ECONOMICS OF GROUND WATER DEVELOPMENT IN THAILAND

CH. CHUAMTHAISONG
Ground Water Division, Department of Mineral Resources Bangkok, Thailand

ABSTRACT

Alluvial deposits of river basins and plains are the most important highly productive aquifers in Thailand. Shale and siltstone in the Khorat plateau and limestones in other areas are moderately productive aquifers which could be developed for ground water utilization.

There are about 70 private companies which own facilities to drill wells of different sizes and depths. More than 9,000 private wells in Bangkok and other big cities are recorded. About 15,000 wells throughout the country have no record. Five government agencies have completed about 48,500 domestic wells in villages under the National Potable Water Project with an additional 6,000 being drilled annually.

Budgeting by the unit cost system can reduce ground water well drilling and development costs for the government agencies. Using local engineering technology to produce materials and equipment for well construction can minimize the overall expenses of both private and government sectors. The cost of well construction by different methods and for different areas of the country as well as drilling expenses are discussed.

1. INTRODUCTION

Thailand is located in the tropical monsoon zone of southeast Asia. The country, with an area of 514,000 km^2, lies in the central part of the Indo-China Peninsula, and is bordered to the west and the north by the Socialist Republic of the Union of Burma, and to the east by Democratic People's Republic of the Loas and Democratic Kampuchea; to the south, the southern Peninsula of Thailand stretches to the Malaysian border between the Andaman Sea and the Gulf of Thailand (see figure 1).

A. Physiography

The main physiographic regions can be characterized as follows: 1) the Northern Highlands; 2) the Western Highlands; 3) the Southern Peninsula; 4) the Central Plain; 5) the Southeastern Coast; and 6) the Northeast or Khorat

Plateau (see figure 1).

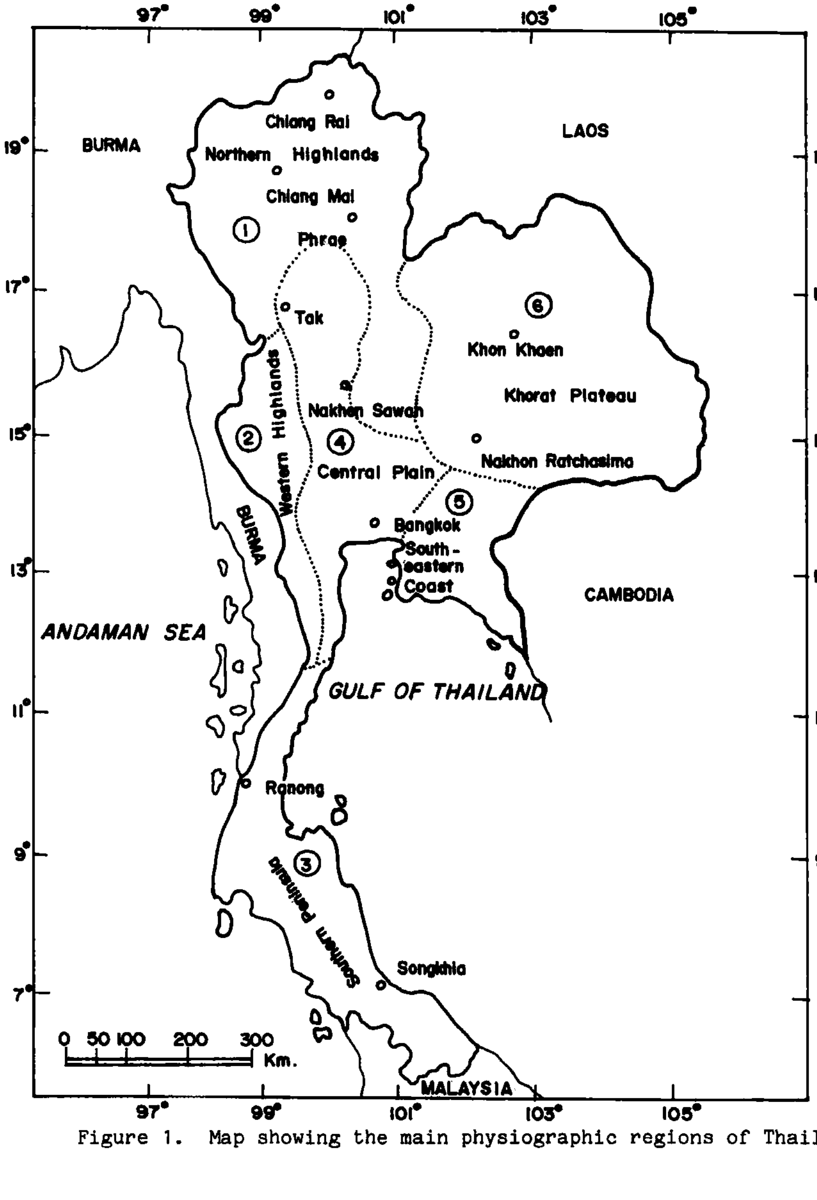

Figure 1. Map showing the main physiographic regions of Thailand.

