Dugwell as an Option of Skimming Well

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INTRODUCTION

Background of skimming wells and pressurized irrigation systems project

Exploitation of groundwater for agricultural, municipal and industrial uses is severely hampered in many parts of the world by the encroachment of brackish groundwater in response to fresh water withdrawals. Examples of brackish groundwater intrusion are common in coastal aquifers, but are sometimes present in inland aquifers as well. Probably, the most important example of the latter case exists in the Indus Basin Irrigation System (IBIS). The IBIS has caused disruption of hydraulic regime due to seepage from extensive water conveyance and distribution system, as well as deep percolation from irrigation and precipitation. The native groundwater that existed in the pre-irrigation period (early 19th century) was saline because of the underlying geologic formation being of marine origin. Now, this native saline groundwater is overlain by fresh groundwater due to seepage from rivers and canals of the IBIS. Thus, shallow fresh groundwater zone occurs between the native pre-irrigation and the present day water tables.

Near the rivers and canals, the fresh surface water seepage has improved the quality of the native groundwater to 120 to 150 m depths. However, in some areas, the thickness of the shallow groundwater zone ranges from less than 60 m along the margins of Doabs (area enclosed between two rivers) to 30 m or less in the lower or central parts of Doabs. Recently, it has been estimated that nearly 200 billion m^3 of fresh groundwater (mostly in the form of a thin layer) is lying on saline groundwater. Obviously, if proper technology is applied, the referred thin fresh groundwater layer can be skimmed from the aquifer with minimum disturbance of the saline groundwater zone. In the short irrigation water supply environment of Pakistan, such extractions would become a significant part of supplemental irrigation.

The explosion of pumping technology in the private sector, high capacity tubewells of more than 28 lps discharge are being installed even in the thin fresh groundwater zones. Framers are normally interested to install tubewells of higher discharges to have efficient basin irrigation by reducing the advance time. This can be regarded as a psychological issue rather than based on techno-economics of tubewells or physical conditions of the aquifer. The discharge of skimming wells might be as low as 3 lps and thus pressurized irrigation technology is necessary for efficient application.

In such zones, these tubewells are likely to draw a substantial portion of their discharge from the saline groundwater. The primary problem is that the tubewell discharges are too large for the given physical situation of the aquifer. This is particularly true for the tubewells located in the central regions of Doabs in Punjab province of Pakistan. The exception would be tubewells located adjacent to rivers and large canals where large quantities of seepage are recharging the groundwater reservoir.

Thus, if such tubewells are not replaced with fractional skimming wells, there is a serious concern that the pumped groundwater will become increasingly saline with time. Already, many high capacity public tubewells are being shutdown at the request of farmers in these areas, as the pumped water has become saline. In addition, there is a high expectation that many private tubewells will have to be abandoned during the next coming years. Therefore, it is imperative to introduce fractional skimming well and pressurized irrigation technology to address these future concerns.

Taking into consideration the vital importance and urgent need for developing fractional skimming wells and pressurized irrigation technology, a tripartite institutional arrangement Water Resources Research Institute (WRRI), National Agricultural Research Centre (NARC); Mona Reclamation Experimental Project (MREP), Bhalwal; and the International Water Management Institute (IWMI) was developed to initiate a collaborative project entitled "Root-Zone Salinity Management using Skimming Wells through Pressurized Irrigation Systems". The project was financed by WAPDA under the National Drainage Programme (NDP) and initiated in the Target Area at the Mona Reclamation Experimental Project, Bhalwal during November 1998.

Objectives of the project component

The project objectives are to:

1. Identify and test limited number of promising technologies of fractional skimming well in the shallow fresh groundwater aquifers, which could control the saline groundwater upconing phenomenon as a consequence of pumping;
2. Encourage and support in-country manufacturers to develop low-cost pressurized irrigation application systems adaptable within the local setting of Pakistan; and
3. Prepare and implement guidelines for irrigation scheduling with skimmed groundwater applied by low-cost pressurized irrigation systems to manage root zone salinity.

