Aaksh ganga: Water from Sky

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1.0 Need for Aakash Ganga in Rajasthan

More than two thirds of India's population, over a Billion, lives in rural and semi-rural areas. Rajasthan, the largest state, has a population of 56 million, spread over its 32 districts and 41,538 villages. The State is drought prone: it has experienced 40 droughts during the last 52 years and has 11 desert districts. In 2000-2001, 31 districts out of 32 districts faced acute shortage of water. A large number of villages, estimated 30,583, have over 50% deficit crop yield, jeopardizing the lives of nearly 32 million people.

Groundwater is fast disappearing. There is little or no surface water. The water table has receded to 300 – 500 feet depth, dropping 10 – 15 feet every year for the last 10 years. About 30% of the hand pumps have gone dry. A large percentage of livestock is lost for lack of water. Women have to walk long distances to fetch water. Farmers are abandoning cattle and are migrating to cities.

Aakash Ganga was conceived to find a lasting and sustainable solution to the chronic shortage of drinking water. Through this collaboration Aakash Ganga aims to develop or deploy novel technologies, innovate social enterprise structures, build economic models, ensure community participation, mobilize beneficiaries, and effect cultural integration.

These requirements, or a large part thereof, are used to implement the rainwater- harvesting scheme in few villages. When perfected, the model will be economically viable ─ replicable and self-sustainable. Till today the scheme has been implemented in six villages and The activities for each of the six villages are summarized below and subsequently the different aspects of the scheme has been explained.

BITS Campus: The BITS Campus is the first site where Aakash Ganga was implemented on an experimental basis. It serves as laboratory for research and development, design innovation, and experimentation. The site needs a fence to protect the revenue generating plants and trees. BITS will set up an account to collect the revenues from the produce and use the income to pay for the upkeep and related operational expenses of Aakash Ganga beyond the period of this project.

Raila: Raila was the first pilot site. The major activities are social innovation, operations, lac production, and shade for the care-taker. The local government has contributed 10,000 M^2 adjoining the Gram tanka or shared reservoir.

Harinagar: Aakash Ganga was implemented in Harinagar with the World Bank funding. Major activities to be undertaken are leveling the land, fencing, drip irrigation, and planting the trees for revenue generation. Other activities are social innovation, operations, lac production, and shade for the care-taker.

Lasedi and Indrasar: Aakash Ganga was implemented in Lasedi with the World Bank funding. It has more than 50 Griha tankas and one Gram tanka. The local government will contribute 10,000 M^2 land adjacent to the Gram tanka. Major activities to be undertaken are leveling the land, fencing, drip irrigation, and planting the trees for revenue generation. Other activities are social innovation, operations, lac production, and shade for the care-taker.

Indrasar is just 2 Kilometers from Lasedi. Aakash Ganga implementation was funded by private sector. It has a large number of house-attached tanka or Griha tanka but does not have a Gram tanka. A single individual or social entrepreneur will take care of both Lasedi and Indrasar. The major activities are cultural integration, operations, and on-going maintenance; which are minimal...

Kakreu Kalan: Kakreu Kalan was implemented with the World Bank grant. It too has more than 50 Griha tankas that are connected to a Gram tanka. Given its population, we will implement additional up to 20 Griha tanka and one Gram tanka. The local government will contribute 10,000 M^2 land in adjacent to the Gram tanka. Major activities to be undertaken are leveling the land, fencing, drip irrigation, and planting the trees for revenue generation. Other activities are social innovation, operations, lac production, and shade for the care-taker.

The scheme has the following engineering aspects:

2.1 Network Design

Aakash ganga is a comprehensive scheme and has many aspects. One of the major aspects is to harvest the rainwater, store it, and use it for different purposes like drinking, irrigation, etc. The other aspects are described somewhere else in complete report. This section talks about the engineering aspects of the rooftop rainwater harvesting, storing it in tanks, and its usage.

Rooftop rainwater harvesting systems, both small and large are comprised of six basic components as described below:

- *Catchment Area/ Roof:* Surface upon which rain falls.
- *Gutters and Down Spouts:* Transport channels from catchment surface to storage.
- *Leaf Screens and Roof Washers:* Systems that remove contamination and debris.
- *Cisterns or Storage Tanks:* Where collected rainwater is stored.
- *Conveying:* The delivery system for treated rainwater, either by gravity or pump.
- *Water treatment:* Filters and equipment and additives to settle, filter and disinfect.

Aakash ganga is a very comprehensive scheme and apart from the basic components of rooftop rainwater harvesting, it also includes other components as shown in figure. It is a network of different tanks and connecting pipelines. It is a broad based integrated modular scheme, which allows the construction in modular form, i.e. part of the scheme can be constructed at any time and then other parts can be added to it, if desired and required.