The features of the highlands and the peninsula include several north-south oriented mountain ranges which extend from the northwestern part of the country downward to the Malay Peninsula. The plain occupies most of the central part of the country forming the Chao Phya plain which includes two extensive alluvial plains: the Upper Central Plain of the north and the Lower

Central Plain of the south. The Khorat Plateau is characterized by an undulating surface structure. The Southeast Coast is comprised of lower elevation highlands and occupies parts of the Eastern Provinces.

B. Regional ground water resources

The aquifers of Thailand are mainly recharged by rainfall and induced seepage from streams. It has been estimated by many different studies that infiltration represents 3 to 10 per cent of the total rainfall. The net recharge in the Central Plain region also ranges from 3 to 10 per cent (AIT, 1982); while in the Khorat Plateau and the Eastern Provinces, it is estimated that about 5 per cent of total rainfall can reach the aquifers. In the Northern Highlands, the recharge computed from the flow net analysis is 6 per cent (Intrasuta, 1982), while that of a water balance model is 9 per cent (SEATEC, 1978). These values of recharge are regarded as the safe yield of the ground water reservoirs. Hydrogeologically and geomorphologically, Thailand is divided into six general ground water provinces, which are described in table 1.

2. HISTORY OF GROUND WATER DEVELOPMENT IN THAILAND

Ground water resources in Thailand have been developed by both the public and private sectors. Starting in 1905 the Department of Public Works (DPW) and the Department of Mineral Resources (DMR) had started to drill some test holes in the North-eastern region, the country's most water-short region. In 1914 a private entrepreneur brought a bamboo rig from China to drill water wells in Bangkok. Two percussion rigs were purchased by DPW in 1933 to drill ground water wells in hard rock. From 1955 to 1960 real ground water development based on investigation and exploration was successfully carried out under a co-operative arrangement between DMR and the United States Geological Survey (USGS). Direct rotary drilling methods have been used since 1955, and hydrogeological maps of various scales were compiled and issued by DMR from 1975 to 1983.

TABLE 1

Ground water provinces of Thailand

Hydrogeologic provinces	Geographic location of aquifers	Lithology of aquifers	Average depth (m)	Yield (m^3/hr)	Water quality and remarks
Northern Highlands	River valleys of intermontain basins (e.g. Chiang Mai)	Alluvium	35	20-200	Generally suitable but iron-rich in many places
		Terrace sediments	130		
Central Plain					
Upper Central Plain	Ubiquitous	Alluvial flood plains	60	10-70	Suitable
		Alluvial fans and buried valleys	very shallow	25	Suitable
		Terrace sediments	75	200	Central part
				10	Periphery
					Often artesian
Lower Central Plain	Northern part	Similar to Upper Central Plain	40	100-300	Suitable
	Southern part (from Sing Buri to Chao Phraya estuary)	8 multilayered aquifers separated by clayey aquitards	20 (Bangkok clay to penetrate)	over exploitation	Good except for upper 2 aquifers land subsidence and salt water intrusion
Western Highlands		Carbonate hard rock	40	limited (1-7)	Suitable
		Alluvial plain	50	40	Suitable
Southern Peninsula	Mountain range	Karstic limestone	40	10-200	Suitable
		Granitic and metasedimentary rocks	45	limited	High iron
	Coastal plain	Alluvium	35-140	5-250	Warm water 40-45°C in some areas
Khorat Plateau	Escarpment regions	Permian limestone	40	10-100	Suitable
		Shale and metasedimentary rocks	50	10	High iron
		Sandstone	200	1-5	Suitable
	Peneplain areas (Phu Phan range)	Fractured shale, siltstone and sandstone	20-60	5-25	Good quality
	Undurating terranes	Fractured shale and siltstone	20-40	5-10	Increase of chloride with depth; saline water when interlayered with rock salt
	Maekhong River Basin	Alluvium	30	100	Good quality (irrigation)
	(Chi and Mun Rivers)	Alluvium	30	25	Brackish
Eastern Provinces	Uplands	Granite and metamorphic rocks	35	10	Good quality
	Ridges and valleys	Valley sediments sandstone/shale	50	7-10	Good quality (potable)
	Coastal plain	Beach sand	10	2-3	Fresh to brackish

