Investigation of water supply systems in semi-arid regions of Iran: A case study of western part of Tehran Province

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ABSTRACT

At present, drought problem has been resulted social and economical effects in several arid and semi-arid regions of Iran. Especially, on environmental and agricultural aspects. Tehran Province involves three river basins and seven regions according to the classification of water management study units employed in the Master plan. In this regard, long-term records (27 years) of precipitation and runoff that concern to more than four hydro-meteorological stations, which located in different sites have been analyzed. Water production in the study area despite that Tehran’s water supply is currently groundwater (40%) and surface water (60%) conveyed from Karaj, Latian and Lar dams. The area recently experienced its worst water crisis due to excessive water consumption by Tehranis and that will be further aggravated not only by the impacts of uncontrolled immigration to the capital city of Tehran along with rapid population growth but also by uncontrolled pumping up of groundwater. Appropriate measure are thus required to exploit new surface water resources, as well as the effective use of available water resources including a legal framework and institutional strengthening to limiting ground water use.

Keywords: Water management, drought, surface water, groundwater.

1. Introduction

Tehran province has expanded rapidly and largely westward after the revolution with its population increased about 7 million in 1996 to 12 million at present. At the time of revolution of Iran, approximately 400 MCM of municipal water was consumed annually in Tehran Province, of which 150 MCM was supplied from Latian dam constructed on Jajrud River located in the east of Tehran city and 250 MCM was provided from Karaj dam on Karaj River in the west of Tehran (Bybordi, 1989). Both dams are multi-purpose for water supply and irrigation, however, rapid increase of demand for municipal water supply due to migration of urban population and industries has forced conversion of water use from irrigation to municipal water supply. As a result of such a conversion, both dams have been supplying 300 MCM of annual water to Tehran after 1993 showing a critical level that cannot accommodate any further increase in additional water to Tehran, except some 100MCM of Karaj water that are utilized for agricultural purpose at present. To cope with increasing demand of water supply in Tehran, consuming of groundwater has increased rapidly since 1993. According to the western capital area, surface water of Karaj River has been fully developed together with excessive development of groundwater by means of deep and shallow wells. Shortage of irrigation water from surface resource resulted in connection with conversion of agricultural water to municipal water has forced the scale-downs of irrigation as well as...
dependence on groundwater in the agricultural areas of southern Tehran plain and
downstream reaches of Karaj and Jaj-rud Rivers. Decreasing progress of production as well
as levels of groundwater together with contamination of water quality due to waste-water
from municipal areas has become serious social problems in the area.
Demand of municipal water supply in Tehran city in 2021 is estimated at 1230 MCM
corresponding to the projected population of 10.7 million with an increase of 230 MCM
against the present demand of 910 MCM. No concrete plan of water resource development
and water allocation has, however, been formulated.

2. Materials and Method

2.1 Site description

The study area covers Tehran province that is one of the thirsty Provinces of Iran. The area
under study lies between 50° 10’ and 53° 8’ North latitudes and 35° 1’ and 36° 20’ East
longitude. The study area is located to the north of the central plateau of Iran. The Province
of Tehran has over 12,000,000 inhabitants and is Iran's most densely populated region.
Approximately 84.15% population resides in urban areas and 15.85% in rural areas of the
Province. The highest point of the Province is mount Damavand situated at an elevation of
5,678 m and the lowest point of the Province in the plains of Varamin, 790 m above sea level.
The largest rivers of this Province are Karaj River and Jajrud River. Geographically speaking
the study area is located, in the depression surrounded by areas of the great Alborz mountain
massif, west Zagros highlands and western part of the Kavir salt desert, specified by altitude
ranging from 800 m to 4300 m above mean sea level. The highest recorded summer
temperature in study area has been 42°C while the lowest has been registered at -8°C.

The climate of the area is Mediterranean with air mass brought from west in winter and from
east in summer. Pluvial air mass visits the area from west or north with humidity which gives
precipitation on the way when crossing Azerbaijan, Zagros and Alborz mountains, losing its
influence as it advances further towards east and south. For this reason intensity and amount
of precipitation of the area is controlled by latitude and altitude. The area receives 700 mm or
more rainfall in the western and northern highlands and 100 mm or less in the southern and
eastern border near the Kavir salt desert.