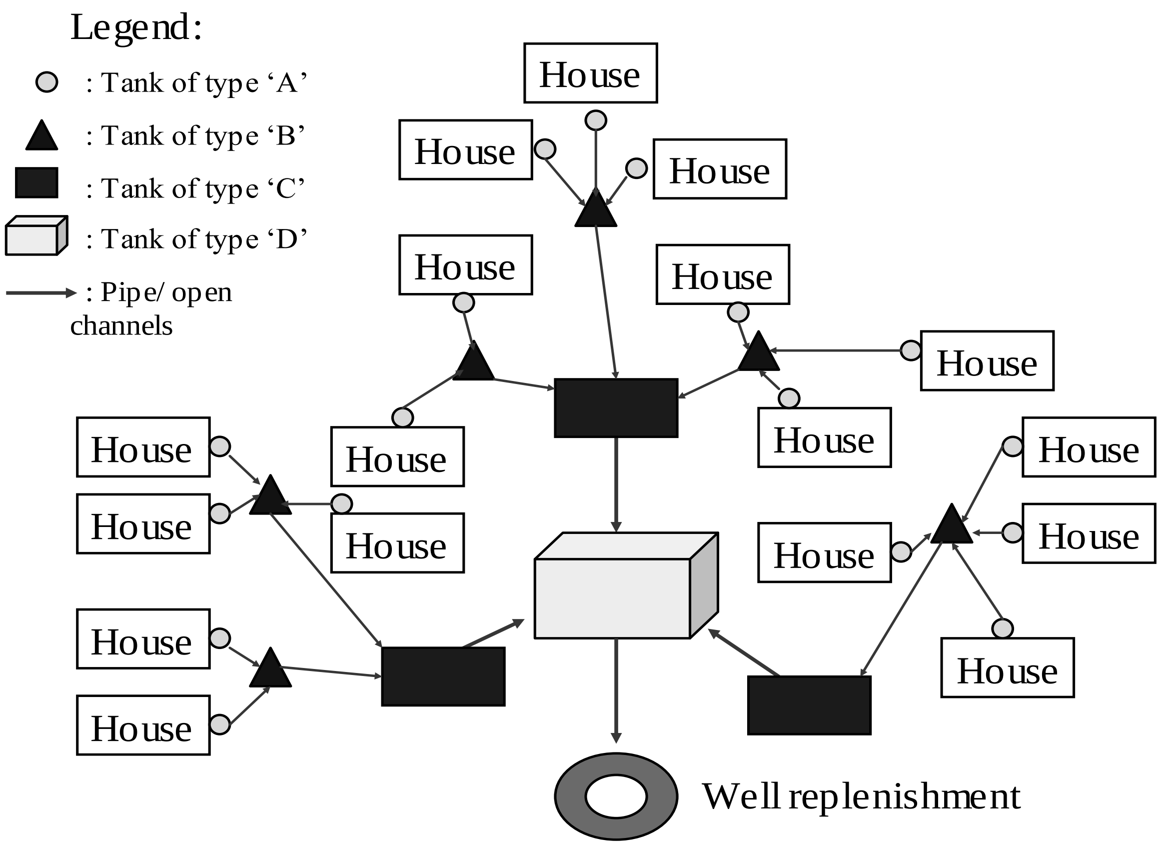

Figure 1 Tanks and pipe network

- **Type A (greh) tank:** This tank is built at household level, intended to collect roof top water. These tanks are built at each house depending on the space available and type of the roof. Capacity of the tank depends upon roof top area, and no. of members of the family. This tank is connected to rooftop through pipes directly. However, if roof area is not available, a catchment area is created around the tank to collect the rainwater.
- **Type B (Samooh) tank:** This tank is fabricated for a community purposes. The community will be defined by a cluster of houses in a town/village. Its capacity will be decided by number of connecting house. This tank will be collecting ground intercepted water passing through a filter media. Filter media will be running over a perforated pipeline that in turn will be connected to tank. Filter media will be made of sand and gravel layer. The stored water can be used for bathing and washing purposes.
- **Type C (Sanja) tank:** This type of tank will be collecting overflow from Type B tank and also from roof top from public structure like school, hospital, etc. The collected water can be used for the purposes like marriages, sawa mani, other public functions, etc. on nominal charges.

- **Type D (Gram) tank:** Overflow from type C tank will be directed to a larger capacity tank, Type D. Here the water also can be collected through perforated pipes which are laid one feet below the ground level mainly connecting the type C and type D tanks. Water from this tank can be used for agricultural purposes and drinking water for cattle, etc. as it is not suitable for drinking purposes.
- **Well Replenishment:** Overflow of water from tank D can be used for the recharge of ground water table with the help of a recharge bore after the treatment of water. Depending on the depth of water table, the depth of boring is decided. It is recommended to have a 8” pipe with slits made circumferentially around it and the pipe is packed in ground with pebbles of 10-12mm.
- **Pipe network:** The roof top of the house is connected to ‘Greh tank’ by PVC pipes varying in diameter of 4”-6” by drainages all around the roof. The water of Greh tank is mainly used for drinking purposes. Greh tanks are connected to Samooh tank and subsequently Samooh to Sanja and Sanja to Gram by either normal pipe or perforated pipe depending on the purpose of water collection. If the water is meant for drinking purpose then it would be regular pipe otherwise it would be perforated pipe. lying below filter media collecting filtered water and passing it to a storage tank. Slit size in pipe is determined keeping in mind filter media constituents.
- **Filter Media:** The filter media will be composed of different layers of sand and gravel (grain size from 0.15-20 mm). The topmost layer is of large aggregates of grain size 12 to 20 mm followed by finer particles of grain size 0.15 to 2 mm. The last two layers are of particle size 2-6 and 6-12 mm respectively. Finer particle layer plays the most important role in removing smaller contamination and also effects infiltration rate.

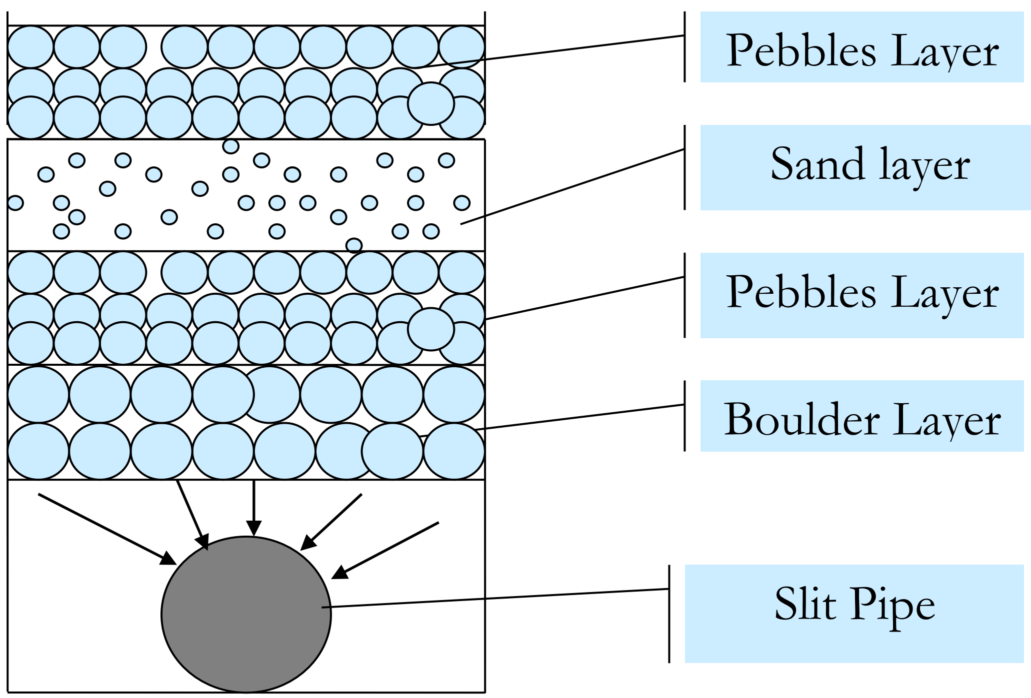

Figure 2 Cross Section of Perforated Pipe with Filter Media

2.2 Construction Methodology

Simple construction technology is suitable for rainwater harvesting projects. The type of technology and materials used for different components are discussed here.

