated at PhP8.6 million from the production of 160 MT garlic and 197 MT onion in 58 ha.

In Pasuquin, the selected scenario suggests estimated economic benefits of total production may reach PhP28.4 million from production of 810 MT in 90 ha. This would be achieved without increasing cropped area but shifting dry-season production from areas with poorly suitable soils to areas with more highly suitable soils.

Problems relative to sustainable use of shallow groundwater are technical, institutional and policy-related in nature. Specifically, these include absence of efforts to address the threat of deteriorating water quality and quantity (technical), absence of local institutions in groundwater management (institutional), and poor implementation of policies for shallow groundwater management (policy issue).

Currently, there are insufficient data to allow three quite different candidate models calibrated at each site to be differentiated and the best model to reflect the actual situation to be identified. Thus the sustainable volume of pumping from each site is still uncertain. Therefore further data acquisition on groundwater levels and salinity, pumping and rainfall will be needed to refine estimates of sustainable volumes of pumping. A groundwater model was selected at each site (Bobon5 and Pas4) and used within the economic modelling to determine crop types and areas, and by matching with land capability maps, the production value could be calculated.

The area planted to garlic can be expanded in highly suitable areas to ensure that high production could be achieved with lesser inputs. Sustainable water use and demand management strategies should include empowerment of farmers for them to understand groundwater concepts and availability, its impact on crop production, and the role of institutions in ensuring the sustainability of the resource;

The application of Aquifer Storage and Recovery (ASR) system in the Philippines based on the results of Australian counterpart’s research study should not only focus on the technical aspects of project development. More importantly, the social aspect (i.e. farmers understanding, acceptability and capability to maintain the system) and institutional aspect (i.e. LGU’s ability to establish and maintain the system) of its development should need further studies in the future. It is recognised that up-coning from saline groundwater underlying the fresh groundwater may be a major constraint on groundwater extraction in the dry season, and that additional recharge during the wet season, if the aquifer has the capacity to store it, is unlikely to substantially increase supplies of fresh water. This reinforces the importance of effective demand management for sustainable enhancement of agricultural production.

The project was able to develop a (Philippine) groundwater basin approach to groundwater investigation and management that could help other LGUs in undertaking similar projects in the future to determine sustainable yield and effective management strategies to deal with projected increasing demand for groundwater for dry season irrigation.

The establishment of farmer-managed groundwater system (FMGWS) through farmer water school (FWS) was warmly accepted by the farmers, LGUs and concerned agencies and institutions (e.g. ATI, MMSU). This is reflected by the enthusiasm and perseverance of farmers and trainers to complete the full FWS sessions. The action plan which the farmers prepared could generate a multiplier effect that could facilitate the adoption of farmer-managed groundwater system within Ilocos Norte and then later to other neighbouring provinces. This is a positive step toward a combined supply-side and demand-side groundwater management as inter-sectoral efforts are strengthened.

9.2 Recommendations

While the project focused more on the technical aspects of groundwater investigation and management, sustainable shallow groundwater use to enhance agricultural production could not be achieved without looking at the social, institutional and policy aspects of groundwater management. Hence, the following are recommended based on the conclusions above:

1. Technically, the result of the assessment of the shallow groundwater resource in both sites requires that the management should integrate both the supply side and demand side. Supply side management would mean increasing the supply by

allowing more infiltration of good quality water into the shallow groundwater reservoir (i.e. through watershed management) or through artificial recharge by aquifer storage and recovery (ASR) systems. On the other hand, demand side management would mean restricting shallow groundwater extraction to avoid overdraft. The preferred approach is to manage groundwater demand so that recharge enhancement is not required.

2. Ongoing monitoring is required to test and validate the existing models and thereby discriminate between them and refine the estimates of sustainable utilisation of the fresh shallow groundwater resource.
3. Technical strategies to manage up-coning of saline groundwater underlying Burgos and possibly parts of Pasuquin are needed. This may involve defining the depth, rates of pumping, drawdown and spacing of wells in order to prevent recovery of saline groundwater. Analytical techniques and density affected groundwater flow and transport models, such as FEFLOW, could play a valuable role.
4. The application of a specific management strategy should be based on the social acceptability and capability of farmers, the direct water users, to implement such a strategy. This requires empowerment and creation of an enabling environment that could be achieved by establishing a farmer-managed groundwater system in the pilot sites. The project has laid the ground on this aspect through the establishment of the first ever Farmer Water School (FWS) in the two study sites. The farmers prepared an action plan to disseminate and facilitate the adoption of the knowledge they gained from FWS. As a potent group, they require technical and logistic support from government agencies to implement the plan. Therefore, it is strongly recommended that FWS be mainstreamed in the regular activity of concerned training agency (i.e. ATI) and the LGU to sustain the efforts started by the project.
5. Local policies anchored on existing national policies should be put in place to ensure that water use and management strategies will be implemented within certain legal framework that demands their application and adoption in other shallow well areas within each municipality (i.e. Pasuquin and Burgos) and within the province of Ilocos Norte.

10 References

10.1 References cited in report

Bureau of Soils and Water Management (BSWM). 2007. Aquifer Characterization Report. A report presented during the project mid-term review held at the BSWM Convention Hall on April 11-12, 2007.

Bureau of Soils and Water Management (BSWM). 2007. Comparative Economic Assessment of Agricultural Productivity Using Shallow Groundwater and Surface Water in Ilocos Norte. A report presented during the project mid-term review held at the BSWM Convention Hall on April 11-12, 2007.

Bureau of Soils and Water Management (BSWM). 2007. Economic Modeling Report.

Bureau of Soils and Water Management (BSWM). 2007. Geo-information for Sustainable Shallow Groundwater Management.

Bureau of Soils and Water Management (BSWM). 2007. Groundwater Modeling Report.

McDonald, M.G., and A.W. Harbaugh. 1988. A modular three-dimensional finite-difference groundwater flow model. US Geological Survey, Reston, VA.

National Water Resources Council. 1980. Groundwater of the Philippines. Quezon City, Philippines

10.2 List of publications produced by the project

The publications arising from this project in addition to the above reports are listed in section 8.4. The total includes 3 videos, 8 posters, 6 brochures/hand-outs, 10 reports, 2 journal papers, 7 conference papers, and a series of training resource materials for three different audiences (BSWM staff, agricultural technicians (training of trainers) and Farmer Water School).