A. Private sector

By 1982 there were over 20,000 privately drilled ground water wells of 50 to 400 mm in diameter in Thailand, mainly used for domestic, industrial and small agricultural purposes. There are about 70 contractors dealing with well drilling and well development. Most of the firms are located in Bangkok and other large provincial capitals. However, there are only 3 to 5 well-established contractors with adequate equipment and rigs capable of drilling large and deep ground-water wells.

B. Government agencies

The two main categories of government activities in ground water development are: development of water supply for cities and towns and irrigation; and, development for villages or rural communities under the National Potable Water Project (NPWP). Under the first category productive wells for water supply or irrigation have mostly been completed by local and foreign contractors. The Royal Irrigation Department (RID) is responsible for development of ground water for irrigation. Besides tubewell development, RID specialists have also studied the costs and benefits of various tubewell technologies and the cropping patterns of both rice and upland crops.

The Department of Mineral Resources (DMR) started drilling wells in 1955 and has continued to be the most important government agency in ground water development for domestic water supply. DMR also carries out pump maintenance and service, hydrogeological mapping and investigations, chemical analysis and hydrogeological research. DMR drilled over 27,000 wells from 1955 to 1987; the Department is currently responsible for drilling 2,500 wells annually with 46 drilling rigs. Most of them are installed with handpumps, while about 5 per cent are intended to supply large communities and therefore are installed with deep well turbine or submersible pumps.

The Department of Public Works (DPW) has been responsible for the potable water programme since 1959, and in the beginning concentrated on providing water supply to specified sanitary districts. By 1986 DPW had drilled over

6,700 wells, most of which are operated by handpumps. The Department has the capability to drill 1,200 wells annually using 39 drilling units.

From 1969 to 1986 the Engineering Division of the National Security Command (NSC) has assisted the National Potable Water Supply Project by drilling 1,800 wells in sensitive border areas.

Moreover, since 1970 the Ground Water Resources Development Sub-Division of the Office of Accelerated Rural Development (ARD) has been drilling wells with 42 percussion rigs and seven rotary rigs. Until 1986, ARD had constructed 9,300 wells, both shallow and deep, which are mainly operated by handpumps. The ARD also installed more than 2,500 bucket auger wells in villages using 58 bucket auger drilling units.

Finally, prior to 1977 the Department of Health (DOH) was responsible for providing clean water from dug wells for schools in water-short areas. Since 1977 the DOH has joined the NPWP in developing ground water wells. DOH currently has 39 drilling units capable of completing 1,000 small wells each year. It had installed over 5,800 wells by 1986, most of which were installed with handpumps.

3. COSTS OF GROUND WATER DEVELOPMENT

All government agencies involved in ground water development are now being co-ordinated by the National Economic and Social Development Board (NESDB). Because of limited national budgets, each agency is attempting to reduce expenses in its area of expertise.

During the period of ground-water exploration in north-east Thailand from 1955 to 1958, the average cost of drilling in shale and sandstone regions was very high, averaging US $ 65 per metre. The variation in drilling costs from 1972 to 1986 for DMR is shown in table 2. The average drilling cost per metre (generally between US $ 60 and US $ 75 per metre) remained relatively stable from 1977 to 1986, with costs in the north-east somewhat higher than costs in other areas. This is partially because the average depth of wells drilled since 1972 is shallower than those drilled during the earlier exploration phase.