Storage Tanks

- **A Type Tank**: Storage tanks at individual houses are underground tanks constructed in Brick masonry with cement sand (1:4) mortar. It is finished with 15mm cement plaster (1:3) and by neat coat of cement. Bottom of the tank is of 6" thick PCC (1:3:6) and is finished with 40 mm CC flooring (1:1.5:3). Tank is covered with 5" thick RCC slab. It is having a opening of size 450mmX450mm to take out water and also to clean the tank. At the inlet of the tank a filter unit is provided. This filter unit is made up of 20 liters steel drum filled with filter media. Filter unit bottom is perforated to allow the water to enter the tank after getting filtered through it. The materials used in filter unit are discussed above. An outlet is there for taking the overflow water from the tank to the next tank i.e. B type tank.
- **B, C, D Type Tanks**: These tanks are also underground tanks but these will be of completely RCC tanks. These tanks will be having cover for cleaning as well as for taking out water. These are circular tanks covered by dome shaped roofs. One opening will be at top for the purpose of ventilation.

Water Conveyance System

- **At House Level:** PVC pipes are provided to convey the water from rooftop to the tanks. They may vary in diameter depending on the roof size, peak flow, and the portion of the roof coverage. Vertical pipes are plain pipes but underground horizontal pipes are either plain or one third perforated at the top side. Underground pipes are laid in slope of 1:100 and 1.0' feet deep from ground level. These pipes are covered with the filter media as discussed above. Care should be taken while laying and jointing the pipes so that there should be no leakage in future.
- **At Village Level:** Here only underground pipes will be there and all other things are similar to the house level pipes.

2.3 Capacity of the rainwater harvesting

It is proposed to have the total capacity of the scheme to capture and store sufficient rainwater to meet the drinking water needs for atleast 12 months. It is assumed that the requirement is 10 lpcd for drinking and cooking purposes. Houses where roof area is not sufficient to harvest the sufficient rainwater, the catchment area can be enhanced by other techniques. Other needs are secondary and it is expected that the scheme should meet them also to make the scheme sustainable. During the drought year, the scheme should provide the drinking water by cleaning the water of Tank 'D', if required.

2.4 Design Automation

It is proposed to have the design of the scheme to be computerized and automated so that it can be used by even local people. The satellite images or autocad maps are used to fix the location of the different tanks. Maps are created using Digital Elevation Model by taking the slope, resistance to flow, and other factors. The ground surveys are conducted using Global positioning system and superimposed on the maps/ satellite images. Geographical Information system along with Genetic algorithm is used to optimize the location of the tanks, and pipe network. The automation in design will improve the accuracy, reduce the cost and time to design the scheme for a village.

2.5 Scalable

The scheme is scalable and can be implemented to suit a small rural community, rural towns, and urban areas with varying demand and conditions for differing annual rainfall. The design is flexible for scaling the project and is adaptable to the economic model. The implementation is easy and can be replicated in towns, and even cities apart from small village or community.

2.6 Maintenance

The materials used are mainly local materials and hence the scheme requires low upkeep and maintenance. It is possible to train local people for maintenance, operation, and management. The individuals may require not more than 2 weeks of training for the first level of maintenance. The staff needs to know how to read layouts, identifies maintenance needs, spotting emergency repairs, keeps records and notifies project engineer. It is expected that 1-2% of construction cost would be the annual maintenance cost for the structure and pipe lines with a life span of 25 years. A mechanism is being designed to clean the storing tank regularly and speedily. A scheme should be in place to detect the underground leakages either by pressure transducers or by other mean. It is expected that before every rainy season the tanks are clean and white-washed by the owner of the tank/ village committee. A mechanism is being developed to keep the water clean by a continuous cleaning process like by dipping a packet with lime which continuously kills the bacteria. This is apart from the cleaning filters which are provided at the time of collection. A hand pump is being provided so that there is no need to open the gate to fetch the water.

2.7 Numbering Scheme

A numbering scheme is designed to locate the position of the tank. This number would be unique for a tank and will help in maintenance and monitoring. It is based on latitude and longitude of the position which can be used in part of seconds to increase the accuracy. It can work globally. To make the scheme simpler, it is assumed that the location of the villages will not be very close to each other. It is an alphanumeric scheme and requires ten digits. An example is given in Appendix-I

2.8 Inscriptions on tanks

It is planned to have a name plate on each storage unit bearing donor's name, year of construction, and identification number. The plate is of marble stone and inscriptions are written using local material 'Lac'. The inscription are: Project Name: Aakash Ganga, Donor's Name: allow for multiple sponsors, year of construction, Identification Number, and mason's name.

2.9 Water Quality

The collected rainwater was tested at BITS laboratories for several parameters like pH, colour, chlorides, hardness, calcium, dissolved oxygen, and fluoride. The test results found that all parameters are within the permissible limits recommended by the World Health Organization (WHO) and Indian Standards (IS). For measured values see Appendix V 'Riala Test Results'. The quality is superior to the local groundwater. To measure the deterioration, if any, due to prolonged storage, BITS conducted further tests in the second week of January 2005, that is, after 6 months after rainwater collection and the results were found to be same.

2.10 Cost Considerations

The requirements of "replicability and sustainability" dictate that the economic viability is of paramount importance. To ensure economic viability, the scheme should deploy ingenious "bullock cart" technologies, local materials, improvised construction methodology, and local skills as far as possible.

In the first few villages the scheme has been implemented partially and it is expected that once the scheme is perfected on gaining the experience, it would be implemented in other villages with much lesser cost and more efficiently. The cost reduction may be achieved through various methods and techniques.

3.1 Village Participation:

1. The villagers' were not forthcoming. They had to be constantly urged and prodded. There is no institution to mobilize them. Consequently, the maintenance cost has to be born by us till a commercial model is implemented.
2. BITS constantly strived to get the villagers involved in decision-making and implementation. Consequently, they contributed labor for their individual tankas.
3. A government, non-government or private body is essential to look after the scheme and to ensure maintenance.

3.2 Challenges

1. The major challenge is to meet the cost targets. The actual costs are substantially higher than the original targeted costs. For cost-effective implementation of the scheme in any village, a topographical survey is essential. The survey should be conducted through satellite image and field observations. BITS is investigating the cost effectiveness and practicality of selected options for conducting topographical surveys.
2. The rainwater-harvesting scheme faces significant challenge from "free" water. The prevailing expectation is that water supply is government responsibility. As long as water is supplied free, the villagers are not likely to be enthusiastic. For common activities, female participation is a must.
3. It is essential to make the scheme economically viable. A model has to be developed and tested.
4. People have to be trained for long-term implementation and success.