2.2 River Basin related to the Tehran Province

River Basin related to the Study Area can be divided into three category, one is basin of three
rivers, Abhar-rud, Khah-rud and Haji Arab, being expanded in the south plateau area of
Qazvin plain and the other one is the sefied-rud basin including the shah-rud river located at
the downstream of the Taleghan and Alamout rivers and the last one is Saheli basin which
Hableh and Haraz rud are the main rivers of that, located in the eastern part of Tehran
Province.

2.2.1 Three river Basins in Qazvin South Plateau

Three River Basins in Qazvin South Plateau produce the annual runoff of more than
250MCM in total, flow down in the area of Takestan, Shal and Buin and finally empty in to
the salt marsh. As the surface water of those three rivers has been used for irrigation and for
recharge of groundwater in the southern Qazvin plain, it is necessary to identify the
possibility to use those surface water for irrigation project in the southern Qazvin plain.
2.2.2 Sefied-rud River Basin

There exists Manjil dam with its reservoir capacity of 1,600MCM providing water to the large Giran irrigation area of about 230,000 ha in the basin. The Manjil dam is constructed at the conjunction point of Shah-rud and Qezel Ozan rivers, and has been under operation for more than 30 years. Proposed water diversion plans from the Taleghan and Alamout river to Qazvin plain and western area of the capital Tehran will reduce the flow in Shah-rud river and in turn will give some influence of the operation of the Manjil dam. Irrigation service area of Giran plain will be suffered from some water shortage problem; hence it is necessary for the study to cover the basin, to make study of the Manjil dam operation to evaluate impact of the proposed water diversion plans.

2.2.3 Saheli Basin

The Lar dam which is constructed over the Haraz River with 1MCM reservoir volume (one of the largest dams in Iran) exists in this basin. It is situated at the distances of 75km and 100km from Tehran and Amol cities respectively (North West of Study area). Hableh Rud River, which is organized from main branches of Namrud, Firuzkooh and Goorsefied is also the other main river which exists in this basin.
3. Surface Water

Water collecting on the ground or in a stream, river, lake, wetland, or ocean is called surface water, as opposed to groundwater or atmospheric water. Surface water is naturally replenished by precipitation and naturally lost through discharge to evaporation, and subsurface seepage into the groundwater.

3.1. River Systems and Observation of Surface Water

The study area is divided into seven sub-basins; namely, 1) Taleghan and Almout river basins as the donor basin of water resources, 2) Tehran City, 3) Tehran region surrounding Tehran city, 4) Karaj region, 5) Hashtgerd region and 6) Qazvin plain 7) Firuzkooh region. Six sub-basins other than Taleghan/Almout are the consumers of water supplied and are drained by Karaj, Jaj-rud, Shour and Haraz rivers. The Taleghan and Almout rivers traverse the Alborz Mountains westward and join each other at about 15km upstream of Siahdasht, located on the northwestern boundary of the study area. After joining the river has been renamed Shah-rud that runs further westward until flowing into the Sefied-rud (Mangil) dam. The other main tributary branch of Qezel Ozan River joins at the Mangil dam and the downstream is called Sefied-rud River. The total catchment of Manjil dam reported at 56,600 sq.km of which about 5,070 sq.km is drained by Shah-rud River.

The Shoor River is drained by number of rivers and small streams. In its western part, Khah-rud River and Abhar-rud River have a wide outflow basin. Tributary branches of Khah-rud river are Avaj, kalanjinchay located to the south of Haj arab river. On the northern part, there are several small creeks that are considered as drains for higher part of the Qazvin plain having seasonal discharges with a low basic flow only. In the northern part of the basin, there is Kurdan River draining the highest mountainous part of the basin having a considerable amount of seasonal stream and basic flow. Various small and seasonal streams such as Mortezaabad, Aoolak, Barajin, Rashtghan, Ashnestan, Shotrak, Behjatabad, Ziaran, Sarab, Fashand, Ardehe and Valian are also originated from the northern ridge of the mountainous part and flowing into Qazvin plain. Some part of these seasonal flows is used for irrigation and majority is considered as the source of groundwater recharge. The Shoor River drain surplus of surface water during the peak flood season and excess of groundwater from a deep aquifer underlain Qazvin plain and finally empties into the Salt Lake.