Based on the project objectives, the WRRI was assigned to conduct research on skimming dugwells and pressurized irrigation systems. After finalizing the methodological studies, the dugwell and Raingun sprinkler irrigation study was conducted initially at the Phularwan Experimental Farm of the MREP, Bhalwal. The activities initiated were:

- Renovation of the existing skimming dugwell located at the Phularwan Farm and installation of the electric and diesel powered prime movers;
- Hydraulics of the skimming dugwell;

- Design and layout of the Raingun sprinkler irrigation system and hydraulics study; and
- conceptual framework for design and operation of irrigation systems.

REVIEW OF LITERATURE

Traditional dugwells

A dugwell consists of a pit dug to the aquifer or to the material where permeability is reasonable. The pit is often lined with masonry or pre-cast concrete rings to support excavation. Due to difficulty in digging below the water level, dugwells normally do not penetrate in the zone of saturation to a depth sufficient to produce high yield (Zuberi and Mc Whorter 1973).

Dugwells have been used for thousands of years but have become less popular with the advent of tubewells (Gibson and Singer 1969). The dugwells are usually shallow wells, generally less than 15 m in depth and several meters in diameter. In the past they were usually constructed by hand, and even today in many areas this is the principal method of construction (Israelsen and Hansen 1962; Koegel 1977). Today, interest in dugwells is reviving, and they still hold much promise for arid lands. Modern materials, tools, and equipment may transform crude holes in the ground, hosts for parasitic and bacterial diseases, in to more safe, soundly engineered, hygienic, and reliable sources of water (Wagner and Lanoix 1959; Cembrowicz 1984). Dugwells are inexpensive and easy to construct and maintain by fairly unskilled labour. They provide storage for water, as well as a source (NAS 1974).

The well penetration depth and diameter are the main design parameters that influence the performance of the dugwell. The rate of pumping is much less responsive to changes in well diameter as compared to the changes in well penetration depth. It means that in a given aquifer, the well wetted perimeter has less contribution in increasing the yield of a dugwell as compared to the hydraulic gradient that exists between the water surface in the well and in the surrounding groundwater (Koegel 1977). Thus, the well penetration depth in relation to the aquifer characteristics is one of the important design parameter to achieve higher discharge rates.

Dugwells can be sunk only a few meters below the water table. This seriously limits the drawdown that can be imposed during pumping, which in turn limits the yield of the well. A dugwell that taps a highly permeable formation such as gravel may yield 0.6 to 2 lps or even more in some situations with only less than a meter drawdown. If the formation is primarily fine sand, the yield may be less than 0.6 lps. Because of their shallow penetration in to the zone of saturation, many dugwells fail in times of drought when the water level recedes or when large quantities of water are pumped from the wells (USDEW 1963).

In Afghanistan, Pakistan and India, dugwells are being seriously reconsidered (GOI 1962; NAS 1974). Since the use of rock drills became common, many existing dugwells have been deepened by digging from formations that had blocked previous equipment. In the last 25 years, Pakistan and India has also improved many dugwells solely by adding pumps. Powered by diesel engines or electric motors, inexpensive centrifugal or turbine pumps, installed on platforms 1-2 m above the water level, boost the water up to ground level. Suitable pumps are now made in many developing countries, including India and Pakistan.

Dugwells have contributed significantly in the rural development programs of the Barani and arid regions of Pakistan, India and Sri Lanka. In Pakistan, several hundreds of dugwells were installed by the Second Barani Area Development Program to provide water for rural communities to raise high value crops. The On-going Village Development Program has also included dugwells as one of the interventions. The project review had revealed that dugwell was one of the most promising intervention in the target area (ABAD 1998). In Madhya Pradesh, India, dugwell was one of the interventions of the integrated rural development program, which helped the rural communities in raising their livelihood (NBARD 1994). In Sri Lanka, the Agrowell Program was aimed to provide support to farmers to construct dugwells in the intermediate and dry regions of the country. There were serious concerns for the sustainability of dugwells based on aquifer characteristics and profitability of the cropping patterns (IIMI 1994).