4.0 Future considerations

It is proposed to implement a comprehensive scheme of rainwater harvesting in 100 villages of Rajasthan, India to eradicate the problem of drinking water. Along with the scheme a complete technology and methodology has to be developed which can be implemented in other areas of world as per requirements to strike the equilibrium in terms of drinking water. BITS will help in executing the following for a sustainable and efficient water harvesting:

4.1 Technical

1. Ground water exploration: Identification of confined and unconfined aquifers and their replenishment.

2. Development of sensors:

   - Under ground water level
   - Water quality Index

3. Sensor based irrigation system

4. To assist increased food production, increased bio-diversity, reduced dependence on chemicals (biofertilization) using biotechnology, tissue culture & genetic engineering.

5. To develop technologies to harness non-conventional energy sources like solar energy for agriculture and human habitat.

6. Low cost, low maintenance water filter

7. Software: GIS – GPS based, user-friendly for comprehensive Rainwater harvesting scheme for any area.

8. Manual / Guidelines to develop RWH scheme along with usage of harvested water at village/ town/ city level.

9. Alternative material/ design.

10. Mathematical modelling: The underlying concept is to form a non-government societal entity with social responsiveness. This entity will acquire the rights to harvest rainwater from individual households for a fee. The harvested rainwater will be stored, filtered, and supplied back to the people for a fee. Some of the water may be used to generate revenue and to pay for operational expenses. The entity will have a board of advisors made of the village representatives. These board members will have the right to advise the entity and have access to the financial books. The entity will have its own management.

11. Implementing the scheme for Pilani as knowledge/ technical know-how/ training/ data centre and connecting it to world.

12. A remotely located operations center should collect data, monitor the network, measure the quality of water, and alert for potential infections and pollutants.

    - Historical rainfall data: number of rainy days, average rainfall, maximum rainfall, etc.

- Demographic data: number of houses, male or female, animal count, roof size, name, address, average income etc.
- Water Quality Data: Chlorides, Fluoride, dissolved oxygen PH, bio-pollutants, suspended particles, hardness, etc.
- Design data: Soil condition, pipe size, tanka size, etc.
- Financial: Per liter cost, maintenance cost, cost per house, revenue generation data etc.

For design automation acquire the satellite imagery for Rajasthan (resolution 10-20cm). Identify any other automation tools that are critical to the success of the project. Justify the procurement of these tools, economically.

4.2 Knowledge Management Center

The knowledge center is a facility to collect, validate, store, and disseminate knowledge pertaining to rainwater harvesting. The center should be a repository of, for example:

a. Satellite images for the region
b. Demographic information (names, addresses, family size, animal count, roof size, unique location identifiers, etc.)
c. Design information including sample designs of pipe network, cost estimation, requirements document, rainfall, soil type, etc.
d. Water Quality measurements including biological, chemical, and mineral pollutants.
e. Best practices and innovative solutions

The knowledge center will be the central nerve system. It will maintain a database essential for operation, maintenance, and expansion.

4.3 IT Network

AG will deploy an IT network to connect all the villages to the central repository of data. This network will facilitate communication among the villagers, NGOs, and SI; repair and maintenance of the reservoirs; and monitoring of water quality and utilization. The data will include:

- Demographic data (number of family members, male, female, dairy animals)
- Water management (utilization, storage, cultivation, water quality)
- Design data (roof size, population density)
- Maintenance and Upkeep

This data will help in monitoring water quality on a continual basis for each and every reservoir. Periodically, the water testing laboratory will receive samples from every reservoir. The samples will be tested as per the WHO guidelines. The test results, and alerts, if any, will be posted on AG's web site. SI is working with BITS to plan laboratory capacity to service expansion of AG. That is, the water testing laboratory should have equipment, space, personnel, and processes to receive a few thousand samples and test them, promptly.

The water utilization patterns may shed light on determining social policy for water collection and distribution. In August 2006, the "Water a Fundamental Right" Convention debated social policy for rainwater harvesting. The Convention cited a model similar to that of Aakash Ganga, storage of harvested water in small reservoirs. The considerations are: Is water a commodity or a human right? What is equitable tariff and cost-recovery policy? How does policy protect people below poverty line? What is the policy impact on health, livelihood, and employment? What are individual vs. community vs. state ownership rights?

4.4 Water Quality Testing

It is proposed to measure the water quality in each tanka on a periodic basis. The water quality would be compared on a periodic basis with accepted standards of, for example, World Health Organization or Government of India. Treatment plan would be provided for contaminations. The treatment plan would be simple, easily understandable, and specify right amount of chemicals to be used. It is proposed to create the water testing facilities at BITS laboratory where the water sample will be collected from each village and water will be tested for physical, chemical, and biological contamination. It is expected that:

1. Water of each tank has to be tested twice in a month by water testing Field Kit
2. Water of each tank has to be tested once in every six month in Lab
3. In a Day, on an average, 5 field tests can be conducted
4. In a day, max. two tests can be conducted completely
5. There would be one technical expert and a team who would be working continuously in lab and 5 teams in field through out the year.
6. For field tests, in six months villagers are to be trained.
7. Field Test kids have to be purchased after six months (at least one in every village)

4.5 Cost consideration

One of the main components of the scheme which contributes maximum to the cost of the project is tanks of different capacities. Hence, it is being tried to reduce the cost of the tanks either by using a different material like fly ash, etc, or different techniques like, ferro cement, polymer tanks, pre-cast tanks, etc. under no circumstances, the substitute material contaminate the water supply. The other proposals to reduce the cost are using reduced wall thickness, labour reduction, usage of local material, low cost pipes, etc.

Appendix I

Numbering Scheme

XX LA LO WW 00

1. First X is Latitude in degrees represented by alphabet letters A through K (values from 20 to 30 degrees: covers both Rajasthan and Gujarat, see the values below. A will be 20, B will be 21, etc.)

2. Second X is Longitude in degrees represented by alphabet letters L through V (values from 68 through 78 degrees: covers both Rajasthan and Gujarat, see the values below)

3. LA is actual Latitude in minutes (values from 00 through 59)

4. LO is actual Latitude in minutes (values from 00 through 59)

5. WW is either the Latitude OR Longitude in minutes at a unique location of the village (Mandir/Mosque, school, etc.) (This can be a fixed location throughout the project and should be selected based on actual field experience. Another thing you can do is to make it Longitude for Rajasthan and Latitude for Gujarat or reverse it)

6. Last two digits are the numeric number of the tank (values from 00 through 99).

Refinement: Refining the scheme further, the last two digits will be expanded to 3 digits as follows:

"D"00

Digit "D" will be the direction from the center of the village and will be interpreted as follows:

D = E East of village center, D = W West of village center, D = N North of village center,

D = S South of village center, D = A NNE of the village center, D = B NE, D = C ENE,

D = G ESE, D= H SE, D= I SSE, D= J WNW, D= K NW, D= L NNW

The last two digits will continue to be the individual tank numbers.