The Karaj and Jaj-rud Rivers, originated from the northern deep mountains in the study area, keep perennial flows and are major sources of surface water supplied to Tehran City. Amir Kabir dam (Karaj dam) on Karaj River is under operation since 1963 and outflow released from dam is Latian dam on Jaj-rud River has also been operated 1968 and major part of river water is brought together with water transferred from Lar dam to Tehran City through a diversion tunnel. Lar dam is constructed over the Haraz River in Firuzkooh region. The Karaj and Jaj-rud Rivers flow southward and after joining small rivers of Kan and Damavand finally empty into Shoor River.

3.2. Surface Water Quality Indices

Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and Total Suspended Solid (TSS) are the selected indices for evaluation of water quality of Tehran Province Rivers. BOD is one of the most valuable and commonly used indicators for assessing water quality (Allen, 1996). BOD is the amount of oxygen, which is used by microorganisms to aerobic
decomposition of organic matter. BOD is negatively correlated to stream flow. Standard value of BOD required ensuring a healthy environment and aquatic life is less than 3 mg/l. The DO of water is another indicator of pollutant levels in an aqua environment, where under DO lower than 5 mg/l aquatic organism’s activity will decline. In critical conditions (DO=0), the river lies in anaerobic state and big species will die or migrate to other places. BOD and DO correlate reversibly.

Insoluble solids in water, which appear in suspension state, are called TSS. Turbidity is the direct and physical result of suspended solids in water. Turbidity causes less sun radiation penetration to water. This condition declines the aquatic photosynthesis and result to low DO in the river. Also, settlements of suspended materials on river bed destroy the habitat of aquatic organisms and change the suitable places for fish nursery and spawning. TSS has an inverse correlation with river flow and high levels of TSS causes a decrease in the potential of the river to decay pollutants. Standard levels of TSS are 30 mg/l.

3.2.1. Sources of Pollution in the Rivers

Main sources of the river pollution can be categorized into three groups including domestic effluents, industrial, and agricultural return flows (Anonymous, 1993). Eighteen stations measure the limnological parameters of the Study Area Rivers are maintained by Tehran Regional Water Board Jamab consulting Engineers. Because of huge volume of raw data especially on water quality, analyzed values of selected stations are extracted from the master plan report of Iran as shown in the following table. It is remarked here that, even though high salinity of water taken from the Shoor River is reasonable because the river originate from the salt marsh.

| BOD (mg/l) | COD (mg/l) | TSS (mg/l) |
|------------|------------|------------|
| Inflow     | Outflow    | Inflow     | Outflow | Inflow | Outflow |
| Mean       | 241        | 33         | 510      | 86     | 281     | 44       |
| Max        | 330        | 36         | 600      | 110    | 440     | 38       |

3.3. Water Demand

Tehran province has for centuries provided the basis for important economic activities. These activities can be categorized in three sectors including agricultural, industrial and domestic consumptions (Afiei, 2002). Water Supply is the dominant water user that consumes more than 60% of the rivers yield. So, there has normally been insufficient water to irrigate the total Irrigable area. It is estimated that water consumption per hectare varies from 10,000 to 14,000 cubic meters. Huge industrial complexes have been located in Tehran Province. The most important ones Tehran cements Factory, Mino Complex and number of textile factories that consumes about 3000 MCM water per year. Population of Tehran Province is over 12 million and domestic water use is estimated to be 80 m³/yr per capita.

4. Groundwater
Groundwater is often called underground water which occurs below the surface of the earth. The formation of underground water takes place when under hydrostatic pressure the permeable rocks get saturated with water from the surface water that moves down by gravity to enter this zone, the upper surface of which is called the water-table. For this reason, groundwater is sometimes called subterranean water.