Types of Dugwells in Pakistan

Dugwells in Pakistan are open wells drawing their water mostly from shallow unconfined aquifers. The two common types of dugwells are: a) those located in consolidated formations (hard rock areas); and b) those located in unconsolidated formations (Ahmad 1976).

The consolidated underground formations usually known as hard rock areas are normally outside the Indus basin especially in the sub-mountainous and mountainous regions. The shallow groundwater reservoir is the only source of limited supplies of groundwater in these areas, in the absence of any deeper aquifers. The aquifer is dependent on precipitation for recharge and as such water table is prone to considerable fluctuations in relation to the incidence of rainfall. Due to poor permeability of consolidated formations, bore dugwells or tubewells are usually unsuitable in such formations. It is therefore, desirable in such formations to have dugwells capable of storing fairly large supplies of water during a given period. Thus, the available supplies of water can be obtained at small drawdown in relatively short periods, thereby allowing for sufficient recuperation periods between successive periods of pumping. Dugwells also expose a greater surface even of the aquifer for infiltration.

Dugwells in the Indus basin are normally constructed in unconsolidated formations. The depth is normally 5 to 10 m below the static water level and dug in the dry period. The open excavation is usually circular in shape, the diameter varying from 1.5 to 4.5 m. The well in general derive their water from unconfined aquifers. Their large-diameters permit the storage of large quantities of water.

Dugwells in unconsolidated formations are usually provided with lining to prevent cave in of the walls. The common materials used for lining are brick, stones laid in cement mortar or pre-cast concrete rings. To make the design safe in case of drought, it is assumed that the well is empty and there is no internal pressure acting on it.

Hybrid wells

In Pakistan number of farmers has combined the dugwell concept with drilled bore, and such wells are named as dug-bore wells. These wells are of two types. The first type of dug-bore well consists of a drilled bore in the centre of the working dugwell, where both dugwell and bore contribute towards recharge. The second type of dugpit-bore well consists of a dug pit almost 1-2 m above the static water level and then bore is drilled to have an access to the aquifer. In this type of well only bore contributes for water, as pumping system is installed in the dug pit. The purpose is to reduce the suction lift of centrifugal pumps to keep the pumping cost as low as possible. Therefore, this type of well can be regarded as bore-well because the pit is dug purely for the purpose of reducing the suction lift. The bore drilled inside the working dugwell where both the dugwell and bore contribute towards recharge fulfils the definition of the hybrid well.

The dugpit-bore system was adopted in India in early 70s, where farmers were drilling one or more bores inside their dugpits to modify these for getting higher discharges (20-24 lps). Generally, these bores had a depth ranging from 15-30 m, and centrifugal pump was major mode of extraction. However, this kind of modification reduced the life of the well from 15-20 years to only 5-7 years (Nagaraj 1994; Nagaraj et al 1999). This type of well is subjected to continuous lowering of bores with the lowering of water table. The WRRI has recently conducted some field surveys in the Toba Take Singh area, where farmers are lowering the bores after every 4-5 years or even earlier in the un-commanded area. Most of the time farmers have to abandon the dugpit-bore well for purpose of lowering and they prefer to dug the pit and drill the bore at a new site.

Advantages of Dugwells

In Pakistan, dugwells are still used even after the explosion of the low-cost tubewell technology in the country, because tubewells are not feasible for areas where only shallow groundwater is available due to limited deep aquifer and/or quality concerns. Dugwell is the most efficient system of pumping thin layer of fresh groundwater overlain the brackish groundwater in the Indus basin. The depth of the dugwell can be kept less than the depth to the interface of the fresh and brackish groundwater zones. This depth is normally less than 15 m in major part of the Punjab province having marginal to brackish deep groundwater. The depth of fresh groundwater is very thin in the Sindh province, where tubewells cannot be used for skimming of fresh groundwater.