Appendix II Drawings of Tank

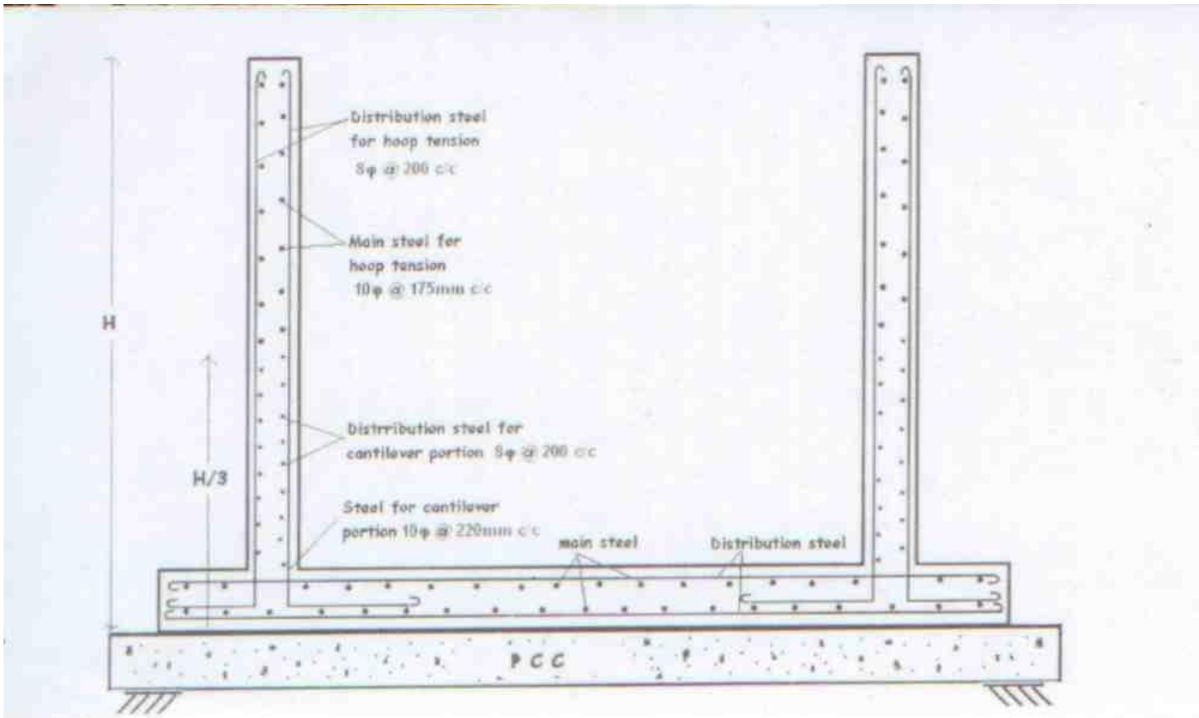

Fig. 1 Reinforcement details in the base and cylindrical wall

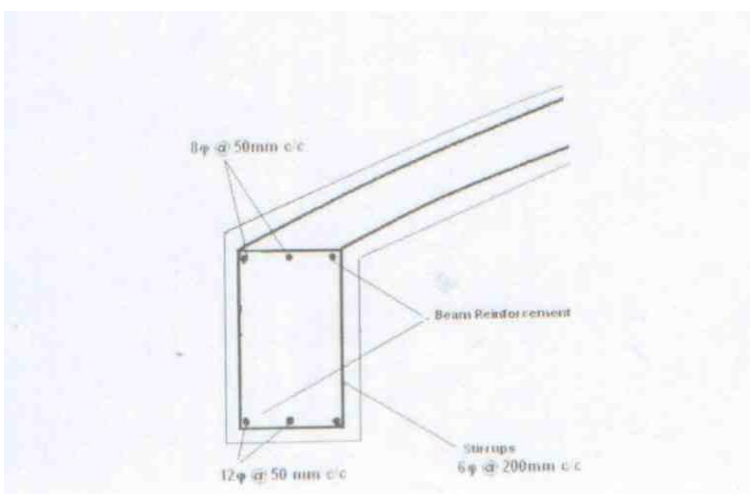

Fig. 2 Reinforcement details of the ring beam

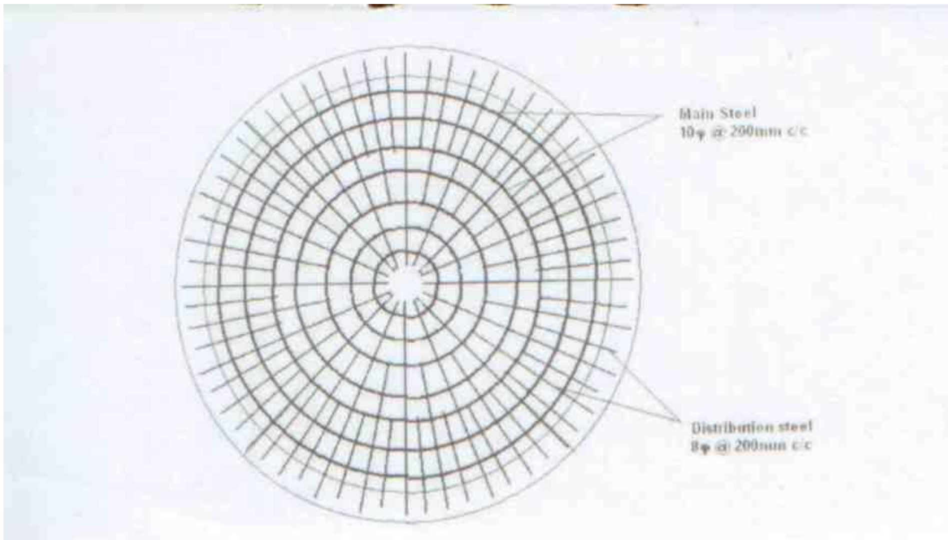

Fig. 3 Reinforcement details of the Dome-slab

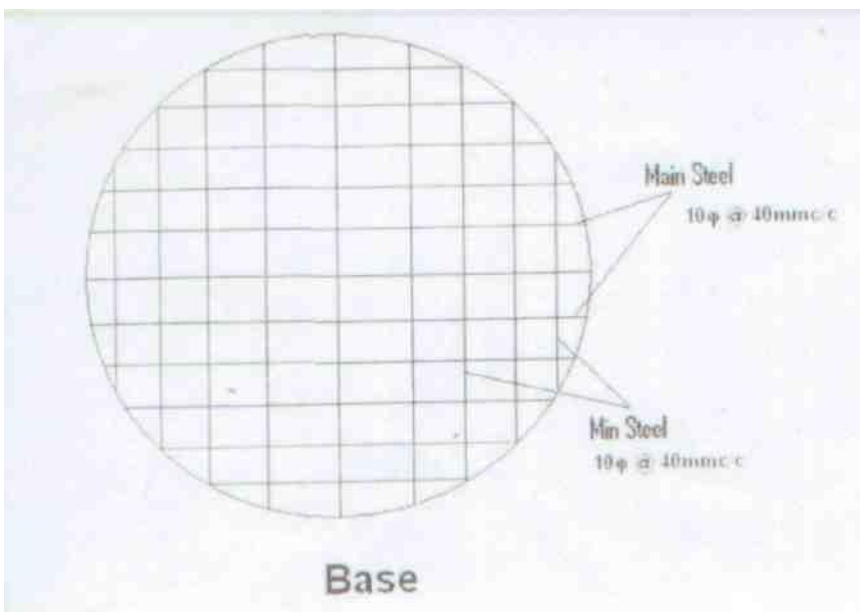

Fig. 4 Reinforcement details of the Base-slab

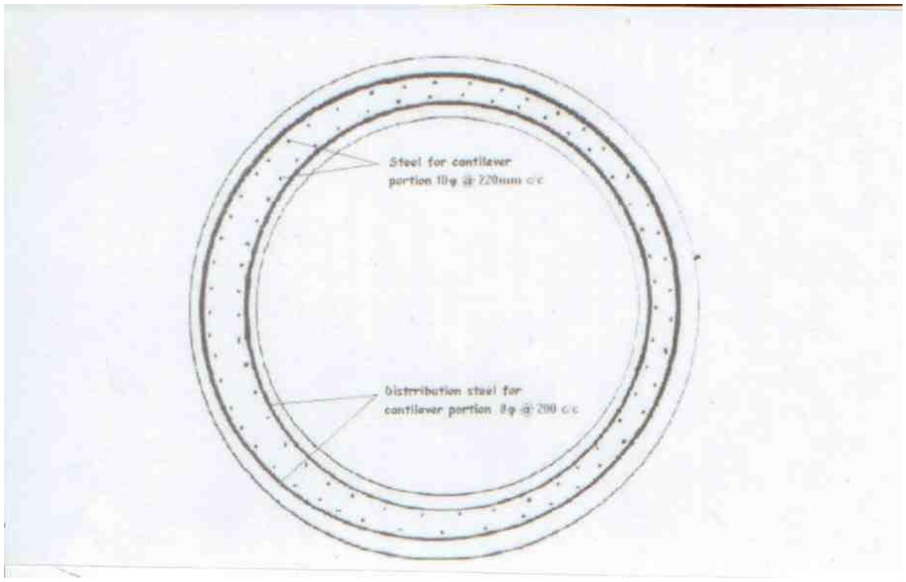

Fig. 5 Reinforcement details of the Wall (Bottom cantilever part

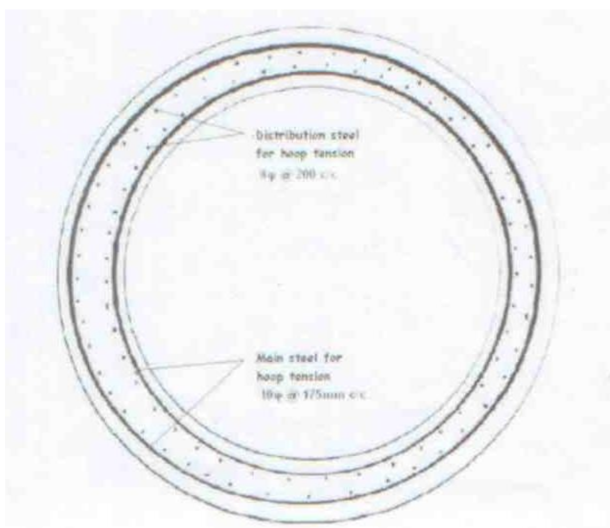