4.1. Aquifer Structure and Classification of Groundwater Basin

In groundwater basin, water supply and irrigation water have been traditionally used to depend on qanats-system. At the mother wells of qanats, the ground water tables range from as much as 50m below the surface near the mountains, and is rising to within one meter in central part of the plain in last few decades, these qanats-system have been replaced by a pumped supply system with tube wells sunk in to aquifer even to 300m deep.

4.2. Groundwater Table and Changes

Though the measurement of groundwater table is a relatively easy task, the data thus obtained are rich and valuable. The measurement data can be utilized for qualitative as well as quantitative review on recharge, storage, and flow of groundwater. Records of groundwater tables were observed by seasonal or monthly-basis operation. The collections of records were made for ten years from 1995 to 2005. Among these the set of records in the month of Oct.1999 were presented as rather high quality/density than those in order duration. Therefore, the month of Oct.1999 was selected as the calibration timing for the evaluation of groundwater recourses. The groundwater table change judge from groundwater hydrographs was summarized as follows:

**Table 2: Groundwater Storage of Aquifer Estimated from Storage Coefficient and Aquifer Thickness**

| Sub-Areas    | 1995/96 | 1996/97 | 1997/98 | 1998/99 | 1999/2000 | 2000/2001 | 2001/2002 | 2002/2003 | 2003/2004 | 2004/2005 |
|--------------|---------|---------|---------|---------|-----------|-----------|-----------|-----------|-----------|-----------|
| Tehran City  | 878     | 876     | 887     | 891     | 885       | 879       | 870       | 857       | 843       | 836       |
| Tehran north | 4,360   | 4,360   | 4,368   | 4,349   | 4,332     | 4,313     | 4,290     | 4,263     | 4,259     | 4,237     |
| Tehran      | 6,555   | 6,498   | 6,517   | 6,472   | 6,433     | 6,433     | 6,382     | 6,305     | 6,267     | 6,174     |
| Karaj       | 2,819   | 2,818   | 2,830   | 2,835   | 2,834     | 2,823     | 2,804     | 2,764     | 2,718     | 2,666     |
| Hashtgerd   | 10,73   | 10,78   | 10,83   | 10,89   | 10,948    | 11,04     | 11,07     | 10,96     | 10,92     | 10,78     |
| Qazvin (north) | 7     | 8       | 8       | 0       | 22,513    | 0         | 1         | 7         | 7         | 0         |
| Qazvin      | 22,53   | 22,52   | 22,51   | 22,50   | 13,409    | 22,58     | 22,58     | 22,36     | 22,32     | 22,02     |
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4.3. Existing Production Wells

In order to summarize features of groundwater facilities, reference were made to “Statistical Reports of Groundwater Resources” prepared in 1997/98 and 2001/02 for five sub-areas. It should be noted here, however, that the data collection works were still on the way and existing available data probably contained some incorrect data and therefore was not quite accurate. Aside from that, according to existing available data of groundwater wells, about 12,385 of deep wells and 17,145 of shallow wells have been excavated in the area. Average features of groundwater wells are summarized as follows

Table 3: Average Features of Groundwater Wells

| Sub Areas          | Number of Wells | Average features of Groundwater wells |
|--------------------|-----------------|---------------------------------------|
|                    | Deep | Shallow | Total | Depth of Well | Depth of Water | Discharge (lit/sec) | Operation Hour (hrs) |
| Tehran City        | 2,374 | 6,825 | 9,199 | 79 | 35 | 6 | 1,095 |
| Tehran             | 3,848 | 2,488 | 6,336 | 80 | 43 | 9 | 2,450 |
| Qazvin South       | 1,894 | 1,505 | 3,399 | 87 | 33 | 80 | 3,592 |
| Qazvin North       | 476 | 401 | 877 | 113 | 29 | 66 | 3,497 |
| Karaj              | 1,393 | 1,760 | 3,153 | 61 | 29 | 14 | 1,828 |
| Hashtrgerd         | 860 | 2,166 | 3,026 | 69 | 27 | 18 | 2,715 |
| Firuzkooh          | 1,540 | 2050 | 3590 | 71 | 34 | 27 | 2,130 |
| Total(Average)     | 12,385 | 17,145 | 29,580 | 80 | 33 | 31 | 2,472 |
4.4. Existing Qanats