TABLE 2

Average cost for well development by DMR in Thailand

Fiscal year	North-east			Other than north-east		
	Mean depth,m	US $/m	US $/well	Mean depth,m	US $/m	US $/well
1972	51	23	1,186	90	16	1,421
1973	42	28	1,181	77	20	1,523
1974	45	25	1,148	73	23	1,683
1975	40	41	1,652	66	32	2,115
1976	38	42	1,614	64	35	2,257
Average	43	32	1,358	74	25	1,800
1977	38	48	1,847	58	47	2,757
1978	38	55	2,091	55	56	3,095
1979	38	47	1,817	65	46	2,991
1980	41	51	2,060	71	46	3,373
1981	39	59	2,117	71	52	3,724
Average	39	52	1,986	64	50	3,188
1982	35	72	2,499	62	51	3,181
1983	36	73	2,637	58	64	3,735
1984	36	62	2,236	57	56	3,233
1985	36	67	2,418	62	52	3,283
1986	36	70	2,522	56	55	3,153
Average	36	69	2,462	59	56	3,317

Note: Baht 20 = US $ 1.00 until 1981
Baht 25 = US $ 1.00 1982-1986

Since early 1987, the average cost per well at 35 to 52 m in depth has been estimated at US $ 2,240 to US $ 3,000. The cost of drilling can be reduced by minimizing exploratory drilling, except in specific areas of low ground water potential.

As described below, the costs of ground water development are comprised mainly of the following expenses: drilling costs; well construction materials; pump and power supplies; and well maintenance.

A. Drilling costs

It is important to select the size and type of drilling rig best suited for the ground water conditions and well depth of a given drilling area and to set up the drilling programme before the commencement of the drilling operation each year. In Thailand a moderate capacity drilling rig is the most suitable equipment for drilling in most areas, which keeps site preparation and rig maintenance costs lower. Over the last decade rig maintenance costs have been considerably reduced because both rigs and spare parts can now be produced locally, and moderate quality drilling bits can now be purchased from China, rather than the high quality bits formerly bought from the United States.

B. Well construction materials

Well casings and well screens are the major expenses in well construction. High quality imported well casings have now been replaced by locally-produced "ASTM standard" well casings and perforated pipes. which has reduced costs by 20 to 30 per cent. The locally-made PVC and fibreglass pipes are cheaper than the ASTM standard and are now being quality tested. The PVC or fibreglass pipes may be used for shallow wells in the near future, reducing costs further

TABLE 3

Unit cost for well construction installed various types of pipe for government agency, Thailand, 1987

Well dia mm	Well Depth m	Expenses, US $ Fuel & Lubricant	Maint.	ASTM-Pipe & Parts	Crew Per diem	Cost per Well, US $ ASTM 6m-P	ASTM 3m-S	API 6m-P	API 3m-S	PVC 6m-P	PVC 3m-S
100	30	244	180	788	238	1,448	1,866	1,531	1,680	1,292	1,474
	36	271	216	880	299	1,664	1,816	1,767	1,915	1,482	1,664
	48	327	288	1,063	397	2,075	2,238	2,208	2,360	1,832	1,919
125	30	244	180	1,125	238	1,786	1,972	1,797	1,980	1,531	1,752
	36	271	216	1,285	299	2,071	2,257	2,086	2,269	1,767	1,987
	48	327	288	1,605	397	2,614	2,801	2,633	2,816	2,212	2,432
150	30	244	180	1,300	238	1,961	2,162	2,037	2,242	1,756	2,066
	36	271	216	1,490	299	2,276	2,478	2,367	2,573	2,033	2,284
	48	327	288	1,869	397	2,800	3,082	3,006	3,211	2,569	2,816

Remark Fuel : Diesel US $ 0.247 per litre, gasoline US $ 0.346 per litre, P = perforated pipe, S = stainless steel screen, Crew = 11 men, 2 shifts. Source: Bureau of the Budget, Ministry of Finance, 1987.

by 25 per cent. Imported well screens from the United States or Australia are expensive, but those purchased from Singapore can reduce costs by 20 per cent. These cost differentials can be seen in table 3.

C. Pumps and power supplies

More than 90 per cent of ground water wells drilled by government agencies are fitted with handpumps for domestic water supply in rural areas. These handpumps have long been locally produced and cost an average of about US $ 140. While the handpumps have been continuously improved, the costs of maintenance remain high, because the local people often do not follow the operation manual. A submersible pump system for shallow wells has been produced in Thailand since 1985, which costs about 30-35 per cent less than the European or American model. Quality testing of the pump has improved it. The price of a small (2-3 m^3/hr) submersible pump is about US $ 200. These small submersible pumps can discharge about double quantity of water and at a lower maintenance cost than the handpump. However, the costs of operation (about US $ 0.04/m^3 of water) have to be supported by the community. The cheapest and most reliable power for ground water extraction is electricity. Electricity for pumping irrigation water is subsidized in Thailand at US $ 0.05/kWh, while for domestic purposes it costs US $ 0.07/kWh.