Fig. 6 Reinforcement details of the Wall (Top part)

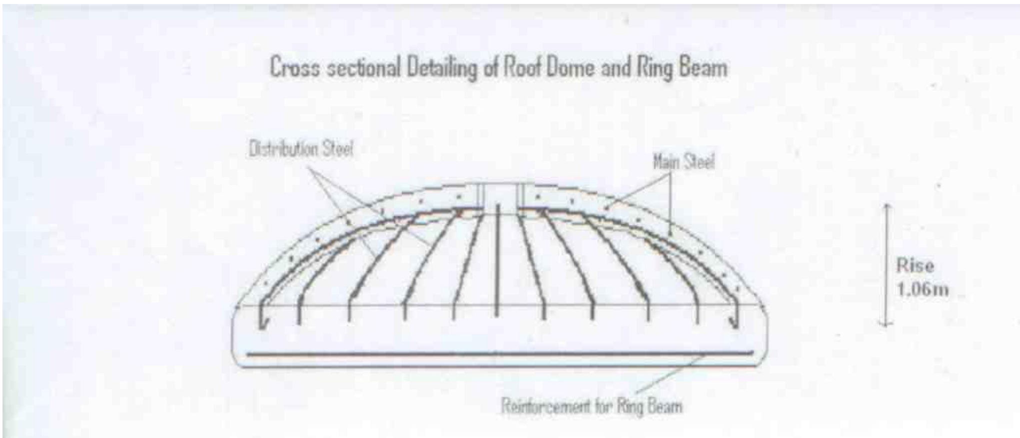

Fig. 7 Reinforcement details of the Dome-slab (Cross-sectional view)

Appendix III

Design of the Tank

A RCC tank of 4,00,000 liters capacity is required to harvest the roof top rainwater from New Library and Lecture theatre buildings. The tank is under ground. The structural details are presented here. The design of the tank is done in accordance with the Indian Standard specification (code of practice for concrete structures for the storage of liquids, IS:3370 (Part 1 & 2) –1965).