With reference of “Statistical Reports of Groundwater Resources” prepared in 1997/98 and 2001/02 for five sub-areas by Tehran Regional Water Board, the number of facilities for regions of Qazvin , Karaj, Hashtgerd, Firuzkooh and Tehran City is 870 and total discharge amount are summed up as 475 MCM/year as summarized below :

| Sub-area        | Qanats Discharge(MCM/year) |
|-----------------|----------------------------|
| Tehran city     | 147                        |
| Tehran          | 125                        |
| Qazvin North    | 31                         |
| Qazvin South    | 38                         |
| Karaj           | 35                         |
| Hashtgerd       | 23                         |
| Firuzkooh       | 76                         |
| **Total**       | **475**                    |

**Table 4:** Qanats Discharge

**Table 5: Summary of Groundwater Extraction**

| Summary of Groundwater Extraction Basis of current Study (2001,MCM/year) | Groundwater Extraction Estimated in Planning and Budget Organization (MCM/year) |
|------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Nos. of Wells | Extraction | Total | Agricultural | Water Supply | Total |
|------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Tehran Capital Area | | | | | |
| Tehran City | 13,304 | 269 | 0 | 269 | 269 |
| Tehran | 6,300 | 590 | 430 | 160 | 590 |
| Karaj | 3,200 | 833 | 419 | 414 | 833 |
| Hashtgerd | 3000 | 328 | 296 | 32 | 328 |
| Firuzkooh | 4,800 | 700 | 307 | 393 | 700 |
| **Subtotal** | **30,604** | **2,720** | | | **2,720** |
4.5. Evaluation of Existing Groundwater Use

According to existing statistics of wells, about 269 MCM of ground water were extracted from 13,304 deep and shallow wells in the area of Tehran City. In the Tehran plain and Shahriyar plain, about 590 MCM were extracted from 6,300 wells, while in the Roboatkarim and Kordan/Karaj plain, 833 MCM was withdrawn by 3,200 wells. Simultaneously, 328 MCM by 3,000 wells in the Hashtgerd, 700 MCM by 4,800 wells in Firuzkooh and 1,240 MCM by 4,843 wells in Qazvin plain were consumed in 2001/02 as shown below:

| Location | Wells | Groundwater Consumption |
|----------|-------|-------------------------|
| Qazvin   | 4,843 | 1,240                   |
|          | <==>  | 1147                    |
|          | <==>  | 93                      |
|          |        | 1,240                   |
| Total    | 35,447 | 3,960                   |
|          | <==>  | 2,592                   |
|          |        | -                       |
|          |        | 3,960                   |

It is noted here that statistic of groundwater wells are rather old expect for Qazvin plain, and therefore rapid increase of extraction to cope with population growth especially in the Tehran capital area in recent years is not reflected. Further, the actual usage of well was not surveyed and accessed properly in aforesaid report (Statistical Reports of Groundwater Resources” 1997/98 and 2001/02).

Hence, this extraction value is regarded as “facility capacity of production wells to be extracted in maximum usage”. In order words, net value accounted as actual extraction must be less than this extraction amount which is exceeding 3,960 MCM/year. Accelerated trend of groundwater extraction has already resulted in severe downfall of groundwater level as well as production in many parts of aquifers, inevitably requiring monitoring and management of limited groundwater resources for future rational groundwater exploitation.

4.6. Evaluation of Potential Groundwater

The present state of social and economic development throughout the study area is characterized by a sharp increase in groundwater exploitation. This is due in part to the fact that the available surface water is often fully developed and committed; surface water is utilized throughout the study in large amount for irrigation, industrial, and domestic water supplied. Instead of the use of surface water, in groundwater resource is utilized as a result of man’s activity in the recent drought (Beaumont, P. M. and K. Mclachlan, 1989). Especially in Karaj and Hashtgerd and even in Qazvin south, the mining of the non-renewal water has been habitually progressed.

In case that exploitation in those areas is to be planned in the Master plan of Iran (M/P), strict control within a “permissible yield” against either water demand or a planned period of tie must be considered throughout the “Groundwater Balance Study”. Then, the reliability of groundwater exploitation recommended in M/P must be guaranteed.