D. Well maintenance

The government unit-cost budget for well and pump maintenance is US $ 60 per year for a well with handpump and US $ 74 for well with submersible pump. The cost of well maintenance is 55 per cent for spare parts and 45 per cent for travel expenses. Another US $ 260 per well is provided to redevelop sluggish wells.

The cost of water well drilling is closely related to the world oil price. The highest cost per metre for drilling was experienced during the oil crisis of 1982-1983 (see table 2). The drilling cost decreased in 1984 and considerably climbed again in 1986, when the local price of diesel increased.

4. FACTORS AFFECTING GROUND WATER DEVELOPMENT IN THAILAND

A. Facilitating factors

The major factors facilitating ground water development in Thailand can be summarized as follows:

1. A tremendous expansion in industry over the last 20 years has caused a very rapid increase in industrial consumption of ground water (currently 200 Mm^3/yr). There are about 1,500 wells in the Bangkok Metropolitan Area being used for industrial purposes. Moreover, the Provincial Water Works Association (PWWA) has expanded its services by providing piped water supplies to municipalities, Sanitary district areas and communities with more than 5,000 inhabitants. In many cases, ground water is viewed as the prime source of raw water for the expanded systems. The National Potable Water Project, through the various government agencies, provides clean water for rural areas at a rate of 6,000 wells each year.

2. From a preliminary economic analysis of RID's ground-water irrigation projects, it appears that new investments in ground-water irrigation for other areas are attractive.

3. DMR's Ground Water Division has established the Ground Water Data Centre at its Bangkok office. The water well data collected from various parts of the country since 1958 are being systematically stored on a VAX computer system and are usable for ground water development and management purposes.

4. As a result of the rapid growth in ground-water development, a large number of skilled contractors are now capable of constructing drilling rigs locally which are specially designed for different hydrogeologic settings.

B. Constraints to development

The major impediments to more widespread ground water development in Thailand are the following:

1. The quantity of recharge from surface water has decreased, largely due to deforestation. Rainfall becomes run-off and the replenishment of ground water is reduced, having a significant impact on the ground-water balance.

Pollution from insecticides, fertilizer and mine tailings has imposed a serious limitation on the availability of good quality surface and ground water. Along the coast of the Gulf of Thailand, salt-water intrusion has affected the quality of ground water; in the north-east, where fresh water lies above brine, salt water intrusion can become serious if drilling and pumping schemes are not carefully planned.

2. The costs for drilling equipment and drilling supplies, including casings, screens, pumps, drill bits and fuel, have risen and normally have to be imported, requiring expenditure of foreign currency. Most of the budget is spent just these items.

3. Currently, there is no Government authority responsible for quality control or standardization of drilling equipment, supplies and accessories, nor with the relationship between price and product. The quality of materials, tools and equipment, therefore varies from reliable imported or custom-made products to poorly-built locally manufactured products or locally rebuilt equipment. Poor equipment may lead to a shorter service life for the equipment or hihger maintenance costs.

5. GROUND WATER COSTS FOR DIFFERENT CONDITIONS

A. Sukhothai: Ground water development project

The project has development ground water from the alluvium and terrace aquifers of the Yom River Basin in the Upper Central Plain for irrigation purposes. Wells of 100 to 130 m deep can produce 150 to 300 m^3/hr. The individual well command areas are about 58 ha (360 rai, 1 ha = 6.25 rai). The total budget for this project was US $ 24 million for 170 production wells of 400 mm in diameter. The proper design of wells, motor driven pumps, irrigation and drainage systems, access roads and power supply are included in the capital investment costs. In fact, the well and pump units account for only 32 per cent of the total estimated capital costs. Representative annual costs for these types of pump units are shown in table 4.

TABLE 4

Estimate cost of well of 400 mm in dia, 100 in depth in Yom Basin, Thailand, 1984

Capital cost estimated

Description	Cost US $	Per cent
1. Well, fibreglass pipe	22,078	14
2. Pump unit	20,444	13
3. Pump house and operator house	11,172	7
4. Irrigation and drainage system & land levelling	84,854	54
5. Access road	6,954	4
6. Power supply	11,400	7
7. Engineering & administration	3,382	2
8. Physical contingencies	7,828	5
Total	168,112	
Annualized cost a/	345 per year/ha	

Breakdown of annual O & M costs

Description	Total US $/58 ha		Annual cost US $/ha
1. Maintenance	2,108		36
2. Energy b/	1,877		32
3. Other operations,	551		9
		Total	77

Source: Royal Irrigation Department, 1983.
Notes: a/ Based on investment cost of US $ 2,921 per ha, assumed lives (10-30 years) of the various elements of the irrigation system, 14 per cent/yr interest.
b/ Based on US $ 0.044 kWh; 1900 operation hours; 200 m^3/hr discharge.