Under ground tank (4,00,000 liters) design

Design parameters

Grade of concrete	= M20
Grade of reinforcement	= Fe 415
Permissible tensile stress in conc. in direct tension	= 1.2 MPa
Permissible tensile stress due to bending tension in conc.	= 1.7 Mpa
Permissible compression stress in conc. due to direct compression	= 5.0 Mpa
Permissible compression stress in conc. due to bending compression	= 7.0 Mpa
Permissible tensile stress in reif. due to direct tension	= 150 Mpa

Tank Capacity = 4,00,000 liters

Let thickness of dome = 100 mm

Water depth in tank (H) = 4.0 m

So volume of tank $= \frac{\pi D^2}{4} \times H = 400$ cum

$$= \frac{\pi D^2}{4} \times 4.0 = 400$$

$\therefore$ Inner diameter of the tank (D) = 11.50 m

Let rise of dome(h) $= \frac{11.50}{7} = 1.64\,\text{m}$ say 1.65 m

Radius of dome(R) $= \frac{h}{2} + \frac{D^2}{8h}$

$$= \frac{1.65}{2} + \frac{11.5^2}{8 \times 1.65} = 10.84\,\text{m}$$

Loads of dome:

Dead load $= 0.10 \times 25 = 2.5 kN/m^2$

Live load = 1.5 kN/m^2

Total load (w) = 4 kN/m^2

Inclination of the dome near the wall(θ),

So $$\tan\theta = \frac{D/2}{R-h} = \frac{5.75}{10.84 - 1.65} = 0.625$$

$$\therefore \theta = 32^0$$

The entire dome is in hoop compression since $\theta = 32^0 < 51^0 48'$

Meridional thrust (T) $= \frac{wR}{1+\cos\theta} = \frac{4 \times 10.84}{1 + 0.848} = 23.49 kN/m$

Compressive stress $\sigma_c = \dfrac{T}{\sigma_{st}}$

Compressive stress $\sigma_c = \dfrac{23.46 \times 1000}{1000 \times 150} = 0.156 < 5$ MPa   OK

Provide 0.30 % minimum compression reinforcement in each direction.

$$A_{st}(required) = \frac{0.30}{100} \times 100 \times 1000 = 300mm^2 / m$$

Provide 8 mm bars @ 150 mm c/c in each direction.

$$A_{st} \text{ (provided)} = \frac{50 \times 1000}{150} = 333mm^2 > 300mm^2 \text{ (OK)}$$

Design of Ring Beam

Horizontal component of Meridional thrust = $T \cos\theta$

$$= 23.49 \times 0.848 = 19.92 N/m$$

Hoop tension in ring beam $= 19.92 \times \dfrac{11.50}{2} = 114.54kN$

Area of hoop reinforcement required $= \dfrac{114.54 \times 10^3}{\sigma_{st}} = \dfrac{114.54 \times 10^3}{150} = 763.60mm^2$

Provide 16mm ϕ 4 bars

A_{st}(provided) $= 201 \times 4 = 801mm^2$

To find the ring size of ring beam

Hoop tension = Permissible tensile stress in concrete $\times$ equivalent area of concrete

Thus

$$114.54 \times 10^3 = 1.20 \times [A + (m-1)A_{st}]$$
$$114.54 \times 10^3 = 1.20 \times [A + (13-1) \times 804]$$
$$\therefore A = 85799mm^2$$

Provide ring beam of size $300 \times 300mm$ >85799 mm^2 (OK)

Design of Vertical Wall

Thickness of wall as per empirical formula (t_w) = 30H+50 = 30×4 +50 = 170 mm

Provide t_w = 150 mm

Find maximum BM, maximum Hoop tension and its position using IS code method.

Max. Hoop tension will be at 0.64H from top.

Calculate coefficient $K^{'}$ for max. Hoop tension and $M^{'}$ for maximum BM using IS code tables for: -

$$\frac{H^2}{Dt} = \frac{4.0^2}{11.50\times 0.15} = 9.275$$

For $\frac{H^2}{Dt} = 8$ $\quad$ K' = 0.575 & $M^{'} = -146\times 10^{-4}$

For $\frac{H^2}{Dt} = 10$ $\quad$ K' = 0.608 & $M^{'} = -122\times 10^{-4}$

By using above values & interpolations we get

$$K^{'} = 0.596 \;\&\; M^{'} = -130.70\times 10^{-4}$$

Max. Hoop tension $= K^{'} wH \frac{D}{2}$

$$= \quad 0.596\times 10\times 4\times \frac{11.50}{2} = 137.08kN$$

Max. B.M. causing tension on inner side

$$= M^{'} wH^3 = -130.70\times 10^{-4}\times 10\times 4^3\times 1000 = -8364.80kNmm$$

Check for thickness of vertical wall

Effective thickness from B.M. consideration

$$= \sqrt{\frac{B.M.}{R\times b}} = \sqrt{\frac{8364.80\times 10^3}{1.15\times 1000}} = 85.28 \text{ mm}$$

Say ($d_{eff.}$) = 90 mm

So t_w (required) = 90 + 25 + 5 = 120 mm< 150 mm provided (OK)

So($d_{eff.}$) = 150 – 25 – 5 = 120 mm

Area of Reinforcement for maximum B.M.= $\frac{B.M.}{\sigma_{st} \times j \times d} = \frac{8364.80 \times 10^3}{150 \times 0.874 \times 120} = 531.70 mm^2$

Provide 10 mm ϕ bars at a spacing $= \frac{79 \times 1000}{531.70} = 148.58 mm$ (say 140 mm c/c)

Maintain c/c spacing of vertical bars 140 mm for a height of 1.60 m from bottom, there after curtail every alternate bar.

Area for hoop tension reinforcement $= \frac{Max.hooptension}{\sigma_{st}} = \frac{137.08 \times 10^3}{150} = 913.87 mm^2$

Provide 12 mm ϕ bars for hoop reinforcement at a spacing = $\frac{113 \times 1000}{913.87} = 123.65 mm$

So for a wall height of 1.60 m (from top of the base slab) provide 12 mm ϕ bars @ of 120 mm c/c.

No. of bars required in 1.0 m height of wall $= \frac{1000}{120} + 1 = 9$

Area of A_{st}(provided) in 1.0 m height of wall $= 113 \times 9 = 1017 mm^2$

Check against tensile stress on composite section of the wall by equivalent area consideration.

Equivalent Area of composite section $= 1000 \times t_w + (m-1) \times A_{st}$

$= 1000 \times 150 + 12 \times 1017 = 162.20 \times 10^4 mm^2$

Tensile stress on equivalent area = Max. Hoop Tension / Equivalent Area

$= \frac{137.08 \times 10^3}{162.20 \times 10^3} = 0.84 < 1.20$ Mpa (OK)

Hoop Tension, hoop reinforcement and spacing at different depths from max. water level.

(1) At 1.0 m depth

Hoop Tension $= \frac{\gamma_w \times H \times D}{2}$

Hoop Tension $= 10 \times 1.0 \times \frac{11.50}{2} = 57.50 kN$

Hoop reinforcement A_{st} $= \frac{57.50 \times 10^3}{150} = 383.33 mm^2$

Spacing $= \frac{113 \times 1000}{383.33} = \frac{113 \times 1000}{383.33} = 294.78 mm \cong 290 mm$

So provide 12 ϕ bars @ 290 mm c/c from top to 1.0 m depth.