4.7. Method of Groundwater Balance Used

A water balance study was carried out to evaluate groundwater potential and the reasonable limit of groundwater utilization for renewal groundwater resources. On regional water balance, the equation consist of rainfall, surface runoff, evaporate-transpiration, drafting, inflow and outflow of groundwater and so third is commonly applied, are as below:
Groundwater Recharge (Gr)
Groundwater Runoff (Gf)
Change in Groundwater Storage (Δs)

As per equation, the current groundwater balance as well as an available groundwater resource was provisionally examined in the study.

4.7.1. Groundwater Recharge (Gr)

In previous studies completed since 1960’s at Qazvin, Tehran and Shahriyar areas, the potential of groundwater recharge was elaborated by using several kinds of methods (Sabetraftar, 2000). In this study, the estimation of groundwater recharge was followed in three approaches due to different sources for recharges:

1. Direct recharge from precipitation
2. Seepage through streambeds
3. Return flows from city water supply, well and qanats extraction for industrial and irrigated areas

After several ten times of iterations with trial calculations, the final parameters or coefficients were determined as appropriate amount matched with the those of existing studies. Resulting in provisional estimations, 48 MCM/year direct by precipitation, 605 MCM/year river flow and 471 MCM/year by return flow were calculated as amount natural groundwater recharge in the study area. In addition to above, 31 MCM/year (average 1997/98-2001/02) through artificial recharge ponds was account to the recharged amount and totaled with 155 MCM/year was obtained from all over the groundwater basin.

4.7.2. Groundwater Runoff

The amount of groundwater flow in to the groundwater basin is considered to be only recharged water caused by precipitation and applied /irrigation water outside the basin. Meanwhile the groundwater out flow outside the watershed is taking place near its outlet. This generally occurs as a form of groundwater out flow through Quaternary deposit underlain along the basin border (Keshavarz, A. and K. Sadeghzadesh, 1999). In the study area, this deposits were recognized all the surrounding of groundwater basin. Their transmissivity was relatively assumed to be 500 to 4,000 m²/day. With the use of these values, the inflow and outflow crossing basin border was estimated. Groundwater in /out flow amount were estimated as 1,172 MCM/a while 92 MCM/year out-flow amount as shown below:

| Groundwater In /out-flow through Sections | Groundwater In/out-flow into sub-areas |
|------------------------------------------|----------------------------------------|
| Calc. section | G.In/out flow | width of sectio | G.In/out-flow through sections | Qazvin south | Qazvin north | Hashtgard | Karaj | Tehran | Tehran city | Total |
|---------------|---------------|----------------|-------------------------------|--------------|-------------|-----------|------|--------|-----------|-------|

Table 6: Summary of Groundwater Inflow
| rate | n | (m³/d) | (MCM/a) | (MCM/a) |
|------|---|--------|---------|---------|
| 1 | 16.9 | 47,23 | 796.44 | 291 | 291 |
| 2 | 7.9 | 3 | 13 | 13 | 13 |
| 3 | 4.4 | 4,431 | 34,827 | 83 | 83 |
| 4 | 0.2 | 51,63 | 227,66 | 0 | 0 |
| 5 | 0.8 | 7 | 8 | 17 | 17 |
| 6 | 1.7 | 4,824 | 1,000 | 42 | 17 | 25 | 42 |
| 7 | 1.7 | 60,44 | 45,788 | 28 | 28 | 28 |
| 8 | 2.6 | 1 | 115,19 | 31 | 31 | 31 |
| 9 | 5.6 | 68,95 | 3 | 51 | 51 | 51 |
| 10 | 4.0 | 3 | 76,609 | 54 | 5 | 49 | 54 |
| 11 | 11.4 | 43,82 | 85,592 | 130 | 39 | 91 | 130 |
| 12 | 0.5 | 1 | 138,87 | 2 | 2 | 2 |
| 13 | 16.4 | 32,91 | 8 | 201 | 201 | 201 |
| 14 | 3.2 | 0 | 148,31 | 28 | 3 | 25 | 28 |
| 15 | 9.3 | 24,83 | 7 | 202 | 20 | 181 | 202 |
| 16 | 1.7 | 9 | 355,05 | 62 | 0 | 0 |
| 17 | 5.3 | 37,51 | 4 | 156 | -12 | -12 |
| 15-16 | -1.0 | 4 | 6,630 | -19 | -19 | -19 |