B. Drilled shallow tubewell

Since 1985 the Australian Development Assistance Bureau has implemented the shallow tubewell project in Pichit province in the Upper Central Plain. The estimated costs per well are shown in table 5.

C. DMR wells for small irrigation

By 1986 there were more than 2,270 wells drilled by DMR, each yielding over 30 m^3/hr. This discharge is sufficient for irrigation of small holdings and is suitable for high value crops, such as vegetables or soyabeans. From 1971 to 1978 DMR and the Office of Agricultural Economics undertook many pilot studies to evaluate costs and benefits of ground-water irrigation and O & M costs of ground water utilization from existing wells. These demonstrated that for certain crops such as vegetables or tobacco, the profit was sufficient for farmers to pay at least for pumping costs.

TABLE 5

Capital cost for shallow tubewell

Description	Cost (US $)
Well, PVC pipes	1,562
Pump	156
Prime mover	466
Total	2,184
Annualized cost a/	133 ha/yr
Annual O & M cost b/ for 3.2 ha (20 rai)	54 ha/yr
Total yearly cost	187 per ha

Notes: 100 mm diameter well, yields at least 30 m^3/hr, irrigates 3.2 ha (20 rai.)
a/ Amortized at 14 per cent, varying repayment periods depending on service life of equipment.
b/ Field data indicate O & M for pump and motor is about US $0.007 per m water. Assume discharging of system is 700 hr/yr for 3.2 ha (20 rai.)

D. Ground Water Act and tariffs on ground water use

Heavy pumping in the "Bangkok ground water area" has led to severe problems of water quality deterioration and land subsidence. Therefore, a "Ground Water Act" was implemented in 1978. Under the Act, ground water wells drilled in the Bangkok area are registered and the pumping rates are recorded.

Since 1985 users of ground water have been required to pay a fixed rate per m^3 used. The rate is determined by a formula based on annual payments, interest rate and average well discharge. The Ground Water Committee approved a rate of US $ 0.10 per m^3 in 1985. This is much less than rates of US $ 0.16-0.35 charged to different categories of consumer for tap water. Government income from the ground water fee was about US $ 4.0 million in 1986.

It is expected that the Ground Water Act will be extended to other major cities, where heavy pumping needs to be controlled. It is estimated that an additional US $ 8.0 million per year could be collected from ground water fees, which would be enough to drill almost 3,000 wells each year in rural areas.

E. Cost of well construction in the private sector

Some sample costs of drilling and construction by the private sector are shown in table 6. The wells range in diameter from 100 to 300 mm and in depth from 30 to 320 m, and costs range from US $ 43 to US $ 129 per metre.

TABLE 6

Average cost per metre for water well development

Method	Well diameter(mm)	Average depth (m)	Total cost (US $)	Average cost (US $/m)	No of wells evaluated
Direct	100	31	3,471	118	5
Rotary	150	100	4,091	43	22
Reverse	200	173	204,510	47	12
Rotary	250	230	287,983	50	10
	300	111	356,841	129	6

Notes: Costs do not include overhead charges, net profit, etc.;
Pipe: API-steel, standard stainless steel screen.

The major costs included in the total comprise: pipe and screen; salary and per diem for a 4-man crew; fuel and lubricant; maintenance; transportation; gravel pack; chemical analysis and supervision; bentonite; travelling fare; and office expenses.

6. LOW-COST TECHNOLOGIES

In Thailand, as in many developing countries, the most effective means to lower costs of drilling and construction is to produce the drilling equipment, tools, pumps and spare parts locally. The efficiency of locally-made parts and equipment in Thailand is about 75 per cent of the original imported ones. A comparison between costs for imported and locally-made equipment is shown in table 7.

Another method of keeping costs lower is to use electricity for pumping ground water, because it is the cheapest source of power. Submersible pumps reduce both operation and maintenance costs.

Based on average well depths throughout most parts of the country, the selection of locally-made drilling rigs with a maximum capacity of 150 to 300 m, will minimize the budget and reduce operation and maintenance costs.