(2) At 2.0 m depth

Hoop Tension $= 10 \times 2.0 \times \frac{11.50}{2} = 115 kN$

Hoop reinforcement A_{st} $= \frac{115 \times 10^3}{150} = 766.67 mm^2$

Spacing $= \frac{113 \times 1000}{383.33} = \frac{113 \times 1000}{766.67} = 147.39 mm \cong 140 mm$

So provide 12 ϕ bars @ 140 mm c/c from 1.0 m depth to 2.0 depth.

(3) At 2.40 m depth

Hoop Tension $= 10 \times 2.40 \times \frac{11.50}{2} = 138 kN$

Hoop reinforcement A_{st} $= \frac{138 \times 10^3}{150} = 920 mm^2$

Spacing $= \frac{113 \times 1000}{383.33} = \frac{113 \times 1000}{920} = 122.83 mm \cong 120 mm$

So provide 12 ϕ bars @ 120 mm c/c from 2.0 m depth to bottom of wall.

Design of base slab

The base slab supports the wall and rests on soil. The weight of the water is directly transferred to the soil through bearing. A tensile force is developed in the base slab due to lateral thrust of water in the walls. A local moment is also produced near the walls.

Thus, the base slab is designed for the following forces:

- Up ward soil reaction,
- Horizontal tension from walls, and
- Bending moment from walls.

When a member is subjected to axial tension and bending moment, and the tension occurs on the water face, IS : 3370 requires that the stresses must satisfy the following interaction condition :

$$\frac{\sigma_t'}{\sigma_t} + \frac{\sigma_{bt}'}{\sigma_{bt}} \le 1$$

Thickness of the base slab near the vertical wall(t_b) = 325 mm

Horizontal thrust of water on the wall $= \frac{1}{2}wH^2 = \frac{1}{2}\times 10\times 4^2 = 80kN/m$

Additional B.M. in base slab due to the horizontal tension $= \frac{1}{2}\times 0.3\times 80 = 12kNm/m$

Total B.M. in the base near the wall = B.M. due to tensile stress + B.M. due to horizontal thrust.

= 10.56 + 12 = 22.56 kNm/m

Gross area of the slab $= b\times t_b = 1000\times 325 = 32.5\times 10^4\,mm^2$

Section modulus $= \frac{bt_w^2}{6} = \frac{1000\times 325^2}{6} = 17.60\times 10^6\,mm^3$

Check the interaction condition:

$$\frac{80\times 10^3 / 32.50\times 10^4}{1.20} + \frac{22.56\times 10^6 / 17.60\times 10^6}{1.70} = 0.955 < 1 \quad \text{(OK)}$$

Vertical load from dome $= \frac{2\pi Rhw}{\pi D} = \frac{2\times 10.84\times 1.65\times 4}{11.50} = 12.44kN/m$

Vertical load from ring beam $= 0.3\times 0.3\times 25 = 2.25kN/m$

Vertical load from wall $= 0.15 \times 4 \times 25 = 15kN/m$
Vertical load from slab just below of wall $= 0.325 \times 0.15 \times 25 = 1.22kN/m$

Total vertical load $= 30.91\,kN/m$

This load will disperse at 60^0 at the junction of wall and the base slab to the soil through bearing. At the bottom of the base slab,

Effective width of dispersion $= 150 + 150\tan 60^0 = 409.81$ mm

Hence net bearing capacity of the soil $= 80 \times 0.40981 = 32.78kN/m > 30.91/m$ (OK)

Weight of water $= w \times H = 10 \times 4.0 = 40kN/m^2$

Weight of slab (100 mm) thick) $= 10 \times 25 = 2.5kN/m^2$

Total weight $= 42.50\,kN/m^2 < 80kN/m^2$ (OK)

This load will be transferred to the soil directly through bearing.

Provide a minimum of 0.30 % reinforcement in the slab in each direction that is,

$$= \frac{0.30 \times 100 \times 1000}{100} = 350mm^2$$

Provide 8 mm ϕ bars at a of spacing $= \dfrac{50 \times 1000}{350} = 142.85mm$

Provide 8 mm bars @ 140 mm c/c both ways in the middle of the slab. Also, provide 12 mm bars @ 140 mm c/c on each face, circumferentially, in a 1 m distance from the wall.

Cover to reinforcement

Clear cover to the bottom reinforcement in the base slab should be 40 mm and elsewhere, it should be 25 mm.

Appendix IV

WATER QUALITY TEST REPORT

Date of sampling 15-10-2004 Date of testing 16.10.2004 Source - I

S.No.	Examination/ Test	Unit	WHO Standard 1971		Ministry of works & Housing 1975		Indian Standards IS: 10500-1983	NAME OF SOURCES
			Highest Desirable	Maximum Permissible	Acceptable	Cause of Rejection	Desirable Limit	Village (Riala)
1	PH	-	7.0-8.5	6.5-9.2	7.0-8.5	6.5-9.2	6.5-8.5	8.20
2	Colour	Hazen Unit	5.00	50.00	5.00	25.00	10.00	-
3	Chlorides	Mg/1	200.0	600.0	200.0	1000.0	250.0	13
4	Total Hardness	Mg/1	100.0	500.0	200.0	600.0	300.0	60
5	Calcium As Ca	Mg/1	*	*	*	*	75	10.4
6	Dissolved Oxygen	Mg/1	*	*	*	*	*	-
7	Fluoride	Mg/1	1.0	1.5	1.0	1.5	0.6-1.2	0.25

Appendix - V

Table 1: Calculation of capacity of tanks to be installed in a village based on demand and supply at different location of tanks

S.No.	Supply from	Demand at	Balance
1.	Rooftop of 80 houses = 80(houses)X100(sqmt)X0.417(mt)X0.85(coeff) = 2836 cum	A type tanks = 80(houses)X22(cum) + 80(houses)X5(persons)X365(days)X10(liters)/1000 = 3220 cum	2869-1760 = -384.4 cum
2.	Balance of A type tanks + pipe network from A type tanks to B type tanks = ()+4(mt)X746(mt)X0.417X0.3 = 373 cum	B type tanks = 21X50 = 1050 cum	373-1050 = -677 cum
3.	Balance of B type tanks + pipe network from B type tanks to C type tanks = ()+4X1995X0.417X0.3 = 998 cum	C type tanks = 3X100 = 300 cum	998-300 = 698 cum
4.	Balance of C type tanks + pipe network from C type tanks to D type tanks = 698+4X500X0.600X0.3 = 948 cum	D type tank = 1X675 = 675 cum	948-675 = 273 cum = 2,73,000 liters