Disadvantages of Dugwells

Dugwells, however, do have distinct limitations (NAS 1974), which are listed as under:

- They can not be used to reach groundwater deeper than 20-30 m;
- Their water production is usually low; and
- Well-digging technology is understood and used in most countries, but the art of lining has regressed, and there is an important need for improved linings.

The liner protects against caving and collapse and prevents polluted surface water from entering the well. The main problem is lining the walls below the level of the water table. Another need is for safer, more rapid, more efficient digging techniques (NAS 1974).

Skimming Dugwells

The extraction of fresh groundwater from an aquifer is desired to be at minimal cost. Furthermore, such extractions should not exhaust or ruin this groundwater resource for future use. Similarly, local customs and traditions for extracting groundwater should be given full consideration. In this context, dugwell may provide a simple, cost-effective, and traditionally familiar option as compared to other potential options for skimming fresh groundwater from fresh and brackish groundwater aquifers (Zuberi and McWhorter 1973).

Skimming dugwells provide the only source of fresh groundwater in areas like Sindh province, brackish groundwater zone in the Punjab, NWFP and Balochistan provinces, where thickness of fresh groundwater is less than 15 m. In these areas tubewells can not provide fresh groundwater because the deep groundwater is brackish and the salinity ranges between 1500-4000 ppm. Furthermore, the dugwells can also provide an effective way of managing waterlogged areas, where concept of horizontal galleries or radial well points can be introduced to increase the recharge rate. WRRI has tested the concept of horizontal galleries at the Tropical Plants Introduction Centre, Karachi, to increase the yield of fresh groundwater.

Northwest India has large areas of land under irrigation from the Bhakra and Yamuna canal systems, but these areas are under severe constraints of low surface slopes, ineffective subsurface drainage and rising water table. Drainage options (subsurface drainage or skimming wells) are being considered for areas with shallow groundwater. Hybrid Eucalyptus with shallow rooting depth and varying water uptake levels is being considered as a biological management drainage measure and additional source of income (Diwan 1997).

FINDINGS OF INITIAL FIELD EXPERIMENTATION

Renovation of dugwell and installation of pumping systems

Experimental well located at the Phularwan Farm was an abandoned dugwell. This well was selected for renovation, therefore after cleaning the well, water was pumped 4-5 times for development of the well.

Both the diesel and electric powered pumping systems were designed for installation at the dugwell. Door, window and gate were installed at the well site for security measures. A wooden platform supported with steel frame was also constructed covering about half of the diameter of the dugwell.

Quantity of water

A permanent benchmark was established at the platform of the skimming dugwell to be used as a reference point for hydraulic and other measurements. Measurements of depth to the static water level and depth of water column were made at least once a month to document variation in the dugwell. Volume of water available in the skimming dugwell was estimated by multiplying the cross-sectional area of the well with the depth of the water column at a particular time.

Depth to the static water level in the skimming dugwell varied between 0.70 m to 1.98 m from the ground surface. This variation was not only due to the seasonal variations but also due to the pumping of water from the tubewell located adjacent to the dugwell. The tubewell operation had direct effect on the depth to the static water level and recharge rate of the dugwell. The average depth to static water level was around 1.38m from the ground surface (Table 1).

The depth of water column varied from 4.30 m to 5.55 m in the skimming dugwell. The average depth of water column was 4.89 m. Quantity of water available in the skimming dugwell varied from 31.39 m^3 to 40.52 m^3. Thus the average volume of water available in the skimming dugwell was around 35.7 m^3. This quantity of water as a dead storage is sufficient to irrigate one ha area with a depth of 3.6 mm or 0.72 ha with a depth of 5 mm. A net peak demand of 5 mm is suitable for most of the crops in the Target Area.