TABLE 7

Reduction in costs from using locally-made equipment in Thailand

Item	Imported price		Locally-made price		Percentage reduction
	(Baht)	(US $)	(Baht)	(US $)	
1. Equipment					
Drilling rig	12,000,000	480,000	7,000,000	280,000	42
Drilled pipe	12,000	480	7,500	300	38
Drilled collar	15,000	600	10,000	400	33
2. Spare parts					35
3. Pumps					
Hand pump	7,000	280	3,500	140	50
Submersible pump (1 HP)	10,000	400	5,500	220	45

Note: All costs are estimated.

CONCLUSIONS AND RECOMMENDATIONS

It is planned that about 56,000 villages in Thailand will be provided with adequate potable water under the National Potable Water Project. Up to 1986, about 48,500 wells had been completed, but an additional 6,000 wells are to be drilled each year by five government agencies to fulfill requirements. At present the pump maintenance costs for water are still very high, because several different types of hand pumps have been installed by the government agencies. Most of the spare parts are different and not interchangeable. Maintenance would be cheaper and more easily managed if one standard high-efficience hand pump were used for all agencies. Another solution is to install small submersible pumps having low maintenance costs, since electricity is now available in more than 80 per cent of the villages, and most villages can pay for the operating costs.

Even though the local production of equipment, spare parts and pumps has considerably reduced costs, the locally-produced equipment is still less efficient than imports. However, it is expected that the local products will soon be improved to the level of imports. The ASTM-AI20 steel casing, PVC and fibreglass pipes are now manufactured in Thailand. Therefore, the overall costs of ground water development in the country are much lower than previously. In addition, the government system of budgeting on a unit cost basis has reduced cost in water well construction and maintenance.

Costs of jetted or shallow drilled wells are low enough, so that some farmers can own their own wells for irrigation purposes. However, rapid private expansion of these types of ground water development may lead to adverse hydrogeological conditions. Therefore, planning for development and management of ground water must be carried out by the concerned government agencies. Moreover, large ground-water development for irrigation, such as the Sukhothai project, are very expensive; econnmic studies of such projects are required. Detailed planning for the conservation of ground water for each area is necessary to prevent adverse consequences. It should also be considered to charge farmers for agricultural use of ground water. The most practical means of developing ground water for irrigation would be to do so in conjunction with water supply from existing village wells.

Since 1986 the Ground Water Data Centre has been established by DMR's Ground Water Division. Water well data are available, as well as an excellent series of maps at scales 1:500,000 and 1:1,000,000 covering the entire country and classifying aquifers by well productivity and water quality. Now the government is charging a fee to ground water users in the Bangkok area, bringing in revenue of US $ 4 million per year. It is expected that in the near future industrial users in other large cities will be charged for water use, and eventually even agricultural users. It is hoped that information on all new wells drilled in the country will be stored in the Ground Water Data Centre.

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ANNEX

SYMBOLS AND UNITS

Currency Equivalents

Before 1981	After 1981
US $ 1.00 = 20 baht	US $ 1.00 = 25 baht
B 1.00 = US $ 0.05	B 1.00 = US $ 0.04

Metric Equivalents

1 metre (m)	= 3.28 feet (ft)
1 hectare (ha)	= 2.47 acres (ac) = 6.25 rai
1 million cubic metres (Mm^3)	= 810 acre-feet (ac-ft)
1 litre per second (l/sec)	= 0.0353 cubic ft per second (cfs)
1 cubic metre per second (m^3/sec)	= 35.3 cfs
1 cubic metre per hour (m^3/hr)	= 0.125 US gallons per minute (gpm)

Abbreviations

ARD - Office of Accelerated Rural Development
BAAC - Bank for Agriculture and Agricultural Cooperatives
DMJM - Daniel, Mann, Johnson and Mendenhall International
DMR - Department of Mineral Resources
DOH - Department of Health
DPW - Department of Public Works
EGAT - Electricity Generating Authority of Thailand
MWWA - Metropolitan Waterworks Authority
NESDB - National Economic and Social Development Board
NPWP - National Potable Water Project
NSC - National Security Command
NWRB - National Water Resources Board
O & M - Operation and Maintenance
PWWA - Provincial Waterworks Authority
RID - Royal Irrigation Department
USGS - United States Geological Survey

Thai Fiscal Year : October 1 - September 30