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|    | 4 | 6 | 53,357 | 51,65 | 1 |
|----|---|---|--------|-------|---|
|    | 100,7 | 92 | 80,03 | 5     | 59,45 |

In/flow 420 141 88 93 224 207 1,172
Outflow /40 /10 /22 0 /19 0 /92
(In)-(out) 381 130 65 93 204 207 1,080

Calculation was made based on ‘Oct 2000

1,172 MCM/year of total amount of groundwater inflow accounts for 26% of all rainfall discharge (4,404 MCM/year) of all surrounding sub-basins. This can be regarded as very possible rate in view of regional hydrogeology.

4.7.3. Change in Groundwater Storage

Each of the hydraulic water balance in the basin contains item on “change in groundwater storage (± Δ S) which signifies the change in water contents of aquifer or the groundwater storage or both. The interpretation as to which of these storage locations are used in the balance equation depends on the definition or zone to which the equation is applied.

The change of storage term (± Δ S) is significant only if the hydrologic balance equation is applied for a short period of time. If the period is longer and steady state, this term becomes insignificant in relation to the other terms and may taken to be zero. In the study area, the hydrologic balance may be beginning as a negative balance from 1980’s. The system therefore has not been in a steady-state or in a quasi-steady state. The” change in storage volume (± Δ S) from Oct.1995 to Sep.2005 calculated the observation record of groundwater table, net groundwater storage (± Δ S)” is presumably estimated as below:
Table 7: Annual Changes in Groundwater Storage from 1995 to 2005

| Sub-areas     | 95/96 | 1996/97 | 1997/98 | 1998/99 | 1999/2000 | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 |
|---------------|-------|---------|---------|---------|-----------|---------|---------|---------|---------|---------|
| Tehran city   | -5    | 1       | 19      | 4       | -1        | 1       | -21     | 0       | -20     | -1      |
| Tehran        | -8    | 31      | -13     | 5       | -12       | 2       | -39     | 44      | -10     | -26     |
| Karaj         | -14   | 12      | -27     | 4       | 15        | 93      | -160    | -88     | -66     | -288    |
| Hashtgerd     | -15   | 13      | 15      | 51      | 77        | 156     | -34     | -13     | -69     | -273    |
| Qazvin(north) | -20   | 34      | -17     | 14      | -2        | 32      | -51     | -2      | -58     | -47     |
| Qazvin(south) | -50   | 27      | -74     | 16      | -1        | -21     | -66     | -15     | -42     | -125    |
| Firuzkooh     | -42   | 28      | -56     | 12      | 1         | -10     | -58     | -13     | -40     | -118    |
| Total         | -154  | 146     | -153    | 106     | 77        | 253     | -429    | -87     | -305    | -878    |

(MCM/year)

Note: the change in groundwater storage is calculated as a difference within each water year (from Oct. to Sep)

In the groundwater basin, the drastic decreasing of groundwater table is recorded since 2001/02. Thus, the saturated zone has been lost in last four years at the rate -74 to -76 MCM/year. Therefore in particular, Karaj, Hashtgerd, Firuzkooh and Qazvin sought area were suffering by serious deficits in these days.

5. Conclusion

Average annual temperature and rainfall, and also explosive rate of population (2.8%), of Province, are main reasons of existing and widening gap between supply and demand. It seems the only alternative left is to capitalize and utilize various techniques to reduce consumption; otherwise Tehran will face a continuous and uninterrupted water crisis. Proposed strategic management viewpoint should also cover other areas such as supply, transfer, treatment, storage and also distribution and consumption. For each of above aspects, special operational management should be considered and executed. Although, there were many reasons behind the recent water crisis, one of the main reasons was non co-ordination among various management divisions which ended up in rationing. Tehran's water crisis was handled successfully by utilizing various strategic management techniques, but in order to prevent such crisis repeating itself, one must adopt long-term strategic policies and demand management, also various techniques of efficient use of water.

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