Table 1. **Depth to static water level, depth of water column and volume of water in the skimming dugwell at the Phularwan Farm, MREP, Bhalwal.**

Month	Date	Depth to Static Water Level (m)	Depth of Water Column (m)	Volume of Water (m^3)
September, 1999	15	1.95	4.30	31.39
October, 1999	15	1.83	4.42	32.27
November, 1999	18	1.30	4.95	36.14
December, 1999	16	1.01	5.24	38.25
January, 2000	15	0.99	4.96	36.21
February, 2000	16	0.70	5.55	40.52
March, 2000	15	1.45	4.80	35.04
Average		1.32	4.89	35.69

Quality of water

During the pumping tests conducted on around 15th of each month, the groundwater samples were collected from different depths of the skimming dugwell using an interval of 0.5 m depth. These samples were analyzed for pH and total dissolved solids (TDS).

There was not much variation in the TDS of the groundwater at different depths of the skimming dugwell. There was a slight improvement in the TDS of the groundwater since the start of the dugwell operations in September. During September 1999, the TDS ranged from 1032 ppm to 1069 ppm, while these were decreased to 986 ppm to 997 ppm during the month of March 2000 (Table 2). The pH of groundwater did not change much with the increase in the depth of the skimming dugwell. Even it did not change much with time. It ranged from 7.2 to 7.8 (Table 2).

Table 2. Quality of groundwater (in terms of TDS and pH) as a function of depth of the skimming dugwell and time at the Phularwan Farm, MREP, Bhalwal.

Depth (m)	Water Quality											
	Sept., 99*		Oct., 99		Nov., 99		Dec., 99		Feb., 2000		March, 2000	
	TDS (ppm)	pH	TDS (ppm)	pH	TDS (ppm)	pH	TDS (ppm)	PH	TDS (ppm)	pH	TDS (ppm)	pH
0	1043	7.5	974	7.5	957	7.4	998	7.6	993	7.5	997	7.5
0.5	1042	7.7	956	7.4	954	7.4	996	7.7	989	7.6	991	7.3
1.0	1041	7.5	963	7.4	948	7.3	992	7.7	986	7.5	989	7.3
1.5	1053	7.6	960	7.5	955	7.4	996	7.6	991	7.4	986	7.2
2.0	1044	7.6	960	7.4	954	7.4	994	7.6	991	7.5	989	7.2
2.5	1032	7.7	960	7.6	957	7.4	991	7.7	988	7.5	988	7.4
3.0	1057	7.5	964	7.6	957	7.3	993	7.7	989	7.5	991	7.2
3.5	1056	7.8			960	7.3	992	7.8	993	7.5	988	7.2
4.0	1068	7.5			961	7.4	995	7.7	990	7.6	990	7.3
4.5	1069	7.7			960	7.4	991	7.7	992	7.5	989	7.3
5.0							993	7.9	992	7.4		

* Represents first systematic pumping after closure of dugwell in the past years.

Recharge rate

Measurements for recharge were made after de-watering the well using the pumping system installed at the dugwell site, and then the rise in water level was measured as a function of time. An interval of one hour was used for these measurements. The cumulative recharge rate was estimated by dividing depth replenished with elapsed time since the start of the recharge. Measurements were made during the months of September 1999, October, January 2000, February and March.

The depth of groundwater replenished in the skimming dugwell in the month of September indicated that the cumulative recharge rate was initially 0.48 m/hr, which was reduced to 0.40 m/hr after 4 hours. This was reduced to 0.30 m/hr after 9 hours. After 24 hours, it was reduced from 0.48 to 0.17 m/hr (Table 3). Thus the cumulative recharge rate was reduced to one-third after 24 hours. Similar trend was observed in other months.

Depth of water depletion in dugwell using raingun sprinkler

Electric operated Raingun (Py1-30) sprinkler irrigation system was used to determine depth of groundwater depleted in the skimming dugwell at the Phularwan Farm with respect to time. The groundwater depth was measured at an interval of 30 minutes of pumping.

The depth of water depleted in the skimming dugwell indicated that there was not much variation as a function of time. The minor variation was due to variation in the groundwater level of the skimming dugwell. Within 4-5 hours duration 3 to 4 m depth of water was depleted (Table 4).

Table 3. **Depth of water replenished and recharge rate of the skimming dugwell at Phularwan Farm, MREP, Bhalwal.**

Month	Time (hrs)	Depth Replenished (m)	Cumulative Recharge Rate (m/hr)
September, 1999	1.00	0.48	0.48
	2.17	0.96	0.44
	3.00	1.25	0.42
	4.17	1.67	0.40
	5.00	1.85	0.37
	6.00	2.09	0.35
	7.00	2.32	0.33
	8.00	2.52	0.32
	9.00	2.70	0.30
	10.00	2.87	0.29
	11.00	3.02	0.27
	12.00	3.16	0.26
	13.00	3.28	0.25
	14.20	3.42	0.24
	15.00	3.50	0.23
	16.00	3.62	0.23
	17.00	3.69	0.22
	18.00	3.77	0.21
	19.28	3.88	0.20
	20.00	3.92	0.20
	21.00	3.97	0.19
	22.00	4.05	0.18
	23.00	4.07	0.18
	24.00	4.15	0.17
	25.00	4.18	0.17
	26.00	4.19	0.16
October, 1999	1.00	0.42	0.42
	2.00	0.77	0.39
	3.00	1.09	0.36
	4.00	1.37	0.34

	5.00	1.60	0.32
	6.00	1.83	0.31
	7.00	2.03	0.29
	8.00	2.20	0.28
	13.50	2.95	0.22
	14.00	3.00	0.21
	15.00	3.11	0.21
	16.00	3.20	0.20
January, 2000	0.50	0.16	0.32
	0.75	0.28	0.37
	17.33	3.27	0.19
	21.33	3.48	0.16
February, 2000	1.00	0.28	0.28
	2.67	1.04	0.39
	4.42	1.59	0.36
	6.00	1.94	0.32
	8.42	2.40	0.29
	17.50	3.38	0.19
March, 2000	1.00	0.36	0.36
	2.00	0.79	0.40
	3.00	1.12	0.37
	4.00	1.38	0.35
	5.00	1.69	0.34
	6.00	1.89	0.32
	7.00	2.12	0.30
	8.00	2.29	0.29
	9.00	2.49	0.28
	10.00	2.65	0.27
	11.00	2.79	0.25
	12.00	2.93	0.24
	13.00	3.07	0.24
	14.00	3.18	0.23

Table 4. **Depth of water depleted in the skimming dugwell as a function of time using Raingun (Py_1 - 30) sprinkler irrigation system at Phularwan Farm, MREP, Bhalwal.**

Time (hrs)	Depth of Water level Depleted in the Skimming Dugwell (m)						
	Aug. 1999	Sep. 1999	Oct. 1999	Nov. 1999	Jan. 2000	Feb. 2000	Mar. 2000
0.5	0.61	0.50	0.59	0.59	0.63	0.64	0.56
1.0	1.24	1.09	1.10	1.05	1.22	1.09	1.06
1.5	1.73	1.62	1.51	1.51	1.70	1.54	1.51
2.0	2.13	2.08	1.94	1.93	2.22	1.96	1.96
2.5	2.56	2.49	2.29	2.23	2.56	2.35	2.31
3.0	2.92	2.89	2.61	2.58	2.94	2.68	2.69
3.5	3.20	3.22	2.93	2.87	3.30	3.00	2.97
4.0	3.50	3.50	3.15	3.13	3.59	3.17	3.24
4.5	3.78	3.78	3.40	3.34	3.84	3.49	3.35
5.0	4.01	3.96	3.59	3.53	4.13	3.69	3.67

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